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Executive Summary

Aeronautics is a valued sector of the U.S. economy and critical to maintaining national security. In 2009, civil aviation supported 10.2 million jobs, and contributed $1.3 trillion in total economic activity, accounting for over 5% of U.S. gross domestic product. The aircraft and aircraft parts manufacturing industry is also the number one U.S. net exporter, contributing over $66 billion in net exports to the trade balance in 2012. In recognition of the importance of aeronautics to the nation, Executive Order 13419 was issued in December 2006. The Executive order led to the creation of a National Aeronautics Research and Development (NARD) Policy and subsequent plans to guide aeronautics research and development (R&D) through 2020.

Section 3(c)(ii) of the Executive order called for Federal departments and agencies involved with aeronautics to develop and implement appropriate measures for improving dissemination of R&D results and facilitating technology transition from R&D to applications, and to identify and promote innovative policies and approaches that complement and enhance Federal Government aeronautics R&D investment.

In assessing its response to the Executive order, the leadership of the Aeronautics Science and Technology Subcommittee (ASTS) of the Committee on Technology of the National Science and Technology Council requested that the IDA Science and Technology Policy Institute (STPI) examine what the ASTS can do to help accelerate the transition of Federal aeronautics R&D products in a manner that promotes U.S. national security, job growth, and economic competitiveness. The STPI research team's study goals were to:

- Facilitate identification and prioritization of barriers to effective innovation and technology transfer[1] from federally sponsored aeronautics R&D programs into the private sector for use in civil and national security applications;
- Clarify areas that could be addressed by the ASTS and its membership under existing policies; and

[1] While the term of art used in the report is *technology transfer*, the study focuses on the interactions between government laboratories and industry, regardless of whether the exchange is in the form of technology transfer, transition, innovation, or commercialization.

- Highlight successful technology transfer or innovation pathways that can serve as model practices for aeronautics-related Federal agencies.

Methodology

The STPI research team reviewed the literature on the history of aeronautics and technology transfer, and engaged with stakeholders in the aeronautics industry and at Federal laboratories that conduct aeronautics-related research at the Department of Defense, National Aeronautics and Space Administration, and Federal Aviation Administration. The literature review documented the range of expert views on the barriers to and recommendations for improving technology transfer in the aeronautics R&D community. In addition, a Request for Comments was administered via the *Federal Register* to solicit input from the community. Interviews were conducted with more than 30 leaders from over 20 aerospace firms. Two industry roundtables supplemented the written comments and interviews. Written input—followed by verbal clarification—was also obtained from leaders at 10 aeronautics-related Federal laboratories. Responses were synthesized and analyzed using content analysis methods to inductively code and classify the responses by theme.

Findings

A review of the history of U.S. aeronautics illustrated that over the last century, the United States has accomplished much in the air and space fields making the United States truly an "air and space nation." However, complacency and risk aversion has cost the United States its global leadership more than once since its invention of flight. Though the United States regained its lead each time, the recovery was not serendipitous. In 1915, for example, the United States established the National Advisory Committee on Aeronautics, modeling it on its British counterpart, recreated European laboratory structures, established the Guggenheim fund to promote aeronautics, imported some of the best European minds, and began using the racing aircraft as a technology demonstrator. While some external factors that helped—the strength of the U.S. economy helped the aeronautics sector much more than the war-ravaged European economy—the United States was also fortunate to have several strong "czar" figures in positions of continuing authority and direction over national scientific and technological programs. This leadership was a critical factor in the United States regaining its lead in each manifestation.

The interviews and the literature review yielded a wealth of aeronautics industry success stories and best practices. Respondents highlighted over a hundred unique practices, programs, technology standards, and partnerships that they found to be exemplary. These practices showcased successful approaches to mapping strategic plans into implementation plans. using public-private partnerships and bridging organizations to improve stakeholder engagement and leverage funds, using demonstrators and platforms creatively to mature technology faster; promoting risk-taking and fail-fast systems,[2] and simplifying contract and intellectual property negotiation, among others. Respondents from both government and industry also identified over 40 distinct mechanisms for technology transfer in aeronautics, although they did not always agree on which mechanisms were the most useful.

While respondents found technology transfer generally effective, they also identified almost 70 barriers. The barriers fell in a range of levels, not all of which are addressable within the ASTS's authorities. For example, many of the barriers related to intrinsic issues in aeronautics—that technology development is inherently complex—or external challenges such as a worsening fiscal outlook. Some of the barriers articulated, such as siloed decision-making, were more consequences of behaviors than barriers per se. The following table organizes the categories of barriers by these levels.

Barriers to Innovation Act at Multiple Levels

Intrinsic and structural issues…	combined with external challenges…	lead to risk-averse behaviors…	resulting in unintended outcomes
• Market structure of the aerospace sector* • Development of complex products that must operate in difficult environments • Incomplete understanding of the technology development process • Laboratory culture of Insularity • Misaligned incentives • Lack of meaningful metrics to measure progress	• Increasing global competition • Uncertain fiscal and workforce outlook • International trade and regulatory issues (World Trade Organization, International Traffic in Arms Regulation, and others)	• Reduced investment especially in mechanisms related to communication and coordination • More contentiousness over ownership of intellectual property • Increased caution, review, and oversight (government) • Focus on incremental improvements (government, industry) • Pushing immature technologies to next level • Regulations not keeping pace	• Increasingly fragmented knowledge base • Siloed decision-making • Less disruptive Innovation • Longer development cycles

* The market for most aeronautics products is neither competitive on the buy side (usually only one buyer, the government; such a market is called a monopsony) nor on the sell side (a small number of sellers; an oligopoly). Such a market is a form of imperfect competition, and this holds important implications for innovation.

Of the barriers that were addressable by the ASTS, most fell into four broad categories: coordination and communal awareness in the execution of NARD plans, communication and liaison among stakeholders, maturity of new technology, and institutional practices and culture. The STPI research team developed goals and recommendations around these four categories.

[2] A fail-fast system is designed to immediately report any failure or condition that is likely to lead to failure.

Goals and Recommendations

The STPI research team's goals and recommendations for overcoming barriers to technology transfer are summarized in the table below and explained in the paragraphs that follow.

Recommendations for Overcoming Barriers to Technology Transfer

Goal	Recommendation
1. Achieve greater coordination and communal awareness in the execution of National Aeronautics Research and Development (NARD) plans	1.1. Consistent with its mandate in Executive Order No. 13419, the Office of Science and Technology Policy (OSTP), in conjunction with the Office of Management and Budget, should ensure that agency priorities, budgets, and programs formally reflect and are traceable to NARD plans
	1.2. OSTP, in its mandated biennial review of the implementation of NARD plans, should include more opportunity for industry participation and feedback
2. Improve R&D-related communication and facilitate liaison among key national aeronautics stakeholders	2.1 Federal aeronautical departments and agencies should inform their own R&D plans and programs by obtaining more information on aeronautics firms' independent research and development (IR&D) projects that are allowable costs on Federal contracts
	2.2. Federal aeronautical departments and agencies should review the status of their current and proposed aeronautics partnerships to ensure that they are outcome driven and have common goals, transparency and trust, shared risk, and strong leadership
	2.3. The Aeronautics Science and Technology Subcommittee (ASTS), working with the Office of the U.S. Trade Representative and the Department of Commerce, should provide guidance to departments and agencies and industry regarding R&D practices consistent with recent World Trade Organization findings
3. Ensure new technology is matured more effectively	3.1. Each department and agency should ensure that its R&D-related experimentation and demonstration activities appropriately emphasize the principles of failing fast, testing on the margin, and balancing risk aversion with the need for experimentation
	3.2. OSTP should make an effort to better understand if industry-funded technology development is more cost-effective and why, and which industry practices could be incorporated in government-funded technology development activities
4. Minimize institutional barriers that hinder technology transfer	4.1 The ASTS should engage with government and industry with respect to appropriate sharing of intellectual property rights for aeronautics R&D and use this engagement as a starting point to ensure that the government's intellectual property practices are realistic, achievable, and beneficial to both parties
	4.2. Federal aeronautical departments and agencies should develop specific incentives to promote outcome-oriented technology transfer and cross-organizational collaborations
	4.3. Federal aeronautical departments and agencies should develop and employ meaningful metrics for technology transfer based on outcomes and impacts rather than inputs, activities, and outputs

Goal 1: Achieve Greater Coordination and Communal Awareness in the Execution of National Aeronautics Research and Development (NARD) Policies and Plans

Most industry respondents who were aware of the NARD plans found them to be useful, but believed that more could be done to integrate them into agency plans and activities. A review of agency budgets, congressional testimonies, and other government documents corroborated the industry view that NARD plans were not an explicit guide to governmental budgeting and planning.

Independent of alignment with NARD plans, industry respondents also felt that individual plans and technical goals of Federal aeronautics organizations and agencies are unclear and insufficiently articulated across the aeronautical community. Some agency and department efforts to develop their own strategies and implementation plans were also perceived as contradictory, confusing, and unhelpful. As a result, the beneficial unity of purpose and effort that could come from aligning the efforts of the national aeronautical community to the NARD plans and policies has been difficult to achieve.

Recommendation 1.1: *Consistent with its mandate in Executive Order No. 13419, the Office of Science and Technology Policy (OSTP), in conjunction with the Office of Management and Budget, should ensure that agency priorities, budgets, and programs formally reflect and are traceable to NARD plans.*

Recommendation 1.2: *OSTP, in its mandated biennial review of the implementation of NARD plans, should include more opportunity for industry participation and feedback.* More formal industry input would help ensure NARD plans and policies are realistic, achievable, desirable, and relevant to defined national needs. This involvement could be coordinated with support from standing advisory bodies, industry associations, and professional societies.

Goal 2: Improve R&D-Related Communication and Facilitate Liaison among Key National Aeronautics Stakeholders

Industry respondents reported that they had limited visibility and input into government-sponsored research that is foundational for both government and private sector aeronautics technology development. Government respondents similarly felt that they had less than needed and desired insight into industry goals, plans, and progress.

In addition to this knowledge fragmentation, cultural differences between government and industry—mission mismatch, in particular—hinder interactions among all stakeholders. While several partnerships between government and industry are in place to address these barriers, not all were seen as being as productive. Successful partnerships also appeared to have certain common features that the less successful ones did not.

Respondents also identified some emerging challenges. For example, in March 2012, the World Trade Organization through its Large Civil Aircraft (Second Complaint) case ruled that the United States caused adverse effects to the interests of the European Union through the use of certain subsidies. In response, the Federal Government has discontinued and scaled back several programs. This has caused confusion among both government and industry researchers, and both groups seek guidance regarding which collaborations are suitable.

Recommendation 2.1: *Federal aeronautical departments and agencies should inform their own R&D plans and programs by obtaining more information on aeronautics firms' independent research and development (IR&D) projects that are allowable costs on Federal contracts.* The Department of Defense (DOD) has recently gained increased visibility into firms' IR&D, and authorized users can now examine IR&D project summaries submitted by firms. This increased visibility has been enabled in a way that does not interfere with the independence of IR&D. The DOD has concurrently acted to make more and better information available to its contractor base so that firms can better focus IR&D on DOD priorities. Other aeronautics agencies should similarly inform their R&D planning and programs by obtaining more information about aeronautics IR&D in industry. As private and public partners gain increased insight into each other's R&D, additional opportunities for technology transfers of mutual benefit can be identified.

Recommendation 2.2: *Federal aeronautical departments and agencies should review the status of their current and proposed aeronautics partnerships to ensure that they are outcome driven and have common goals, transparency and trust, shared risk, and strong leadership.* A review of partnerships, both in aeronautics and other sectors, revealed that there are common threads to successful partnerships. To increase the efficiency and cost-effectiveness of current and future public-private partnerships, aeronautics departments and agencies should evaluate each partnership along the following dimensions of success:

- *Outcome driven.* Any partnership worthy of significant attention from national leaders ought to be driven by a needed capability, not by a desire to promote a particular discipline or technology.
- *Common goals.* The partnership should be selective about including participants that share the same goals (not just have common interests), and it should be periodically evaluated to ensure that goals remain relevant and are being met.
- *Transparency and trust:* Given the common goals of participants, their interactions should be transparent and based on trust.
- *Shared risk:* All participants should have a material stake in the outcome of the partnership, including monetary or in-kind contributions.

- *Strong leadership:* Leaders of the partnership should be selected for their ability to enforce discipline as to partnership's outcome and goals and participants' trust and risk.

Recommendation 2.3: *The ASTS, working with the Office of the U.S. Trade Representative and the Department of Commerce, should provide guidance to departments and agencies and industry regarding R&D practices consistent with recent World Trade Organization findings.*

Goal 3: Ensure New Technology Is Matured More Effectively

Both interviewees and the literature review highlighted premature exploitation of technology as a contributor to the challenges of rising program stretch-out and delay, increased cost overruns, and failure to fulfill desired program goals and expectations. Insufficient maturation was linked (among other things) with inadequate R&D-related experimentation and demonstration. As with other activities in R&D, this stage is also being increasingly constrained by risk aversion, with a focus on avoiding failure at all cost, and an increased predisposition to lengthy program review and technical oversight. While appropriate review and oversight are crucial, inappropriate application of review and oversight may constrain experimentation; add to program costs, uncertainties, and stretch-out; and risk hindering the maturation of a technology before other pressures may force its premature application to a production system. Consequently, researchers and design and production teams across the government and industry aeronautical community increasingly pursue incremental innovation rather than disruptive or radical innovation.

Raising cases in point such as Sikorsky's development of the X2 aircraft, and SpaceX's Falcon rocket and Dragon capsules, many of the respondents also pointed to lower costs of technology development and maturation when funded internally by industry. Studying such developments may reveal lessons applicable to government-funded technology development.

Recommendation 3.1: *Each department and agency should ensure that its R&D-related experimentation and demonstration activities appropriately emphasize the principles of failing fast, testing on the margin,[3] and balancing risk aversion with the need for experimentation.* Furthermore, in its mandated assessment of aeronautics-related infrastructure, OSTP, together with the ASTS, should examine the effectiveness of these approaches in accelerating technology development and recommend best practices across the Federal aeronautics research enterprise. Re-emphasizing test along the research

[3] "Testing on the margin" refers to a technique that seeks to identify when systems that typically operate on the precipice of a failure threshold become susceptible to exceeding the threshold by intentionally varying parameters and observing the result.

maturation cycle will help reduce uncertainties and risk, and relating experimentation and demonstration to the NARD plan will create greater unity of effort and efficiency in aeronautical R&D.

Recommendation 3.2: *OSTP should make an effort to better understand if industry-funded technology development is more cost-effective and why, and which industry practices could be incorporated in government-funded technology development activities.*

Goal 4: Minimize Institutional Barriers That Hinder Technology Transfer

In his 1832 book *On War*, Prussian military strategist Carl von Clausewitz identified "fog and friction" as impediments to the successful and timely conduct of military operations. In the present study, the phrase "fog and friction" refers to institutional hindrances that form a viscous drag to progressive occurrence of technology transfer. The metaphor is especially apt to technology transfer; as the "fog" is lifting, the "friction" is becoming more evident. Respondents referred, in particular, to three institutional characteristics that have gotten worse over time with respect to hindering timely and effective technology transfer:

- *Government intellectual property practices.* Industry respondents were virtually unanimous in their assertion that negotiations related to contracts and intellectual property rights are a major hindrance to industry's interactions with the Federal Government. Respondents also suggested that the problem has worsened in recent years, with the government raising the stakes and seeking to exert rights to "background intellectual property" (referring to pre-existing intellectual property that a party brings to a research project) or rights when industry was sharing costs. Government respondents stressed limitations generated by the requirement to ensure a "level playing field" where no single firm has an undue advantage or receives preferential treatment.
- *Culture of Federal laboratories.* Most government leaders shared the view that Federal laboratories continue to foster a culture where the focus is on invention, rather than on innovation and development of practical user-oriented technology. The literature pointed to a lack of incentives to engage in technology transfer. Over the years, many recommendations have been offered regarding culture change, but the challenge persists.
- *Lack of meaningful metrics for success.* Under pressure to show progress on technology transfer, most laboratories have begun reporting data on activities and simple outputs, such as the number of laboratory personnel involved in technology transfer, number of attendees at outreach and cross-community activities, or the number of patent disclosures. While these are useful metrics,

they say little about the actual outcomes and impacts of technology transfer activities.

Recommendation 4.1: *The ASTS should engage with government and industry concerning appropriate intellectual property rights for aeronautics R&D and use this engagement as a starting point to ensure that the government's intellectual property practices are realistic, achievable, and beneficial to both parties.* The ASTS could engage industry through professional societies and associations, annual meetings between the ASTS and industry, or other means (such as agenda items in standing partnerships). Engagement could also occur under the review mandate of the October 2011 Presidential memorandum on technology transfer and commercialization. Departments and agencies should also leverage known best practices in the areas of streamlining contracts and processes; capturing and managing intellectual property; effective organization and staffing of technology transfer offices; and empowering, training, and rewarding scientists and engineers.

Recommendation 4.2: *Federal aeronautical departments and agencies should develop specific incentives to promote outcome-oriented technology transfer and cross-organizational collaborations.* Organizational incentives to participate in technology transfer and cross-organizational collaborations include making technology transfer-related activities a more explicit part of organizations' goals and staff performance evaluations. Departments and agencies should also consider promoting cross-pollination with industry using mechanisms such as Intergovernmental Personnel Act assignments. OSTP, as part of its review of the implementation of the technology transfer mandate of NARD plans, should review the use and effectiveness of these incentives.

Recommendation 4.3: *Federal aeronautical departments and agencies should develop and employ meaningful metrics for technology transfer based on outcomes and impacts rather than inputs, activities, and outputs.* While the practice of collecting data on input and output metrics (such as counts of publications and patents) should not be discontinued, the focus should shift to collection of data on outcome —however qualitative—and impact-oriented metrics, such as companies' adoption of new technology developed at laboratories or development of enabling regulatory standards, among others.

Summary and Conclusion

Throughout the history of flight, the U.S. Government has played a leading role in advancing the fundamental scientific principles and technologies on which modern aviation is built. Many of the advances that made the industry's success possible came from hard-fought victories on the frontier of aeronautical research from the first digital fly-by-wire, computer-controlled aircraft to unmanned aerial vehicles and from chevron nozzles that reduce jet engine noise to winglets that improve aerodynamic efficiency.

As this report highlights, barriers to U.S. aeronautics innovation and technology transfer are complex, and not all result from problems at the *interface* between government laboratories and industry. Many of them relate to larger challenges such as fiscal pressures, and increasing international competition. Some challenges are long-standing, but have exacerbated over the years. Others are relatively recent. Still others are related to aeronautics' unique market structure, which must be compensated for.

Despite these barriers, the aeronautics sector has opportunities that few other industry sectors do. The NARD policies and plans give the aeronautics leadership in the Federal Government unprecedented leverage to guide the enterprise, much more so than is feasible in other areas of R&D or was conceivable in previous decades. The recommendations from this study are meant to be actionable within existing legislative authorities, and if implemented, they are likely to have measurable payoffs by helping to promote U.S. national security, job growth, and economic competitiveness.

Contents

1. Introduction

Aeronautics is a vital sector in the U.S. economy, and critically important for national security. According to the Federal Aviation Administration (FAA), in 2009 civil aviation economic activity supported 10.2 million jobs, contributed $1.3 trillion in total economic activity, accounting for over 5% of U.S. gross domestic product (FAA 2011). The U.S. aircraft and aircraft parts manufacturing industry is also the number one net exporter, contributing over $66 billion in net exports to the trade balance in 2012 (Sánchez 2012). Many of the advances that made the industry's success possible came from hard-fought victories on the frontier of aeronautical research. Among those victories are digital fly-by-wire, computer-controlled aircraft, unmanned aerial vehicles, chevron nozzles that reduce jet engine noise, winglets that improve aerodynamic efficiency, composite fan casings that increase fuel efficiency and safety, and the FACET software that helped transform national airspace (Bargsten and Gibson 2011; National Research Council (NRC) 2012) And throughout this history, the U.S. Government has played a leading role in advancing the fundamental scientific principles and technologies on which modern aviation is built.

Despite these achievements, the aerospace industry cannot be naively optimistic about the future. During the past two decades, and particularly in the past decade, NASA's aeronautics budget has shrunk substantially, from more than $1 billion in 2000 to approximately $570 million in 2010. As a percentage of the NASA budget, aeronautics research has declined from ~7in 2000 to ~3% in 2010 (NRC 2012). With the continued decline in NASA's aeronautical research budget, in addition to an unstable economic environment, research activities are "likely to have serious long-term consequences relative to the development of innovative aerospace technology and could ultimately result in the erosion of the U.S. leadership position in aerospace relative to other nations such as China" (NRC 2012, 46)

Given the importance of aeronautics to the nation, Executive Order No. 13419 was issued to guide Federal aeronautics research and development (R&D) through 2020. Section 3c(ii) of the Executive order called for Federal departments and agencies involved with aeronautics to develop and implement appropriate measures for improving dissemination of R&D results and facilitating technology transition from R&D to applications, and to identify and promote innovative policies and approaches that complement and enhance Federal Government aeronautics R&D investment (Executive Order No. 13419 2006). In working out its response to the Executive order, the leadership of the Aeronautics Science and Technology Subcommittee (ASTS) of the Committee on

Technology of the National Science and Technology Council (NSTC), has become concerned that a legacy of past practice, outdated policies, and burdensome and conflicting government regulations is hindering the successful laboratory-to-market transfer of research results generated by Federal institutions and agencies to the non-Federal community, thus stifling U.S. competitiveness and endangering future American aeronautical supremacy.

This concern is echoed by corroborating anecdotal evidence from the National Research Council (NRC), Government Accountability Office (GAO), and others that current practices do not adequately address (and may actually, in certain instances, inhibit) effective transfer of the products of aeronautics R&D to the private sector (Toregas et al. 2004; NRC 2006a; NRC 2012; GAO 2006; GAO 2011). As a result, the ASTS requested that the IDA Science and Technology Policy Institute (STPI) examine what the government, particularly the ASTS, can do to help accelerate the transition of Federal aeronautics R&D in a manner that promotes U.S. national security, job growth, and economic competitiveness.

A. Objectives of the Study

This study aims to help the ASTS identify areas where it can influence innovative means for Federal agencies conducting aeronautics research to accelerate the transfer of technological advancements to the non-Federal community and increase the effectiveness of the aeronautics enterprise.[4]

Specific study goals were to:

- Facilitate identification and prioritization of barriers to effective innovation and technology transfer from federally sponsored aeronautics R&D programs into the private sector for use in civil and national security applications;
- Clarify areas that could be addressed by the ASTS and its membership under existing policies; and
- Highlight successful technology transfer or innovation pathways that can serve as model practices for aeronautics-related Federal agencies.

It is worth drawing the reader's attention to the second goal as it emphasizes the subcommittee's desire for recommendations that call for action that is feasible within its

[4] Readers are reminded that *aeronautics* and *aerospace* are not synonymous terms. The term *aerospace* comprises many technologies in the three primary disciplines of aeronautics (lifting flight within the atmosphere and transatmosphere), astronautics (spaceflight typically as defined by Keplerian trajectories and Hohmann transfers), and aerostatics (flight within the atmosphere via enclosed lifting gases such as hydrogen, helium, or heated air). This study deals with technology transfer in the realm of aeronautics.

authorities. This excludes the examination of many challenges to aeronautics that are, for example, under the purview of the legislative branch.

B. Defining Concepts of Interest

Technology transfer is an inherently complicated concept. Indeed, one article on the topic begins with the epigraph, "In the study of technology transfer, the neophyte and the veteran researcher are easily distinguished. The neophyte is the one who is *not* confused." (Bozeman 2000). Technology transfer involves many different stakeholders, and can range from formal legal agreements on intellectual property rights to tacit knowledge exchanged through conversation. Defining the term is itself not a straightforward task, as it can refer to processes and procedures as well as to physical technologies. Building on the definitions used by Hughes et al. (2011) and the Organisation for Economic Co-operation and Development (OECD 2005), the STPI research team defined "technology transfer" as the

> *process* of skill transferring, knowledge, technologies, methods of manufacturing, samples of manufacturing and facilities among governments or universities and other institutions *to ensure that scientific and technological developments are accessible* to a wider range of users who can then further develop and exploit the technology into new products, processes, applications, materials or services.

Technology transfer can occur indirectly through transfer of knowledge or directly by way of networks with the goal to commercialize the technology. *Technology transition* is a different but related concept. Also known as *spin-in*, technology transition describes the process of a Federal laboratory or agency engaging in a cooperative effort that brings technology created by an external entity into the agency to enhance the government's efforts.[5] Another related concept is that of *technology commercialization*, which refers to the process of transforming new technologies into commercially successful products.

The final term of interest is *innovation*, which has as many different definitions as there are experts on the topic.[6] A 2008 blue ribbon advisory committee to the Secretary of the Department of Commerce (DOC) defined it as follows (DOC 2008):

> The design, invention, development and/or implementation of new or altered products, services, processes, systems, organizational structures, or

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[5] Terminology varies across agencies and departments. Within the Department of Defense (DOD), technology transfer encompasses spin-off, spin-in, and dual-use technology. See DOD Instruction 5535.8 at http://www.dtic.mil/whs/directives/corres/pdf/553508p.pdf.

[6] See Stone et al. (2008) for a list of key definitions.

business models for the purpose of creating new value for customers and financial returns for the firm.

For the purpose of this study, the research team defined *innovation* as the creation of better or more effective products, processes, services, technologies, or ideas that are accepted by markets, governments, and society (Lundvall 2005; Trott 2008).

This study focuses on the interactions between government laboratories and industry, regardless of whether the exchange is in the form of technology transfer, transition, innovation, or commercialization.

C. Methodology

The STPI research team reviewed literature and engaged with stakeholders at Federal laboratories and in industry to better understand each side's point of view on the barriers to technology transfer in the aeronautics R&D ecosystem and solutions for improving the situation. This section describes each of the three methods used to develop actionable recommendations for the ASTS.

1. Literature Review

The purpose of the literature review was to distill relevant information in the available literature on technology transfer, technology transition, and innovative business practices, with a focus on aeronautics and other federally funded R&D/technology disciplines. The review addressed two specific questions:

- What are the barriers to Federal technology transfer?
- What are the strategies to increase the effectiveness of technology transfer?

To address these questions, the team searched bibliographic databases (including Web of Science, Scopus, and Google Scholar), the repositories of the GAO and the Congressional Research Service CRS, and revisited previous STPI studies on the topics of Federal laboratory technology transfer, technology transition, and technology innovation. Articles on university technology transfer, and university-industry partnerships fell outside the realm of the search, although a few recent and relevant studies were included. As articles and books led to related topics, including Federal laboratory economic development, entrepreneurship, and small business development, the team explored those as well. Figure 1 lists the types of reports reviewed. All articles were scanned briefly to determine their relevance to the questions above, and then summarized using a one-page format.

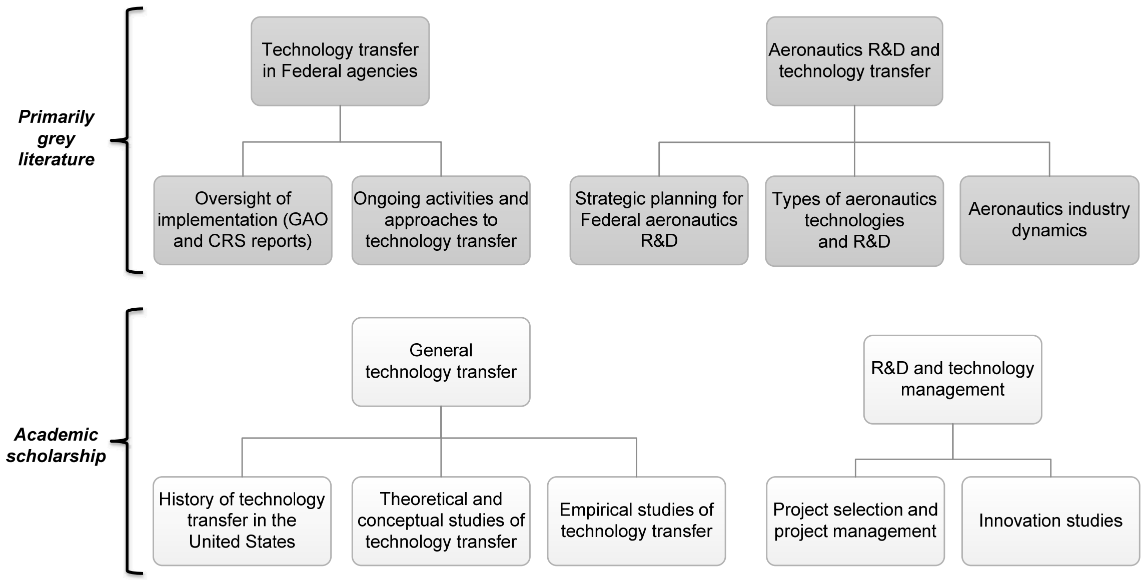

Figure 1. Literature Showcased as Academic Scholarship and Grey Literature

The final list contained in the literature review includes academic scholarship (with empirical studies, theoretical studies, case studies, and review articles), and documents from the "grey literature," including government studies, individual agency reports, and briefings. Of the documents reviewed, 37% (26 of 71) are related to aeronautics technology transfer; the rest relate to general technology transfer. Of the 71 documents, 25% (18 of 71) are specific to NASA, 6% (4 of 71) are specific to FAA, and 14% (10 of 71) are specific to the Department of Defense (DOD). Another 15% of the reports are GAO reports and 8% are NRC studies.

2. Data Collection

Public comments were sought via a request for public comment (RFC) in the *Federal Register* on ways to maximize the benefits of Federal aeronautics research and development (R&D) investments. The request yielded of 13 industry and other non-Federal stakeholder responses. A similar set of questions was administered to aeronautics leaders at 10 Federal laboratories. One of the laboratories submitted two responses, leading to a total of 11 Federal laboratory responses. Nearly 40 interviews were conducted with leaders from over 20 aeronautics-related companies.[7] Additional experts (including technology transfer personnel, intellectual property lawyers, and aeronautics experts) provided additional input in the form of interviews. Input was collected from two roundtables with about 20 senior corporate representatives from the aeronautics industry.

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[7] The firms included eight of the largest U.S. aerospace and defense R&D spenders. Together, their R&D spending represented 67% of the total U.S. R&D funding in the aerospace sector in 2010 (Batelle 2011).

Appendix A provides the RFC and the interview questions used for data collection, and Table 1 lists the affiliations of the respondents.

Table 1. Affiliations of Respondents to Public and Agency Requests for Comments, Roundtables, and Interviews

Federal Government	Industry and Private Sector
DOD Army Research Laboratory	Aurora Flight Sciences
DOD Naval Research Laboratory	Cessna Aircraft Company
DOD Office of Naval Research	Connecticut Center for Advanced Technology, Inc.
DOD Air Force Research Laboratory	Connecticut Innovations
DOD Air Force Research Laboratory, Technology Transfer Office	General Aviation Manufacturers Association
FAA Office of Environment and Energy	General Electric, Aviation
FAA Office of NextGen, Advanced Concepts and Technology Development Office	Georgia Aerospace
FAA Office of NextGen, Hughes Technical Center Office	Gulfstream Aerospace Corporation
NASA Ames Research Center	Honeywell Aerospace
NASA Dryden Flight Research Center	L3 Communications, Aircraft Modernization and Maintenance
NASA Glenn Research Center	Lockheed Martin Corporation
NASA Langley Research Center	Lockheed Martin, Skunk Works
	MITRE Center for Advanced Aviation System Development
	Parker Aerospace
	Pratt & Whitney
	Raytheon Aerospace
	Rockwell Collins
	Rolls Royce, Liberty Works
	Sierra Lobo
	Sikorsky Aircraft
	The Boeing Company
	University of Alaska
	USfalcon Inc.
	Williams International
	9 individual respondents not representing organizations

3. Coding of Interviews and Written Responses

The STPI research team conducted this analysis using content analytic methods that allowed the team to inductively code and classify the data according to the themes. Data were grouped according to emergent themes to allow for more detailed analysis. Codes were applied to each individual response, which allowed data to be refined and nuances to be drawn out.

For written responses to the RFC, text was the basis for the analysis, combined with notes from follow-up interviews. For input gathered via interviews, notes from the interviews formed the basis for the analysis.

The responses and interviews were coded into several higher level categories: Whether the text dealt with barriers, recommendations, mechanisms, metrics, or success models, and whether they dealt with visibility, industry input into Federal research and development planning, industry access to technology transfer products, innovation, or the utility to industry of National Aeronautics Research and Development plans. Subcodes were created or combinations of those categories (for example, text could be coded as a "mechanism for innovation" or a "barrier to industry input into Federal research and development planning"). Text falling into more than one category (such as a recommendation that applied to visibility and access) was double-coded.

Additionally, success models, several higher level topics such as intellectual property and facilities and infrastructure, and the role of the U.S. Government in the aeronautics enterprise were coded for organizational purposes.

As the interviews were not for attribution, interview notes were rendered anonymous (as far as is possible) in the codebook. Appendix B contains a summary of the coded responses.

D. Report Outline

The study report is organized into seven chapters. Chapter 2 provides context to the study by taking a step back and reviewing the history of aeronautics in the United States. Chapter 3 presents the literature review and the recommendations that emerged from it. Chapter 4 summarizes the barriers to innovation and technology transfer, and Chapter 5 provides examples of best practices to address them, as articulated in the written responses and interviews. Chapter 6 takes a step back again, and examines the barriers in the context of the aeronautics ecosystem. The team's recommendations for the ASTS are presented in Chapter 7, and concluding thoughts are provided in Chapter 8.

Supporting data, including the study protocols and coded responses from all written questionnaires and interviewees are assembled in Appendixes A and B. Appendix C presents data related to R&D funding in the aerospace sector. Appendix E contains historical information on the evolution of aeronautics.

2. History of U.S. Aeronautics

Humanity entered the nineteenth century moving at the speed of an animal-drawn vehicle, about 6 miles per hour. It entered the twentieth century at the speed of a steam locomotive, about 60 miles per hour, and it entered the twenty-first century at the speed of a trans- or intercontinental jet airliner, about 600 miles per hour. Might U.S. aeronautics enter the twenty-second century at 6,000 miles per hour? Critics say no—but such negative prognostications have often proved to be shortsighted. This chapter positions the rest of this report by recapping the history of aeronautics in the United States and highlighting the roles of complacency and risk aversion, topics to which future chapters in this report return. A fuller version of the history is available in Appendix D.

A. American Triumph and Loss

Though the invention of the airplane was a genuine triumph for the United States, the exploitation of the airplane was not. Indeed, in less than a decade after brothers Orville and Wilbur Wright first flew, the United States had lost its lead not only in aeronautics, but also in the aeronautics market share. As with many such "tortoise and hare" stories, the root of this decline began with complacency.

The Wrights, convinced they possessed an insurmountable advantage over any possible rivals, turned from technical development of their craft to the challenge of marketing. In October 1906, Wilbur Wright wrote to fellow aviation pioneer Octave Chanute, "We do not believe there is one chance in a hundred that anyone will have a machine of the least practical usefulness within 5 years." In this judgment, he was wrong; within just 3 years, in fact, European aviation would have caught up with and surpassed that of the United States. When the European nations went to war in 1914, Europe had, respectively by country, 244 Russian, 232 German, 162 French, and 113 British aircraft. The United States possessed but 23 (Kriegswissenschaftlichen Abteilung der Luftwaff 1939, 8−9, Table 3, 106; Hardesty 1998, 22; Weller 1919, 63; Gollin 1989, 307; Hunsaker 1956, 243). In short, the United States, the birthplace of powered, heavier than air flight, accounted for at best only 2.5% of the military aircraft then in service with leading nations. Indeed, even the best-remembered U.S. aircraft contribution to the World War I effort, the Curtiss Model JN "Jenny," was the product of European practice. At best, the Wrights demonstrated to the Europeans the importance of lateral control and rational design.

In addition to simple complacency, there are several notable reasons why the United States fell behind Europe, not least of which is that the U.S. geostrategic position at the time did not generate the same kind of pressures for incorporating new technology into the military that worked to accelerate European aviation. European aviation was also quicker to take advantage of a strong and growing industrial and academic laboratory tradition, characterized by the creation of the first genuine aeronautical research laboratories in France, Germany, Russia, Italy, and England from 1904 onwards. When, at last, U.S. airmen recognized the growing superiority of European practice, the natural tendency was to import foreign machines and airmen and emulate European technology and institutions. Indeed, when in 1915 the United States at last created the National Advisory Committee for Aeronautics (NACA), it copied the *exact* legislative language and even the institutional title of a comparable British committee. Further, government experts had traveled to Europe to study the European laboratory structure at close hand before returning to the United States to attempt to convince Congress to furnish a similar institution in this country. Even so, the fight for a U.S. laboratory took several years and involved overcoming both active and passive opposition as well as continued complacency.

But there were other reasons for the decline as well. The Wrights knew how to make the first airplane. They did not know how to make its successors. In particular, they underestimated how desirable and appealing the positively stable airplane, particularly the tractor airplane, was. They had built an unstable and difficult-to-fly aircraft with a complicated means of takeoff and landing. Yet though they could fiddle with it, relocating its canard elevator to the rear, making it marginally stable, and replacing the takeoff catapult with a wheeled undercarriage, it, at heart, remained at best a derivative of the original 1903 machine. Worse, even as the value of the technology they possessed declined (compared to world standard), they tried to ensure market dominance through a series of lawsuits against foreign and U.S. competitors, charging patent infringement over their means of lateral control. The lawsuits accomplished virtually nothing against the Europeans, and little else except the hamstringing of U.S. aeronautical development. In particular, they accomplished even less against the wily and aggressive Glenn Curtiss, the Wrights' major rival. By the end of 1918, Curtiss designs would account for the vast majority of U.S. military aircraft, with Wright or Wright-Martin airplanes accounting for a much smaller percentage.

Within 15 years of the invention of the airplane, the United States had lost control of its own creation. The European "fast seconds," thanks to their own innovative insight, and aided by U.S. complacency, sequential disinterested administrations, a cost-obsessed Congress, and, worst of all, an enervating series of patent suits, had raced ahead to secure dominant leadership of the aeronautics revolution. Attempts during the war to catch up simply by throwing money at the problem failed miserably. U.S. wartime efforts to match the latest state of the art in aeronautical design failed both in design excellence and in achieving basic production goals.

B. Road to Recovery

Overcoming the European lead took considerable time and required revamping and rebuilding the U.S. aeronautical base, which the United States accomplished over the next approximately 15 years. Several notable developments made the recovery of U.S. aviation possible:

- The establishment of the NACA and the beginning of an indigenous program of rigorous laboratory research.
- The creation of The Daniel Guggenheim Fund for the Promotion of Aeronautics, which expanded U.S. aeronautical engineering education, undertook basic research on the problems of blind flight and safe aircraft design, and undertook demonstrations of airline operation complete with the establishment of a West Coast "Model Air Way" with real-time weather and radio communication and state-of-the-art Fokker trimotor transports.
- A Russo-European aeronautical migration similar to the 1960s and 1970s "brain drain" that witnessed some of the best and most capable individuals in European aeronautics and related fields depart (for various reasons) to the United States.
- The adaptation by U.S. designers of state-of-the-art European thinking in the field of all-metal design and streamlining, which served as a departure point for subsequent U.S. work.
- The regulatory and administrative infrastructure that resulted from key legislation, particularly the Kelly Act of 1925, the Air Commerce Act of 1926, and the Army and Navy 5-year plans of the same time period.
- The rise of "air mindedness" among U.S. citizens in general and children in particular, and the development and implementation of aviation curriculums in primary and secondary schools, together with the widespread proliferation of model airplane building as a youth activity.
- The development of powerful new aero engines, both liquid and air-cooled, together with advances in engine supercharging, fuels, and variable-pitch propeller and engine cowling/nacelle design.
- The use, in the 1920s of high-speed government-sponsored (and, to a lesser extent, privately sponsored) racing aircraft as technology demonstrators blending leading-edge advances in aerodynamics, structures, propulsion, and controls. Virtually all the significant technical developments in the 1920s and 1930s appeared on various air-racing aircraft.

Taken together, these developments acted to quickly reshape and redirect U.S. aviation down an approximately 15-year path of recovery. Here the "fast second" syndrome assisted the United States, which quickly surpassed Europe in the design of commercial aircraft.

But there was another factor as well that had tremendously benefited the transformation of U.S. aviation: the economic climate of the United States after World War I. The strength of the U.S. economy, compared to the war-ravaged economies of the European nations (both winners and losers) enabled a level of expansion and aeronautical investment—particularly commercial and general aviation aircraft production—impossible for others to match. After World War I, the United States, by itself, was responsible for fully 42% of the world's annual industrial output.

By the end of the 1930s, the United States had already emerged as the leading commercial and military air power exporter, selling nearly 40% of its production overseas. Under the Roosevelt administration, exports rose from $9.2 million in 1933 to $627 million in 1941 (equivalent, respectively, to $115 million and $7.6 billion today)—and this despite that the United States was locked in the throes of a severe and enduring economic depression (Vander Meulen 1991, 186, Table 7.2).[8]

The building of that national aeronautical industrial base dramatically benefited the country during the World War II. In that war, U.S. air power would prove of overwhelming significance, and, as well, the U.S. industrial colossus would furnish tens of thousands of aircraft to the Allied cause. This reflected first, the general ability of U.S. technologists and companies to rapidly integrate various cutting edge technologies to a far greater degree than their foreign opposite numbers, and, second, the ability of the United States to build what would today be termed a "system of systems" approach.

This capacity for industrial organization and output might, in fact, be considered the great strength that U.S. aviation possessed, and that it has largely continued to possess to the modern era.

C. Confronting the Turbojet and High-Speed Revolutions

No sooner did the United States catch up and then surpass European practice than Europe advanced again beyond the United States, this time in the area of high-speed flight and, particularly, turbojet propulsion. In fact, the United States was third, behind both Germany and England, while its leading technical establishment, the NACA had little interest in any form of reaction propulsion aside from a short burst of interest over a Secundo Campini-inspired ducted fan propulsion system. Only after Whittle engine technology was imported and used in a U.S. airframe (the Bell XP-59A) would the country enter the jet age, in October 1942, nearly 18 months after England, and over 3 years after

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[8] The value of $1.00 in 1993 was $12.49 in 2001; the value of $1.00 in 1941 was $12.15 in 2001.

Germany. Thus, when the German Messerschmitt 262 appeared in European skies in mid-1944, no equivalent U.S. fighter existed in service that could contest it. Lockheed's P-80, which could have, did not enter widespread service until after World War II. Overall, the United States owed a debt to British engine development. That the NACA had missed the significance of the jet engine was one of the compelling reasons General Henry H. "Hap" Arnold established the postwar Air Force Scientific Advisory Board.

As was the case with the jet engine, the United States lagged badly in pursuing high-speed aerodynamics, particularly the technology of high-speed aircraft design. Again, wartime research went a long way to overcoming deficiencies in prewar research emphasis and direction, but could not completely close the gap. In 1935 and afterwards, U.S. engineers (including von Kármán) missed the significance of the high-speed sweptwing postulated by Adolf Busemann at the Volta Congress on High Speeds in Aviation in 1935. The sweptwing was only taken seriously after its independent rediscovery by Robert T. Jones of the NACA and the subsequent discovery of comprehensive German work amid the rubble of the Third Reich. High-speed wind tunnel development lagged in the United States as well. By 1945, few U.S. supersonic wind tunnels existed. In contrast, Nazi Germany had no less than eight, six exceeding Mach 3 and one exceeding Mach 4.

However, as with the results of the World War I, the post-World War II economic environment was such that the United States continued, and, indeed, even expanded its position as the dominant economic power in the Free World. Such a position put particular demands upon the United States, which launched ambitious multinational defense and aid programs to help Western European and Far Eastern nations, particularly as they faced communist expansionism in both Europe and Asia.

The Vietnam air war constituted a shock to the United States, for many of the combat aircraft systems employed in that conflict suffered from real deficiencies in utility, survivability, and role fulfillment. While much of this performance reflected a combination of poor strategy, political meddling in military planning, poor tactics, and poor training, it reflected as well the price of having overemphasized one model of warfare—nuclear war—at the expense of more conventional conflict. (Today, in the wake of 9/11 and the wars in Iraq and Afghanistan, the United States faces a similar challenge, in possibly overemphasizing special operations and low intensity conflict at the risk of losing its ability to wage wars against high-technology opponents operating increasingly sophisticated systems).

The Vietnam War had a profound impact on all U.S. military services, particularly, military acquisition and training. U.S. combat aircraft of the modern era are the direct result of this experience, the tremendous investment in precision attack, the emphasis upon electronic combat, and, of course, the stealth revolution (the latter inspired, ironically, by a 1967 Soviet paper on wave diffraction that a Lockheed engineer read and recognized as the key to cracking an enemy's integrated air defense network). These developments were made possible by multiple technological revolutions that took place after World War II in the fields of computers, sensor development, new materials, advanced gas turbine propulsion, and advanced electronic flight controls.

Overall, U.S. aviation from 1945 to the early 1970s might be considered to have enjoyed a "Golden Age." Projects proliferated, and numerous companies (now gone or merged) enjoyed healthy, independent existences. Military services operated hundreds, and occasionally thousands, of essentially competing airplanes, and airlines had large and diverse fleets of their own. While there were some glitches—the collapse and then slow recovery of the postwar general aviation market, for example, the tortuous development of the F-111 experimental tactical fighter or the supersonic transport debacle of the early 1970s—the pace of aeronautical research and development ensured that plenty of work was left to do. Aside from the brief threat of the De Havilland Comet airliner, and a briefer threat from turboprop foreign airliners such as the Viscount and Britannia, the U.S. airline market was securely in the hands of Seattle, Washington, and Santa Monica and, to a lesser extent, Burbank, California. Again, this was largely due to the strong national industrial process the United States had first pioneered in the aviation business in the 1930s (a legacy, it may be said, of a strong industry-airline-military partnership of the kind that rapidly grew out of social favor from the 1960s onwards). But it also reflected some weaknesses in U.S. international economic rivals: nations such as Britain and France, despite the brilliance of concepts such as the Viscount, the Comet, or the Caravelle, were not in a position to compete successfully against the United States. Neither was the Soviet Union, except in the field of military systems and space.

D. Impact of *Sputnik*

It is no surprise that the launching of *Sputnik* shook the country's faith in its air and space leadership—indeed, so great was the change in thinking that *Sputnik*, in fact, spawned the word "aerospace," an indication that the world had moved beyond merely the consideration of aeronautics. The result was a complete restructuring of U.S. aeronautical research establishment; aeronautics was out, astronautics was increasingly in. The low-profile, laboratory-focused NACA gave way to the high-profile research center-focused NASA (the difference, wags said, was between NA¢A and NA$A). Then came the Kennedy mandate to go to the Moon in a decade, and the explosive Apollo program, which succeeded, despite the deaths of three astronauts in a prelaunch fire on Apollo I, in placing multiple teams of astronauts in orbit around, and on the surface of, the Moon. But along the way, promising programs were considered and discarded at a rapid rate. The Boeing X-20 Dyna-Soar, a lofted hypersonic boost-glider under development since 1957, was one such victim, cancelled in 1963 and replaced by the Gemini-based Manned Orbiting Laboratory, which was itself cancelled half a decade later. Both of these programs, in retrospect, were deserving of strong support, and might well have dramatically influenced the future course of near-earth orbital operations and capabilities in the United States.

NASA's inheritance of the NACA's aeronautics mission—including key facilities and personnel—meant that the legacy of aeronautics work within the agency was powerful. It was this "legacy engine" that, though slowly winding down, fueled some of the most important contributions NASA made to aeronautics in this time period, including definition of advanced high lift-to-drag wing planforms for sustained supersonic cruise aircraft, configurations for hypersonic winged vehicles, the supercritical wing, the wingtip drag-reducing winglet, and digital flight and propulsion controls. Some of these were transferred into civil and military practice—most notably the supercritical wing, winglet, and fly-by-wire systems. But as more and more of the "aeronautics" centers' work was increasingly devoted to supporting NASA's space mandate, a growing number of NASA engineering professionals (most of whom were NACA veterans) began expressing serious reservations about the ability of the agency to fulfill its aeronautics mandate.

E. Twenty-First Century and Beyond

By December 17, 2003, the time of the centennial of powered, winged flight, the United States was in a different position than it had been in December 1953, at the time of the 50th anniversary of Kitty Hawk.

- *The United States had lost its traditional dominance of long-and-medium-range commercial aviation*. Despite bold visions of future aeronautics, the U.S. commercial industry was sorely taxed. Of the world's top four airliner manufacturers, only one—Boeing—was based in the United States. Flying in 2003, a passenger had only a 50-50 chance of flying a U.S.-built airliner on a transcontinental or transatlantic flight, a situation unknown to U.S. aviation since the invention of the global-ranging airliner.
- *The United States had abandoned the field of regional commercial aircraft design.* The United States was virtually a nonplayer as a regional jet competitor (and it has continued so since). By 2003, a passenger had almost zero chance of flying in a U.S.-built regional airliner. Instead, imaginative, high-performance turbo-propeller and turbofan-powered aircraft produced by a wide range of manufacturers in Sweden, France, Canada, Germany, Brazil, and Great Britain, flourished in U.S. skies—and have continued to do so since.
- *The United States possessed a seriously weakened airline industry.* Post-9/11 airline passenger declines (upwards of 60% after the attacks on the World Trade Center and the Pentagon), cargo traffic reductions (nearly 10% worldwide) and

costs associated with new security measures stressed many carriers (both U.S. and foreign) to the breaking point.

- *The United States had an air traffic control system with an aging infrastructure* and equipment beginning to hinder overall system effectiveness and performance, measured by delays and cancellations. Modernization programs for air traffic control were already forced to compete for scarce post-9/11 funding.
- *The United States had already experienced the collapse of its general aviation industry*. Largely due to predatory legal actions, delivering just 941 aircraft in 1992. Thanks to the General Aviation Revitalization Act of 1994, the country was just beginning to recover from a total loss of its market dominance.
- *The United States had seriously aging military aviation forces.* The average age of the bomber and tanker force was already over 40 years. Eleven Air Force aircraft types were over 30 years of age, and aging fleet problems extended into the "high performance" fighter world as well.[9] New aircraft programs were struggling to receive sufficient funding and numbers, even as foreign aircraft and missile threats proliferate, particularly as global aerospace entered the era of the Super Flanker, the Eurofighter, the Gripen, the Rafale, and the "double digit" surface-to-air missile.
- *The United States already faced an uncertain space future.* Increasingly, new foreign boosters competed with older U.S. ones, often for launching U.S. payloads into orbit.[10] The Space Shuttle's promise of reduced cost and safe and routine access to space had not been met; worse, the future of reusable heavy lift was in doubt following a second tragic loss of a Space Shuttle, the venerable *Columbia,* during re-entry from orbit.[11] Cost pressures resulted in programs being cancelled, and others placed under stringent review.[12] Here too, U.S. market dominance had already been lost.
- *The United States had witnessed the winnowing down of its aircraft industry and workforce.* From a high of 47 aircraft companies that built not quite 300,000

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[9] Twenty years had passed since the vaunted F-117 stealth fighter reached its Initial Operational Capability. Older fighters such as the F-15 (over two-thirds of which were over 21 years of age) were already encountering dangerous age-related problems, including in-flight high-Mach structural failure leading to catastrophic break-ups and imposition of safety limitations.

[10] The United States had to rely on military or commercial derivatives of its first generations of intercontinental and intermediate-range ballistic missiles (Atlas, Thor, and Titan), systems that were already nearly a half-century old by 2003.

[11] Heavy lift to space then cost approximately $450 million per launch or higher for a fully expendable Titan III/IV class booster, and higher still ($600+ million) per partially expendable Shuttle flight.

[12] Such as the X-33, X-34, and X-38.

airplanes in World War II, the industry shrank to just three mega-manufacturers in 2003: Boeing, Lockheed-Martin, and Northrop-Grumman.[13] States that once symbolized the aircraft industry—for example, New York and California—either had a minimal industry left, or had lost their industry entirely. Increasingly, the aerospace industry looked to foreign partnering and even to inviting foreign manufacturers (such as Airbus) to build their products on U.S. soil, with a U.S. workforce.

- *The United States increasingly sought aircraft from abroad.* The last four trainers procured for the U.S. military (the T-45, T-1, T-3, and T-6) have been of foreign origin. As noted, airlines increasingly do the same, particularly with the proliferating Airbus family and products of regional airliner manufacturers. Foreign helicopters were increasingly acquired for business, police, off-shore, news, or casualty/emergency services purposes, even as a possible Presidential transport.
- *The United States had a constantly declining investment in future aerospace research and development funding*. Overall, both Federal and private aerospace research and development funding had been in a steady decline.[14] From the heyday of aeronautical research in the 1950s and the most creative years of space research in the 1960s and 1970s, the air and space research and development establishment was increasingly troubled by internal competition for resources. The traditional partnership of industry, the military services, the old NACA, and the academic community, that so greatly benefited aeronautical development in the pre- and post-World War II era, was gone. Instead, the research community was increasingly pressed between the twin dangers of money taken to support future acquisition of existing programs and money diverted into operational needs.[15] "Overall, reductions in aeronautics research and technology," a 2002 NASA report concluded, "may ultimately have *irreversible consequences* if the United States cedes to foreign competitors the leadership position we have held for the last half of the 20th century."
- *The United States* had growing negative trade balances in areas traditionally thought to be "American," such as semiconductor equipment, computer components,

[13] Aerospace employment plummeted: from 1.3 million in 1989 to 689,000 at the end of 2002—a decline of 47% (Crock 2003).

[14] From 1987 to 2000, Federal and private aeronautical research investment fell from nearly $35 billion to $15 billion, a more than 50% decline.

[15] The classic case, perhaps, is that of the Space Shuttle's effect upon NASA. Another is the breakdown of research dollars within research establishments—the internal competition for resources—and the decline in research investment by industry. Basic R&D investment, as a percentage of net sales, by U.S. companies, ranges between 1% and 10%, and the all-manufacturing average is but 3%. See Tassey (1999, Figure 2 and supporting text).

robotics, and advanced structural materials. They eerily recollect earlier declines in such traditional U.S. industries as steel, shipbuilding, and automobiles.

- *The United States faced serious problems in introducing new or innovated products*. By 2003, programs such as the F-22 and the F-35 Joint Strike Fighter were already seen as reflecting failures in the acquisition process to produce timely, cost-effective, and technologically advanced systems. Critics were already noting that aircraft development times were running counter to a general trend in industry to go from concept to production on an average new product in not quite 2 years (23 months). As one thoughtful observer of the acquisition scene noted, “We cannot afford to have the air and space star hitched to a Model T acquisition system.”
- *The United States faced a critical shortage of trained scientists and engineers, particularly in the Federal Government*, something that continues to be watched carefully if the stewards of U.S. aeronautics are to ensure continued national competitiveness in the years ahead.

These problems have arguably accelerated, rather than eased. In part, this stems from what might be considered social and cultural issues. Air and space no longer has the appeal for U.S. students that it once had. Instead, many young people—are opting for more generalized life sciences and environmental programs, not technological or overtly engineering ones.

F. Summary and Conclusion

Over the last century Americans accomplished much in the air and space fields making the United States truly an “air and space nation.” However, complacency and risk aversion has cost the United States its global leadership multiple times since the invention of flight. The Wright brothers attempted to hold onto their leadership through lawsuits and patents instead of innovation, hamstringing U.S. industry enough that within 15 years after the Wrights’ first flight, the United States had lost not only its lead but also its market share in aeronautics. This happened again before World War II when the aeronautics establishment (including NACA) missed the significance of the turbojet revolution.

Though the United States regained its lead each time, the recovery was not serendipitous. In 1915, for example, the United States copied European language to establish the NACA, imported the European laboratory structures, established the Guggenheim fund to promote aeronautics, imported some of the best European minds, and began using the racing aircraft as a technology demonstrator. While there were some external factors that helped—the aeronautics sector was helped by the strength of the U.S. economy, much better than the war-ravaged European one—the United States was also fortunate to have several strong “czar” figures in a position of continuing authority and direction over national scientific and technological programs. This leadership was a critical factor in the United States regaining its lead.

Despite mistakes and missteps over the years, emerging primarily from complacency, American air and space investment, technology, and examples have become known around the world. But today it would be inaccurate to state that the United States will inevitably remain the unsurpassed leader in the air and space world. Given the seriousness of the challenges, the United States should not be naively optimistic about the future. In the remainder of this report, we focus on these challenges and potential ways to address them.

3. Barriers to Technology Transfer—Literature Review

A. Introduction and Overview

The purpose of the literature review was to distill relevant information in the available literature on technology transfer, technology transition, and innovative business practices, with a focus on aeronautics and other federally funded R&D and technology disciplines. As mentioned in the methodology section in Chapter 1, the literature review addressed two specific questions:

- What are the barriers to Federal technology transfer?
- What are the strategies to increase the effectiveness of technology transfer?

It is valuable to mention that the literature on technology transfer reviewed has largely been separated from the broader literature on research and technology management and innovation studies. Given that technology transfer can be considered a subset of innovation and a part of research and technology management, the research team attempted to supplement the literature review with key findings from those other two sources of literature where appropriate.

The literature shows significant limitations that should be mentioned. There is little literature that specifically deals with technology transfer in the aeronautics sector; much of the work reviewed herein has a broader focus. The literature also predominantly focuses on technology transfer via commercialization, which is only one way in which technology transfer can occur. A key premise underlying much of the literature is the notion of an invention leading to a patent leading to a license agreement with a company that then commercializes a new product. This oversimplifies the reality of technology development and technology commercialization.

Although much of the literature focuses on technology transfer that leads to commercialization through the model above, the Federal laboratories are also responsible for technology transfer that leads to indirect economic and social returns such as the creation of knowledge. As described in Hughes et al. (2011, 12):

> Federal laboratories provide services to other laboratories and agencies, state and local governments, and other governments around the world. Many state agencies depend on the information, products, and capabilities of the Department of the Interior’s U.S. Geological Survey (USGS). The National Oceanic and Atmospheric Administration (NOAA) Earth

Systems Research Laboratory (ESRL) provides instrumentation to the Department of Energy for climate change research. Laboratories also transfer the results of their research to other laboratories or entities within the same agency. Results from basic research performed by the Naval Research Laboratory are often used by applied research laboratories within the Department of Defense. These activities may lead to commercialization of a product further downstream, yet the transfer of technology at the point it leaves the laboratory does not have that commercial focus.

In fact, many of the technology transfer successes from the Federal laboratories do not involve the commercialization model described in the literature. For example, since its establishment in 1862, the Department of Agriculture has developed and transferred technology to the private sector through a variety of mechanisms (e.g., demonstration projects). Such research and technology transfer is generally considered a major driver of the efficiency gains the U.S. agribusiness sector has seen over the past century.[16] These points should be kept in mind while reading this chapter.

The findings from the literature review are organized around the barriers to technology transfer that scholars have found—and best practices or suggestions for overcoming those barriers. These barriers exist because of actions by specific parties at different stakeholder levels, including:

- *Congressional Level*—actions taken by the Congress that can impact technology transfer at the Federal laboratory level
- *Executive Office of the President and Federal Agency Level*—actions taken by the President, the Office of Science and Technology Policy, inter-agency groups, or individual Federal agencies that can impact technology transfer at the Federal laboratory level or technology transition at the agency level
- *Laboratory Level*—actions taken by laboratory leadership and management that can impact technology transfer from their laboratories
- *Technology Transfer Office Level*—actions taken by laboratory technology transfer offices that can impact technology transfer from their laboratories
- *Researcher Level*—actions taken by laboratory researchers and research managers that can impact technology transfer from their laboratories
- *Acquiring Firm Level*—actions taken by the company that is receiving the transferred technology that can impact the transfer

[16] Information from the U.S. Department of Agriculture's Agricultural Research Service, "ARS Timeline," http://www.ars.usda.gov/is/timeline/comp.htm, accessed July 6, 2012.

Barriers are also found at specific stages of the technology transfer process, including:

- *During the Transfer Negotiation Process*—issues that can arise once an industry partner has been found, regardless of the mechanism of transfer, and strategies for overcoming the issues for those mechanisms involving formal agreements
- *Creating Start-ups or Spin-outs*—issues that can arise in transferring technology via start-ups or spin-outs, and strategies for overcoming them
- *Undertaking Joint Research Ventures*—issues that can arise when laboratories and companies undertake joint research projects, and strategies for overcoming them
- *Transitioning Technology*—issues that can arise in transitioning technology to the next stage of development or infusing technology, and strategies for overcoming them

The literature did not provide a one-to-one match between barriers and recommendations; where possible they have been matched or an implied recommendation or barrier has been extracted. The research team did not limit recommendations to those where the ASTS may play a role, but did highlight those specifically at the end of the review. Furthermore, because the literature on the transfer of aerospace R&D was sparse, the research team did not include that as a separate section but instead explicitly marked when a study was focused on aeronautics R&D. Aeronautical innovations tend to involve large complex systems such as air traffic management systems and aircraft, both made up of numerous technologies and requiring system-level integration for technological advancement.[17] It should be noted that studies have shown that the context of these unique engineering systems may require unique policies for optimal implementation.[18]

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[17] One article (Moody and Dodgson 2006) describes complex product systems as involving high costs; long product cycles; participation of several firms in development; high complexity; one large product; organizational users (rather than individuals); policy/regulatory sources; user-driven requirements rather than market-driven needs; an oligopolistic market; a requirement for distinct management capabilities; and a focus on systems integration.

[18] Examples of two large survey studies that compared engineering with life sciences were based on Canadian government-funded research (Landry, Amara, and Saihi 2007a, 2007b) and showed that the differences in technology transfer in engineering and life sciences are significant. Therefore, different policies are needed to increase knowledge transfer in different research fields and to accommodate differences between spinoff formation and patenting.

B. Barriers and Recommendations by Level

1. Congressional Level

a. Overview

Congress has historically played a larger role in Federal laboratory technology transfer than in university technology transfer. Congress sets the budgets for Federal agencies, can set research priorities for the Federal agencies, provides legal authorities for laboratories to engage in technology transfer, provides funding for specific technology transfer initiatives (such as providing funding at the Department of Energy [DOE] specifically for technology partnerships in the early 1990s,[19]) and also plays an oversight role for the laboratories in general.

With respect to planning for aeronautics R&D, the NRC recommended that Congress and the executive branch engage in a national dialogue to articulate national goals in civil aviation (NRC 2006a, 2006b). However, the recommendations for an aeronautics policy predate the NRC 2006 report by several years—most prominently in a 2002 President's Commission report (Commission on the Future of the United States Aerospace Industry 2002). Congress reacted to these reports in the National Aeronautics and Space Administration Authorization Act of 2005 and the Science, State, Justice, Commerce, and Related Agencies Appropriations Act of 2006, which magnified the need for a policy by calling for "the development of a national policy to guide Federal aeronautics R&D program through 2020" (NSTC 2006). Executive Order No. 13419 established the National Aeronautics Research and Development Policy published in December 2006 and called for its implementation. As a result, goals for civil and military aeronautics established in the National Aeronautics Research and Development Plan have been updated biennially.

b. Barriers

One recent study states that congressional support for technology transfer and commercialization programs has been considered unpredictable and insufficient by technology transfer professionals working in the Federal laboratories (Hughes et al. 2011). These professionals felt that commercialization priorities from Congress changed quite often, leading the laboratory leadership to not be able to plan for the future. In that same study, technology transfer professionals said that congressional oversight on

[19] Starting in FY 1991, Congress provided funding for the Technology Partnership Program at the National Nuclear Security Administration laboratories and the Technology Research Program at the Office of Science laboratories; both were phased out by FY 2003 (GAO 2002b).

technology transfer can lead to a risk-averse culture both in the laboratory generally and in the technology transfer office specifically (Hughes et al. 2011).

Congress set in place the authority for Federal laboratories to engage in technology transfer through several acts of legislation but most broadly and more recently through the passing of the Stevenson-Wydler Technology Innovation Act of 1980 that established technology transfer offices at the large Federal laboratories and pronounced that, “technology transfer, consistent with mission responsibilities, is a responsibility of each laboratory science and engineering professional” (15 U.S.C. § 3710(a)(2)). Despite this, some studies have argued that the missions of Federal laboratories are not conducive to transferring technology to industry (Spivey et al. 1997), and that without an explicit mission, laboratories will not adequately commit resources to accomplishing it (Papadakis 1995). In the past, suggestions have been made to more fully redirect Federal laboratories to support industrial competitiveness (U.S. Congress 1993; Missions of the Laboratories Priority Team 1993). Others have specifically commented that the way in which the aeronautics laboratories disseminate information is based on a framework of “information-seeking” scientists as opposed to an engineering framework, leading to difficulties in the transfer to industry (White 2001).

At a more operational level, an oft-cited barrier to Federal laboratory technology transfer is the inability for Government-Owned, Government-Operated (GOGO) Federal laboratories to copyright software, which would provide instantaneous protection upon invention (Gillespie 1988; Erlich and Gutterman 2003; Hughes et al. 2011). Government-Owned, Contractor-Operated (GOCO) laboratories are able to copyright software, and cite it as a technology transfer mechanism of great utility, especially as increasingly more research relies on software. This is crucial because exclusivity is important for commercialization (Hughes et al. 2011). However, while GOGOs are able to secure patent protection for software, it is a slow process unsuited to the fast-paced software industry, making patents of limited utility if the software is obsolete or has limited application potential by the time a patent has been secured.

c. Recommendations

In a study from the 1990s, a GAO report recommended that Congress more specifically define what invention income can be used for (GAO 1993b), suggesting that if more licensing revenue were returned to the laboratory for research, laboratory directors would be incentivized to support technology transfer activities. Note that this suggestion is focused on the commercialization model of technology transfer. Federal agencies may regard other forms of technology transfer as a primary mission.[20]

A dedicated source of funds for technology transfer from congressional appropriations has also been recommended by technology transfer professionals (Hughes et al. 2011). Although this could also be done at the laboratory level, congressional authorization and requirements might ensure cross-agency and cross-laboratory action.

2. Executive Office of the President and Federal Agency Level

a. Overview

The Executive Office of the President can create priorities for technology transfer, manage the Federal agencies in implementing technology transfer, and facilitate cross-agency coordination, among other things. One example of Presidential involvement in technology transfer is the October 28, 2011, Presidential memorandum that directed agencies to undertake a number of actions to accelerate technology transfer and commercialization (Presidential Memorandum 2011).[21]

Federal agencies translate congressional and Presidential priorities for research and technology transfer into actual implementation. Federal agencies may have their own specific mechanisms for coordinating technology transfer across their Federal laboratories, perhaps including a specific technology transfer coordinator, and may have specific funding for technology transfer and commercialization activities. Reporting of technology transfer outputs occurs at the Federal agency level. Thus, an agency influences the culture of technology transfer throughout the agency, and, in many agencies, the emphasis has changed over time. For example, the NASA technology transfer program emphasized technology utilization and spinoffs from the space industry through wide dissemination of scientific and technical information and technology briefs. More recently, the agency practices more proactive technology transfer through innovative partnerships, seed capital, and nationwide calls to address key agency mission requirements. The focus of the literature on the agency's technology transfer has changed with these trends. Seely (2008) and others have written about the history of the NASA technology transfer program. McMillan (2008) addressed how tools such as Business

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[20] For reference to royalty legislation, see 15 U.S.C. § 3710c, http://www.gpo.gov/fdsys/granule/USCODE-2011-title15/USCODE-2011-title15-chap63-sec3710c/content-detail.html.

[21] The memorandum charged all Federal agencies with accelerating technology transfer activities, and, thus, the benefits of federally funded research and development investments. It also required that agencies submit plans on their goals and measures of progress and that the Office of Management and Budget, in consultation with OSTP and the Department of Commerce, review and monitor implementation of the plans.

Process Re-Engineering were used strategically to reinvent the technology transfer program, and Comstock (2008) has written about the new program's best practices, noted in various sections that follow.

b. Barriers

Little of the literature reviewed focuses on the role that Federal agencies play in the technology transfer process (although a few studies look at inter-agency technology transition). One study, from the early 1980s, claimed that a lack of interagency program consistency and a lack of interagency coordination and cooperation on technology transfer efforts were barriers to technology transfer (O'Brien and Franks 1981). This may be a barrier that has been overcome or at least ameliorated by interagency efforts such as the Interagency Working Group on Technology Transfer (IWGTT) and the Federal Laboratory Consortium for Technology Transfer (FLC). The same study also remarked on the lack of coordination at the agency level with user needs and the lack of dissemination of research results to non-Federal stakeholders (O'Brien and Franks 1981). Other agency-level barriers that have been corroborated in more recent studies are the lack of agency commitment for nonmission resources (O'Brien and Franks 1981; Bozeman and Crow 1991; Spivey et al. 1997; Hughes et al. 2011). A study of some FLC laboratories found that lack of agency support was a major barrier to commercialization activities (Chapman 1994). Finally, agencies may put in place conflict of interest policies that restrict government scientists and engineers from engaging in entrepreneurial activities, including consulting work, or participating in start-ups—barriers in the commercialization model of technology transfer (Markusen and Oden 1996; Erlich and Gutterman 2003; Hughes et al. 2011).

Although not a barrier to technology transfer itself, the lack of formal evaluations of technology transfer by agencies has prevented a better understanding of which factors and activities are effective in technology transfer (O'Brien and Franks 1981; Hughes et al. 2011). In fact, most agencies cannot provide a definition of a successful technology transfer, which is directly reflective upon the lack of successful technology transfer metrics (Hughes et al. 2011). The technology transfer metrics that are collected from all R&D agencies and reported by the Department of Commerce focus primarily on output and do not provide information about how well partnerships are working and information that is provided about downstream outcomes and impacts is inconsistent.[22] Several related studies suggest that the agencies may want to examine how their own government-sponsored research partnerships are different from other strategic research partnerships (Bozeman and Dietz 2001; Pertuze et al. 2010; Hughes et al. 2011).

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[22] The annual reports for several years are available from the National Institute of Standards and Technology website, http://www.nist.gov/tpo/publications/federal-laboratory-techtransfer-reports.cfm.

The agencies have agency-specific rules and regulations for interacting with external users and these affect their performance in technology transfer. For example, the NASA Aeronautics Research Mission Directorate (ARMD) has a history of irregular dealings with industry users due to changing regulations and the difficulty of reaching union users, such as air traffic controllers, through FAA. The technology transition and implementation process is bifurcated in civil aeronautics, with FAA regulating and buying into new technologies, while other end users purchase the technologies—including FAA, DOD, and local airport authorities.

c. Recommendations

With respect to conflict of interest policies, at least one study recommended that agencies could clarify them and increase their flexibility in the case of scientists and engineers attempting to work on technology transfer (Markusen and Oden 1996). A recent presentation from the FLC implies that the IWGTT intends to explore this issue with the Office of Government Ethics (Zielinski 2012).

A GAO report stated the importance of explicitly articulating agency-wide goals with respect to technology transfer and setting of performance metrics (GAO 2009). In a 2004 study of NASA's technology transfer, Toregas et al. (2004) recommended that NASA develop a comprehensive system for evaluating its technology transfer efforts, considering both outputs and longer-term impacts of NASA technology transfer.

GAO has also recommended that agencies develop a means to share information about research results across laboratories and with non-Federal parties (GAO 2009); this was also reflected in the Presidential memorandum that directed agencies to develop online portals to showcase available technologies (Presidential Memorandum 2011). Note that NASA recently revamped its online technology transfer portal.[23]

A National Academies committee tasked to make recommendations for facilitating and accelerating aeronautics innovation said the ARMD should cultivate close relationships with external partners, and work aggressively to solidify its own reputation as a trustworthy reliable partner (NRC 2006a). The committee said that the FAA NextGen Joint Planning and Development Office may be a model for ARMD technology management.

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[23] The portal is available at http://technology.nasa.gov/.

3. Laboratory Level

a. Overview

Federal laboratories themselves are the home for the research to be transferred, and certain laboratories can perform both in-house work and work contracted from industry. A range of success factors have been associated with innovations from Federal laboratories, in general, including intellectual property protection, market/technology readiness, and expected profitability (Heslop, McGregor, and Griffith 2001).

Federal laboratories set the incentives, contain the culture, and provide the resources for technology transfer to occur. Industry will turn to the Federal laboratories when seeking research results, and the laboratories themselves are located in regional innovation systems that will affect the ability of technologies to be transferred from the laboratory. Many laboratories participate in local/regional economic development initiatives, undertake science, technology, engineering, and mathematics (STEM) educational outreach to area schools, and provide small businesses technical assistance services. These activities have been shown to help laboratories further reach potential technology users (Innovation Associates 2003).

b. Barriers

The nature of research undertaken at a Federal laboratory may itself be a barrier to technology transfer. The GAO has noted that basic research may not be suitable for commercialization, and is more effectively transferred through publications (GAO 2006). Some of the Federal laboratories may also undertake a fair amount of classified research that is not amenable to usual forms of technology transfer (GAO 2006), or the presence of such research can also lead to the laboratory having a secretive culture that is not conducive to widespread transfer (Markusen and Oden 1996).

Some experts believe that the overall laboratory system for federally funded research in aerospace is "oriented toward the information seeking behavior of scientists than that of engineers, and may be ineffective as a result" (Pinelli et al. 1997). Policy expectations of commercial impacts are inconsistent with policy requirements that laboratories conduct pre-commercial basic and applied research. And because of this set-up, "there is no reason to believe that the current Federal laboratory system can directly enhance U.S. competitiveness" (Papadakis 1995).

Other cultural and behavioral issues that can inhibit technology transfer include laboratory management discouraging employees from leaving the laboratory for a start-up venture because of the difficulty in hiring staff or a desire to maintain budgets (Markusen and Oden 1996); laboratory line managers avoiding invention reports if they believe the patenting costs will take away from their budgets (GAO 1993b) or they have an overall view of technology transfer as consuming R&D funds (Spivey et al. 1997); and laboratory management in general not monitoring technology transfer activities (Franza and Grant 2006; Hughes et al. 2011).

Most of the research undertaken at Federal laboratories is of a basic or applied nature and is far from commercialization. Many laboratories often do not have specific funds for further development of technologies to a point that they would be of interest to an industry partner (Brown 1997; GAO 2009; Hughes et al. 2011). This may be less of a problem in the DOD, where specific processes are in place for transitioning technologies. The NASA technology transfer program has an annual Seed Fund Call for Proposals, distributed to the NASA research centers, for joint development of technology of mission interest to NASA. The call solicits proposals for cost-shared partnerships with industry, universities, national laboratories, and other agencies—and is developed in coordination with all its mission directorates.

In their study of start-ups emerging from Federal laboratories, Carayannis et al. (1998) noted that the geographical isolation of some Federal laboratories was a barrier for entrepreneurs, as they did not have access to the financial and legal services, suppliers, and other parties that are present in more populous regions (Carayannis et al. 1998). Markusen and Oden noted a similar finding in their study (1996). In terms of laboratories working with entrepreneurs and small businesses, it should be noted that NASA and DOD laboratories have the option to make themselves available as partners to small firms through the Small Business Technology Transfer (STTR) program.[24] The STTR program is similar to the Small Business Innovation Research (SBIR) program, but requires that the small business team with a Federal laboratory or university.[25] Both programs have been studied and discussed extensively in the literature, but they are coupled together in most analyses.[26] While it is easy to distinguish outputs for each program separately in those studies, they do not identify outcome-related findings that are related to the STTR program only.

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[24] Only departments and agencies whose R&D budgets exceed $1 billion participate in the STTR program. The DOD, DOE, Department of Health and Human Services, NASA, and National Science Foundation are required to reserve 0.3% of their extramural R&D budgets for STTR awards.

[25] The SBIR and STTR programs differ in two major ways. First, under SBIR program, the principal nvestigator must be primaryly employed with the small business concern at the time of award and for the duration of the project period; however, under the STTR program, primary employment is not stipulated. Second, the STTR program requires research partners at universities and other nonprofit research institutions to have a formal collaborative relationship with the small business concern. At least 40% of the STTR research project is to be conducted by the small business concern and at least 30% of the work is to be conducted by the single, "partnering" research institution (http://grants.nih.gov/grants/funding/sbirsttr_programs.htm).

[26] NRC (2000) is an example of a best-practice study.

c. Recommendations

Several studies have recommended specific technology maturation funds to further early-stage technologies to the point that they are more easily transferred (Carr 1992; Hughes et al. 2011). Others have suggested that in order to raise the visibility of technology transfer and to change the culture of the laboratory to be friendlier to technology transfer that laboratories should appoint a technology transfer/industrial relations professional to report directly to the laboratory director (Markusen and Oden 1996). In order to be more aware of which technologies might be appropriate for transferring, studies have recommended undertaking a review of laboratory publications before they are published to see if there are inventions that should be protected (GAO 2009), and to proactively scan laboratory research to look for commercial opportunities (Markusen and Oden 1996; GAO 2009)—perhaps by using local business students as "technology scouts" (Carr 1992; Meyer et al. 2011). Third-party organizations known as "partnership intermediaries" have supported Federal laboratories through many of the above activities (Swearingen and Dennis 2009). For example, the Navy facility at Patuxent River in Maryland has worked with intermediaries to establish networks of community partners in aviation (Innovation Associates 2003).

Yet others have suggested that, for laboratories to contribute to competitiveness, they must have more explicit missions to do so (Papadakis 1995).

4. Technology Transfer Office Level

a. Overview

The Technology Transfer Offices (TTOs)—or Offices of Research and Technology Applications (ORTAs), as they are officially known at many laboratories—are interfaces between industry and the laboratory during the technology transfer process. The roles and responsibilities of the TTO are many and varied. Technology transfer requires professionals who are well versed in technology, business, and law, and who are committed to making deals happen.

b. Barriers

Since ORTAs were formally established by law as part of the Stevenson-Wydler Technology Innovation Act of 1980, technology transfer as a profession is a relatively new career path for Federal employees. Some studies have found that a lack of expertise within technology transfer offices has been a barrier to effective technology transfer (Spann, Adams, and Souder 1993; GAO 1993a). Perhaps due to this lack of expertise, another stated barrier is that TTOs may not market technologies to the most relevant industries (Franza and Grant 2006). A more recent STPI study on Federal technology transfer professionals found reason to doubt whether the lack of TTO professional expertise is still true today (Hughes et al. 2011). A more commonly cited barrier is the relative underfunding of technology transfer offices and activities within Federal laboratories relative to the level of expectations (Tran and Kocaoglu 2009; Hughes et al. 2011). For this reason, a number of TTOs make use of tools to assist their tasks like software to manage complex technology transfer projects and track technologies being transferred, or systems to organize requests for assistance coming in from industry (Zurcher and Kostoff 1997; Harper and Rainer Jr. 2000). Federal laboratory technology transfer officers must also abide by strict legal requirements in developing technology transfer agreements; this has been cited as causing industry to be wary of working with the laboratories (GAO 2009; Hughes et al. 2011).

Similar to the Federal agency level, TTOs themselves often do not set goals and performance measures to monitor their performance (Spann, Adams, and Souder 1993; Hughes et al. 2011). At the laboratory level, most performance measures focus on output (such as counts of Cooperative Research and Development Agreements [CRADAs] and patents) rather than the effectiveness of those mechanisms or downstream outcomes and impacts (Hughes et al. 2011).

c. Recommendations

A study of NASA's technology transfer recommended that performance time standards be developed for patents, licenses, and partnerships (Toregas et al. 2004). Spann et al. recommended that TTOs set objectives for each technology transfer project and manage projects to meet those objectives (Spann, Adams, and Souder 1993). The use of impact-based metrics and measures of effectiveness of actions as opposed to counts of output has also been suggested (Hughes et al. 2011; Pertuze et al. 2010). The GAO recommended more formalized and standardized procedures for timely and consistent selection of which inventions to patent (GAO 1993b).

5. Researcher Level

a. Overview

Researchers are themselves the source of the technology and knowledge that is to be transferred to industry. One study (Galbraith, Ehrlich, and DeNoble 2006) showed that they are a good source for predicting future technology success during the laboratory technology review process. However, researchers work within an overarching framework of incentives, culture, and rules and regulations when it comes to performing research and transferring its results. A fair amount of literature has focused on the motives of scientists and engineers to invent and to be involved in the transfer process, either by working with industry or by becoming entrepreneurs themselves.

b. Barriers

It is important to note that much of what follows is focused on the commercialization model of technology transfer. Many of the barriers to technology transfer at the researcher level focus on the lack of researcher knowledge in this sphere. Brown found that Federal laboratory scientists and engineers do not have business acumen (Brown 1997); while Markusen and Oden (1996) discovered that scientists and engineers do not have exposure to business drivers. In the process of doing research, scientists and engineers may not know what constitutes an invention with commercial potential (Greiner and Franza 2003; GAO 2009). A recent report by the NASA Office of the Inspector General (NASA 2012a) provided examples of lack of knowledge at the researcher level leading to missed opportunities, including:

> Algorithms designed to enable an aircraft to fly precisely through the same airspace on multiple flights—a development that could have commercial application for improving the autopilot function of older aircraft—was not considered for technology transfer because project personnel were not aware of the various types of innovations that could be candidates for the program.
>
> Project personnel failed to capitalize fully on a unique NASA facility used for aeronautic testing services, the Flight Loads Laboratory at Dryden, and had to turn down commercial requests, because they did not recognize the facility as a transferable technology and consequently had not developed a Commercialization Plan to manage growing customer demand.
>
> Project personnel did not form partnerships with industry end-users who are a potential source of funding because they did not realize that transfer and commercialization planning could lead to such partnerships. As a result, managers of a precision landing and hazard avoidance project failed to seek commercial partnerships that could have provided additional funding to help the project mature.

Barriers inhibiting scientists and engineers from becoming entrepreneurs themselves have been traced to a lack of knowledge of the process of starting a company (Carayannis et al. 1998; Riggins and London 2009) and a lack of incentives to become entrepreneurs (Markusen and Oden 1996; Carayannis et al. 1998).

The research culture at the laboratory may also discourage researchers from moving between the laboratory and industry (Markusen and Oden 1996), and financial incentives for inventions may be insufficient to financially motivate scientists and engineers (Hughes et al. 2011; GAO 1993b).

c. Recommendations

Many studies have recommended that researchers be further educated about the technology transfer process (Carr 1992; Erlich and Gutterman 2003) and also about the key business drivers of potential technology adopters (Spann, Adams, and Souder 1993). For those laboratories that are geographically isolated, it is recommended that business courses be taught on site, allowing researchers to attend with minimal burden (Markusen and Oden 1996).

To incentivize entrepreneurship, Carayannis et al. (1998) recommend the use of entrepreneurial leave policies in which researchers are guaranteed their position within a certain amount of time after leaving. Others have recommended that employees should be allowed to consult for the laboratory or work part-time while they also work to launch their start-up (Markusen and Oden 1996; Carayannis et al. 1998).

Some suggest that scientists and engineers should be encouraged to develop commercial technologies, and be given "corporate time" in which to work on their transfer projects (Franza and Grant 2006; NRC 2006a). Although the law states that technology transfer should be used as a measure in Federal laboratory researchers' performance evaluations, this is not often implemented (Hughes et al. 2011), and studies have suggested that it be more rigorously be used (Erlich and Gutterman 2003; Hughes et al. 2011). A study of NASA's technology transfer recommended that performance standards be developed for all individuals involved in technology transfer (Toregas et al. 2004). Finally, the GAO has recommended that inventors be more adequately rewarded (GAO 1992). The NRC Committee on Innovation Models for Aeronautics Technologies strongly recommended more flexible personnel practices be instituted at NASA's ARMD to help promote technology transfer and transition, including personnel rotation such as at Defense Advanced Research Projects Agency, for example); fostering external customer contact throughout careers; and allowing some fraction of time for free thinking and presentation at employee idea fairs that attract external stakeholders. The committee recommended that the directorate should pilot a dual-track pay-for-performance program similar to that in place at the Air Force Research Laboratory (NRC 2006a).

6. Acquiring Firm Level

a. Overview

Little of the literature is focused on the motives and needs of the firms that take on technologies from the Federal laboratories, despite that the firms are a key player in the technology transfer process.

b. Barriers

Several researchers have found that industry is generally not aware of the activities, expertise, and available technologies of the Federal laboratories (Gillespie 1988; Spann, Adams, and Souder 1993; Erlich and Gutterman 2003; Hughes et al. 2011). This is especially a problem for small businesses that may not have the established networks and resources to connect with the laboratories (Spann, Adams, and Souder 1993; Hughes et al. 2011).

Once a firm is aware of the laboratories, there may be additional barriers to transfer. Industry has been noted as having a “not invented here” attitude and is reluctant to bring in new technologies from outside (Gillespie 1988; Spann, Adams, and Souder 1993). Schoening and Spann (1997) also studied companies transitioning from being defense contractors to commercial companies during a period of defense funding cuts, and found that the successful companies shared such characteristics as, for example, spending more on internal R&D and marketing and being manufacturers or technical service providers rather than research firms.

Others have noted that the lack of connection between government and industry may be less prevalent in recent years as the concept of “open innovation” has been embraced (Perkmann and Walsh 2007). Either way, it helps to have a “technology champion” in the receiving firm (Rubenstein, Geisler, and Abeysinghe 1997). In developing a transfer agreement with the Federal laboratories, industry is often wary of the government rights to the intellectual property (Spann, Adams, and Souder 1993; Hughes et al. 2011).

Once a firm has taken on a technology from the Federal laboratories, there are additional barriers to commercialization. The acquiring firm may not have a business or commercialization plan for the technology or they may not devote sufficient resources to develop the technology (Franza and Grant 2006). Kremic (2003) explores the differences in motives between government and corporations and how these need to be considered when engaging in technology transfer (Rubenstein, Geisler, and Abeysinghe 1997).

c. Recommendations

In general, the literature on both technology transfer and R&D management makes it clear that engaging stakeholders and industry users is a particularly important element of successful innovation. To provide more visibility to the Federal laboratories, Spann, Adams, and Souder (1993) recommend that laboratories do more marketing to industry, while others have recommended developing a web portal to showcase available technologies (Hughes et al. 2011; Presidential Memorandum 2011). To alleviate fears about intellectual property rights, the laboratories should educate potential industry partners about the technology transfer process (Spann, Adams, and Souder 1993). Informal technology transfer processes and sharing personnel may also build trust between the laboratory and industry researchers (Franza and Grant 2006). The use of intermediary organizations has also been recommended (Kremic 2003; Hughes et al. 2011).

To increase the likelihood of commercialization, Franza and Grant (2006) recommend that the acquiring firm develop a commercialization plan and ensure a complementary match between the technology and the existing operating units of the business. The importance of complementarity has been echoed in a recent study of university-industry partnerships (Pertuze et al. 2010). The same study also recommended that companies build broad awareness of ongoing joint research ventures so that the researchers (both industry and university) are given feedback on project alignment with company needs.

C. Barriers and Recommendations by Stage of Technology Transfer

The previous section focuses on the players involved in Federal laboratory technology transfer, highlighting barriers that generally affect many different types of technology transfer. This section focuses on specific types of technology transfer, as these can have unique barriers that involve multiple players. The barriers and recommendations listed here highlight that technology transfer involves complex multi-actor activities influenced by many factors, and they reinforce the idea that collaboration among all actors is needed.

1. During the Transfer Negotiation Process

a. Overview

Once an industry partner is engaged with a Federal laboratory, a formal agreement can be arranged to set up a joint research project, license a patent, or otherwise set in place the transfer of technology. Often this process requires the negotiating of an agreement. Studies have uncovered problems in this negotiation process that inhibit efficient and effective technology transfer.

b. Barriers

Some studies have found that the negotiation process takes too long for industry (Markusen and Oden 1996; Bozeman 2000); and that the negotiation is often over specific clauses that must be included in government agreements (Hughes et al. 2011). These clauses are shown on the next page. When agencies have an overly centralized process, requiring signatures from agency headquarters, agreements can also be slowed down (Hughes et al. 2011; GAO 1993a). Technology transfer offices may not include the inventor when developing the transfer strategy and this may cause the TTO to seek inappropriate transfer mechanisms (Toregas et al. 2004; Franza and Grant 2006; Galbraith, Ehrlich, and DeNoble 2006). Others have said that laboratory TTOs may only look for an agreement with large firms, in the hopes of attracting funds to the laboratory through a "funds-in" CRADA (Markusen and Oden 1996).

a. Recommendations

Markusen and Oden (1996) suggest that Federal laboratories should streamline their licensing procedures to speed up negotiation times. Shorter, easier-to-use forms for small businesses have been suggested and implemented by some laboratories (Erlich and Gutterman 2003; Hughes et al. 2011). To increase the likelihood of success in reaching an agreement, close contact and frequent communications between partners is also suggested (Amesse et al. 2001; Franza and Grant 2006). The use of partnership intermediaries in the transfer negotiation process to facilitate communication and resolve any problems that could arise in the process has been noted in the literature (Hughes et al. 2011; Swearingen and Dennis 2009).

Selected Federal Technology Transfer Contract Terms

Required by statute:

Royalty-free license to practice (or "government-purpose rights"): The government is required to preserve a license to practice or have practiced on its behalf patent licenses or licenses stemming from CRADAs (15 U.S.C. § 3710a(b)(2)).

Rights to compel a license: If the patent licensee has not taken effective steps toward application, and the invention is necessary to alleviate health or safety needs or meet requirements for public use, the government may use its rights to compel the contractor to grant a license to the invention to a responsible party (15 U.S.C. § 3710a(b)(1)(B)-(C)).

Recommended by statute:

U.S. manufacturing preference: The laboratory director in deciding what cooperative research and development agreements to enter into shall give preference to business units located in the United States which agree that products embodying inventions made under the cooperative research and development agreement or produced through the use of such inventions will be manufactured substantially in the United States and, in the case of any industrial organization or other person subject to the control of a foreign company or government, as appropriate, take into consideration whether or not such foreign government permits United States agencies, organizations, or other persons to enter into cooperative research and development agreements and licensing agreements (15 U.S.C. § 3710a(c)(4)(B)).

Preference for small businesses: The laboratory director in deciding what cooperative research and development agreements to enter into shall give special consideration to small business firms, and consortia involving small business firms (15 U.S.C. § 3710a(c)(4)(A)).

Common terms:

Product liability insurance: The participant (or the contractor for GOCO laboratories) agrees to purchase and maintain adequate product liability insurance to protect the government (and the contractor for GOCO laboratories) against product liability claims.

Indemnity: Participant agrees to indemnify the government (and defend the contractor if a GOCO) against any claim or proceeding and pay all damages, costs, and expenses, including attorney's fees, arising from personal injury or property damage occurring as a result of the making, using, or selling of a product, process, or service by or on behalf of the participant, its assignees, or licensees, which was derived from the work performed under this CRADA.

Source: Hughes et al. (2011).

2. Creating Start-Ups/Spin-Outs

a. Overview

As many of the technologies developed at Federal laboratories are in the early stage of development, firms may be reluctant to license them, given the amount of further development needed to understand if there is commercial potential. Disruptive technologies may also be difficult to license, as organizations may not have existing product lines with which to absorb the technology. Thus, some technologies emerging from the laboratories may be more suitably transferred via a start-up or spin-out firm. This form of entrepreneurship is also recognized as a strategy for creating a regional innovation system.

b. Barriers

Two major barriers to creating start-ups from Federal laboratories are found in the literature. The first is that Federal laboratory scientists and engineers face more strict constraints than do academic researchers in being involved in a start-up, either directly or via consulting (Markusen and Oden 1996; Hughes et al. 2011). Even entrepreneurial leave policies that have been developed to encourage researchers to form start-ups may not be suited to successfully starting a new venture, due to intellectual property restrictions and other features (Markusen and Oden 1996). The second major barrier is that there is a lack of venture funding for early-stage start-ups (Markusen and Oden 1996; Carayannis et al. 1998; Hughes et al. 2011). A less commonly mentioned barrier for start-ups is the lack of affordable space for start-up ventures (Markusen and Oden 1996).

c. Recommendations

Several recommendations have been made for Federal laboratories to support start-ups. Using local business school students to help scientists and engineers to form business plans for their start-ups or commercialization plans for their technologies has been observed (Carayannis et al. 1998). The laboratory can also help in the form of CRADAs or technical assistance programs (often funded by the state or region) to further test and develop the technology (Markusen and Oden 1996; Carayannis et al. 1998). To raise the visibility of start-ups with the hopes of garnering venture funding, laboratories can sponsor venture capital forums that bring inventors and investors together (Markusen and Oden 1996). Laboratory participation in these forums is said to bring credibility to the events (Innovation Associates 2003). Laboratories can also work with regional economic development organizations to leverage economic development programs, funds, and relocation incentives for the parties involved (Markusen and Oden 1996; Hughes et al. 2011). Some laboratories have donated buildings or offered incubator space for start-ups (Markusen and Oden 1996; Carayannis et al. 1998). Other laboratories have established research parks to house businesses and public-private collaborations (NRC 2001; NRC 2002; Innovation Associates 2003). The Ames Research Park at NASA's field center in California—Ames Research Center—is a science and technology park that brings together high-tech companies and universities. A unique feature of this research park is that it was not necessarily established for regional economic growth and "outward technology transfer," but rather to enable NASA to achieve its mission through access to technological capabilities external to the agency.

3. Undertaking Joint Research Ventures

a. Overview

Joint research projects between industry researchers and Federal laboratory researchers are another way in which technology can be transferred between laboratories and industry. The literature contains case studies of joint research projects (often done through the CRADA mechanism), and offers insights into some of the challenges that these projects can face. As an example, a CRADA between FAA and Boeing Corporation established the National Airport Pavement Test Machine at the FAA's William J. Hughes Technical Center (DOC 2012).

b. Barriers

Collaboration on joint research projects can be a problem, especially if the parties are geographically separated (Franza and Grant 2006). Industry has complained that laboratory researchers do not fully understand their needs (Tran and Kocaoglu 2009). Industry partners are also often concerned that intellectual property that they divulge as part of the project may be shared with third parties, and are especially worried about competitors (Spann, Adams, and Souder 1993). Laboratories, on the other hand, have stated that the lack of dedicated funds for CRADAs prohibits them from taking on cooperative research with industry (GAO 2002a; Hughes et al. 2011). Because of the uncertainty of research outcomes, negotiating intellectual property rights in setting up a CRADA can also be difficult (GAO 1993a).

c. Recommendations

Sharing personnel across the laboratory and industry has been recommended as a way to increase familiarity of both user needs and researcher capabilities. (Franza and Grant 2006; NRC 2006a; Tran and Kocaoglu 2009; Pertuze et al. 2010). One study recommends appointing a dedicated boundary-spanning project manager to work across the teams (Pertuze et al. 2010). A high degree of commitment and continuous interaction, with face-to-face meetings between the teams on a regular basis, is recommended even if personnel exchanges are not possible (Tran and Kocaoglu 2009; Pertuze et al. 2010).

Ham and Mowery (1998) examine five case studies of CRADAs and recommend that successful CRADAs should include: (1) incentives that ensure commitment; (2) awareness by laboratory researchers of the needs of the company; (3) flexibility to reduce missteps in executing the project; (4) using CRADAs only in areas that are consistent with capabilities of the laboratory. Laboratories should be given more budgetary and managerial flexibility in implementing CRADAs so that they may adjust as the project progresses (Tran and Kocaoglu 2009). Also, the industry partner should ensure that sufficient internal R&D expertise exists so that the results of the collaboration can be properly absorbed (Tran and Kocaoglu 2009).

Note that public-private R&D partnerships are another mechanism for transferring technologies. They involve cooperative R&D activities among government laboratories, industry, and universities who work together to bring innovations to the point where the private sector can introduce them to the market. Experience shows that such R&D partnerships work and contribute to national missions (NRC 2002). A National Academies 2002 report summarized a series of best practice studies of public-private partnerships, including, as an example, the Department of Transportation's Intelligent Vehicle Highway Systems program (NRC 2002).

4. Transitioning Technology

a. Overview

Aeronautics programs, both weapons systems and civilian projects, involve a form of technology transfer that the Federal aeronautics agencies perform. The movement of these program technologies from the laboratory into a fielded system is known as "technology transition" (or sometimes "technology infusion" when a single agency is involved). Barriers to technology transition are different than the barriers to other forms of technology transfer. Less has been written in the academic literature about the challenges in technology transition; the GAO and other oversight and advisory organizations such as the NRC have performed most of the available studies.

b. Barriers

Many of the problems in technology transition have been found to be due to a lack of effective management. Programs do not often engage in strategic planning to identify user needs (GAO 2006). A key issue relates to the difficulty in defining the transition path from basic research to implementation, and the communication between partners about that (NRC 2008a). Transition programs often lack effective selection, management, oversight, and assessment procedures (GAO 2005). Similar to the early stage technology problem in transferring technologies from the laboratory to industry, moving technologies along the transition pipeline can be impeded by a lack of technology maturation funds, especially when moving between agencies (GAO 2011). For example, NASA may have limited funding to move a technology past fundamental research when the technology has not yet matured to a point where the FAA can assume the risks of investing in it (GAO 2011; NRC 2006b). The GAO noted that differences in agencies' mission priorities can make coordinating between technology transition challenging (GAO 2011). A NASA technology transfer manager notes that the biggest barrier to technology infusion is the perceived risk by in-house program/project managers of adopting a new technology (Comstock 2008).

c. Recommendations

Both the GAO and the NRC recommend that, in the case of inter-agency technology transition, such as between FAA and the NASA aeronautics directorate, agencies define common outcomes, identify and address needs, establish joint strategies, agree on roles and responsibilities (including testing, evaluation, and financial commitments), and establish compatible procedures for technology transition programs (GAO 2011; NRC 2008a). To better enable transition, they also recommend that agencies develop well-defined technology transition agreements, and in the case of aeronautics technologies also take into consideration important related technology transfer mechanisms such as standards and training (GAO 2006; NRC 2008a). The creation of relationship managers or research transition teams who would communicate across agencies, laboratories, and product lines has also been recommended to smooth the transition process and better deliver requirements to technology users (GAO 2006; NRC 2008b).

Incentives may be needed to help win user acceptance of research outcomes (NRC 2008a). For example, to promote NASA technology transition, the agency's technology transfer program established a Centennial Challenge—prize contests to stimulate innovation in NASA mission areas, where the awards are based on actual technologies and initiatives instead of proposals. The NRC advisory committee on aeronautical technology innovation recommended that NASA should expand this program to offer high-profile aeronautics prizes of a magnitude sufficient to generate considerable participation and public attention (NRC 2006a).

In summary, the NRC committee said documented planning for technology transition to external stakeholders should be a universal managerial practice for all NASA ARMD R&D projects and integral to the portfolio planning and prioritization process. Comstock (2008) offers this summary of best practices for increasing the likelihood of success in technology infusion: (1) develop a technology that is needed; (2) cultivate interest with the customer as technology is being developed; (3) develop an infusion plan early, and keep updating it as the technology matures; (4) understand the technology as part of the system it may be infused into, and be prepared to communicate that understanding.

D. Summary and Conclusion

The foregoing literature review revealed about forty barriers that fall into five major categories: lack of incentives; lack of information, access, and visibility; lack of resources; mission or organizational mismatch; and challenges with existing technology transfer mechanisms. Recommendations from the literature that address these barriers and their sources are summarized in Table 2.

Table 2. Summary of Recommendations from the Literature

Creating incentives	
Use entrepreneurial leave policies in which researchers are guaranteed their position within a certain amount of time after leaving (Carayannis et al. 1998) Allow employees to consult for the laboratory or work part-time while they also work to launch their start-up (Markusen and Oden 1996; Carayannis et al. 1998) Use more rigorously technology transfer as a measure in Federal laboratory researchers' performance evaluations (Erlich and Gutterman 2003; Hughes et al. 2011) Develop performance standards for all individuals involved in technology transfer (Toregas et al. 2004) Reward inventors more adequately (GAO 1992) During the course of project planning and execution, articulate how research results are tied to capability improvements and how results will be transferred to users (Erlich and Gutterman 2003) Encourage scientists and engineers to develop "commercializable" technologies, and give "corporate time" in which to work on their transfer projects (Franza and Grant 2006; NRC 2006a)	Introduce shorter, easier-to-use forms for small businesses (Erlich and Gutterman 2003; Hughes et al. 2011) Improve contact between partners to increase the likelihood of success in reaching an agreement (Amesse et al. 2001; Franza and Grant 2006) Use partnership intermediaries in the transfer negotiation process to facilitate communication and resolve any problems that could arise in the process (Hughes et al. 2011; Swearingen and Dennis 2009) Use intermediaries, so these organizations can assist, accept credit, compete or collaborate with industry, and advertise (all the things the government cannot do) (Innovation Associates 2003) In order to speed up negotiation times, streamline Federal laboratory licensing procedures (Markusen and Oden 1996) Pilot a dual-track, pay-for-performance system as at Air Force Research Laboratory (NRC 2006a)
Correcting for the lack of information, access, and visibility	
To provide more visibility to the Federal laboratories, conduct more marketing to industry (Spann, Adams, and Souder 1993) Develop a web portal to showcase available technologies (Hughes et al. 2011; Presidential Memorandum 2011) (Firms) build broad awareness of ongoing joint research ventures so that the researchers (both industry and university) are given feedback on project alignment with company needs (Pertuze et al. 2010) Incentivize a high degree of commitment and continuous interaction, with face-to-face meetings between the teams on a regular basis, even if personnel exchanges are not possible (Tran and Kocaoglu 2009; Pertuze et al. 2010) (NRC 2006a) (Firms) ensure that sufficient internal R&D expertise exists so that the results of the collaboration can be properly absorbed (Tran and Kocaoglu 2009) Incorporate market research into Federal research programs (Tran and Kocaoglu 2009) Establish a more direct link with industry to provide for tech transfer in a way that does not necessarily include the immediate, public dissemination of results to potential foreign competitors (NRC 2008b)	To raise the visibility of start-ups with the hopes of garnering venture funding, support sponsor venture capital forums that bring inventors and investors together (Markusen and Oden 1996; Innovation Associates 2003) Donate buildings or offer incubator space for start-ups; establish research parks (Markusen and Oden 1996; Carayannis et al. 1998; NRC 2001; Innovation Associates 2003) Share personnel across the laboratory and industry to increase familiarity of both user needs and researcher capabilities (Franza and Grant 2006; Tran and Kocaoglu 2009; Pertuze et al. 2010; NRC 2006a) Further educate researchers about the technology transfer process (Carr 1992; Erlich and Gutterman 2003) and also about the key business drivers of potential technology adopters (Spann, Adams, and Souder 1993) For those laboratories that are geographically isolated, teach business courses on site, allowing researchers to attend with minimal burden (Markusen and Oden 1996) Develop mechanisms that focus on improving interagency communication about the specific needs and outcomes of existing research that may be applicable to other agencies (GAO 2010)

(Continued on the next page)

Table 2—*Continued*

Correcting for the lack of resources	
Use local business school students to help scientists and engineers to form business plans for their start-ups has been observed (Carayannis et al. 1998) Work with regional economic development organizations to leverage economic development programs and funds (Markusen and Oden 1996; Hughes et al. 2011) (Innovation Associates 2003)	Develop a gated process that includes a transition phase and identifies criteria that can be used to support funding decisions (GAO 2006).
Correcting for mission or organizational mismatch	
Appoint a dedicated boundary-spanning project manager to work across the teams (Pertuze et al. 2010) (NRC 2008a) Improve research planning to ensure that the results are likely to be available in time to meet the future needs the National Aeronautics R&D Plan calls for (NRC 2008b) Use informal technology transfer processes and sharing personnel to build trust between the laboratory and industry researchers (Franza and Grant 2006)	Enable sharing of personnel across the laboratory and industry as a way to increase familiarity of both user needs and researcher capabilities (Franza and Grant 2006; Tran and Kocaoglu 2009; Pertuze et al. 2010) Foster closer connections between agency principal investigators and the potential external and internal users of their research (NRC 2008b; NRC 2006a) [Firms] develop a business plan and ensure a complementary match between the technology and the existing operating units of the business (Franza and Grant 2006)
Improving existing technology transfer mechanisms	
Better utilize CRADAs or technical assistance programs (often funded by the state or region) to further test and develop the technology (Carayannis et al. 1998; Markusen and Oden 1996) Ensure that the technology detailed in CRADAs matches the technical capabilities of the acquirer's operating unit or operating markets (Pertuze et al. 2010; Tran and Kocaoglu 2009)	Ensure that successful CRADAs include: (1) incentives that ensure commitment; (2) awareness by laboratory researchers of the needs of the company; (3) flexibility to reduce missteps in executing the project; (4) using CRADAs only in areas that are consistent with capabilities of the laboratory (1998) Give laboratories more budgetary and managerial flexibility in implementing CRADAs so that they may adjust as the project progresses (Tran and Kocaoglu 2009)

These recommendations are directed at different actors; in some cases, the ASTS may have the ability to influence or directly implement action. For example, although the ASTS does not focus solely on technology transfer, its leadership could work with the IWGTT to better understand its efforts on lessening conflict-of-interest rules, or the ASTS could examine agency-specific documents on technology transfer to ensure that they are aligned with one another and to learn best practices from each other. In other cases, it may not be within the ASTS's purview to effect change. Little of the literature specific to the topic of technology transfer focuses on barriers and recommendations specifically dealing with inter-agency issues.

The literature review also revealed that technology transfer is not an easily bounded concept; it is affected by actors at different levels and it can take many forms. The literature on technology transfer, while growing in volume over the past decade, still remains incomplete and contains studies often peripheral to the questions the ASTS seeks to answer. While technology transfer is a component of overall technology management, it has not typically been studied (or implemented) within that context.[27] In addition, much of the available literature on Federal technology transfer is over a decade old, raising questions about its relevance in today's social, political, and economic realities. In many instances, the policies and programs have evolved into broader discussions of partnerships and collaborations that incorporate technology transfer mechanisms, concepts, and practices.

The literature does not include information on how industry can provide input into research priorities, although the question has been raised with regard to aeronautics programs (NRC 2008a). Specific insights into how industry can be engaged to give feedback into ongoing Federal laboratory R&D activities have not been identified, although some agency technology transfer programs and IWGTT members have been involved with the Industrial Research Institute's "external technology network" to address this need. These two areas in particular are important areas in terms of the industry and laboratory input.

Lastly, most of the literature is on R&D in general rather than aeronautics R&D, yet it is known that technology development and commercialization pathways depend on the type of technology and the dynamics of the industry to which the technology is to be transferred.

Despite these limitations, the literature provided a framework for the data the research team collected through interviews and data calls to industry and the aeronautics Federal laboratories. Where answers confirmed or denied existing findings from the literature, this was noted.

[27] NASA has recently recommended that technology transfer be engaged at all stages of technology development, including the earliest stages of program formulation (NASA 2012c). The Air Force attempts a similar engagement through its Technology Transfer Master Process, as described in the *Air Force Technology Transfer Handbook* (http://www.federallabs.org/education/t2trdb/profile/?id=540&dm=4).

4. Barriers to Technology Transfer—Respondent Feedback

As explained in the methodology section of Chapter 1, a request for public comments posted in the *Federal Register* for the general aeronautics community and a questionnaire administered to agency leaders were the instruments used to obtain feedback on barriers to technology transfer in the U.S. aeronautics industry.[28] These instruments are included in Appendix A. Industry leaders were further probed through interviews and two sets of roundtables. The collected responses were then coded and analyzed. The coded responses are provided in Appendix B.

The approximately 70 barriers articulated by respondents fell primarily into the following categories:

- Execution and communication of National Aeronautics Research and Development (NARD) plans
- Communication and coordination across agencies and between government and industry on matters related to R&D
- Technology maturation, particularly the chasm between R&D and product development
- Institutional "fog and friction" surrounding intellectual property contracting and negotiations and an ingrained culture of devaluing technology transfer
- Other barriers related to lack or instability of funding, changes in regulations, trade issues, and so on

Each category is discussed in turn in the sections that follow.

A. Execution and Communication of NARD Plans

The 2006 National Aeronautics Research and Development (NARD) Policy and the 2007 National Plan for Aeronautics Research and Development and Related

[28] In this chapter, the term "industry" refers to all groups other than government, including nonprofit organizations, universities, and individuals who did not indicate their affiliation.

Infrastructure (Aeronautics Plan) are the strategic planning tools that are expected to guide aeronautics R&D through 2020.[29]

Several industry representatives were not aware of the Aeronautics Plan or the technical goals associated with it. Others complained that the documents did not articulate future Federal Government plans and technical goals with sufficient clarity. Yet others found it perplexing that agency budgets and strategy documents did not reflect the NARD plans and policies. Among the responses were the following:

> Work in Aeronautics is generally focused on mission-specific technology challenges not specifically supporting the National Aeronautics R&D plans.
>
> The NARD plans cover a lot of ground and say a lot of the right things, but if people asked them if they are following that, people say what policy and what plan.
>
> In general [NARD plans] don't specify actionable, quantifiable goals that allow for research progress to be tracked and reported on over time.

Some respondents also expressed frustration over the lack of opportunity to contribute to the plan.

Independent of NARD plans, industry respondents commented that agency goals and activities were not aligned well with each other, referring to them as "contradictory and confusing."

> These documents use different frameworks and styles and one can't easily identify connections (or duplications!) by reading them. It is not easy to determine which agencies ultimately are responsible and accountable for accomplishing which research goals.

Lastly, industry representatives expressed concern over frequent policy changes at the agencies, stating that the changes make it hard for them to commit to a plan. As one industry representative stated,

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[29] In December 2006, the National Aeronautics Research and Development Policy was published (http://www.aeronautics.nasa.gov/releases/national_aeronautics_rd_policy_dec_2006.pdf), marking the first time that a national policy for government-performed or -sponsored aeronautics R&D was approved by the President. The Federal Government published its initial National Plan for Aeronautics Research and Development and Related Infrastructure in 2007, with follow-on updates published in 2010 and 2011. In 2008, an initial assessment of progress against the 2007 plan was also published. Likewise, in December 2011, an assessment against the 2010 aeronautics research and development plan was published. With the completion of the 2011 Progress Assessment of the 2010 National Aeronautics Research and Development Plan, the ASTS has completed a 5-year national aeronautics R&D planning and assessment cycle. The ASTS seeks public comment on the contents and utility of these plans and assessment documents as a means to improve the effectiveness of the Federal aeronautics enterprise. See, for example, http://www.gpo.gov/fdsys/pkg/FR-2012-06-05/html/2012-13586.htm.

> [Industry's] near-term investment focus is further exasperated by the uncertainty of the government's execution of its plans which makes it challenging for industry to make similar long-term investments to match perpetually changing government plans.

B. R&D-Related Communication and Coordination

Industry respondents commented that they have limited visibility, input, and access to government-sponsored research that is foundational for both government and private sector aeronautics technology development. They also reported that government did not leverage enough private sector technology: "The big hurdle there is how to integrate IR&D [independent R&D] more into their strategic planning."

Similarly, government laboratory personnel reported that they have little insight into industry plans and progress. Almost all government respondents protested that this hurdle had gotten worse since restrictions on conference attendance and travel were tightened.

> For IR&D, the government is reimbursing four billion plus above and beyond—the labs are probably investing competitively in similar areas.

> Recent Executive Orders and congressional restrictions have significantly limited [our] ability to do…events (such as conferences). They're setting thresholds that escalate the approval necessary to hold an event.

Formal partnerships came up organically in several interviews. Industry and government agree that the constant turnover of government programs due to politics and bureaucracy, resulting in the cancellation of programs, are barriers to partnerships. Industry respondents expressed a reluctance to engage in partnerships when the benefit to them is not clear. As one industry respondent stated:

> One significant challenge is providing clear frameworks for proposed joint initiatives so that the business case for participation is clearly understood. Success of any initiative cannot be expected unless it is advantageous to all parties to participate.

C. Technology Maturation

Some respondents expressed concern over premature technological exploitation, which they believed was increasingly manifested in rising program stretch-out and delay, increased cost-overruns, and failure to fulfill desired program goals and expectations. One respondent stated, "The problem is this is the valley of death."

Overall, the development cost and time issues were blamed on challenges in the acquisition process:

> The government puts requirements on top of requirements without realizing the additional costs, so then they get sticker-shock. That's

> especially true on the DOD side, which is driven by commercial consumerization.

However, technology transfer was seen as having a role in these delays as well. Several industry respondents pointed to challenges in the level of technology at which industry was brought in. At times, they were brought in too soon, before the technology was ready for industry application into a product, and at times too late for the technology to be relevant for industry. Some respondents also spoke of Technology Readiness Level (TRL) "creep" where a technology was assessed as more mature than it was. For example:

> Overall, 6-2, work is being done as 6-3, 6-3 as 6-4, and so one. To make sure funding remains, technology must go to TRL 5 at least before production begins, which sometimes does not happen for funding reasons. Government wants industry to cost share too, so allows for TRL levels to creep up. This has gotten worse over the years, it takes more patience to do long-term research, but everyone is looking for short term payback.

According to industry respondents, some of the TRL creep occurs because engineers are overly optimistic, presuming a technology to be at a higher level of maturity than it actually is, but other times government managers lack the technical capabilities to assess the technology state, thus enabling overly optimistic assessments of technology maturation. Some respondents also asserted that in recent years, the balance between various types of research has shifted away from demonstration/prototyping activities. As one respondent asserted, "There aren't enough TRL 6 demonstrators in the aero propulsion environment."

According to another industry respondent, lack of properly set up collaborations makes the problem worse:

> One significant challenge is providing clear frameworks for proposed joint initiatives so that the business case for participation is clearly understood. Success of any initiative cannot be expected unless it is advantageous to all parties to participate.

Funding and other constraints can cause program managers to push a technology into production in an effort to achieve production without expending more of their scarce Research, Development, Test, and Evaluation (RDT&E) funding. Ironically, this sometimes has the opposite effect.

The topic of technology maturation was an area where there were differences between military and civil aeronautics. Within the military, the handoff is less controversial (since government takes part of the risk during the product development phase), but for commercial aeronautics, industry prefers to integrate technology that has achieved a higher TRL. Furthermore, at time of handoff, industry is also more particular about intellectual property and flexibility. In both cases, industry stakeholders would prefer to get involved sooner (at TRL 3) than later, so they have a hand in guiding research to products that are of greater use to them.

D. Institutional "Fog and Friction"

In his classic (and posthumous) text *On War*, Prussian strategist and General Carl von Clausewitz identified "fog and friction" as crucial problems impeding the successful and timely conduct of military operations. More broadly speaking, the phrase suggests the unknowns and institutional hindrances that effectively form a viscous drag to progress. Respondents identified two challenges in particular that work to hinder timely and effective technology transfer, government intellectual property practices and corporate culture within Federal laboratories.

1. Contracting and Negotiations Surrounding Intellectual Property

Cooperative Research and Development Agreements (CRADAs) and Patent Licensing Agreements (PLAs) are among the current practices that enable technology transfer, particularly between agencies and private sector organizations that have experience working together. However, several industry respondents complained that costly delays have resulted when such familiarity does not exist, or when one or both parties believe that they have greater rights to the inventions or technologies than the other. Indeed intellectual property-related negotiations emerged as a key barrier to technology transfer in discussions with industry. Issues raised included inefficiencies increasing costs for government and private parties, disagreements concerning appropriate government and private partner intellectual property rights, and limited department and agency understanding of technology advances within independent research and development (IR&D) programs.

Intellectual property issues were also brought up in the context of IR&D. One industry representative was especially unsatisfied with what was perceived as a burgeoning trend of government beginning to claim intellectual property from IR&D (which incentivizes industry to not put its most cutting edge research in the IR&D bucket).

Interestingly, government respondents did not bring up the mechanical aspects—length of contract negotiations or disputes over retention of intellectual property rights—as a barrier to technology transfer. Indeed, when probed, on the whole, laboratory representatives did not see intellectual property as a stumbling block in engaging with industry.

> Once non-Federal stakeholders are aware of what we offer, access is not an issue. However, it does take resources to reach out and make our progress known. Those resources and leadership encouragement would improve this system greatly.

2. Cultural Barriers

Respondents spoke of two specific cultural barriers to technology transfer. The first was addressed by the government respondents. Federal laboratories continue to stay steeped in a culture where the focus is on invention and novelty, and there are few incentives to engage in technology transfer. Several interviewees spoke of the lack of interest in technology transfer on the part of government laboratories and their technical staff. This lack of interest stems possibly from a lack of recognition that technology transfer is important or part of the agency's mission.[30] As one respondent stated,

> It is not widely recognized in NASA that technology transfer is a profession with specific skill requirements—not everybody can do it. Anyone who has worked with the private sector's technology transfer professionals recognizes that few people if any currently in NASA have these skills.

The second issue, acknowledged both by government and industry respondents, was that organizations and individuals, both within the government and industry, are becoming more risk-averse, causing industry to focus more on incremental innovation, and government to increase review and oversight. In both cases, the focus is on avoiding failure at all cost. In the case of industry, risk aversion emerged in the form of industry preferring research where all their costs were reimbursed:

> Firm Fixed Price (FFP) contracting is inconsistent with the goals of R&D programs. R&D is exploratory by its very nature, so FFP contracting is a hindrance to collaboration with the USG as it requires industry to carry the majority of the risk for developing new, advanced technologies which have uncertainty in what it takes to develop and mature the technologies to product application.

Government respondents said that they did not have support or "top cover" to pursue risky research:

> R&D is inherently risky, and you don't go into a particular research effort with complete confidence that you will succeed. You need to plan for a certain amount of failure, which means you can't pick one solution to each big problem and just go for it. You need a large and diversified enough portfolio that you'll have enough successes to solve the problems you want to solve. They are not there right now.

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[30] DOD Instruction 5535.8 (http://www.dtic.mil/whs/directives/corres/pdf/553508p.pdf) explicitly assigns responsibility for technology transition to both laboratories and program offices:

> …T2 activities shall be an integral element of the DoD national security mission, a high-priority role in all DoD acquisition programs, and recognized as a key activity of the DoD laboratories and/or technical activities and all other DoD activities that may make use of or contribute to T2.

E. Lack of Funding

Lack and instability of funding was the most cited barrier by all respondents. It related not just to technology transfer but also other areas of investment, like aging infrastructure, which, according to one respondent, was driving industry to use facilities abroad. Some emerging areas of research, being funded in other nations, could not be funded as a result. As one respondent noted:

> International agencies are seeking plans for funding they have available, whereas the U.S. has a plan but insufficient funds to execute that plan. Long-range funding mechanisms are needed to support strategic plans vs. short-term funding cycles. While the U.S. R&D Aeronautics plan is good it tends to be more tactical addressing near term needs and, it should be more strategic to cover long range technologies and opportunities.

Respondents commented not only on lack of funding, but also its declining levels, and its consequences, like decreased emphasis on technology transfer, lower instances and levels of risk taking, and loss of expertise in the laboratories. Furthermore, interviewees noted that as funding gets constrained, portfolios become less diverse, in the direction of fundamental research, with lowered focus on technology maturation. As one laboratory representative said,

> Since 2000, NASA's technology transfer budget has decreased steadily. Funding is about half of what it was in 2005, while additional partnership development and innovation work has been levied upon the Agency's technology transfer offices. As such, some core personnel and capabilities have been lost.

Industry in general resisted efforts to get its "skin in the game" any more than it had to:

> Firm Fixed Price (FFP) contracting is inconsistent with the goals of R&D programs. R&D is exploratory by its very nature, so FFP contracting is a hindrance to collaboration with the USG as it requires industry to carry the majority of the risk for developing new, advanced technologies which have uncertainty in what it takes to develop and mature the technologies to product application.

Funding challenges become especially complex when U.S. firms have opportunities to have their R&D funded by international governments or parties. This came up in a few discussions where U.S. firms were struggling to decide if they would accept foreign funds and collaborations—and turn over (or share) intellectual property to (with) foreign interests. For example, one firm was able to procure funding from governments in Europe and China, but its product's development had to be done abroad, and integrated with non-U.S. products. An unfavorable funding landscape in the United States may be a contributing factor when firms whether to pursue partnerships internationally.

The challenge of aging infrastructure was a frequent concern brought up by several interviewees. Industry respondents also brought up certification and other regulatory issues that delayed innovation.

Several respondents commented that declining government funding will not only lead to fewer research breakthroughs, but also a general weakening of the infrastructure. Several of the interviewees spoke of U.S. firms going to Europe to take advantage of their infrastructure, wind tunnels in particularly. Weakening government funding is accompanied by other changes. For example, industrial laboratories, once considered the drivers of innovation, are nearly nonexistent.

The fiscal attenuation is also accused of hollowing out government expertise. Several respondents suggested in various ways that the government used to have technical expertise that was lost for a variety of reasons, and this allowed large systems integrators running outside of the government, not all to the benefit of the sector.

ITAR and other export and trade-related barriers came up in several discussions.

> As we understand it, a single ITAR part in an entire aircraft may prevent the sale of that entire aircraft to foreign countries. Such restrictions limit the market, which in turn, limits the number of high-wage, high-skill jobs that create and build such aircraft.

With respect to the aeronautics workforce, many of the respondents spoke of retirements and the resulting loss of expertise. Data back these observations: the average age of the broad U.S. aerospace and defense industry workforce was 45 in 2008, and the average age among engineers was 43 (Hitachi Consulting 2009, 12). Some of the interviewees commented on the "alarming lack of technical interest in younger generations." While production in aerospace may be steadier than other STEM fields, the increasing number of STEM students in other countries has been of concern among industry leaders.

Yet other experts commented on the lack of technology fundamentals among young workers as compared with college graduates 20 years ago. Finally, given long development cycles (it takes more than 20 years to develop a new aircraft system), there are concerns that jobs in aeronautics firms are becoming less attractive to graduates. For example, decades ago aerospace engineers could work on many aircraft throughout the course of their careers; today, aerospace graduates are more likely to work on a single project for most of their careers.

Industry respondents were also concerned about the broader ramification of the recent World Trade Organization ruling in the Large Civil Aircraft (Second Complaint) case that the United States caused adverse effects to the interests of the European Union through the use of certain subsidies.[31]

Government respondents also spoke of barriers to collaboration with industry because of personnel caps on the government side. Respondents on both sides spoke of challenges with respect to cost sharing in the use of facilities.

F. Summary and Conclusion

When responses from industry and government are parsed separately, several differences between the sectors come to the fore, two of which are especially noteworthy. The first difference relates to the motives of the two sectors. The government wishes for findings to be disseminated widely for maximum leveraging of taxpayer dollars. As an illustration, most government responses cited dissemination of government laboratory research through technical presentations at professional societies as an important technology transfer mechanism while no industry responses cited such dissemination as being important. NASA's focus on broad dissemination is evident in its public pronouncements as well. In a July 2012 statement before a subcommittee of the House Committee on Science, Space, and Technology, NASA's Chief Technologist, Mason Peck, said:[32]

> Since its inception, NASA has been charged by its founding legislation The National Aeronautics and Space Act of 1958 to "provide for the widest practicable and appropriate dissemination of information concerning its activities and the results thereof." As we seek to achieve our national objectives in human space exploration, aeronautics, and scientific discovery, we create signposts in the form of data and research results that serve as pathfinders for subsequent advancements within the aerospace community. To give a sense of the magnitude of data available, NASA's Technical Reports Server (NTRS), which makes the Agency's technical literature and engineering results available to the public, holds over 500,000 aerospace-related citations, 200,000 full-text online documents, and 500,000 images and videos. Each year over 3.3 million people access NTRS. NTRS content continues to grow as new scientific and technical information is created or funded by NASA. The types of information found in the NTRS include conference papers, journal

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[31] See the Office of the United States Trade Representative website, "Reporter Memo: United States Complies with World Trade Organization Ruling in Aircraft Dispute," http://www.ustr.gov/about-us/press-office/press-releases/2012/september/US-complies-wto-ruling-aircraft.

[32] Statement of Dr. Mason Peck, Chief Technologist, National Aeronautics and Space Administration before the Subcommittee on Space and Aeronautics, Committee on Science, Space and Technology, July 12, 2012, http://science.house.gov/sites/republicans.science.house.gov/files/documents/hearings/HHRG-112-SY16-WState-MPeck-20120712.pdf.

articles, meeting papers, patents, research reports, images, movies, and technical videos.

Industry on the other hand, for competitiveness reasons, preferred “strategic partnerships” or other interactions where the dissemination was as narrow as feasible. This mentality was also evident in industry pushback on intellectual property. The respondents’ comments reveal their differing views of the process of innovation. Government respondents on the whole, through their emphasis on dissemination, view innovation much more as a linear process, where research moves in stages, and innovation is “pushed” by technology and science. There is some focus on market “pull” as well; however, the mental model is still a linear sequential process. On the other hand, industry respondents, with their focus on “strategic collaborations,” appear to conceptualize innovation occurring within a network of internal and external stakeholders. In many of the interviews, a common refrain was that the government emphasizes *novelty* of technology over *efficiency* “because ‘it’s interesting’ as opposed to because ‘it’ll deliver real value’.”

A second difference was between respondents in the military versus the civilian domain. Both domains face many of the same challenges, but some challenges are unique to each of the cultures. Companies that work with DOD, for example, tended not to have as many complaints about intellectual property disagreements. From these companies comments, it seems that DOD is likely more flexible with respect to intellectual property than is NASA. Companies that work with NASA found NASA more aggressive about intellectual property. On the other hand, companies that work with both DOD and NASA tended to be more frustrated with the DOD’s requirements and frequent design changes, and found NASA easier to work with, mainly because NASA has little interest in guiding technology development after technology is handed off.

5. Exemplars and Best Practices

The aeronautics research enterprise has had considerable accomplishment and influence. The interviews and the literature review, in addition to identifying and prioritizing barriers to technology transfer, also yielded a wealth of success stories and best practices. This chapter itemizes many of these practices organized by areas in which they emerged.

- Execution of strategic planning
- Communication and coordination
- Technology maturation
- Elimination of Institutional "fog and friction"
- Compensating for lack of funding

A. Execution of Strategic Plans

Strategic planning is generally considered difficult enough; it is harder to convert strategic plans into implementation plans, and there are few best practices in the aeronautics sector. Two exemplars are discussed in this section, one within aeronautics (the DOD R2 reporting process) and one outside (reforming clinical trials at the National Cancer Institute).

1. DOD's R2 Reporting Process

As Table 3 shows, R2s present technical objectives and strategies and show the resources dedicated to these goals and activities. Because technology development for aeronautics systems and subsystems requires sustained effort, documents that present goals and associated funding for multiple years are particularly important. One interviewee suggested that this is the kind of information that private partners need to inform development of their independent research and development plans.

Table 3. Illustrative R2 Page from Air Force Budget Submission

Exhibit R-2, RDT&E Budget Item Justification: PB 2013 Air Force | **DATE:** February 2012

APPROPRIATION/BUDGET ACTIVITY
3600: *Research, Development, Test & Evaluation, Air Force*
BA 2: *Applied Research*

R-1 ITEM NOMENCLATURE
PE 0602203F: *Aerospace Propulsion*

COST ($ in Millions)	FY 2011	FY 2012	FY 2013 Base	FY 2013 OCO	FY 2013 Total	FY 2014	FY 2015	FY 2016	FY 2017	Cost To Complete	Total Cost
Total Program Element	198.878	207.406	232.547	-	232.547	200.918	165.900	168.511	177.525	Continuing	Continuing
623012: *Advanced Propulsion Technology*	22.074	20.367	23.637	-	23.637	23.345	22.160	24.276	27.254	Continuing	Continuing
623048: *Combustion and Mechanical Systems*	17.734	20.069	15.874	-	15.874	13.886	12.744	12.829	13.103	Continuing	Continuing
623066: *Turbine Engine Technology*	64.278	67.702	102.188	-	102.188	75.523	42.355	42.628	43.520	Continuing	Continuing
623145: *Aerospace Power Technology*	31.346	32.639	30.061	-	30.061	27.801	28.677	28.739	28.848	Continuing	Continuing
624847: *Rocket Propulsion Technology*	56.966	60.390	55.293	-	55.293	54.888	54.689	54.727	59.374	Continuing	Continuing
625330: *Aerospace Fuel Technology*	6.480	6.239	5.494	-	5.494	5.475	5.275	5.312	5.426	Continuing	Continuing

A. Mission Description and Budget Item Justification

This program develops propulsion and power technologies to achieve enabling and revolutionary aerospace technology capabilities. The program has six projects, each focusing on a technology area critical to the Air Force. The Advanced Propulsion Technology project develops high-speed air breathing propulsion engines to include combined cycle, ramjet, and hypersonic scramjet technologies to enable revolutionary propulsion capability for the Air Force. The Combustion and Mechanical Systems project evaluates lubricants and combustion concepts and technologies for new and existing engines. The Turbine Engine Technology project develops enabling capabilities to enhance performance and affordability of existing weapon systems and develops component technologies for ultra high pressure ratio, substantially improved durability, and adaptive cycle engine architecture to provide optimized performance, fuel efficiency, and life for widely varying mission needs. The Aerospace Power Technology project develops electrical power and thermal management technologies for military applications that are part of energy optimized aircraft development. The Rocket Propulsion Technology project develops advances in rocket propulsion technologies for space access, space maneuver, missiles, the sustainment of strategic systems, and tactical rockets. The Aerospace Fuel Technology project evaluates hydrocarbon-based fuels for legacy and advanced turbine engines, scramjets, pulse detonation, and combined-cycle engines. Efforts in this program have been coordinated through the Reliance 21 process to harmonize efforts and eliminate duplication. This program is in Budget Activity 2, Applied Research, since it develops and determines the technical feasibility and military utility of evolutionary and revolutionary technologies.

Source: Department of Defense Fiscal Year (FY) 2013 President's Budget Submission. February 2012. Air Force. Research, Development, Test & Evaluation, Air Force, http://www.saffm.hq.af.mil/shared/media/document/AFD-120210-115.pdf .

Table 3—*Continued*

Exhibit R-2A, RDT&E Project Justification: PB 2013 Air Force		**DATE:** February 2012
APPROPRIATION/BUDGET ACTIVITY 3600: *Research, Development, Test & Evaluation, Air Force* BA 2: *Applied Research*	**R-1 ITEM NOMENCLATURE** PE 0602203F: *Aerospace Propulsion*	**PROJECT** 623012: *Advanced Propulsion Technology*

COST ($ in Millions)	FY 2011	FY 2012	FY 2013 Base	FY 2013 OCO	FY 2013 Total	FY 2014	FY 2015	FY 2016	FY 2017	Cost To Complete	Total Cost
623012: *Advanced Propulsion Technology*	22.074	20.367	23.637	-	23.637	23.345	22.160	24.276	27.254	Continuing	Continuing

A. Mission Description and Budget Item Justification

This project develops combined/advanced cycle air breathing high-speed (up to Mach 4) and hypersonic (Mach 4 to 8+) propulsion technologies to provide revolutionary propulsion options for the Air Force. These new engine technologies will enable future high-speed/hypersonic weapons and aircraft concepts. The primary focus is on hydrocarbon-fueled engines capable of operating over a broad range of flight Mach numbers. Efforts include modeling, simulations, and proof of concept demonstrations of critical components; advanced component development; and ground-based demonstrations.

B. Accomplishments/Planned Programs ($ in Millions)	FY 2011	FY 2012	FY 2013 Base	FY 2013 OCO	FY 2013 Total
Title: Major Thrust 1. ***Description:*** Develop advanced fuel-cooled scramjet engine technologies to support flight demonstration and enable the broad application of hypersonics to meet future warfighter needs. ***FY 2011 Accomplishments:*** Developed and demonstrated flight weight engine components and advanced engine control logic. Assessed advanced instrumentation with control logic to improve scramjet operability. Performed trajectory optimization for flight test. Conducted ground test of advanced scramjet start technique. Completed fabrication of flight test hardware to demonstrate ramjet to scramjet transition. ***FY 2012 Plans:*** Develop and demonstrate advanced engine control systems and flight weight scramjet engine components. Develop and demonstrate closed loop engine control system with advanced instrumentation to increase scramjet engine operability at low scramjet Mach numbers. Conduct flight test using sounding rocket launch to demonstrate transition from ramjet to scramjet. ***FY 2013 Base Plans:*** Continue development and demonstration of advanced engine control systems and flight weight scramjet engine components. Based on prior ground and flight testing, refine and demonstrate closed loop engine control system with advanced instrumentation to increase scramjet engine operability at low scramjet Mach numbers. Conduct direct connect testing of flight weight scramjet components for cold start systems. ***FY 2013 OCO Plans:***	2.565	1.650	1.650	-	1.650

Source: Department of Defense Fiscal Year (FY) 2013 President's Budget Submission. February 2012. Air Force. Research, Development, Test & Evaluation, Air Force, http://www.saffm.hq.af.mil/shared/media/document/AFD-120210-115.pdf.

2. Implementing Recommendations to Improve Clinical Trials

In 2005, the Director of the National Cancer Institute (NCI) tasked its Clinical Trials Working Group (CTWG) to recommend ways the NCI-supported national clinical trials enterprise should be transformed to "realize the promise of molecular oncology in the 21st century."[33] To meet this challenge, working with stakeholders—Cancer Centers, physicians, patient advocacy groups, and others—the CTWG first reached consensus on four critical goals for designing a more efficient national system for clinical trials conducted or supported by NCI. Building on these goals, CTWG then developed a framework for 22 initiatives. This was a time-consuming effort because all stakeholders had to be onboard and agree to the plan. The result was a report that included recommendations (similar to prior recommendations on how to improve the cancer clinical trial enterprise) and implementation plans that included timelines, milestones, and budget allocations.[34]

The most unusual aspect of the CTWG was the inclusion of recommendations for a quantitative and qualitative, evidence-based evaluation plan to assess measures of program management process, system performance process, and system outcomes. Most strategic plans typically do not include detailed evaluation plans. The CTWG evaluation plan consisted of a baseline feasibility analysis, interim evaluations of specific initiatives related to these measures, and final evaluations at specified intervals after implementation of the initiatives.

B. Communication and Coordination

1. Public-Private Partnerships (PPPs)

PPPs, in which the government jointly funds and participates in projects that would not otherwise be initiated within one sector alone, came up in several discussions and in the literature. The four PPPs specifically mentioned in interviews are described in the subsections that follow.

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[33] See https://www.fbo.gov/index?s=opportunity&mode=form&id=5b3b2bb77afb1fc150e215fd60ef84e4&tab=core&_cview=1.

[34] The June 2005 report is available at http://transformingtrials.cancer.gov/files/ctwg-report.pdf.

a. Versatile Affordable Advanced Turbine Engines (VAATE)

The VAATE program is the follow-on effort from the successful Integrated High Performance Turbine Engine Technology (IHPTET) program and serves as an overarching framework for military turbine engine science and technology development.

VAATE expands the goals of IHPTET to move beyond the basic engine to include integration of the inlet, exhaust, power generation system, and thermal management system. The science and technology goals for the turbine engine sector are established based on user needs, and are executed and managed through the VAATE program. This ensures that the technology development programs across the Federal Government are coordinated and aligned to provide a maximization of funds and limitation of duplication.

The VAATE program leadership includes all of the key agencies and departments that perform research and development of aircraft propulsion systems. In addition to the government members, the engine producing industry is also an active participant. VAATE is guided by the VAATE Steering Committee, which includes members from the military departments, the Office of the Secretary of Defense (OSD), Defense Advanced Research Projects Agency (DARPA), NASA, and DOE. In addition to the government leadership, there is an Industry Panel that provides representation for the aircraft engine developers and manufacturers and aircraft system integrators.

Several interviewees considered the VAATE program as a best practice. According to the interviewees, VAATE technology significantly increases the effectiveness of DOD systems and platforms necessary to enable air domain superiority. It develops new and enhanced operational capability options for warfighters and strategic decision makers by transitioning technologies to acquisition programs and the warfighters; reduces the risk for acquisition programs; dramatically impacts the affordability of DOD systems and capabilities; and enhances the sustainment and upgrade of existing weapon systems. Turbine engine propulsion systems enable advances in aircraft capabilities, including speed and altitude, aircraft size, range and payload, environmental compatibility, efficiency, and the ability to safely operate in adverse conditions.

Respondents considered the program a model for other PPPs in aeronautics. The program was well regarded for having well-defined goals, objectives, and milestones; for its integration of a variety of disciplines; and the effectiveness of its coordination across government/industry efforts. Respondents also commended it for its strong leadership. But the term that came up most often in the interviews was “trust.” Participants, especially industry participants, found the forum to be a dependable source of government plans, funding, and activities.

b. Continuous Lower Emissions, Energy, and Noise (CLEEN) and Commercial Aviation Alternative Fuels Initiative (CAAFI)

Other PPPs presented as exemplars included two FAA-led programs—Continuous Lower Emissions, Energy, and Noise (CLEEN)[35] and Commercial Aviation Alternative Fuels Initiative (CAAFI).[36] These two partnerships seem to be effective because they require industry to contribute significantly to technology development and be accountable for bringing technology to market. In return, the government facilitates technology development by providing a portion of the funding and helping to address barriers to commercialization.

CLEEN, established in 2009 to accelerate technology transition to the commercial aircraft fleet, is lauded for its semi-annual consortia established as a communication tool for the Government to share program progress amongst industry participants, as well as to communicate future plans and solicit industry input for future R&D efforts. CLEEN is a good example of how the push and pull of information between industry and government can work. CAAFI, created to address the business, research and development, environmental, and certification issues related to creating "drop-in" alternative jet fuels for today's commercial aircraft, is lauded for its efforts that have led to the certification of two alternative jet fuel pathways, the first such approvals in over 20 years.

A particular example of a well-coordinated effort was the *ecoDemonstrator*, a modified American Airlines 737 aircraft, which showcases technology developed under CLEEN. Under the program, the FAA awarded cost-sharing agreements to Boeing, General Electric, Honeywell, Pratt & Whitney, and Rolls Royce North America to test innovations in sustainable alternative jet fuels; lighter, more efficient gas turbine engine components; noise-reducing engine nozzles; advanced wing trailing edges; optimized flight trajectories using onboard flight management systems; and, open rotor and geared turbofan engines.[37]

c. Airbus

Another example that appeared in the literature was the Airbus strategic partnership (Slywotzky and Hoban 2007), although the government was not an overt partner.

> In the 1960s, airplane manufacturing in Europe appeared doomed. U.S. companies, particularly Boeing and McDonnell Douglas, had become the dominant players in the increasingly capital-intensive industry. The

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[35] About CLEEN: http://www.faa.gov/about/office_org/headquarters_offices/apl/research/aircraft_technology/cleen/.

[36] About CAAFI: http://www.caafi.org/.

[37] Interview material supplemented with information from http://www.faa.gov/news/updates/?newsId=69327.

> smaller European manufacturers, scattered across the continent and fighting fiercely with one another as well as with their international rivals, lacked the scale and the capital to compete effectively against their U.S. counterparts in building big, modern passenger jets. Then, in 1970, four of the leading European manufacturers—France's Aerospatiale, Germany's Daimler-Benz Aerospace, Spain's Casa and the UK's British Aerospace—formed the joint venture Airbus, pooling their resources to design, produce and sell jet aircraft. Not only did the venture provide operating economies and temper financial risks, but the combination of capital and talent also led to a surge of innovation. Despite early managerial conflicts, Airbus successfully pioneered new approaches to aircraft design, including fly-by-wire control technology and the introduction of a common cockpit across the entire fleet. Not only had European aircraft manufacturing survived, but Airbus had become in essence the only rival to Boeing (which in 1997 had acquired McDonnell Douglas). Airbus has grown rapidly over the past two decades, to the point where it now often beats its American arch-rival in annual deliveries of new jets.

The literature included examples of PPPs in other nations, such as Fraunhofer Institutes (Germany), IMEC (Belgium/European Union), and Biopolis (Singapore), to name a few.

d. Observations on PPP

In general, PPPs are extolled for providing a mechanism to encourage joint action in areas with high-entry barriers and uncertain profitability; leveraging the diverse skills and exploiting the potential for research synergies, complementarities, scale economies, and knowledge-sharing among participants; allowing higher risk and larger scale projects to be undertaken that are more ambitious and technically challenging than typical company and industry projects; and accelerating the development and deployment of new technologies that have the potential for radical change in one or more industrial sectors and that lead to large economic and societal benefits (STPI 2010; PCAST 2008).

However, PPPs are not trivial to run, and examples of unsuccessful partnerships were also brought up in discussions—two among these were Rotorcraft Industry Technology Association (RITA) and the Vertical Lift Consortium (VLC). Several respondents also named programs that they thought were less than successful, but that were worth examining so lessons could be learned. These programs included: NASA's Environmental Research Aircraft and Sensor Technology (ERAST)and Small Aircraft Transportation System (SATS)programs, and the NASA-DOD National Partnership for Aeronautical Testing(NPAT).

PPPs have also been identified as a mechanism to promote knowledge sharing and technology transfer. To increase efficiency of current and future partnerships, agencies should evaluate major PPPs along the following five success factors:

- *Outcome driven*. Any partnership worthy of significant attention by national leaders ought to be driven by a needed capability, not merely promote the development of a particular discipline or technology. VAATE, for example, has been lauded by many interviewees for having targeted outcome-driven goals. While it is not necessarily a model for all partnerships, it holds useful lessons to consider, especially with respect to the use of outcome-oriented goals.
- *Common goals*. All partners should share the goals of the partnership (and not just common interests). Furthermore, with respect to governance, there is a need to balance everyone's interests to properly suit motivation and goals. The partnership should be periodically evaluated to ensure the goals are relevant, and being met in a timely manner. This evaluation must clearly delineate how success is defined for the partnership. Each partnership will have its own unique metrics that will help its participants determine if they are successful and if it is in their best interest to continue the partnership. Metrics may be precise markers, such as meeting milestones or leveraging funds from other sources, or general ones like knowledge sharing, and networking.
- *Transparency and trust*. The partnership should be selective about including participants that share the goals above. Once part of the partnership, there should be transparency and trust-based interactions among the partners. That includes clearly delineating what is subject to intellectual property protection. Again, VAATE was considered exemplary in this regard.
- *Shared risk*. All participants—government and industry—should place some "skin in the game" by contributing to the partnership—the contributions can be either monetary or in kind. The Vertical Lift Consortium came up in this context as a partnership where there was not enough commitment on the part of participants.
- *Strong leadership*. Leaders of the partnership should be selected for their ability to enforce discipline as to the goals and risks above. Once again, VAATE was mentioned for its strong leadership from the government side.

PPPs are not a panacea. Unless they are designed well, their benefit-to-cost ratio can be low. The community has not previously considered how the design or reconstitution of a PPP relates to limits on practices that are under the oversight of the World Trade Organization. Regardless, many resources are available to design and assess partnerships.[38]

[38] These include resources provided by the National Institutes of Health (NIH) at http://ppp.od.nih.gov/pppinfo/value.asp and the National Academies Government-University-Industry Research Roundtable at http://sites.nationalacademies.org/PGA/guirr/index.htm, among others.

2. National Advisory Committee for Aeronautics

The National Advisory Committee for Aeronautics (NACA) model was brought up in several discussions as a model for dissemination, for its focus on practical application, and for promoting a culture of risk taking.[39] The NACA was also prominent in the literature as an ideal for industry-government partnerships. Appendix D provides some insight on the role of the NACA in the early development of aeronautics.

Generally, on the dissemination front, respondents spoke of several practices they felt improved the visibility of research funded. Respondents from NASA laboratories found NASA's Tech Briefs and NASA Technology Showcases to be best practices. A respondent also considered as an exemplar a recent NASA automotive industry workshop where information on the applicability of NASA's research to the automotive sector was disseminated.

3. Intergovernmental Personnel Act Appointments

Some respondents proposed that an expanded Intergovernmental Personnel Act (IPA) Mobility Program, which provides for temporary transfer of personnel between the Federal Government and other organizations, would improve communication and understanding between the government and industry. The U.S. aeronautics R&D industry would be enhanced through the regular rotation of technical talent. Rotations of government personnel out to industry expand awareness of industry and academia practices, capabilities, and concerns, leading to better regulators and smarter buyers. While IPA appointments are available to persons from academic and other nonprofit organizations, these same types of exchanges are not possible for for-profit industry personnel. Issues include access to acquisition information, participation in development of government plans, and restrictions on how these interactions can take place levied by the Federal Advisory Committee Act (Public Law 92-463) and the Government in the Sunshine Act (Public Law 94-409).

The literature also led the team to other personnel exchange programs. One in particular is the FDA Entrepreneurs-in-Residence (EIR) program, a topic of recent research at STPI. The EIR program allows for the time-limited recruitment of world-class entrepreneurs and innovators to join highly qualified internal government employees in the development of new operational procedures in areas that impact innovation. According to the FDA's website, the EIR program's goal, is to "deliver transformational

[39] NACA engineers "were encouraged to pursue unauthorized 'bootleg' research, provided that it was not too exotic" (Scotchmer 2004).

change by combining the best internal and external talent in testing, validating and scaling what works."[40]

> The EIR program allowed CDRH [Center for Devices and Radiological Health] to bring in vision leaders in business process innovation, decision science, medical device innovation, venture partners, and information technology to work alongside agency staff and leadership, to develop Innovation Pathway 2.0. Fifteen EIR members comprising the Strategic Team served as a sounding board as the program was being built. They provided vision and focus during the development of the Innovation Pathway, including the review of policies, business processes and tools that may be helpful in bringing innovative and safe new products to the U.S. market. Five members served in either a full- or part-time capacity on site, embedded with FDA staff and management, as a boots-on-the-ground Tactical Team to build and implement the Innovation Pathway, including the development of new policies, processes, and tools. Originally created for a six-month duration, the EIR program has been successful and the Center intends to continue the program in order to keep bringing new ideas and fresh perspectives to the Innovation Pathway.[41]

4. Independent Research and Development

Some experts believe that government organizations engaged in aeronautics R&D benefit when they have insight into the technology advances achieved in nongovernment independent research and development (IR&D) projects. Such information would inform planning for example, by identifying potential bidders and by improving government understanding of the advancing state of the art in aeronautics technology. It also might enable identification of more technology transfer opportunities.

The DOD has recently gained increased visibility into firms' IR&D efforts that are allowable costs 10 U.S.C. 2372 and the Federal Acquisition Regulation. Authorized DOD users can now examine IR&D project summaries submitted by firms. This increased visibility has been accomplished in a way that does not interfere with the independence of IR&D provided under 10 U.S.C. 2372. Experts proposed that other agencies engaged in aeronautics R&D would benefit from having comparable visibility. The recent DOD

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[40] "About FDA," http://www.fda.gov/AboutFDA/CentersOffices/OfficeofMedicalProductsandTobacco/CDRH/CDRHInnovation/InnovationPathway/ucm286138.htm.

[41] This and other information on the EIR program is available at http://www.fda.gov/AboutFDA/CentersOffices/OfficeofMedicalProductsandTobacco/CDRH/CDRHInnovation/InnovationPathway/default.htm.

initiative that resulted in a change to the Defense Federal Acquisition Regulation Supplement is a potential model for other agencies.[42]

5. Bridging Organizations

Of the several types of bridging organizations, some improve communication and coordination across sectors, while others help with the challenges of technology maturation and bridging the “valley of death” between basic research and development. Proof-of-concept centers such as the MIT Deshpande Center for Technological Innovation (known as the Deshpande Center) not only provide seed funding to novel, early stage research that most often would not be funded by any other conventional source, but also facilitate and foster the exchange of ideas between the university innovators and industry via various mentors associated with the center. Respondents and the literature also identified programs to identify future customers/users. One of these was DOD’s National Partnership Intermediaries network, which provides both outreach and “inreach” (Gonsalves n.d.).

The DOD is experimenting with the Defense Venture Catalyst Initiative (DeVenCI), which aims to provide a wider “window” on new technology development, an increased potential government supplier base, more leverage of private investment, and more rapid acquisition of new technologies. DeVenCI uses voluntary venture capitalist “consultants” who help link private companies to potential DOD customers. It communicates the needs of its customers to the consultants, who provide information on companies that may be able to fit those needs. DeVenCI then sets up meetings and presentations between the two groups to explore whether there may be a match.

6. Contracting Mechanisms

Several respondents mentioned use of contracting mechanisms to improve communication and coordination. Space Act Agreements (SAAs), for example, were mentioned as “a fantastic way of bringing government and industry together to work jointly on projects.” A respondent specifically mentioned an SAA for Northrup Grumman on the Global Hawk that allowed the adaptation of DOD technology for NASA use:

> NASA gets the use of advanced technologies that industry’s considering and industry gets the use of NASA’s assets to help them perfect technologies that they wouldn’t be able to perfect.

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[42] Additional information on DOD IR&D is available at http:/www.defenseinnovationmarketplace.com.

C. Technology Maturation

Promotion of immature technology was identified as one of the major innovation-related challenges in aeronautics. Several best practices were mentioned both in interviews and the literature related to set-aside funds, transition teams, vertically integrated programs, pipelined programs, and platform approach.

1. Set-Aside Funds

Respondents mentioned several programs specifically created to fund the "valley of death." Most of these examples came from the Office of Naval Research (ONR), including the Navy Transition Assistance Program (TAP), Navy Rapid Innovation Fund, and the Future Naval Capability (FNC) program (ONR n.d.).

Respondents informed team members that NASA partnered with the Navy in 2007 and 2008 via an intergovernmental agreement to pilot TAP, an assistance program for NASA SBIR/STTR Phase II companies through their contractor—Dawnbreaker. The program, was designed to assist SBIR/STTR companies to enhance their strategies for transitioning to Phase III and develop a technical brief, as well as develop a Phase III Transition plan.

Experts also mentioned organizations that serve a venture capitalist-like function to promote the customized maturation of commercial technology for government purposes. An example of such an organization is In-Q-Tel. In-Q-Tel makes either an equity investment, where it receives part ownership in the company, or a work program investment where funding is provided for a company to develop its technology in a way that suits the needs of the intelligence community. The In-Q-Tel Interface Center connects In-Q-Tel to the Central Intelligence Agency (CIA) by matching the technologies in the In-Q-Tel portfolio to potential CIA missions. While In-Q-Tel identifies technology of interest to the government, it also serves a bridging function as well.

Proof-of-concept centers (mentioned in the previous section as examples of bridging organizations) are viewed an important component of technology maturation. These include centers like the MIT Deshpande Center, and the University of California San Diego (UCSD) William J. von Liebig Center for Entrepreneurism and Technology Advancement (known as the von Liebig Center).

The Deshpande Center provides up to $250,000 to prepare MIT technology projects for commercialization. The Ignition Grants (up to $50,000) for novel projects that may be used for exploratory experiments and proof of concept. Innovation Grants (up to $250,000) are awarded to take an innovation into full development.

The von Liebig Center's goal is "to accelerate the commercialization of UCSD innovations into the marketplace, foster and facilitate the exchange of ideas between the University and industry, and prepare engineering students for the entrepreneurial workplace" (Gulbranson and Audretsch 2008, 5). Its funds are not used for basic research, but rather to evaluate the commercial potential of existing research.

Other bridging institutions include government-industry co-funded centers that support industry-focused research that is neither appropriate for academia nor industry. In some cases, these entities serve as incubators and support the successful development of entrepreneurial companies through an array of business support resources and services.

2. Transition Teams

Several respondents brought up research transition teams to coordinate research and transfer technologies from NASA to FAA. The design of these teams is consistent with several key practices that can enhance interagency coordination, such as identifying common outcomes, establishing a joint strategy to achieve that outcome, and defining each agency's role and responsibilities (GAO 2006).

3. Vertically Integrated Programs

Other respondents cited programs created specifically to take technology from low to high Technology Readiness Levels (TRLs). A model cited was the NASA Integrated Systems Research Program (ISRP). The program allows for research to be conducted at an integrated system level on promising concepts and technologies and explore, assess, or demonstrate the benefits in a relevant environment (Waggoner 2012). ISRP is an interim step between fundamental research and full systems integration. By maturing promising technologies from low to medium TRLs, the program validates their feasibility within integrated systems and relevant environments.

DARPA and its Department of Energy counterpart, ARPA-E, are often touted as organizations that excel at technology maturation, and they came up in several interviews and in the literature. Both agencies proactively seek out "white spaces" where it can fill a vital gap in early stage research and development (Majumdar 2011).

ARPA-E's focus is not only on new technology, but rather on a plausible pathway to implementation. Program staff members generally have academic and commercial experience, which ranges from work in venture capital firms and companies to participating in technology-based start-up firms. This breadth of background in both academic and private sectors helps them understand alternative commercialization pathways (Bonvillian and Van Atta 2011).

ARPA-E has taken other steps to accelerate scale up and implementation, starting with encouraging consideration of the implementation process in the selection of technology projects by evaluating the technology "stand-up" process and envisioning how it might evolve). ARPA-E, in effect, has added a variation to DARPA's "Heilmeier Catechism"—a set of questions proposals for DARPA research should answer—by requiring program leaders to "tell me how your story will end and how will you get there" (Bonvillian and Van Atta 2011).

Within the agency, a set-aside commercialization group works with project managers to move technologies into implementation. ARPA-E has also held two highly successful community-building energy technology summits, which helped, among others, to develop a broad support community. The 2011 summit brought together over 2,000 energy researchers, entrepreneurs, investors, corporate executives, and government officials to share ideas for developing and deploying the next generation of clean energy technologies and showcase more than 200 transformational technologies and organizations.[43] At pre-conference workshops and networking sessions, participants got the opportunity to share ideas with ARPA-E program managers, global industry leaders, and energy technologists.

ARPA-E encourages industry consortia around its projects and is planning to use prize authority (Bonvillian and Van Atta 2011). Similar to DARPA, ARPA-E awards create a "halo effect" around the awarded projects, and have encouraged venture capitalists and other private funders to use the funding as a basis for identifying "the next big thing." Since ARPA-E's creation, $360 million in public funding has leveraged $285 million in follow-on private investment (Hourihan and Stepp 2011).

4. Demonstrations

Demonstrations were cited as one of the most efficient ways to mature technology. An example here was the Hypersonic International Flight Research Experimentation (HIFiRE) (Bowcutt et al. n.d.; Barnstorff 2012). HIFiRE is an international collaboration investigating fundamental vehicle and propulsion phenomena and technologies critical to practical and efficient hypersonic flight whose goals are to flight test in less time and at lower cost than traditionally possible. Nine flight experiments, each building on the previous, and each culminating in a flight experiment to address one or more scientific questions or technical challenges, are investigating critical hypersonic phenomena. Participants include NASA and the Air Force Research Laboratory. Industry partners from the United States include Boeing, ATK GASL, CUBRC, Ascent Labs, Kratos, and GoHypersonic. Its international partners include Australian Federal and state governments, universities, and industry (Boeing and BAE Systems).

5. Pipelined Programs

In addition to sharing exemplars and best practices, many respondents encouraged the government to focus more on a balanced portfolio. The literature offered the example

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[43] For details, see "About the Summit," http://www.energyinnovationsummit.com/about/.

of DOE's approach to bridge the gap between the early-stage science and final commercialization of new energy technologies, while reorganizing some existing programs to directly complement the new programs. STPI (2010) listed the following DOE programs to demonstrate the variety of potential agency strategies across the invention to innovation life cycle. These programs each possess management structures designed around specific ends, and they vary extensively in size, aim, and activity.

- *Energy Frontier Research Centers (EFRCs)*—Each center, run by 6 to 12 senior investigators, pursues "use-driven" fundamental research addressing an identified basic research need. They are funded through relatively small, $2 million to $5 million, annual grants sustained over a period of 5 years.
- *Energy Innovation Hubs (EIHs)*—Hubs are larger, multi-institutional and multi-disciplinary pursuits organized through centralized science management practices, based off of successful historical examples (e.g., Bell Laboratories, Manhattan Project). Work spans the range from applied research to development, engineering, and economic analysis supporting early-stage commercialization efforts.[44] Grants are approximately $22 million per year for 5 years, plus startup costs.
- *Advanced Research Projects Agency—Energy (ARPA-E)*—This agency, modeled after the Defense Advanced Research Projects Agency (DARPA), pursues high-risk, high-payoff R&D directed towards near-term commercialization. One-year to 3-year grants ranging from $0.5 million to $10 million are given to single investigators or small teams for work on energy technologies that are viewed as potentially transformative.
- *Industrial Technologies Program (ITP)*—This program, run within DOE's Office of Energy Efficiency and Renewable Energy (EERE), focuses on technology development to providing technical assistance and best practices information to industry in order to reduce industrial energy intensity.
- *Building Technologies Program (BTP)*—Similarly, BTP run by EERE is organized around the goal of improving building energy efficiency. For buildings, this means addressing everything from R&D for building systems integration to energy codes and equipment standards. Since most buildings-related regulation is done at the local level, BTP provides intergovernmental technical and program-design assistance.

[44] In addition, for at least one of the three funded energy innovation hubs, the DOE is experimenting with interagency collaboration to support an Energy Regional Innovation Cluster (E-RIC), which would provide complementary support to commercialization efforts in areas such as local technical training and economic development.

- *Innovative Technology Loan Guarantee Program*—Funded under the Recovery Act, this program provides loan guarantees for large projects that avoid air pollution or greenhouse gas emissions, utilize new or significantly improved technologies, and offer a reasonable prospect of repayment. Loan guarantee amounts and terms vary according to project type, cost, and other characteristics.

6. Platform Approach

The concept of a platform approach for technology maturation came up in some expert discussions as well as the literature. In the automotive arena, for example, the company Johnson Controls Inc. has built five state-of-the-art technology centers to work with automobile companies in researching and designing integrated, modular vehicle interiors (Slywotzky and Hoban 2007). These laboratories have become, in effect, the means through which automobile makers around the world can share in creating expensive but undifferentiated components, rather than duplicating one another's efforts as they formerly did. Having the aeronautics-related agencies establish a collaboration platform can be particularly powerful for two reasons. First, the legacy of hypercompetition often makes it difficult for competitors themselves to take the first step toward collaboration. The government may also have an opportunity to act as a catalyst—a disinterested party that spurs industry competitors to begin collaborating.

In the private sector, Sikorsky Aircraft's X2 helicopter demonstration program and the SpaceX, the firm behind the Falcon family of spacecraft launch vehicles, were mentioned as exemplars of technology maturation through the platform approach.

D. Elimination of Institutional "Fog and Friction"

One of the most difficult challenges mentioned both in interviews and the literature was initiating cultural change. Best practices were offered for two particular aspects of culture at government laboratories—promoting risk taking and providing incentives. Other best practices integrate technology transfer into the laboratory's mission.

1. Promoting Risk Taking

a. Prizes and Grand Challenges

NASA was the first civilian agency to receive the direct authority to conduct prize competitions as part of its mission through its Centennial Challenges program. With the recent passage of the America COMPETES Act, all Federal agencies have the authority to conduct competitions and challenges and develop the policy initiatives that will drive the use of prizes in connection with procurement activities.

NASA has also provided internal incentives to in-house risk taking with its Center Innovation Fund, which aims to elicit creative and innovative thinking on the part of NASA researchers.

b. Seed Funding

Seed programs nucleate and nurture breakthrough by supporting, on a small scale, unformed or not fully formed ideas. These programs aim at jump-starting a new research area for a single or small group of scientists through "seed funding," with the idea that the project may advance enough so that more conventional grants may be sought. The amount of project funding from seed funding is one third or less than the funding obtained through traditional grants, and the funding duration may be shorter. An example is the Intelligence Advanced Research Projects Activity (IARPA) Automated Location Identification program.

Similarly NASA Aeronautics Research Mission Directorate's Seedling Fund provides NASA staff the opportunity to pursue novel early-stage efforts to infuse "promising concepts into the ARMD research portfolio or into NASA's Small Business Innovation Research program for further development."[45]

c. High-Risk, High-Reward Programs

Efforts to promote risk taking have been addressed at other government agencies as well. According to recent STPI research, DOE funds a "Sunshot Initiative," intended to reduce the installed cost of solar energy systems by 75% over the next decade (to one dollar per watt installed) to achieve full competitiveness with fossil fuels for electricity generation.

d. Private Sector Activities

Promoting risk is a common challenge in the private sector as well, and the literature describes efforts to address it. Amazon, for example, is a champion of small innovations that can increase efficiencies and reduce costs of delivering Amazon's products to its customers. Employees are given incentives to move forward on their innovative ideas quickly without waiting for management permission through a "Just do it" award. The award is presented to employees for implementing a well-thought-out idea to increase efficiency. Because Amazon's senior management makes it clear to employees that it is continually trying to remove barriers to innovation and new ideas are always welcome, employees know that they will not be penalized if their idea does not work perfectly.

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[45] From "NASA Facts: NASA Aeronautics Research Institute," http://www.aeronautics.nasa.gov/pdf/nari_factsheet_05_11_12.pdf.

e. Open Innovation

To ensure infusion of new ideas, the literature points to Open Innovation, a major proponent of which is the firm Procter & Gamble. The firm uses its Connect and Develop program to look outward and tap a vast proprietary supplier network, web-based talent markets, entrepreneurs, academics, and government laboratories to connect with external sources of new ideas. Using Connect and Develop, Procter & Gamble is able to leverage the talents of about 1.5 million researchers and idea generators in its worldwide network, in addition to its research staff numbering 7,500 . The company then applies its own R&D, marketing, manufacturing, and purchasing ideas to further develop the sourced ideas and create better and cheaper products in a shorter timeframe (Huston and Sakkab 2006). NASA's Centennial Challenge similarly attempts to seek and support high-risk, high-reward ideas from outside the organization.

2. Providing Incentives

Best practices for incentives to engage in technology transfer were found in the literature but were scarcely mentioned in written responses or interview.

a. Public Acknowledgement

Many laboratories publicly acknowledge researchers (for example provide awards) who file patents, work with companies through Cooperative Research and Development Agreements (CRADAs), and participate in technology transfer activities. Rewarding these researchers encourages them to continue to seek out opportunities to transfer technology to the market. In addition, it raises the visibility of technology transfer to other researchers, which may encourage them to participate in technology transfer activities as well. For example, the Johns Hopkins University Applied Physics Laboratory (APL) has separate awards by category, such as a Copyright Award or Invention of the Year award. The recipients receive a trophy and cash. Some laboratories also provide cash awards for filing an invention disclosure or patent. According to ongoing research on technology transfer at DOD laboratories, some laboratories go beyond providing the minimum financial incentives required by the government.

b. Training and Workshops

Several examples involved training/workshops related to commercialization. NASA, for example, has established an annual SBIR Technology Commercialization Workshop consisting of plenary sessions to discuss NASA direction, technology tracks for in-depth technology discussions, and opportunities for collaboration. These workshops are sponsored by the Human Exploration and Operations Mission Directorate (HEO), but included participation from all the Mission Directorates. The workshops help to provide overviews of projected HEO applications and technology needs; provide a forum for collaboration and partnership development between SBIR companies, larger companies, and government agencies; and identify potential areas of collaboration within the agency and with other government agencies and industry.

APL was home to other best practices as well, according to ongoing research at STPI. APL held a Virtual Entrepreneurship Bootcamp in June 2010. The Virtual Entrepreneurship Bootcamp allowed researchers to participate in lunch-time seminars. One spillover is the Entrepreneurship "Community Group" that formed after the bootcamp and meets once a month for an online discussion group. The laboratory also hosted a 3-day series of lunch-time seminars to present materials about resources available to researchers and entrepreneurs. Presentations were made by organizations such as the state of Maryland's Technology Development Corporation, entrepreneurs who licensed technology from APL, and representatives from local universities who spoke on entrepreneurship.

3. Integrating Technology Transfer into the Mission

Reflecting the complexity of the challenge, none of the interviews or written responses identified best practices related to reducing contract delays and intellectual property disputes. The literature revealed some best practices related to reducing delays in contracting. Unless otherwise noted, this section builds on research at STPI on best practices. Best practices include those related to simplifying the negotiation process, developing better understanding between technical and legal staffs, finding creative ways to clarify intellectual property rights, and using third parties as intermediaries, among others.

a. Simplifying the Contracting Process

The contracting process can be simplified through:

- *Use of templates.* The literature identified development of standardized processes and procedures (including streamlined agreements and contracts as well as templates or checklists for agreements and contracts). One practice was to create contract templates where possible, such as standardizing basic and common contract elements. This leaves room for negotiating all other contract elements. Templates used by the National Institutes of Health and the Office of Naval Research are available online.[46] The literature also addressed other practices that help streamline the negotiation processes.

[46] See NIH templates at http://www.ott.nih.gov/forms_model_agreements/forms_model_agreements.aspx#MLA. See ONR templates at http://www.onr.navy.mil/Contracts-Grants/submit-proposal/contracts-proposal/cost-proposal.aspx.

- *Bundling CRADAs.* One option for process streamlining is the use of a single CRADA for several related projects instead of negotiating a single CRADA for each project. This saves time by reducing the number of passbacks.
- *Use of electronic agreements.* Another option for quick and easy passback is the use electronic agreements to reduce paperwork (Hughes et al. 2011).
- *Use of* Other Transaction Authorities (OTAs) and other contracting mechanisms to help smooth legal issues. OTAs have, for example, been employed in the CLEEN consortium to allow cost-sharing with well-defined data rights. This has allowed the FAA to gain insight into the technology development and to ensure development risks are adequately addressed, while controlling the information released to the public. NASA's SBIR and STTR programs have aided in the successful establishment of high technology firms in small communities leading the way to propel sections of the industry, namely the unmanned aerial vehicles.

An example gleaned from ongoing STPI research relates to the Office of Research and Technology Applications (ORTA) in the Aerospace Federally Funded Research and Development Center (FFRDC), which has developed an Intellectual Property Program Licensing Toolkit to assist in licenses. This document includes an initial questionnaire that inquires how the business with use the license; a licensing worksheet that asks for specific information including execution fees, royalties, and field of use; a standard license agreement; and a license agreement change request that divided the standard license agreement into editable sections. Other offices are using software to help identify and mine intellectual property databases, and evaluate invention disclosures. Use of these tools saves time on all sides.

Another example is that of the Picatinny Arsenal, headquarters of the U.S. Army Armament Research, Development and Engineering Center, which has identified common elements and steps in signing agreements and contracts such as CRADAs. Since 2007, they have worked to develop standard operating procedures, templates, and checklists that enable them to trace problems back to a specific aspect of an agreement, flag projects that need support, and speed up time to agreement. For these general efforts, Picatinny Arsenal became the first DOD organization to win the Malcolm Baldrige National Quality Award for quality and organizational performance excellence, and the 2011 Army Lean/Six Sigma Excellence Awards Program for demonstrating "excellence in the building, sustainment, and use of continuous process improvement."

b. Developing Trust-Based Relationships between Legal and Technical Experts

Based on ongoing STPI research, maintaining strong relationships with attorneys is a technology transfer best practice. Technology transfer is enhanced when patent attorneys and researchers are located geographically close to each other, ideally in the same building or at least on the same post. In addition, strong relationships between the legal offices and the ORTA can accelerate approval processes, especially when quick approval is needed on an occasional basis. For example, at Picatinny Arsenal, the technology transfer office has developed a good relationship with the Chief Counsel's office. This ensures that the technology transfer office talks to intellectual property attorneys for patent work and business/contract attorneys for CRADAs, since a CRADA is a contract. This is especially important when the CRADAs are linked to an acquisition strategy. By talking to the right kind of attorney on a regular basis, office staff can make optimal decisions.

c. Clarifying Intellectual Property Rights Sooner

To address the discrepancies between government and industry regarding intellectual property claims, one option is to make the CRADAs look more like the Defense Federal Acquisition Regulation Supplement (DFARS) guidance.[47] DFARS contract rules for data rights are based on who paid for the technology, so companies try to avoid having the government be involved in funding. Therefore, including DFARS-like language in CRADAs will help clarify intellectual property rights sooner in the negotiation process rather than later.

Understanding the U.S. Government's license rights in data is important for ORTA staff members who are involved in preparing CRADAs. These license rights and other intellectual property issues are not well understood by many in the DOD technology transfer community, thus one major hurdle is informing ORTA personnel of the availability of this training. A best practice to address this challenge was observed in the literature. The Defense Acquisition University course called "Intellectual Property and Data Rights" provides information about the DFARS and the importance to the government of obtaining its data rights up front when working with industry. This particular training module was edited by DOD data rights attorneys who are experts on this topic, and the module was released in June 2012. The new module provides fundamental information about intellectual property, effective management of rights in technical data and computer software, and their contributions to program success. This module is primarily intended for technology managers and other acquisition professionals who are charged with ensuring that the DOD has legal rights to the intellectual property necessary to provide the best technology to U.S. warfighters.

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[47] The DFARS is available at http://www.acq.osd.mil/dpap/dars/dfars/html/current/.

d. Using Third Parties

Another option is the use of a third party, such as partnership intermediaries, to help clarify intellectual property discrepancies. For example, many of the government's contract terms are bound by law and cannot be negotiated to accommodate a company's desires the way a company would be able to with another company or a university. A partnership intermediary agreement (PIA) can help firms clarify which clauses of contracts are open for negotiations and which are not.

NASA is exploring the use of licensing intermediaries to expand and accelerate patent licensing opportunities with U.S. companies. In one such arrangement, NASA entered into a partnership with the company ICAP Ocean Tomo where, at no cost to the government, the rights to license NASA patents were offered at a live intellectual property auction. This pilot program is a novel approach to collaborating with an outside firm dedicated to moving intellectual property from the government laboratory to the market place. NASA introduced this business practice approach to other Federal Government laboratories and other not-for-profit organizations (i.e., universities). The process is consistent with government policy of releasing public notice of the opportunity to license rights to use government intellectual property. The auction allows deliberate valuation of technology and an accelerated approach to licensing and technology transfer results.

e. Bundling Patents

Patent bundling and options to bypass patents have been discussed as ways to simplify discussions related to technology transfer and to license technology or inventions directly.

Ultimately, such activities would be less useful than overall efforts to make partnering easier. In an attempt to address concerns about difficulties raised in responses to a DOE Request for Information on improving technology transfer,[48] the DOE announced Agreement for Commercializing Technology (ACT), a pilot program for industry to engage with participating laboratory contractors. This approach to commercializing technology is expected to make it easier for private companies to gain access to the laboratory facilities and expertise. Agreements under this program reduce barriers surrounding intellectual property rights and create payment parameters that better match industry best practices. The program authorizes a more flexible framework for laboratory contractors to negotiate intellectual property rights and other terms that are better aligned with industry practice to facilitate moving technology from the laboratory

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[48] These concerns included requirements for advance payments, indemnification, and government rights to use intellectual property.

to the market. The pilot is just beginning, but is worth watching for practices that could be beneficial to aeronautics laboratories.

The NIH has also developed practices to encourage staff to become more involved in technology transfer activities. The NIH uses a Start-Up Patent License Agreement, which delays payment for the patent license for several years.[49] In exchange for a patent license, the start-up pays a combination of a percentage of the fair market value at the time of a liquidity event (initial public offering, merger, or sale of the company), stepped up annual royalty payments after 3 years, and a percentage of sales or sublicenses.

E. Correcting for Lack of Funding

Public-private partnerships were often recommended as a potential way to pool resources in light of resource constraints, as previously discussed. Another solution to compensate for lack of funds that came up in responses was use of customer user-fees to maintain software and systems. In the case of two tools that have received government support—CIFER and CONDUIT[50]—in exchange for the license agreement, a commercial company pays for the maintenance and support cost of the codes. This alleviates advertising cost and sustainment effort, thereby increasing the availability of research dollars.

F. Summary and Conclusion

This chapter highlights that aeronautics R&D departments and agencies have been effective in transferring knowledge and technology despite the barriers identified by respondents and in the literature. The DOD R2s, for example, present technical objectives and strategies and map the resources dedicated to these goals and activities. These maps present goals and associated funding for multiple years are particularly important because technology development for aeronautics systems and subsystems requires sustained effort. Finally, a range of programs, partnerships, and mechanisms such as NASA-FAA Research Transition Teams, Versatile Affordable Advanced Turbine Engines (VAATE) Initiative, and Future Naval Capabilities (FNC) are leveraging the total Federal investment in aeronautics R&D, identifying future potential joint technology development, and fostering better understanding of non-Federal stakeholder capabilities, approaches and plans. Table 4 summarizes the best practices and lists the examples discussed in this chapter.

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[49] See http://www.burrillreport.com/article-3894.html for details and http://www.ott.nih.gov/forms_model_agreements/forms_model_agreements.aspx for relevant templates.

[50] University Affiliated Research Center, NASA Ames Research Center, "Aerospace: Flight Control," http://uarc.ucsc.edu/flight-control/index.shtml.

Table 4. Partial List of Best Practices from Interviews and the Literature

Area	Best Practice	Selected Examples
Execution of Strategic Plans	Carefully map, with stakeholder participation, strategic plans into implementation	CTWG (NCI), R2 (DOD)
Communication and coordination	Establish partnerships only when there are shared goals and outcomes, trust-based relationships, metrics determine if success milestones are being met, openness to all is not necessarily helpful	VAATE (DOD), CAAFI (FAA), CLEEN (FAA), Airbus andFraunhofer Institutes (U.S./Germany), IMEC (Belgium), Biopolis (Singapore)
	Combine broadcasting (e.g., web-based databases, dissemination) with "pointcasting" (strategic information for individual industries/firms)	Bridging entities (MIT Deshpande Center, DOD DEVenCI, National Partnership Intermediaries), NACA, IPAs, Entrepreneur-in-Residence (FDA), ecoDemonstator (FAA), IR&D (DOD), NACA
Technology Maturation	Traverse the "valley of death" through set-aside funding, bridging institutions, demonstrations, and integrated programs that take a systems approach	TAP, RIF, and FNC (Navy), In-Q-Tel (CIA), Research Transition Teams (NASA, FAA), HiFiRE (joint government), ISRP (NASA), ARPA-E (DOE), DOE's portfolio approach
Eliminating "Fog and Friction"	Provide additional (financial and institutional) incentives for researchers to participate in technology transfer	Centennial challenge (NASA), Center Innovation Fund (NASA), Seedling Funds (NASA, IARPA), Sunshot Initiate (DOE)
		Prizes for innovators (APL), Virtual Entrepreneurial Bootcamp (APL), Open Innovation (Procter & Gamble)
	Develop standardized processes and procedures; maintain strong relationships with attorneys; simplify the intellectual property process, patent bundling; change the "look" of CRADAs; use third parties as partnership intermediaries; fund programs to promote tech transfer	Use of templates (ONR, NIH), intellectual property licensing toolkit (Aerospace), ACT program (DOE), NIH Start Up Patent License Agreement (NIH)
Correcting for Lack of Funding	Establish public-private partnerships, implement user fees when feasible	User fees for software at NASA Ames

All these successes notwithstanding, it must be pointed out that the movement of people may yet be the most effective way to transfer technology. An illustration of this is provided in "Silicon Valley History," a collection of excerpts from news, interviews, and articles compiled by Gregory Gromov.[51] The history explains how dissatisfied employees of Shockley Semiconductor left the company in 1957 to form the independent firm Fairchild Semiconductor, which resulted in the explosion of information technology firms that were launched over the next 20 years in Silicon Valley. This lesson should not go to waste in the aeronautics sector.

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[51] Available at http://www.netvalley.com/silicon_valley_history.html.

6. Barriers in Context

The literature review and interviews with stakeholders revealed several barriers to technology transfer. This chapter discusses these barriers in the context of the larger aeronautics ecosystem, and helps shed light on which barriers are actionable within the purview of OSTP and the ASTS.

Many of the barriers noted, especially in the interviews, can be better characterized as symptoms of deeper challenges in the larger aeronautics ecosystem. For example, lengthy technology maturation is rooted in the inherently complexity of aeronautics technology. The barriers are not all unique to the technology transfer interface of the aeronautics ecosystem. The concept of risk aversion, for example, permeates the entire system, from program creation within government offices to industry factory floors. Neither is risk aversion restricted to aeronautics; most of the R&D enterprise, at one time or another, has been accused of conservatism.

Further, the barriers do not all occur at the same level. Some are intrinsic to the aeronautics enterprise. For example, the sector produces complex products that must operate in difficult environments. This is not a barrier that is inconsequential to address. Others relate to external challenges. For example, trade and regulatory changes, or program reductions related to World Trade Organization rulings are challenges that the stakeholders have to adjust to, at least in the short term.

Other barriers are results of the interactions between these intrinsic and external factors. For example, shrinking funds leads to decision-making that makes enterprises more risk averse, or push immature technologies out, which could lead to unintended consequences like a dearth of disruptive innovation, and lengthening development cycles.

Table 5 is a notional representation of the barriers organized by these levels, which are explored in greater detail in the sections that follow.

Table 5. Barriers to Innovation Act at Multiple Levels

Intrinsic and structural issues…	combined with external challenges…	lead to risk-averse behaviors…	resulting in unintended outcomes
• Market structure of the aerospace sector • Development of complex products that must operate in difficult environments • Incomplete understanding of the technology development process • Laboratory culture of Insularity • Misaligned incentives • Lack of meaningful metrics to measure progress	• Increasing global competition • Uncertain fiscal and workforce outlook • International trade and regulatory issues (World Trade Organization, International Traffic in Arms Regulation, and others)	• Reduced investment especially in mechanisms related to communication and coordination • More contentiousness over ownership of intellectual property • Increased caution, review, and oversight (government) • Focus on incremental improvements (government, industry) • Pushing immature technologies to next level • Regulations not keeping pace	• Increasingly fragmented knowledge base • Siloed decision-making • Less disruptive Innovation • Longer development cycles

A. Intrinsic and Structural Issues

Most of the barriers identified in Table 5 as being within the aeronautics community that are intrinsic to the sector and its structure are self-explanatory. Two that are not are discussed in the subsections that follow.

1. Market Structure of the Aeronautics Sector

In an ideal competitive market with numerous buyers and sellers, both the consumer's needs and the supplier's capabilities are revealed through the mechanism of price. Innovation occurs through the continual interaction of market pull (the government needing capabilities) and supply push (the private sector offering them). The plurality of buyers and sellers ensures that innovation occurs and prices remain low.

In much of the aerospace sector, however, the market is neither competitive on the buy side (the national security establishment is the sole buyer, making the market a monopsony), nor on the sell side (a small number of firms sell aeronautics products and services, making it an oligopoly[52]). Since it operates in a cost-reimbursable environment, the industry serves up what the government wants without needing to be especially

[52] The industry underwent much consolidation in the 1990s. GE sold its aerospace division to Martin Marietta, which then sold itself to Lockheed. Boeing bought the aerospace units of Rockwell International, and then acquired McDonnell Douglas. Northrop bought Grumman. Lockheed Martin and Boeing both ended up with about 10% of all government aerospace contracts, though joint ventures and teaming remained significant.

innovative (or cost conscious). It especially does not take risk by engaging in disruptive innovation unless market opportunity is perceived.

The situation is likely more complicated. In the classical competitive market structure, there is a large market for any given innovation. If an innovation is not of value to Buyer A, then Buyer B may likely be interested in it. In a monopsony-oligopoly market structure, pursuing innovation is risky unless the one and only buyer is clear about what it wants. If the buyer is unwilling to pay for the innovation up front, or guarantee that it will pay for it when brought to market, innovation is unlikely. As a result, some experts believe that the aeronautics market structure (at least the military side of it) deters innovation, especially disruptive innovation (King and Driessnack 2007).

Both the literature and experts interviewed for this study suggested that without disruptive innovation,[53] the United States will not be able to continue on its path of continued success (Szajnfarber, Richards, and Weigel 2008).

2. Incomplete Understanding of the Technology Development Process

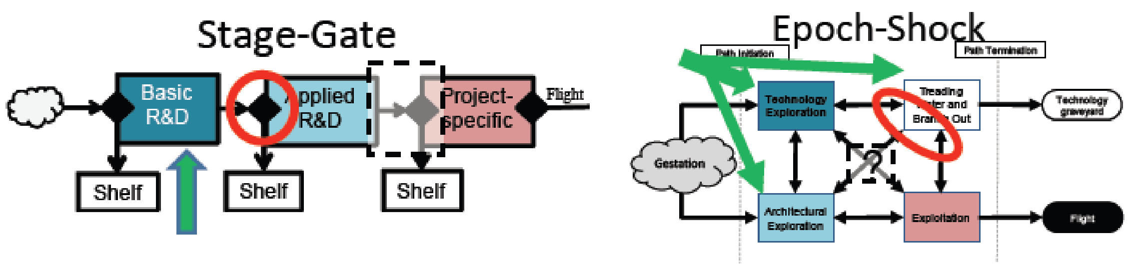
It is commonly believed that complex product innovation involves a stage-gate process (GAO 2006) whereby where progress through stages is reviewed and the set of maturing capabilities that will go through the "gate" to the next stage are selected. In conceptualizing the process as a linear flow from basic to applied research and so on, "the innovation management problem reduces to an optimization problem: Given a fixed set of resources, choose (a) the number of stages, (b) the relative resources allocated to each stage, and (3) the gate decision rules, such that the desired flow of new capabilities is achieved" (GAO 2006).

Recent work in the aerospace sector suggests that the stage-gate model is not just not an oversimplification, but possibly incorrect and misleading (Szajnfarber and Weigel 2013). According to these scholars, innovation does not progress monotonically from left to right. Instead, resources are drawn simultaneously from different stages, and "switchbacks" are observed. A more correct representation is likely one encapsulated in an "epoch shock" model (right side of Figure 2). In the model, the system exhibits "epochs of persistent stable (and identifiable) behaviors punctuated by transition inducing shocks."

The stage-gate model implies that proportionally more funding for basic R&D will increase the pool of early-stage concepts (green arrow in the left side of Figure 2). It also

[53] A disruptive innovation is an innovation that helps create new markets and value, and eventually goes on to disrupt an existing market and value network, displacing an earlier technology. In contrast to disruptive innovation, a sustaining innovation only evolves existing ones with better value, allowing the firms within to compete against each other's sustaining improvements.

implies that gate decisions control progression to the next stage (red circle). It also implies that adding more stages will facilitate transitions between difficult-to-bridge stages (represented by the dotted rectangle), such as the "valley of death." However, if the model is a poor representation of reality, none of these stages would improve speed or quality of innovation.



Source: Szajnfarber (2011).

Figure 2. Stage-Gate and Epoch-Shock Models of Technology Development

If reality resembles the epoch-shock model on the right side of Figure 2, resources cannot easily be allocated to early stage or basic research because this funding stream is in reality split between basic concepts and others (green arrow) and actively controllable gates (red circle) do not really exist. As long as teams can draw resources from multiple levels simultaneously, no gate can control the flow. Finally, the lack of linear progression invalidates the concept of bridging transitions by adding additional stages and gates (Szajnfarber and Weigel 2012).

B. External Challenges

The intrinsic and structural barriers discussed in the previous section are combined with both longstanding and relatively new external challenges, as shown in Table 5. The principal external challenges are discussed in the sections that follow.

1. Increasing Global Competition

The aeronautic sector's competitive position in the global market is an important factor in industrial decision-making. U.S. aircraft manufacturers depend heavily on the international market for their sales. The large commercial jet aviation market is currently a competitive duopoly between the U.S. aircraft manufacturer Boeing and the European aircraft maker Airbus. The regional jet market is dominated by two non-U.S. headquartered manufacturers, Brazil's Embraer and Canada's Bombardier, both of which use a high level of U.S.-produced content in their products. The general aviation market includes companies such as Cessna and Gulfstream (Platzer 2009).

Globalization and increased competition for domestic and international aircraft markets from these companies is viewed by many as a threat to the nation's aeronautic enterprise (Atkinson and Ezell 2012). In addition to increased competition from current players like Airbus, a host of foreign companies, some with state support, are poised to enter the aviation market. For example, it has been suggested that Commercial Aircraft Corporation of China Ltd. (COMAC) is likely to emerge as a low-cost value player, and a likely competitor to the current leaders in aviation (Cameron 2012). Similar changes are occurring in the lower-tier supplier system as well.

2. Uncertain Fiscal and Workforce Outlook

Despite the size of the aeronautics sector's international markets, a large fraction of its revenue comes from the U.S. government (see Figure C-2 in Appendix C). However the share of government as a customer is decreasing. According to analysts, military investment spending on new acquisitions and R&D (which includes aircraft and other weapon systems) could decline from $253 billion in 2008 to as low as $150 billion in 2016 (Starr and Anderson 2012).

On the R&D side as well, while government funding has been relatively stable in recent years, it is expected to fall in future years. Figure 3 shows the latest aeronautics R&D budget authority data gathered from the now discontinued Aeronautics and Space Report of the President.[54]

Figure 4 presents data more specifically on the Federal government's aeronautics engineering *research* funding. Figure 5, while drawn from a difference source, and therefore not entirely consistent, presents the trend broken down by agency. In each of these figures, the recent downtown is evident—and has been brought up as a challenge by all parties. Indeed, a recent NRC report on strategic directions of NASA asserts (NRC 2012, 2):

> NASA's aeronautics budget has been reduced to the point where it is increasingly difficult for the agency to contribute to a field that U.S. industry and the national security establishment have long dominated.

While the research downturn is not evident in these charts, primary because of the size of development funds, they do show the government as an increasingly less dominant player on the R&D front. Appendix C provides further time-series data on aerospace (aeronautics data is difficult to isolate) R&D.

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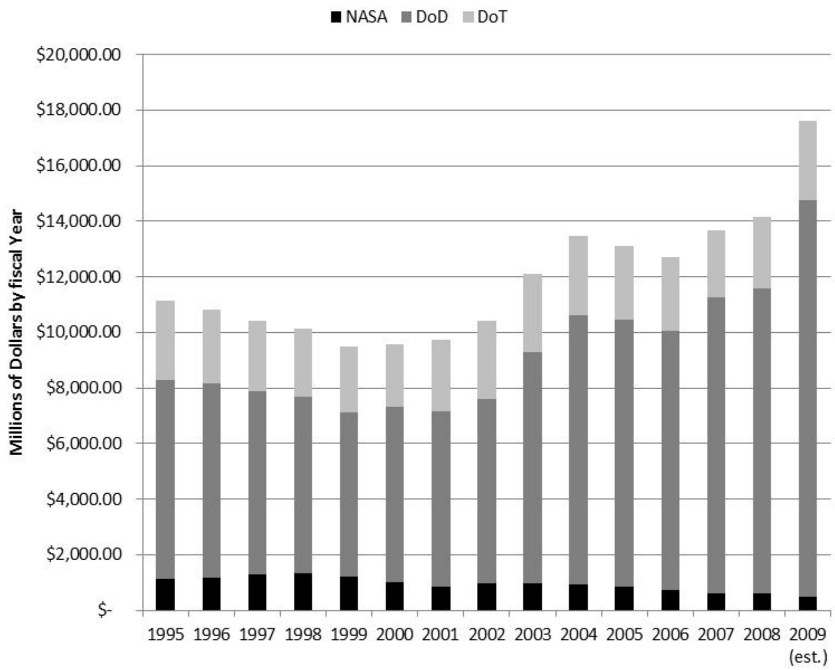
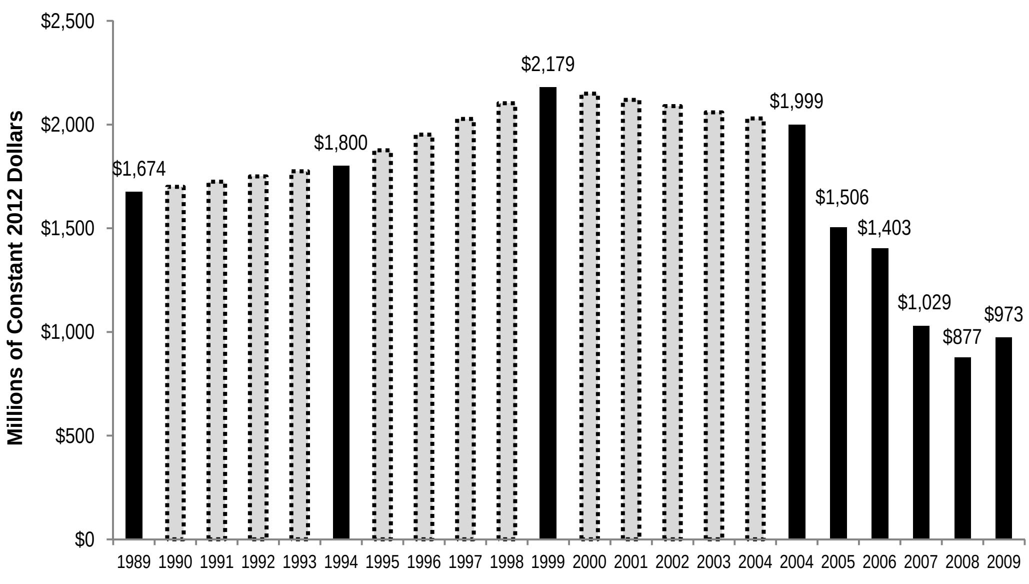
[54] More recent aeronautics R&D data have been difficult to find.



Source: NASA (2008).

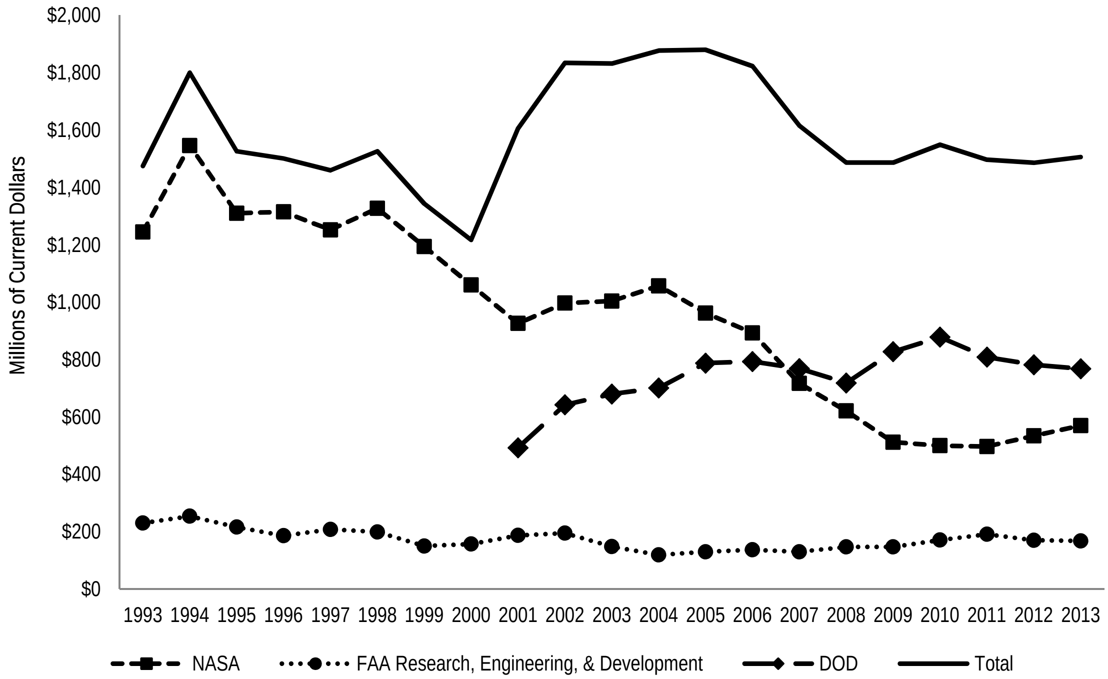
Figure 3. Federal Aeronautics R&D Budget Authority, 1995–2009



Source: Appendix table 4-35, National Science Foundation, National Center for Science and Engineering Statistics, Survey of Federal Funds for Research and Development: FY 2009–11. Science and Engineering Indicators 2012.

Note: No data were available for years 1990–1993, 1995–1998, and 2000–2005, so these points were interpolated using data from years 1989, 1994, 1999, and 2004. Also, to convert constant 2005 dollars to constant 2012 dollars, an inflation factor (derived from the Bureau of Labor Statistics) of 1.18 was applied. The calculator is available at: http://www.bls.gov/data/inflation_calculator.htm.

Figure 4. Federal Obligations for Aeronautics Engineering Research, FY 1989–2009



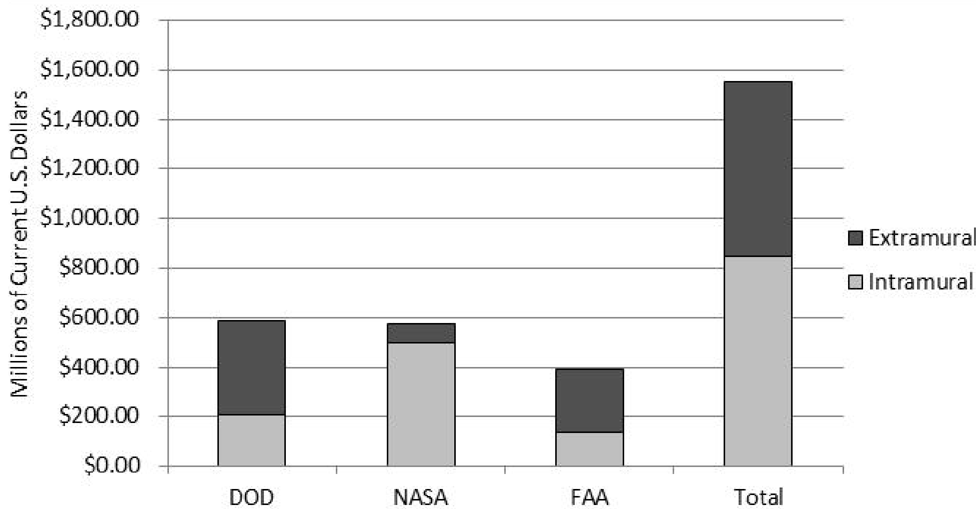
Source: Obtained from email correspondence with ASTS leadership.

Figure 5. Federal Funding for Aeronautics Research by Agency, FY 1994–2012

In the context of funding, it is important to draw attention to the relative role of technology transfer (as distinct from other factors) in influencing the aeronautics ecosystem. First, government funds are not only a small piece of the *total* R&D enterprise, they are also a small piece of the *basic* research enterprise (Figures C-3 and C-4 in Appendix C[55]). Second, the magnitude of research being conducted intramurally (which will give an indication of the magnitude of the research there is to be transferred to extramural parties, industry primarily) shows that only about half the total funds are spent within the government with resultant outputs available for technology transfer (Figure 6). Both these factors together likely illustrate that, based on the total funding value and proportion, technology transfer may not be the biggest factor in improving the sector's innovative capacity. Amounts notwithstanding, the government can and does influence the direction of research in industry.[56]

[55] Although the figures show aerospace, not aeronautics, data (aeronautics-only data are not available readily), trends are likely similar in aeronautics.

[56] Experts point to the value of the "halo effect" that comes with government funding, which can help leverage other funds (such as venture capital).



Source: Email correspondence with representatives of OSTP, NASA, FAA, and DOD.

Figure 6. Estimated Distribution of Funds in 2012 (or Latest Year Available) between Intramural and Extramural Aeronautics Research

3. International Trade Issues[57]

The March 2012 findings and recommendations by the World Trade Organization Dispute Settlement Body (DSB) concerning the Large Civil Aircraft (Second Complaint) case found that the United States caused adverse effects to the interests of the European Union through the use of certain subsidies. In response, the Federal Government has taken actions to withdraw the subsidies found to have caused adverse effects or to remove their adverse effects. These actions have included modifications to contracts; termination of programs; reduction in funding for some aeronautics research contracts; modification of rights accorded to parties under cooperative agreements; initiation of technology investment agreements and other transactions; and termination of the Foreign Sales Corporation and Extraterritorial Income tax benefits.[58] Many NASA and DOD programs have been affected. According to the U.S. Trade Representative:[59]

> NASA has terminated the Advanced Composites Technology, High Speed Research, Advanced Subsonic Technology, High Performance Computing

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[57] Although International Traffic in Arms Regulations (ITAR) was brought up in several discussions on trade barriers, this topic was not explored in this study.

[58] Office of the United States Trade Representative website, "Reporter Memo: United States Complies with World Trade Organization Ruling in Aircraft Dispute," September 23, 2012. http://www.ustr.gov/about-us/press-office/press-releases/2012/september/US-complies-wto-ruling-aircraft.

[59] Office of the United States Trade Representative website, "Notification of the Withdrawal of Subsidies and Removal of Adverse Effects in *United States—Measures Affecting Trade in Large Civil Aircraft (Second Complaint)*," http://www.ustr.gov/webfm_send/3546.

> and Communications, Quiet Aircraft Technology, Vehicle Systems, and Research and Technology Base programs, and reduced funding for aeronautics research contracts with private parties under other aeronautics research programs. NASA has changed its policies so as to remove limitations on access to the results of NASA research and development efforts, including by ceasing the use of limited exclusive data rights ("LERD") clauses. NASA has implemented a policy of seeking greater prompt disclosure of the results of its sponsored research when it purchases research and development services from private entities.
>
> The U.S. Department of Defense ("DoD") has modified the rights accorded to the parties under the cooperative agreements, technology investment agreements, and Other Transactions listed in Annex B so as to make them consistent with commercial practice. The modifications apply to all of the DoD assistance instruments covered by the recommendations and rulings of the DSB. DoD made identical modifications with regard to contracts subsequent to those covered by the recommendations and rulings of the DSB, without prejudice to the U.S. view that those contracts were not subsidies causing adverse effects to EU interests.

Experts believe the ruling may have longer term and broader implications for technology transfer.

C. Risk-Averse Behaviors

The challenges discussed in the previous section have behavioral consequences. Their strong emphasis on success encourages taking safe bets rather than risks. This risk-averse behavior is evident on the parts of both the government—greater oversight and review—and industry—focus on incremental innovation. Ironically, developmental risk has risen even as the aerospace community steadily grows risk-averse, focusing on avoiding failure at all cost. Consequently, across the aeronautical community, both in government and industry, researchers and design and production teams increasingly pursue incremental innovation (for example, the steady evolution over the last six decades of the sweptwing "tube and wing" jetliner) rather than disruptive or radical innovation (for example, the development of stealth aircraft in the 1970s). While funding constraints constitute one reason for this preference, other reasons also exist, including the limited nature of both the civil and military aeronautics market, and the fear—given a now-multi-decade development path characteristic of present and future acquisition efforts—that if a mistake is made, a company may not be able to recover in time to avoid being surpassed by a global rival.

Risk aversion within the Federal Government is manifested through an increased (if understandable) predisposition to lengthy program review and technical oversight. While appropriate review and oversight are crucial[60]—and advocated elsewhere in this document—inappropriate application of review and oversight constrains experimentation; adds to program costs, uncertainties, and stretch-out; and risks seriously hindering the maturation of a technology before other pressures may force its premature application to a production system.

Another consequence—related primarily to incomplete understanding of the technology development process—is that suboptimal decisions are likely to be made with respect to technology maturation. The use of immature technology has been highlighted by the DOD in various reports and was identified by the Government Accountability Office (GAO) as a primary cause of program cost overruns and schedule extensions (GAO 1999). If government program managers see technology development as a stage-gate process, they make decisions to fund in stages, try to control flows, and insert bridging mechanisms. Indeed, GAO even makes such a recommendation (GAO 2006):

> GAO recommends that DOD strengthen its technology transition processes by developing a gated process with criteria to support funding decisions; expanding the use of transition agreements, relationship managers, and metrics; and setting aside funding for transition activities.

Lack of understanding of the technology maturation process leads to less-than-ideal decision-making in other contexts as well. One example that came up in interviews is the outsourcing of critical research skills from within government to contractors. The trend began with the Total Package Procurement process of the 1960s. The concept was to have the government pay one negotiated, upfront price for the entire "cradle-to-grave" development of the system. It did not deliver results as expected, and was seen as a failure.[61] A similarly unsuccessful activity was repeated in the Total System Performance Responsibility process in the 1990s. The underlying premise was also that too much money was being spent on government oversight and compliance and that the contractors should be made completely responsible for the performance of the systems they delivered.

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[60] Title 10 U.S.C. § 2366b(a)(3)(D) requires that all DOD Major Defense Acquisition Programs have, among other items, certification that "the technology in the program has been demonstrated in a relevant environment, as determined by the Milestone Decision Authority on the basis of an independent review and assessment by the Assistant Secretary of Defense for Research and Engineering," http://www.gpo.gov/fdsys/pkg/USCODE-2010-title10/pdf/USCODE-2010-title10-subtitleA-partIV-chap139-sec2366b.pdf.

[61] See Daniel Handlin's essay, "Looking for a Silver Bullet: Tempering Optimism with a Dose of History," in *The Space Review*, http://www.thespacereview.com/article/1619/1.

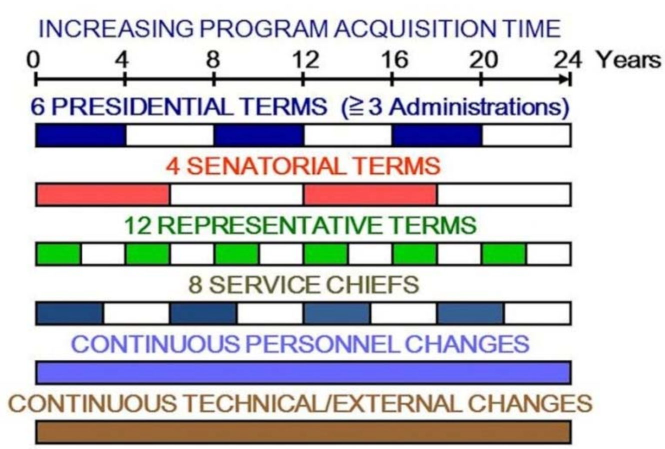
D. Unintended Outcomes

The risk-averse behaviors just described have the unintended consequences of creating silos and fragmenting knowledge across the silos. Efficiency in a top-down system, that aeronautics tends to be, requires that the buyer knows what is possible. Knowing what is possible is already difficult in the realm of complex engineering systems. The creation of siloes and fragmented knowledge exacerbates these challenges (Szajnfarber, Richards, and Weigel 2011).

Based on their research, Szajnfarber et al. (2011) also assert that a culture of risk aversion chills the innovation environment, and leads to fewer disruptive innovations. While, through its demand pull, the government is able to spur top-down innovation, this is to the near exclusion of a push from the bottom up—which is often the source of new ideas and disruptive innovation. Both are required for a continually innovating system.

These consequences build and feed into others, such as longer development cycles. Many of the interviewees, especially in government, expressed concerns about the pernicious effects of the length of aircraft development cycles. History backs up their concerns.

As noted in Appendix D, during the World War II, a radically new aircraft could progress from the designer's drawing board to the operational flight-line of a military base in little over 2 years. This was within a single Presidential term; the term of a single Senator; a little more than one term for a member of the House of Representatives; within the term of office of a military service chief; within the term of service of a company president, chief engineer, and each member of a design team; and within a period where the technology environment and external world were relatively similar both at the beginning of a program and when it reached initial operational capability (Figure 7).

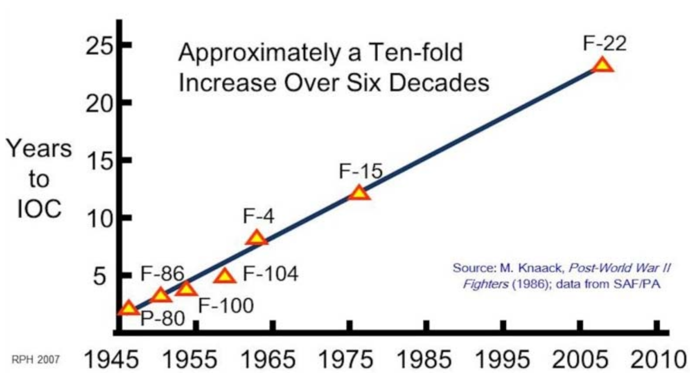


Source: Richard P. Hallion, 2006.

Figure 7. Decision-Making Environment in the United States

Today, the average military aircraft program takes more than 15 years from concept to low-rate production and approximately 20 years from concept to initial operational capability. This timespan crosses over multiple Presidential, congressional, and administrative terms, and the company management and design teams generally change as well over the length of the program. The external world can also vary enormously from factors that include changing geopolitical circumstances (for example, the end of the cold war in 1989 in the midst of the F-22 fighter development, and the 9/11 attacks occurring as the aircraft first entered service) and, of course, ever-changing technology.

Figure 8 presents data on specific programs, and relates the last six decades in high-performance fighter aircraft development time within the U.S. Air Force. The figure tracks the era of the subsonic first-generation jet fighter (the Lockheed F-80), to the fifth-generation jet fighter (the Lockheed-Martin F-22A). As the figure shows, Air Force turbojet fighter aircraft development time went from slightly over 2 years from "drawing board" to initial operational capability in 1944–45 to over 20 years from conception to IOC over 50 years later. While follow-on aircraft like the F-80, F-100, and F-104 had significant advances over their predecessors, on the whole their technological advances were generally within the state of the art, and thus they were able to go from concept through flight test and into operational service relatively quickly.



Source: Richard P. Hallion, 2007.

Figure 8. Time to Initial Operational Capability for Selected U.S. Air Force Jet Fighters

Later-generation aircraft, befitting their more demanding technology, proved complex, and generally resulted in delayed entry into operational service, or entry into service with significant operational limitations that required further research and validation before the aircraft were viable war-fighting assets. The F-15, for example, suffered from serious problems with its Pratt & Whitney F100 afterburning turbofan engine. The F-22, first flown in prototype form in 1990, is an example of an aircraft that had multiple deficiencies that required solution, and the F-35 Joint Strike Fighter is today exhibiting program stretch-out, developmental difficulties, and technical immaturity of its radical new helmet system. In these cases, technological optimism led to overoptimistic predictions of when the total aircraft systems would be sufficiently mature to enter operational service.[62]

Data back up these historical illustrations. The 98 Major Defense Acquisition Programs from FY 2010 collectively ran $402 billion over budget, and were an average of 22 months behind schedule since their first full estimate (Hofbauer et al. 2011). In 67 separate test and evaluation programs, over half of program delays in operational and developmental test stemmed from deficient performance (i.e., overoptimistic prediction that can be caused by too rapidly transitioning immature technology), 20% from managerial development issues, 23% from other programmatic issues, and 5% from delays induced by the testing process itself (Gilmore 2011, 390, Fig. 1).

The problem is not limited to DOD. NASA's James Webb Space Telescope is an example of a NASA program that is already double its original life-cycle cost and is likely to be 4 years late in its launch (NASA 2012b).

Studies have cited several factors that contribute to poor cost, schedule, and performance outcomes in government projects. Principal among these include inaccurate cost estimates, failure to define requirements adequately, and underestimating the complexity and maturity of technology (Dubos, Saleh, and Braun 2008). A NASA Inspector General study identified four factors that appear to present the greatest challenges to successful outcomes: culture of optimism, underestimating technical complexity, unstable funding, and project manager development (NASA 2012b). Other experts assert that it is the assumption of the stage-gate system (where maturing is measured by monotonically increasing TRLs) and a lack of understanding of the complex interplay between TRLs of components versus systems, which is a critical factor.

Long development cycles not only affect delivery of the end product to the customer, but risk continual redefinition and redirection as programs run across multiple administrations with multiple key leadership changes and a dramatically changing external (i.e., "the world") environment. And regardless of the root cause, long development cycles are an unintended consequence of a series of intrinsic and extrinsic barriers, and not a barrier that can be addressed in isolation.

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[62] Other programs such as the V-22 vertical/short takeoff and landing aircraft and the Terminal High-Altitude Air Defense missile system confirmed an equivalent tendency to too-rapidly push an immature technology, sometimes—as in the case of the V-22—with fatal results. See (Krings, Christie, and Adolph 2011).

E. Summary and Conclusion

Barriers to innovation in aeronautics go well beyond those in technology transfer. Furthermore, as the section above explains, some of the barriers are unintended consequences of decisions made upstream, and not barriers in of themselves. As a result, they are far more intractable to address without addressing those upstream barriers. To address these barriers in a systemic way, there needs to be integration of fragmented knowledge that resides in all parts of the system—government, prime contractors, suppliers; engagement with industry to improve the mechanics of interactions; and the promotion of bottom-up R&D in a top-down environment, entailing the need for taking risks, failing fast, testing on the margin, and balancing risk aversion with the need for experimentation. The next chapter breaks down these ideas into actionable recommendations.

7. Recommendations

Building on the data collected through interviews and a review of the literature, this chapter presents recommendations that will help ensure that advanced technologies developed at Federal laboratories transition into industry to improve aeronautic system performance and encourage technical innovation in the aeronautics sector. The recommendations are organized into the same four categories as the barriers they are designed to address: coordination and communal awarenessof NARD plans; communication and liaison among stakeholders; maturity of new technology; and institutional "fog and friction."

Many of the barriers uncovered are neither new nor surprising. Indeed most stem from the innate mismatch between the interests of government and industry. In this, we recognize and acknowledge that the leaders of both government and industry are, generally, highly patriotic, dedicated, accomplished, and public-minded citizens who wish the best for the nation and their fellow citizens. Nevertheless, both the subtle and not-so-subtle differences in the motivations underlying the sectors are worth articulating: theoretically speaking, the goal of industry is and will always be to maximize shareholder profits, and the goal of government is and will always be to maximize public good. There will be times when these goals align and fruitful collaborations are possible; there will also be circumstances under which these goals are at odds, and compromises must be made. This chapter builds on this spirit of compromise and mutual benefit.

A. Achieve Greater Coordination and Communal Awareness in the Execution of NARD Policies and Plans

As noted in the preceding chapters, the 2006 National Aeronautics Research and Development (NARD) Policy and the 2007 National Plan for Aeronautics Research and Development and Related Infrastructure guide aeronautics R&D through 2020 (NSTC 2010). Many of the industry respondents interviewed were not aware of the NARD process or its potential relevance to their planning. Of those who were, most believed that NARD plans and policies have not been integrated sufficiently into agencies' own plans and activities, and coordination between agency-level activities and the overarching NARD plan has been lacking. In other words, NARD plans were not viewed as an explicit guide of governmental aeronautics budgeting and planning.

Review of government documents corroborated industry views, and showed that NARD is not explicitly a guide of governmental aeronautics budgeting and planning. For example, there is no mention of NARD in the NASA Aeronautics Research Mission Directorate (ARMD) R&D budget.[63] Neither do the plans show prominently in the budgets of other aeronautics agencies (Lourdes 2008).

Secondary materials similarly lack the imprint of NARD. For example, a recent NASA aeronautics testimony began with a nod to NARD.[64] However in subsequent parts of the testimony, there was no discussion of how NARD goals drive ARMD's planning activities. Most noticeably, the discussion of the allocations of dollars to specific research areas did not reference NARD goals or match them. Similarly, testimonies of other experts addressed aeronautics research without a single mention of NARD.[65] NARD did not come up in industry testimonies either.[66] In the question period, not once did congressional leaders ask about progress made on NARD goals. Indeed the opposite—experts continued to get queried as to aeronautics' most important priorities—indicating that either congressional leaders either did not know these priorities had been settled, or did not believe them to be the most important ones.

Independent of alignment with NARD plans, industry respondents believed that the Federal Government's plans and technical goals are neither sufficiently articulated across the aeronautical community nor stated with adequate clarity. As a result, the aeronautical community's awareness of national policy and program intent is at best sporadic. Respondents often perceive agency efforts as contradictory, confusing, and unhelpful to developing their own strategy and implementation plan.

In sum, fidelity—that is, aligning the efforts of the national aeronautical community to the plans and policies of NARD to achieve congruency, common purpose, and a common vector—in short, a beneficial unity of purpose and effort—has been difficult to demonstrate.

Recommendation 1.1: *Consistent with its mandate in Executive Order No. 13419, the Office of Science and Technology Policy (OSTP), in conjunction with the Office of*

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[63] See http://www.nasa.gov/pdf/632668main_NASA_FY13_Budget_Aeronautics-508.pdf.

[64] Statement of Dr. Jaiwon Shin Associate Administrator for Aeronautics Research National Aeronautics and Space Administration before the Subcommittee on Space and Aeronautics Committee on Science, Space and Technology U.S. House of Representatives, p. 3, April 26, 2012, http://www.hq.nasa.gov/legislative/hearings/2012%20hearings/4-26-2012%20SHIN.pdf.

[65] Testimony of Marion C. Blakey, Chair, Aeronautics Committee, NASA Advisory Council, "Overview of the NASA Aeronautics Research Mission Directorate's Budget Request for Fiscal Year 2013," http://science.house.gov/sites/republicans.science.house.gov/files/images/HHRG-112-SY16-WState-MBlakey-20120426.pdf.

[66] Testimony of John Tracy, Boeing CTO and Senior VP EO&T, "An Overview of the NASA Aeronautics Research Mission Directorate's Budget Request for Fiscal Year 2013," http://science.house.gov/sites/republicans.science.house.gov/files/images/HHRG-112-SY16-WState-JTracy-20120426.pdf.

Management and Budget, should ensure that agency priorities, budgets, and programs formally reflect and are traceable to NARD plans.

Agencies' aeronautics R&D priorities, budgets, and programs must be directly traceable to NARD plans and policies. If they are not, it may be a sign that either the activities or the NARD plans and policies need to be re-evaluated for relevance to national needs.

The principal challenge to implementing this recommendation is to identify the organizational entity that could best conduct the assessment. As the history of gas turbine and airline development shows (see Appendix D for a review of the history of aeronautics), the practitioners in the field are not necessarily the best judges of themselves—they may be so close to a particular form of technology as to be blind to new opportunities. Worse, they may actually have incentives to reject disruptive innovation. One potential solution is in the mandate provided by Executive Order No. 13491 that requires the Director of OSTP to conduct a biennial review of the implementation of NARD. This review, conducted together with the Office of Management and Budget, can explicitly evaluate the mapping between agency budgets and plans and the NARD plan, and ensure consistency and compliance by the Federal aeronautics community.

Recommendation 1.2: *OSTP, in its mandated biennial review of the implementation of NARD plans, should include more opportunity for industry participation and feedback.*

According to the requirement of Executive Order No. 13419, OSTP, in conjunction with the ASTS, conducts a biennial review of the implementation of NARD plans. The latest review was issued in January 2011 (NSTC 2011). However, as the roundtable discussions and interviews revealed, industry did not appear to be especially informed about the assessment nor had industry expressed buy-in on its findings. To ensure NARD plans and policies are realistic, achievable, desirable, and relevant to defined national needs, it would be useful to include more substantive user input in this assessment.

Industry participation in this assessment would be more likely if Recommendation 1.1 has been implemented and industry sees NARD as a real guide to agency activities. Input to this assessment could be coordinated with help from industry associations and professional societies—Aerospace Industries Association (AIA), General Aviation Manufacturers Association (GAMA), and American Institute of Aeronautics and Astronautics (AIAA) being options. Input could also come via industrial advisory bodies to the individual departments and agencies.

B. Improve R&D-Related Communication and Facilitate Liaison among Key National Aeronautics Stakeholders

The literature, especially on innovation in the aerospace sector, identified fragmented knowledge across stakeholders as a key barrier to innovation. This was confirmed in the interviews. Industry respondents reported that they felt they had limited visibility and input into government-sponsored research. They also reported that government did not leverage enough private sector technology.

Government respondents similarly felt that they had less insight than both needed and desirable into industry plans and progress. They found that the challenge has been exacerbated in recent years through increased restrictions on travel to conferences and other aeronautical community events.

Cultural differences—mission mismatch in particular—between government and industry, and across government agencies affect the nature of interactions between all aeronautics stakeholders, and there are many informal mechanisms in place to promote interactions among stakeholders. Informally, industry is involved in R&D efforts through joint planning meetings, multi-agency research program progress meetings, and general exposure to ongoing industry and government research projects. In an ad hoc manner, industry organizations and firms are also invited to attend government basic research reviews, and to propose topics for inclusion in the government-sponsored programs. Government researchers visit industry research centers, and (especially for DOD) provided access to industry internal R&D activities. These should be continued, and scaled up as needed.

Aeronautics-related public-private partnerships are also in place; however, not all are active or considered as productive as can be, and there do seem to be common factors that make some partnerships more successful than others. Finally, respondents articulated a need for specific interactions to occur to address time-critical challenges to the aeronautics industry.

In addition to informal and *ad hoc* channels, more formal and structured interactions are in order, and the STPI research team proposes three recommendations. The first related to better visibility of government into industry R&D, the second related to better design of public-private partnerships, and the third to a time critical issue of immediate interest to the aeronautics community.

Recommendation 2.1: *Federal aeronautical departments and agencies should inform their own R&D plans and programs by obtaining more information on aeronautics firms' independent research and development (IR&D) projects that are allowable costs on Federal contracts.*

All stakeholders agreed that government should be more aware of technology advances in the private sector to inform its own R&D planning and activities, while concurrently making private partners better informed regarding government plans and technical capabilities. The DOD has recently gained increased visibility into firms' IR&D with costs that are reimbursed by the DOD under 10 U.S.C. 2372. Authorized DOD users can now examine IR&D project summaries submitted by firms. This increased visibility has been enabled in a way that does not interfere with the independence of IR&D. The DOD has concurrently acted to make more and better information available to its contractor base so that firms can better focus IR&D on DOD priorities,[67] including development and publication of a vendor communications plan.[68] NASA also has published a vendor communications plan,[69] and the other agencies' plans are in the works. All aeronautics-related agencies should inform their R&D planning and programs by obtaining more information about aeronautics R&D in industry. As private and public partners gain increased insight into each other's R&D, additional opportunities for technology transfers of mutual benefit can be identified.

Recommendation 2.2: *Federal aeronautical departments and agencies should review the status of their current and proposed aeronautics partnerships to ensure that they are outcome driven and have common goals, transparency and trust, shared risk, and strong leadership.*

Public-private partnerships (PPPs) have been identified as an important mechanism to promote knowledge sharing and technology transfer. Many PPPs are in place in the aeronautics sector, and are successful to varying degrees. To increase efficiency of current and future partnerships, agencies should evaluate major PPPs along the following success factors:

- *Outcome driven*. Any partnership worthy of significant attention by national leaders ought to be driven by a needed capability, not merely promote the development of a particular discipline or technology.
- *Common goals*. All partners should share the goals of the partnership (and not just common interests). Furthermore, with respect to governance, there is a need to balance everyone's interests to properly suit motivation and goals. The partnership should be periodically evaluated to ensure the goals are relevant, and being met in a timely manner. With respect to this evaluation, it must be clearly delineated as to what will define success for the partnership. Each partnership

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[67] Some of this information for firms and background information on DOD IR&D is available at www.defenseinnovationmarketplace.mil/.

[68] The plan is available at http://www.acq.osd.mil/dpap/dars/pgi/docs/DoD_Vendor_Communication_Plan.pdf.

[69] NASA's plan is available at http://www.hq.nasa.gov/office/procurement/vendorplan.pdf.

will have its own unique metrics that will help its participants determine if they are successful and if it is in their best interest to continue the partnership.

- *Transparency and trust*. The partnership should be selective about including participants that share the goals above. Once part of the partnership, there should be transparency and trust-based interactions amongst the partners. That includes clearly delineating what is subject to intellectual property protection.
- *Shared risk*. All participants—government or industry—should place some "skin in the game" by contributing to the partnership—the contributions can be either monetary or in kind.
- *Strong leadership*. Leaders of the partnership should be selected for their ability to enforce discipline as to the outcomes, goals, trust, and risk.

The criteria may apply differently to different PPPs, and must be modified accordingly. The World Trade Organization ruling also creates some new challenges. Aeronautics agencies can use the umbrella of the NARD review process—as it comes with the authorities provided by an Executive order—to evaluate all current and proposed PPPs in aeronautics. Such an evaluation would enhance the value and efficiency of the partnerships, and ensure the continued relevance of their desired outcomes.

Recommendation 2.3: *The ASTS, working with the Office of the U.S. Trade Representative and the Department of Commerce, should provide guidance to departments and agencies and industry regarding R&D practices consistent with recent World Trade Organization findings.*

The World Trade Organization case may have longer term and broader implications for technology transfer in aeronautics, and it would be useful to provide guidelines to both government agencies and industry. OSTP, working with the Office of the U.S. Trade Representative and the Department of Commerce, could provide guidance regarding which types of technology programs, technology transfer, and contracting would be considered acceptable by the U.S. government. These discussions could be conducted via roundtables among stakeholders, or other activities under the aegis of the ASTS.

C. Ensure New Technology Is Matured More Effectively

Both interviewees and the literature review highlighted premature exploitation as a significant contributor to the challenge of program stretch-out and delay, increased cost-overruns, and failure to fulfill desired program goals and expectations.

Factors found to contribute to this trend within government and industry include inadequate test and evaluation, over-reliance on computational analytical methodologies instead of physical tests, a trend away from prototyping and experimentation/ demonstration, overoptimistic technical expectation generating unwarranted enthusiasm, risk aversion, administrative time and funding constraints, urgent mission needs generating pressure to move rapidly into fielding production systems, commercial pressures to fill perceived market needs, and the illusion of apparent opportunity. All these work to encourage premature incorporation of new technological developments into production systems before they are sufficiently proven. Most flight demonstrations in recent years have become known to be conservative, with excessive focus on success, which has come at the cost of reduced disruptive innovation.

Respondents raised cases in point, such as Sikorsky's development of the X2 aircraft, and SpaceX's Falcon rocket and Dragon capsule, and pointed to lower costs of technology development and maturation when funded entirely by the private sector (as distinct from developed by the private sector using government-funded cost-reimbursable contracts), and that there may be lessons for the government. Government studies substantiate these impressions, and have shown private sector practices to have potential best practices for government. For example, GAO found that the private sector merged technology development and product development activities prior to product launch, had strong strategic planning to prioritize technology needs and a structured technology development process, and used a variety of tools such as relationship managers, technology transition agreements, and metrics to support technology transition (GAO 2006). There are also lessons to be learned from other sectors that do technology maturation well (e.g., automotive).

In the area of technology maturation, two recommendations emerge.

Recommendation 3.1: *Each department and agency should ensure that its R&D-related experimentation and demonstration activities appropriately emphasize the principles of failing fast, testing on the margin, and balancing risk aversion with the need for experimentation.*

Furthermore, in its mandated assessment of aeronautics-related infrastructure, OSTP, together with the ASTS, should examine the ultimate effectiveness of these approaches in accelerating technology development and recommend best practices across the Federal aeronautics RDT&E enterprise. Experimentation and demonstration have always constituted a crucial aspect of aeronautical development, and it is through this experimenting and testing that ideas and inventions have passed from the research stage to applications. The list of ideas first proven by experimentation, then matured by continuing developmental test and evaluation, and applied to production systems constitutes virtually all significant elements of an aircraft. The ASTS and OSTP should reassert the primacy of experimentation and demonstration in the R&D process, to emphasize pushing beyond the known and comfortable to ensure that technology is matured faster and developmental risk is reduced. This will require consciously rejecting the risk-averse mindset increasingly predominant within the U.S. aerospace community, recognizing that testing is primarily experimentation, not validation, and that acceptance of the likelihood of failure is not only an option but a necessity for the fidelity of true experimentation.

Executive Order No. 13419 expressed the importance of aeronautics RDT&E infrastructure, and charged the Director of OSTP with recommending to the President, the Director of the Office of Management and Budget, and to the heads of Executive departments and agencies appropriate actions to “maintain and advance United States aeronautics research, development, test and evaluation infrastructure to provide effective experimental and computational capabilities in support of aeronautics R&D.” (NSTC 2011, 3). Accordingly, the STPI team proposes that OSTP—with support from the ASTS—should conduct a review of its aeronautical research-related (i.e., not operational) experimentation and demonstration activities.

The review should look for the use of emerging technology development practices. One of these practices is that of “failing fast.” Failing fast is a property of a system or module with respect to its response to failures. A fail-fast system is designed to immediately report at its interface any failure or condition that is likely to lead to failure. Fail-fast systems are usually designed to stop normal operation rather than attempt to continue a possibly flawed process. Broadly speaking, fail fast is a philosophy that promotes embracing new ideas and trying new things without being overly concerned about the potential for failure. Moreover, if failure should occur, it should happen as quickly as possible to expedite learning valuable lessons from the failure.

Another emerging practice is that of “testing on the margin.” A working system sometimes operates at the precipice of a failure threshold. Such systems are more susceptible to failure caused by subsequently exceeding that threshold. Testing on the margin refers to the testing technique that seeks to identify such situations by intentionally varying parameters and observing the result. Finally, the review should assess if technology development is appropriately balancing risk aversion with the need for experimentation. Together, these practices will help reduce uncertainties, developmental risk, schedule slip, cost-overruns, programmatic uncertainties, and risk of program failure or disappointment.

From an implementation perspective, the activity will involve a review of agency-furnished planning documents emphasizing RDT&E. These plans must address how the experimentation and demonstration will reduce developmental risk, and include measurable metrics for evaluating the maturity of new technologies. Furthermore, the necessity (not just the option) of failure should be integrated into the design of these experiments. OSTP should also review how effectively and rapidly Federal aeronautics departments and agencies are increasing their agency commitment to full-flight experimentation, including use of full-scale and subscale prototypes and technology demonstrators. Users (whether in industry or government) need to be involved in these test and evaluation activities—with or without cost share—to further ensure the relevance of experimentation and demonstration activities to military and civil needs.

But, how should the process be reviewed and by whom? This is a challenging mandate, but there are several options among which OSTP could choose a possible implementation pathway. Table 6 outlines a few.

Table 6. Potential Organizational Options to Conduct Review

Approach	Pros	Cons	Model
OSTP, together with OMB, actively manages T&E review	Executive Order No. 13419 gives OSTP all the needed authorities Could ensure continuity of implementation across reviews	OSTP lead typically an IPA/rotator—lack of continuity OSTP understaffed for such activity OSTP/OMB relations not always the best	
Standing NSTC subcommittee conducts review at the direction of OSTP	Could ensure continuity of implementation across reviews Subcommittees have the technical information necessary to execute plans	NSTC subcommittees have no powers over agencies Subcommittees staffed by volunteers with little spare time Participants include agency leaders, who are likely vested in their agency's interests Requires funding for coordination	ASTS
OSTP establishes a standing coordination office that conducts review at the direction of OSTP	Could ensure continuity of implementation across reviews Offices have the technical information necessary to execute plans	Evaluations show that coordination bodies are unable to get agencies to conform to strategic plans, and typically focus on collection, synthesis, and dissemination Requires funding for coordination and tasking	Networking and IT R&D (NITRD) National Coordination Office (NCO) National Nanotechnology Initiative (NCO)
OSTP establishes an "Aeronautics Coordination Council" that has representation from all stakeholders	Could ensure continuity of implementation across reviews Representation from all stakeholders Decision-making authority vested by OSTP	No recent precedence in aeronautics Takes away power from the Executive Office of the President Requires funding for coordination and tasking	NACA (1915−1958) Clinical Trials Working Group (NCI)
OSTP requests standing FFRDC to provide implementation support	Could ensure continuity of implementation across reviews Could ensure participation and representation from all stakeholders	Requires funding for coordination and tasking	MITRE support for FAA; IDA support for OSD; STPI support for OSTP

Recommendation 3.2: *OSTP should make an effort to better understand if industry-funded technology development is more cost-effective and why, and which industry practices could be incorporated in government-funded technology development activities.*

Perceptions aside, it may indeed be productive to use more evidence-based approaches to examine the hypothesis that industry development is more cost-effective.

A case study-oriented engineering systems analysis could be conducted to examine, for example, the X2 program, and assess what factors, if any, enabled its development to be cheaper and speedier. An analysis performed on 2 to 3 industry projects could be used to identify best practices and lessons that could be incorporated in government-funded development.

D. Minimize "Fog and Friction" Barriers That Hinder Technology Transfer

In his 1832 book *On War*, Prussian military strategist Carl von Clausewitz identified "fog and friction" as impediments to the successful and timely conduct of military operations. Fog referred to the uncertainty of war and the difficulty of gathering reliable information. His use of the term friction was more complex, and referred to the difficulty of executing military plans, where unforeseen problems inevitably surface, and combine to foil plans, delay movements, and turn the tide of battles. The STPI team found through both its interviews and literature review that there is virtual consensus that "fog and friction" barriers need to be removed if U.S. aeronautical research and development is to be successfully rejuvenated. Respondents referred to three in particular that work to hinder timely and effective technology transfer: government intellectual property practices, corporate culture within Federal laboratories, and lack of appropriate metrics and measures.

Government intellectual property practices. Industry respondents were virtually unanimous in their assertions that intellectual property and contracting issues delay collaborations, and that intellectual property-related negotiations have become a barrier to industry's interactions with the Federal Government. The problem has worsened in recent years, with the government raising the stakes by seeking background intellectual property and intellectual property in cases where government involvement was part of a cost-share. Government respondents did not see the issue as troubling as industry respondents did, but they agreed that the intellectual property issue requires examination and resolution. They stressed limitations generated by the requirement to maximize taxpayer value and by legislation intended to ensure a "level playing field" where no single firm receives undue advantage or preferential treatment over another. Neither party furnished recommendations as to possible courses of action beyond simply bringing the issue to the fore.

Corporate culture within Federal laboratories. Most government leaders shared the view that Federal laboratories continue to foster a culture where the focus is on invention (often incremental), rather than on innovation and development of practical user-oriented technology. The literature also pointed to a lack of incentives to engage in technology transfer. Over the years, many recommendations have been offered regarding culture change. Even so, barriers persist, and the lack of results is a sign of how difficult it is to change workplace culture.

Lack of appropriate metrics and measures. Under pressure to show progress on technology transfer, most laboratories have begun reporting data on activities and simple outputs, such as the number of laboratory personnel involved in technology transfer, number of attendees at outreach and cross-community activities, or the number of patent disclosures. However, the extent to which there is a two-way exchange of knowledge and technology and how this exchange is making a contribution needs to be effectively measured to determine if these activities are making a difference. What needs to be measured is the extent to which there is a two way exchange of knowledge and technology, and how this exchange is making a contribution.

As a consequence of reviewing these various "fog and friction" issues, the research team offers the following three recommendations.

Recommendation 4.1: *The ASTS should engage with government and industry concerning appropriate sharing of intellectual property rights for aeronautics R&D and use this engagement as a starting point to ensure that the government's intellectual property practices are realistic, achievable, and beneficial to both parties.*

This recommendation seeks to establish appropriate intellectual property rights while eliminating unnecessary hindrances to timely and effective contracting, thus reducing the number of seemingly intractable cases to a manageable flew. Its implementation would ensure the Federal aeronautical enterprise is meeting national needs for adequate transfer of technical knowledge and practice throughout the U.S. aeronautics community. The engagement could come through professional societies and industry associations, annual engagements between the ASTS and industry, or other means (such as agenda items in standing partnerships). They could also occur under the review mandate of the October 2011 Presidential memorandum on technology transfer.

The STPI team has two secondary recommendations in this category. The first is to build on best practices related to contracting and intellectual property, especially those related to speed of transactions. Best practices have been found in the areas of sreamlining contracts and processes; capturing and managing intellectual property; marketing laboratory technologies and capabilities to industry; effective organization and staffing of Offices of Research and Technology Applications; and empowering, training, and rewarding scientists and engineers. In addition to actively disseminating best practices as described in Chapter 5, the ASTS could support an agency-level effort to identify contracts that had long negotiation lead times, analyzing them to identify common factors, and thereby improving future practices.

Recommendation 4.2: *Federal aeronautical departments and agencies should develop specific incentives to promote outcome-oriented technology transfer and cross-organizational collaborations.*

Examples of best practices for providing organizational incentives to participate in technology transfer and cross-organizational collaboration include technology transfer-related activities being more explicitly part of organizational goals and staff performance evaluations, and use of Intergovernmental Personnel Act (IPA) assignments and other personnel exchange programs to promote inter-sectoral cross-pollination. Examples of best practices to generally change the culture at government laboratories include provision of financial incentives and tailored training. OSTP, as part of its review of the implementation of the technology transfer mandate of NARD plans, should review the use and effectiveness of these and other incentives.

Recommendation 4.3: *Federal aeronautical departments and agencies should develop and employ meaningful metrics for technology transfer based on outcomes and impacts rather than inputs, activities and outputs.*

A recent paper in *Sloan Management Review* included the following assessment (Pertuze et al. 2010, 83):

> What matters is…impact—how the new knowledge derived from a collaboration…can contribute to a company's performance. Are new products made possible? New and more effective manufacturing processes? Novel kinds of computer hardware or software that enable greater logistical efficiencies? Patentable materials designs or processes that enhance competitive advantage?

It may be more useful, for example, to develop and employ more meaningful metrics for technology transfer based on outcomes and impacts (e.g., company adoption of a new technology, or its rise to industry standard), rather than to use the more traditional but occasionally misleading metrics of input, activities, and output." Although traditional metrics can be significant, they should be counted in conjunction with more direct indicators of technology transfer success.

Measuring laboratory success via meaningful metrics can have a larger effect by guiding studies like this one in helping ascertain ifthe nation even has as a technology transfer "problem." For all we know, perhaps the system is working as well as can be, and there is no problem. However, given lack of information, we do not know if there is a problem to be solved.

There are some caveats to developing outcome-oriented metrics. First, while metrics should build on best practices, they should be carefully translated for government. For example, metrics that are relevant to industry (e.g., short-term return on investment) do not necessarily apply to the government, so best practices must be carefully analyzed before being transferred. Second, it should be kept in mind that outcomes and impacts often become evident years to decades after the original research. Metrics should keep this time lag into account. Lastly, metrics guide behavior, and poor metrics are worse than no metrics at all. As a result, metrics may need to be carefully piloted before being rolled out.

OSTP should review these metrics—and their implementation—as part of its biennial review of NARD. Another anchor for this review could be the 2011 Presidential memorandum on technology transfer.

E. Summary

Most recommendations in the literature focus on issues at the interface between organizations, which are, as this study discovered, symptoms of larger challenges in the system. By focusing on the lowest level of the barriers, other studies are recommending solutions to these symptoms—like siloed decision-making. This study focused on the higher levels of barriers to address the *addressable* root causes of the barriers that can be addressed. The research team believes that these recommendations will more useful to the ASTS, which is attempting to strike a balance between addressing the core challenges in the system and doing what is doable within existing authorities.

Table 7 indicates which of the various levels of barriers discussed in Chapter 6 the study recommendations address. In addition to mapping the recommendations to the barriers, the table also emphasizes that the barriers to U.S. aeronautics innovation and technology transfer are complex, and not all result from problems at the *interface* between government laboratories and industry. Many of them relate to larger challenges such as fiscal pressures and increasing international competition, among others.

Some long-standing challenges have exacerbated over the years. For example, intellectual property-related disagreements, never seamless, have become more acute, and legislative changes have reduced government flexibility. Outsourcing of defense- and aerospace-related R&D from within government laboratories to industry or academia has accelerated, and many government laboratory scientists have turned from *doing* science and engineering to managing it, resulting in loss of skills. The aeronautics sector is further constrained by challenges that are unique to it (and relatively recent). For example, as of 2012, the World Trade Organization concerns have limited certain types of government R&D related to the aeronautics industry.

Despite these barriers, the aeronautics sector has opportunities that few other areas do. For example, the presence of the National Aeronautics R&D policy and plans gives the aeronautics leadership in the Federal Government unmatched leverage to guide the enterprise, much more so than is feasible in other areas of R&D, or was feasible in the previous pre-NARD decades. Strategic planning and implementation under the aegis of these plans cannot only guide existing activities, but also benefit from new disruptive innovations (e.g., in microelectronics and unmanned aerial technology) to re-energize the field, and re-ignite public interest—especially that of students—in aeronautics.

Table 7. Connecting Recommendations to Barriers

Intrinsic and structural issues	Rec. No.	External challenges	Rec. No.	Risk-averse behavior	Rec. No.	Unintended outcomes	Rec. No.
• Market structure of the aerospace sector	—	• Increasing global competition	—	• Reduced investment especially in mechanisms related to communication and coordination	1.1, 1.2, 2.1, 2.2	• Increasingly fragmented knowledge base	—
• Development of complex products that must operate in difficult environments	—	• Uncertain fiscal and workforce outlook	—	• More contentiousness over ownership of intellectual property	4.1	• Siloed decision-making	—
• Incomplete understanding of the technology development process	3.1, 3.2	• International trade and regulatory	2.3	• Increased caution, review, and oversight (government)	—	• Less disruptive Innovation	—
• Laboratory culture of Insularity	4.2			• Focus on incremental improvements (government, industry)	—	• Longer development cycles	—
• Misaligned incentives	1.1, 1.2, 2.1, 2.2			• Pushing immature technologies to next level	3.1, 3.2		
• Lack of meaningful metrics to measure progress	4.3			• Regulations not keeping pace	2.3		

8. Conclusion

This report proposes ten recommendations that relate to the goals of **improved implementation of strategic plans** (stronger reflection of strategic planning in budgets, programs and activities; better opportunities for industry to provide input and feedback); **better communication and coordination across stakeholders** (better access of government to industry IR&D; better design and use of PPPs; guidance to both government and industry related to the World Trade Organization ruling); **more effective technology maturation** (use of practices that could make technology maturation more effective; incorporation of relevant private sector practices in government-funded technology development); and **elimination of institutional barriers** (engagement between government and industry with respect to intellectual property; incentives to promote culture change at laboratories; and use of meaningful outcome- and impact-oriented metrics).

As Chapter 2 and Appendix D note, the United States has accomplished much in the air and space fields over the last century, making it truly an "air and space nation." But it is no longer accurate to expect the United States toremain the unsurpassed leader in the air and space world. Given the seriousness of the challenges, we should not be naively optimistic about the future.

Referring to the history of technology, analogies might be made to China and to Spain. At the beginning of the fifteenth century, China possessed a vast and technologically advanced deep-water fleet that ranged throughout the western Pacific and Indian Oceans, even as far as Africa. But, largely from a sense of superiority and complacency, the Ming dynasty turned its back on maritime power; within a generation, China's fleet had collapsed to a fraction of its previous size, and pirates freely raided the Chinese coast. The torch of maritime exploration passed firmly to the Europeans. Here, initially, Spain held sway, as exemplified by the support the Spanish crown offered to Christopher Columbus's voyage of discovery to the "New World" in 1492. For the better part of the next century, Spain predominated. But as a nation it failed to adapt to the times, and the second century of New World investment—one of *exploitation*, not just *exploration*—saw other nations move to prominence (Kennedy 1989, 7–9; Boorstin 1983, 168–201). U.S. aviation today is hardly immune from losing its own aeronautics (and space) advantage in similar fashion to how China and Spain lost their maritime advantage centuries ago.

Two statements of Hap Arnold and Theodore von Kármán are appropriate in closing. One was the commander of a global air force locked in a total war; the other a refugee from Hitler Germany and the most gifted aeronautical scientist of his time, perhaps of all time. In 1944, Arnold charged von Kármán to forecast the future of aeronautics, noting "The first essential of air power is pre-eminence in research." A year later, just before Christmas 1945, von Kármán had a caution of his own: "Those in charge of the future Air Forces should always remember that problems never have final or universal solutions, and only a constant inquisitive attitude towards science and a ceaseless and swift adaptation to new developments can maintain the security of this nation through world air supremacy." Those sentiments, followed imperfectly in the past, must be adhered to in the future if the United States is to thrive, not merely survive, in the second century of winged flight.

Appendix A.
Request for Public Comment and Interview Questions

This document is scheduled to be published in the Federal Register on 06/05/2012 and available online at **http://federalregister.gov/a/2012-13586**, and on **FDsys.gov**

OFFICE OF SCIENCE AND TECHNOLOGY POLICY

Expediting Transition of Government Performed and Sponsored Aeronautics Research and Development

AGENCY: Office of Science and Technology Policy, National Science and Technology Council.

ACTION: Notice of request for public comment.

SUMMARY: The National Science and Technology Council seeks public comment on potential means to expedite the transition of government performed or sponsored research and development (R&D) to the private sector for use in developing new civil and military applications that foster economic growth, the creation of high-quality jobs, and national security. In addition, as a means to improve future national aeronautics R&D plans and progress assessments, the Council seeks public comment on the utility of certain national aeronautics R&D planning documents for providing transparency of goals, priorities, and outcomes, with an emphasis on understanding their utility in aiding investment strategies of non-Federal stakeholders.

DATES: Comments will be received through July 16, 2012, 11:59PM EST.

ADDRESSES: Concise comments are requested and may be submitted by any of the following methods:

- E-mail: *aero@ostp.gov*. Include "AERONAUTICS COMMENTS" in the subject line of the message.

- Mail: Office of Science and Technology Policy, National Science and Technology Council, Eisenhower Executive Office Building, 1650 Pennsylvania Ave, NW, Washington, DC 20504. Attention: "AERONAUTICS COMMENTS."

All submissions must be in English and must include your name and return or email address, if applicable. At the discretion of the ASTS, responders may be contacted to seek further clarification or additional information; if you do not wish to be contacted please so indicate in your response. Submitted comments may be subject to public release under applicable law. Submitters are advised to not submit any personally identifiable information (such as social security numbers), or classified or copyrighted material. Any proprietary or business confidential information that is submitted in response to this notice should be clearly labeled at the top of each page.

FOR FURTHER INFORMATION CONTACT: Dr. Michael C. Romanowski, 202-456-4444. Questions about the content of this notice should be sent to *aero@ostp.gov*. Include "AERONAUTICS COMMENTS" in the subject line of the message. Questions may also be sent by mail (please allow additional time for processing) to: Office of Science and Technology Policy, Eisenhower Executive Office Building, 1650 Pennsylvania Ave NW., Washington, DC 20504. Attention: "AERONAUTICS COMMENTS." Further information or updates related to this notice may be posted at http://www.aeronautics.nasa.gov.

SUPPLEMENTARY INFORMATION:

Purpose

The National Science and Technology Council (NSTC), through the Aeronautics Science and Technology Subcommittee (ASTS) of the Committee on Technology (CoT), seeks public comment on ways to maximize the benefits of Federal aeronautics research and development (R&D) investments.

Background

ASTS seeks to identify innovative means whereby Federal agencies conducting or sponsoring aeronautics R&D can accelerate the transition of advancements to the non-Federal community, thereby further increasing the effectiveness of the National aeronautics enterprise and supporting the creation of high-wage, high-skill jobs within the aerospace sector. ASTS has particular interest in proposals that are actionable within existing legislative authorities, and that would have measurable anticipated payoffs. As rapid progress is desired, it would be helpful if responders identify near-term opportunities as well as improvements with medium-to-long-term payoffs. Responders are encouraged to rank their relative priorities if submitting multiple suggestions.

In December 2006, the National Aeronautics Research and Development Policy was published (see http://www.aeronautics.nasa.gov/releases/national_aeronautics_rd_policy_dec_2006.pdf), marking the first time that a national policy for government performed or sponsored aeronautics R&D was approved by the President. Since then, the first cycle of plans and progress assessments in response to the Policy were completed. The Federal Government published its initial National Plan for Aeronautics Research and Development and Related Infrastructure in 2007, with follow-on updates published in 2010 and 2011. In 2008, an initial assessment of progress against the 2007 plan was also published. Likewise, in December 2011, an assessment against the 2010 aeronautics research and development plan was published. With the completion of the 2011 Progress Assessment of the 2010 National Aeronautics Research and Development Plan, ASTS has completed a five-year national aeronautics R&D planning and assessment cycle. ASTS seeks public comment on the contents and utility of these plans and assessment documents as a means to improve the effectiveness of the federal aeronautics enterprise.

We encourage responders to be specific and to identify innovative approaches, broader use of current best practices, and past practices no longer employed that might be re-implemented. No prioritization is implied by the order in which questions are asked. Please consider the following documents, as appropriate. when responding to the questions:

- National Plan for Aeronautics Research & Development and Related Infrastructure (2007) (http://www.whitehouse.gov/files/documents/ostp/default-file/Final%20National%20Aero%20RD%20Plan%20HIGH%20RES.pdf)
- Technical Appendix to the National Plan for Aeronautics Research and Development and Related Infrastructure (2008) (http://www.whitehouse.gov/files/documents/ostp/default-file/technical_appendix_high.pdf)
- 2010 National Aeronautics Research and Development Plan (http://www.whitehouse.gov/sites/default/files/microsites/ostp/aero-rdplan-2010.pdf)
- 2011 Progress Assessment of the 2010 National Aeronautics Research and Development Plan (http://www.whitehouse.gov/sites/default/files/microsites/ostp/NARDP_2011_Progress_Assessment_final.pdf)

Questions on Technology Transfer and National Aeronautics R&D

Responders are encouraged to respond to any or all of the following questions, and to provide proposed metrics to index improvements where appropriate.

1. Through what mechanisms are you, or your organization, able to obtain visibility into the progress of aeronautics R&D activities conducted or sponsored by the Federal Government? In what ways could your visibility be improved?

2. Through what mechanisms, and to what extent, are you, or your organization, able to access the products of federally sponsored or conducted aeronautics R&D activities? In what ways could access be improved?
3. Since 2007, have you, or your organization, been able to transition any of the products from the specific Federal R&D activities that were performed under the National Aeronautics Research & Development Plans into the products or services developed by your organization? Please discuss, and provide examples of specific mechanisms that facilitated technology transfer or that impeded the process.
4. What other ideas or thoughts do you have for maximizing the benefits of Federal aeronautics R&D, or for increasing the effectiveness of technology transfer from Federally conducted or sponsored R&D to the private sector? Do you have recommendations for success criteria or metrics associated with these areas?
5. Through what mechanisms, and to what extent, are you, or your organization, able to provide input into overall priorities and goals for Federal aeronautics R&D, or into the specific department and agency R&D plans or programs? How could this be improved?
6. What do you perceive to be the impact of the National Aeronautics R&D Policy and its associated plans on the U.S. aeronautics enterprise?
7. To what extent have the national aeronautics plans and assessments helped you, or your organization, understand the overall goals and status of Federal aeronautics R&D?
8. To what extent have the national aeronautics plans and assessments helped you, or your organization, guide your internal R&D strategies, planning or execution?
9. What recommendations would you provide to make future national aeronautics plans and assessments more useful to you or your organization?

Additional (or variations on the same) questions asked of respondents depended on their affiliation—government or industry:

Government Questions

- What formal and informal mechanisms are used to provide visibility to non-Federal stakeholders into the progress of aeronautics R&D activities conducted or sponsored at your center? Do you have suggestions for improving this visibility?
- What formal and informal mechanisms are used to provide visibility to non-Federal stakeholders into the progress of aeronautics R&D activities conducted or sponsored at your center? Do you have suggestions for improving this visibility?
- Since 2007, how successfully has your center been able to transition products or technologies from the specific Federal R&D activities that were performed under the National Aeronautics R&D plans to non-Federal individuals and organizations? Please provide examples of specific mechanisms that facilitated or impeded the technology transfer process.
- What recommendations do you have for maximizing the benefits or effectiveness of aeronautics R&D transitioned from your organization? Do you have recommendations for success criteria or metrics? Do you know of any models, organizational, technological or other, within aeronautics or outside, that could be implemented in the Federal aeronautics R&D enterprise, to improve the effectiveness of technology transfer from your center to non-Federal partners?
- What mechanisms enable non-Federal stakeholders to provide input into overall priorities and goals for the R&D plans or programs at your organization? How well are they working? How could this input process be improved?
- Following up on the preceding questions, please provide one or more specific examples of aeronautics R&D conducted by and/or at your laboratory that is/are illustrative of how your center manages its innovation system. How was consideration given to the shared and unique priorities and interests of Federal and non-Federal parties? What mechanisms were employed? What barriers were encountered? Were they overcome? How?
- What recommendations would you provide to make future national aeronautics plans and assessments more useful to non-Federal stakeholders? Do you have any other suggestions for improving the national aeronautics innovation enterprise?

Industry Questions

- Sector-wide views: What are your aspirational goals for the aeronautics industry in general (and Cessna in particular)? What do you believe are the drivers for reaching these goals? What can the government do to help industry get there more quickly?
- Definitions: How do you define tech transfer? How do you differentiate it from the term innovation? Which do you consider more broken, and therefore more important to fix?
- Barriers and Recommendations: What are the biggest barriers your firm faces when interacting in joint or tech transfer activities with government labs? Do you have any recommendations as to how to overcome them?
- Models: Are there any tech transfer and innovation enhancement models that you believe ought to be disseminated? What are these?
- Roundtable discussion topics: What 2-3 topics would you recommend we drill down into at the OSTP-sponsored roundtable?

Appendix B.
Summary of Coded Responses

Table A-1. Barriers

Barrier Category	Barrier	Example	No. of Federal Responses	No. of Industry Responses	No. of Pre-Roundtable Interviews	No. of Other Sources
Lack of coordination, fidelity, unity of purpose and effort, and communal awareness in the execution of National Aeronautics Research and Development (NARD) plans	The NARD plans are not detailed enough to be helpful.	"In general [NARD plans] don't specify actionable, quantifiable goals that allow for research progress to be tracked and reported on over time."	0	1	0	0
	Lack of awareness of the NARD plans.	"The NARD plans cover a lot of ground and say a lot of the right things, but if people asked them if they are following that, people say what policy and what plan."	0	0	2	0
	The NARD plans are not used.	"Work in Aeronautics is generally focused on mission-specific technology challenges not specifically supporting the National Aeronautics R&D plans."	2	0	0	0
	Expressing that the respondent has conducted NARD-driven work that has not been acknowledged.	"Therefore, there is work being done that is aligned with the NARD Plan, but is not being recognized as NARD Plan Goals."	0	1	0	0
	The respondent has not contributed to NARD plans.	"We have not been part of the NARD plan."	0	2	0	0

Barrier Category	Barrier	Example	No. of Federal Responses	No. of Industry Responses	No. of Pre-Roundtable Interviews	No. of Other Sources
Lack of R&D-related communication and liaison among key national aeronautics stakeholders	Lack of communication and awareness on current technical activities as a barrier.	"Awareness is a problem. Size works against them. If someone gets a phone call about a technology, they might not know everyone. The scale is different, which is a hurdle."	0	0	0	1
	Potential overlap between laboratory work and Internal R&D investments in industry as a barrier.	"For the IR&D, the government is reimbursing four billion plus above and beyond—the labs are probably investing competitively in similar areas."	0	0	0	1
	Inconsistency in government priorities makes long-term planning difficult.	"Money and politics is a barrier. It makes it hard for them to commit to a plan when policies are being changed regularly."	0	3	4	1
	Limitations on government employees' ability to sponsor or attend conferences.	"Recent Executive Orders and congressional restrictions have significantly limited their ability to do those kinds of events (such as conferences). They're setting thresholds that escalate the approval necessary to hold an event."	1	0	0	0
	Difficulty integrating Internal R&D into agencies' strategic planning.	"The big hurdle there is how to integrate IR&D more into their strategic planning, which is a totally different question. "	0	0	0	1
	The government has difficulty marketing its own abilities.	"The biggest challenge is people don't view the DOD as someone they can work with. They're not experts at marketing; they don't put themselves out there that they're available for business."	0	0	0	1

Barrier Category	Barrier	Example	No. of Federal Responses	No. of Industry Responses	No. of Pre-Roundtable Interviews	No. of Other Sources
	The competition process for grants as a barrier.	"The competition for grants is a barrier—there's a 20% chance of anyone getting an SBIR, and even though the proposals are good, if it's not an immediate need it might not get it. So even though the area is good and the reviews are good, sometimes there's no funding. This reduces capabilities in those areas; this can be problematic for small companies that only operate in those areas."	0	1	0	0
	The mechanisms through which to collaborate with government are not visible.	"The federal mechanisms are not very well known, and it's not easy once they find out about it either."	0	1	0	0
	The government has difficulty integrating commercial products into its own needs and missions.	"The government does not know how to capture commercial advancements and integrate them."	0	0	1	0
	The DOD's focus on its military mission can make it difficult for them to see additional, nonmilitary applications for their products.	"To a good fault, they're so focused on finding the right place to put something in the DOD instead of thinking of other applications. Maybe they're too focused on military mission; it helps to broaden S&E's thoughts on what they can do."	0	0	0	1
	Lack of a culture supporting multidisciplinary research.	"Culture for multidisciplinary research was lacking."	1	0	0	0
	Expressing that not having technology transfer processes in place has been a barrier.	"Encountered obstacles in transitioning a certain capability because process did not exist to develop a laboratory model into a user-friendly system available to wider outside user group, and to advertise it."	2	0	0	0
	Redirecting resources to staff large, innovative projects leaves fewer resources for other projects.	"Impact on researchers whose smaller, less priority research was reduced. We allowed transition period to finish old research."	1	0	0	0

Barrier Category	Barrier	Example	No. of Federal Responses	No. of Industry Responses	No. of Pre-Roundtable Interviews	No. of Other Sources
	Expressing that there is a mismatch between stakeholders in the federal R&D process.	"International agencies are seeking plans for funding they have available, whereas the U.S. has a plan but insufficient funds to execute that plan. Long-range funding mechanisms are needed to support strategic plans versus short-term funding cycles. While the U.S. R&D Aeronautics plan is good it tends to be more tactical addressing near term needs and, it should be more strategic to cover long-range technologies and opportunities."	0	2	3	0
	Expressing that previous technology transfer activities have ceased.	"Recently, that regular contact has been reduced, resulting in less reporting requirements on contractors and separating influence on government-industry dialogue."	1	0	0	0
Lack of coordination and communal awareness in the execution of NARD policies and plans	Multiple R&D plans that do not map goals to specific programs make it difficult to use the plans effectively.	"These documents use different frameworks and styles and one can't easily identify connections (or duplications!) by reading them. It is not easy to determine which agencies ultimately are responsible and accountable for accomplishing which research goals."	0	1	0	0
New technology not mature enough to justify its application	The broader safety and workforce contexts of innovative technologies as a barrier.	"Another showstopper is the safety story. The safety case has to be proven that a reduction in workload won't lead to concerns about liability and problems with the union."	0	1	0	0
	Companies are reluctant to engage in partnerships where the business case is not clear.	"One significant challenge is providing clear frameworks for proposed joint initiatives so that the business case for participation is clearly understood. Success of any initiative cannot be expected unless it is advantageous to all parties to participate."	0	3	4	0
	The complexity of modern aeronautics projects as a barrier.	"Organizationally, projects now are more complex. There is lots of overhead burden and oversight requirements."	0	0	1	0

Barrier Category	Barrier	Example	No. of Federal Responses	No. of Industry Responses	No. of Pre-Roundtable Interviews	No. of Other Sources
	Aging infrastructure as a barrier.	"Outdated infrastructure and operating methods hamper the industry's ability to operate efficiently."	0	1	2	0
	Federal projects change requirements mid-course, increasing costs.	"The government puts requirements on top of requirements without realizing the additional costs, so then they get sticker-shock. That's especially true on the DOD side, which is driven by commercial consumerization."	0	0	4	1
Technology insufficiently mature to justify its application	Lack of expertise within government laboratories as a barrier.	"The government used to have technical expertise that was lost that started having large systems integrators running outside of the government."	0	0	2	1
	Technology sometimes transitioned before it's fully matured.	"The government wants industry to cost share too, so allows for TRL levels to creep up."	0	0	1	0
	Certification as a barrier.	"The length of time for certification adds a tremendous amount of cost, sometimes with very little gain. "	0	0	3	0
	The "valley of death" between basic research and development as a barrier.	"The problem is this is the valley of death."	0	0	1	0
	Lack of demonstrators as a barrier.	"There aren't enough TRL 6 demonstrators in the aero propulsion environment."	0	0	1	0
	Difficulties in modeling the projected costs of new projects as a barrier.	"They also don't have a good way of understanding the full cost implications of new technologies. They know development costs, but development costs, including infrastructure changes, training, equipment, and so on. Those models are not well-developed or well-documented and defined."	0	1	0	0

Barrier Category	Barrier	Example	No. of Federal Responses	No. of Industry Responses	No. of Pre-Roundtable Interviews	No. of Other Sources
	Lack of pull from industry can lead to difficulties in transitioning technologies.	"They contracted to do a project and delivered. The program that sponsored the project went away and the product is still there and still has not been transitioned. Something like this can get lost and forgotten."	1	0	1	0
	Formalized Programs of Record can be considerably slower than projects for an immediate need.	"They have had more problems transitioning technologies from programs of record than for immediate needs."	0	0	1	0
	The increasing lifecycle of a project as a barrier.	"When things take so long, and budgets lasting longer then you have less opportunities and more obstacles in transferring tech."	0	0	1	0
	The processes to transfer technology are time-consuming and onerous.	"Finally, all technical efforts are systematically documented and archived through DTIC, but this may not provide visibility in a timely enough manner to drive innovation from non-Federal entities."	3	2	2	0
	The processes to transition technologies are not documented or standardized.	"The current process is ad hoc in nature and impedes private industry's ability to analyze the research results and determine their usability and commercial application."	0	1	0	0
	Budget cuts are creating constraints on researchers' time, giving them less time to pursue innovative activities.	"The full booking of everyone's hours and the shrinking amount of human capital dedicated to aeronautical engineering [e.g., the real boots on the ground] inhibits the time available to create and tinker and study/pursue potential non-traditional applications."	1	0	0	0

Barrier Category	Barrier	Example	No. of Federal Responses	No. of Industry Responses	No. of Pre-Roundtable Interviews	No. of Other Sources
“Fog and friction” from the intellectual property practices of the Federal Government, the culture of the Federal laboratories, and the lack of appropriate metrics of success	Use of firm-fixed-price contracting.	“Firm Fixed Price (FFP) contracting is inconsistent with the goals of R&D programs. R&D is exploratory by its very nature, so FFP contracting is a hindrance to collaboration with the USG as it requires industry to carry the majority of the risk for developing new, advanced technologies which have uncertainty in what it takes to develop and mature the technologies to product application.”	0	2	1	0
	Good ideas may still fall prey to budget cuts, requiring persistent and creative efforts for them to survive.	“But then when there’s a clever idea, it can still die on the line through budget cuts. Example: they’ve had some products (2 or 3) that they’ve had to be persistent to herd a technology to get it to survive in our organization. They weave it through different contracts in order to get it to survive.”	0	0	1	0
	Legal contracting issues as a barrier.	“By formal NASA rules, it is illegal for NASA to contract with certain types of entities for R&D activity.”	0	1	1	0
	Difficulty for new entrants to the field to be successful.	“For joint activities between industry and the Labs, it seems like relationships based on previous programs are very important, so it’s very difficult for a new entrant to break in, even if they have really good proposals.”	0	0	1	0
	Lack of discretionary funding at laboratories as a barrier.	“Freely discretionary money is being replaced with earmarked money.”	0	0	1	0
	Companies being unable to access information from other government projects due to proprietary nature of information.	“If a lab has a contract out for a project, other companies can’t access that information because it’s proprietary.”	0	1	0	0

Barrier Category	Barrier	Example	No. of Federal Responses	No. of Industry Responses	No. of Pre-Roundtable Interviews	No. of Other Sources
	Cost-Plus contracting requirements as a barrier.	"In order to do cost-plus, you need a certified accountant in place. Some small companies might not want to do that."	1	0	0	0
	The threat of litigation as a barrier.	"Litigation has no caps; someone can crash an aircraft where long litigation will follow."	0	0	1	0
	Although large companies have staying power and small companies have incentives such as SBIR, midsized companies may have other difficulties.	"Midsized companies may be unintentionally in stress that they don't have access to the research funds that allow them to advance the state of the art. You can't fund everything, but today's procurement may have gapped the middle groups."	0	1	0	0
	Regulations are not keeping up with innovation.	"Mostly regulations and innovation aren't going hand in hand. Innovation is faster than regulations."	0	0	1	0
	Complications in projects due to World Trade Organization concerns.	"One complication is that recently there's been attention to the WTO interest in whether governments are subsidizing their aero industries both in U.S. and France."	1	1	1	0
	Personnel caps as a barrier.	"Personnel at some labs are artificially capped, limiting the number of personnel available for projects even when alternative funding is available."	1	0	0	0
	R&D portfolios are not sufficiently diversified to ensure successes.	"R&D is inherently risky, and you don't go into a particular research effort with complete confidence that you will succeed. You need to plan for a certain amount of failure, which means you can't pick one solution to each big problem and just go for it. You need a large and diversified enough portfolio that you'll have enough successes to solve the problems you want to solve. They are not there right now."	1	0	0	0

Barrier Category	Barrier	Example	No. of Federal Responses	No. of Industry Responses	No. of Pre-Roundtable Interviews	No. of Other Sources
	The government is afforded more flexibility in intellectual property negotiations than is necessarily used.	"The applicable CRADA regulations provide flexibility, but internal to the department they have agency policies or guidelines that apply to these types of contracting vehicles that provide a pro forma approach to [intellectual property]. If you negotiate outside of certain concerns then you have to go up the chain of command to get approval. What happens then is the lab personnel are less willing to leverage that flexibility because it would require them to go through various levels of approval."	0	0	0	1
	Difficult to receive federal funding for projects with international ties.	"The bad stigma of working an international project is a barrier."	0	0	1	0
	The government emphasizes novelty over value out of new projects.	"The government often picks novel things because they're interesting as opposed to because they'll deliver real value."	0	0	0	1
	Split support for technology transfer activities within laboratories.	"The legal support for royalty distribution is at a different level than the technology transfer personnel."	0	0	0	1
	Trade issues as a barrier.	"Trade issues play a big role."	0	0	2	0
	Small companies are sometimes put off by the complexity of contract agreements.	"When a lab does a CRADA, the law is clear on 90% of what they can or can't do, but with small businesses when you present the template agreement and it has all these definitions and policy statements, that scares people."	0	0	0	1
	Mention of International Traffic in Arms Regulations.	"As we understand it, a single ITAR part in an entire aircraft may prevent the sale of that entire aircraft to foreign countries. Such restrictions limit the market, which in turn, limits the number of high-wage, high-skill jobs that create and build such aircraft."	1	4	2	0

Barrier Category	Barrier	Example	No. of Federal Responses	No. of Industry Responses	No. of Pre-Roundtable Interviews	No. of Other Sources
	Lack of funding as a barrier.	"Companies such as Boeing and Lockheed have approached Dryden to participate in technology development, but budget limitations have prevented these cooperative research opportunities to go unfulfilled."	4	1	4	1
	Expressing that the federal agency does not currently have capabilities or expertise in technology transfer.	"It is not widely recognized in NASA that technology transfer is a profession with specific skill requirements—not everybody can do it. Anyone who has worked with the private sector's technology transfer professionals recognizes that few people if any currently in NASA have these skills."	2	0	0	0
	Expressing that it requires more resources to transition a technology than to create it in the first place.	"It takes considerable time and resources to make this information available. Sometimes it takes more resources to do this than the amount it takes to create the capability in the first place."	1	0	0	0
	Lack of encouragement from leadership to engage in technology transfer activities.	"Once non-Federal stakeholders are aware of what we offer, access is not an issue. However, it does take resources to reach out and make our progress known. Those resources and leadership encouragement would improve this system greatly."	1	0	0	0
	Expressing that when industry and laboratories collaborate on projects, it is unclear who ultimately owns the patent or intellectual property.	"One area of concern is patent right ownership by U.S. government agencies when technologies have been developed jointly."	1	2	0	0
	The sharing of risk and cost between government entities and industry as a barrier.	"Other non-technical challenges include risk aversion (i.e. paying the upfront costs of being the first adopter of technology in both technology developments and potential corporate liability)."	0	1	1	3

Barrier Category	Barrier	Example	No. of Federal Responses	No. of Industry Responses	No. of Pre-Roundtable Interviews	No. of Other Sources
	A lack of incentives for government to partner with small businesses.	"Tax Cuts alone is not a great incentive to help small businesses whether this tough economy."	0	1	0	0
	Difficulties with SBIR as a barrier.	"The SBIR program is problematic—large companies partner with small ones, but the overall result is less innovation because the large companies tell small companies what to do."	0	0	1	1

Table A-2. Recommendations

Barrier Category	Recommendation	Example	No. of Federal Responses	No. of Industry Responses	No. of Pre-Roundtable Interviews	No. of Other Sources
Lack of coordination and communal awareness in the execution of National Aeronautics Research and Development (NARD) plans	The government should conduct studies to solicit input into the National Aeronautics R&D Plans.	"Survey non-Federal stakeholders to find out what they need."	1	0	0	0
	The government should coordinate their research funding more closely with the National Aeronautics R&D Plans.	"A more organized/coordinated research program related to the NARD Plan. There is work being done that is aligned with the NARD Plan, but is not being recognized as NARD Plan Goals. For example, both [ ] and [ ] have received funding from NASA, and DOD agencies, for areas aligned with the NARD Plan, but NARD was not the funding source and was not mentioned when the funding was provided from these agencies. Therefore, a suggestion is that more specific coordination in the NARD Plan occur."	4	0	0	0
	Create an explicit roadmapping process for aeronautics R&D, with concrete and transparent milestones.	"Candidate areas for improvement include a more visible allocation of national goals to investments through a time driven planning/roadmapping process which would explicitly include transition to users."	0	1	0	0
	Create regular meetings for joint groups.	"Recommend regular updates and meetings of the joint government/industry groups for future aeronautics plans and assessments."	0	2	1	0
	Independent bodies should create the National Aeronautics R&D plans to avoid conflicts of interest.	"Progress assessments should be made by independent oversight bodies"	0	1	0	0
	The National Aeronautics R&D plans should use quantifiable and transparent metrics.	"Agency research plans should lay out road maps with specific, objective, quantifiable research outcomes and challenges that allow for progress to be measured via quantifiable means, and that define research "success" (closure) in a meaningful and measurable way."	0	1	0	0

Barrier Category	Recommendation	Example	No. of Federal Responses	No. of Industry Responses	No. of Pre-Roundtable Interviews	No. of Other Sources
	Ensure that industry has easier access to the NARD plans.	"Based on reports from various government agencies to Congress, some—for example NASA—have actually modified their R&D to address NRAD. However, to have a broad impact it needs to be more widely disseminated with a knowledge transfer priority"	1	3	0	0
	Solicit feedback on previous Federal-industry partnerships to increase laboratory confidence in future partnerships.	"OSTP should facilitate a process to solicit and archive Federal feedback on partnership experiences. OSTP can strongly incentivize strong, positive partnering by allowing consideration of this Past Performance in competitive selections. This will move resources towards non-Federal entities that view the Federal Labs as vital partners and away from those that view them as a Federal pocketbook."	#N/A	#N/A	#N/A	#N/A
	Tie the National Aeronautics R&D Plans to funding.	"There needs to be a plan backed up with funding. People respond to that and want to know where they can find the funding."	0	0	2	0
	Use consortia to develop standards.	"To develop standards, consortium is the way to go."	0	0	0	1
Lack of R&D-related communication and liaison among key national aeronautics stakeholders	Leverage the use of the Federal Lab Consortium for Technology Transfer.	"Establish a bigger presence of the WJHTC Laboratory within the Federal Laboratories Consortium (FLC)."	0	1	0	0
	Create organizations and businesses aimed specifically at closing the development gap.	"A technology gap occurs after a prototype is developed and assessment indicates that additional development is required to render the product production ready. To close these gaps, agile, small companies should be formed utilizing the flexibility of a small organization focused on a particular technology objective."	0	1	0	0
	The U.S. government should acquire and develop technologies from noncitizens.	"On my views if the related office of U.S. government such as NASA will fund normally to non-US Ideas(Non-US Invention/s) as a result U.S. government and U.S. companies can take the benefits of those ideas that can be manufactured in U.S. for doing global business of the product/s invented by non-US citizen."	1	0	0	0

Barrier Category	Recommendation	Example	No. of Federal Responses	No. of Industry Responses	No. of Pre-Roundtable Interviews	No. of Other Sources
	Create a formalized technology transfer program by taxing other programs.	"He'd love to see legislation to "tax" the S&T RDT&E 6.1-6.4 to fund tech transfer but keep that in the green book."	0	0	0	1
	Identify subject matter experts to create virtual networks.	"Solicit industry, government and academia identification of subject matter experts and areas of company interest compatible with their respective capabilities for sharing across a virtual network organized by goals outlined in the National Aeronautics Research and Development Plan."	0	1	0	0
	Use a phased approach for technology transition.	"Use a phased approach to move technology into demonstration."	0	0	1	0
	Industry should use their program officers as a resource for technology transfer activities.	"Program Officer intervention can be invaluable. Specifically, making connections and facilitating the flow of information between performers of sponsored research and potential industry [sic] partners."	2	0	0	0
	Expression that industry must ultimately be accountable for technology commercialization.	"To be effective, industry must contribute significantly to technology development and be accountable for bringing technology to market."	1	0	0	0
	The Federal Government should maintain its role of authority in engaging with industry.	"While planning is best done with inputs from all relevant stakeholders, the government roles of leadership and ownership must be maintained as a safeguard against potential stakeholder conflict of interest and the possible reductions of competition."	1	0	0	0
	Federal Government should encourage academia and industry to work together.	"Encourage teaming in research efforts between large businesses and both small businesses and academia. This can create built-in technology transfer paths."	3	0	0	0
	Increase formal partnerships between laboratories and industry.	"Increase partnerships with non-Federal stakeholders to leverage assets. Partnerships are the key to the success of the next generation air transportation system."	1	0	0	0

Barrier Category	Recommendation	Example	No. of Federal Responses	No. of Industry Responses	No. of Pre-Roundtable Interviews	No. of Other Sources
	Government should engage in public-private partnerships.	"For mature areas of research, Public-Private Partnerships offer another mechanism for technology development and transfer; such arrangements have been used on a limited basis by NASA, Department of Defense, and the FAA"	1	0	0	0
	Require universities to engage with industry as a condition for Federal funding.	"We suggest increasing requirements that Universities engage more proactively with industry in order to obtain certain Federal funding."	1	0	2	0
	Measure of the distinct methods of partnerships used in portfolio	"diversity of partnership instruments used"	0	1	0	0
	Leverage use of Centers of Excellence.	"Our National Rotorcraft Technology Center (NRTC) and Vertical Lift Research Centers of Excellence (VLRCOE) programs attempt to provide shared resources for early research into new ideas and disseminate those ideas to all non-Federal industry and academia."	2	0	0	0
	An accreditation system for Federal partnerships should be established.	"OSTP should establish Federal partner accreditation so Laboratories can engage non-Federal stakeholders with higher confidence and trust, even with non-traditional or previously unknown partners."	1	0	0	0
	The government should consider the business case for new projects.	"When a company goes through capital investment, you have to build a business case upfront."	0	0	1	0
	Create incentive structures in laboratories for personnel to engage in technology transfer.	"To this end, it would be prudent if we provide incentives to our researchers to enable simple, easy tech transfer of the latest research."	2	0	0	0
	Create a catalog of Federal R&D programs, with contact information for each program.	"OSTP should improve the traceability of the national aeronautics plans by cataloging the specific national Federal R&D programs for each goal and sub-goal area. This catalog should include information about upcoming national planning activities and provide Federal points of contact to support non-Federal inquiries about opportunities, projections, and issues."	1	1	1	0

Barrier Category	Recommendation	Example	No. of Federal Responses	No. of Industry Responses	No. of Pre-Roundtable Interviews	No. of Other Sources
	Government should coordinate more across different agencies.	“One of the roles that government should do is reduce redundancy between government agencies.”	1	1	0	0
	Create a central database of technology transfer products and information.	“Perhaps something could be done is have academia, industry and government to have a database and understand all that is going on technically.”	0	0	2	0
	Laboratories should develop virtual conferences highlighting high-need areas of technology.	“Develop subject specific “virtual conferences” that explain our major technology challenges in greater detail and how to get involved in solving the problems. Look for consolidation of efforts and the elimination of too many duplicative efforts.”	1	0	0	0
	Increase or emphasize participation in conferences.	“More emphasis on conference participation by Government and Industry performers (presentations, networking, Technical Committee membership). Academic performers already tend to be well-motivated to publish and present.”	2	0	0	0
	Ensure that academia is aware of its technology transfer mechanisms.	“Ensure that academic performers are aware of their institutions’ technology transfer programs and provide data on their research outcomes to them.”	1	0	0	0
	Encourage the use of technical reports in the style of NASA Tech Briefs.	“It would be greatly advantageous to organize a combined DOD ‘Tech Briefs’ around technology and disciplines—not agencies/organizations.”	1	0	0	0
	Enhance advisory committee activities within agencies.	“There are opportunities to enhance the advisory committee functions for some agencies, such as NASA, which in the field of aeronautics has been increasingly inactive.”	3	0	0	0
	Increase Federal interaction with aeronautics press.	“More interviews with aerospace periodicals and literature about what we are doing and what is available to others would increase awareness of our efforts”	0	1	0	0
	The government should maintain a long-term vision of the aeronautics enterprise.	“The government needs to have the vision to look 20, 30 and even 50 years into the future and provide a higher degree of certainty behind its plans.”	0	3	2	0

Barrier Category	Recommendation	Example	No. of Federal Responses	No. of Industry Responses	No. of Pre-Roundtable Interviews	No. of Other Sources
	The government should share its research results with industry and academia.	"There is interagency government coordination for the work being conducted towards this goal. [ ] recommends that the work progress and milestones for both government and private entities working on these efforts be shared while research is being conducted. Results gained through the various research studies may inform concurrent research projects. This collaborative approach will enhance efficiencies among the research organizations. A central, secure (password protected) online site could be developed for posting work progress and milestones with point of contact information provided so that researchers could connect with others for additional information or possible collaboration."	0	1	1	0
	Government should increase funding continuity.	"The most important thing to improve is funding continuity—have the decision cycle not be driven by two-year cycles."	0	1	0	0
	Increase the stability of S&T plans.	"Stable S&T plans."	0	0	1	0
	Increase the traceability from the plans to specific agencies and programs for goals.	"Ensure more traceability from the plan to the executing agency programs and associated budgets;"	0	2	0	0
	The government should be more transparent in selecting projects to fund.	"I believe that a more transparent system of down-selection of technologies and vendors for R&D would greatly enhance the effectiveness of technology transfer."	0	1	0	0
	Make internal government research plans public.	"All of their research is documented in program and project plans. Those plans are working documents for agencies but they are signed and approved by agency HQs. He doesn't think there are any reasons that they can't be publicly disclosed, so why not synchronize the approvals and post them on a public-facing website so that anyone in the industry who's interested in knowing what they're doing and when they're doing it has a reference document to go to."	1	0	0	0

Barrier Category	Recommendation	Example	No. of Federal Responses	No. of Industry Responses	No. of Pre-Roundtable Interviews	No. of Other Sources
	Allow the Federal Government to review peer-reviewed papers before publication and transfer technologies as appropriate.	"In the interest of national security, published works should be made available to the various branches of military via a secure method for review to determine if the technology holds military significance. • If so, then the technology can be classified and utilized internally."	0	1	0	0
	There should be national planning forums to develop National Aeronautics R&D Plans.	"After developing the national aeronautics plans, OSTP should sponsor national planning forums in support of each goal area and provide broad access for non-Federal stakeholders. These forums would improve the national coordination and technical interchange and support informed engagement by non-Federal stakeholders."	2	1	0	0
	Use of personnel exchanges between industry and laboratory personnel.	"A potential approach might be a formal personnel exchange developed with specific goals targeting unique and innovative technologies with high risk/high payoff."	2	1	0	0
	Government should continue promoting technology transfer activities.	"continue promotion of technology transfer awareness"	1	0	0	0
	Expression that industry must also contribute to the technology transfer process.	"To be effective, industry must contribute significantly to technology development and be accountable for bringing technology to market."	1	1	0	0
	Industry must be incorporated into the full lifecycle of projects.	"Transition can also be improved by integrating non-Federal partner participation across the R&D life-cycle."	4	2	0	0
	Keep momentum for policy documents.	"Keeping the momentum and the interest up in the executive branch on the policy documents is very important—he'd hate to see another 20 years go by before they got another one because priorities change faster than that."	1	0	0	0
	The Federal Government should lower the risk in technology transfer to industry.	"Effectiveness of NASA aeronautics R&D could be maximized by growth in higher Technology Readiness Level projects, such as those currently underway in the ISRP; such activities lower the risk to industry in adopting new technologies, tools, and systems"	1	0	0	0

Barrier Category	Recommendation	Example	No. of Federal Responses	No. of Industry Responses	No. of Pre-Roundtable Interviews	No. of Other Sources
	Management of laboratories should acknowledge technology transfer as a priority.	"Get senior management buy-in that T2 is important to the mission and to the economic security mission that they have."	0	0	0	0
	Number of partnership opportunities.	"metrics for success for the Federal Laboratory include the generation of at least three new technical partnership opportunities annually through outreach activities"	1	0	0	0
New technology not mature enough to justify its application	Allow simulations instead of testing for certification.	"Faster and more efficient design and certification, through high fidelity virtual testing, would increase opportunities to develop and field new vehicle systems."	0	0	0	0
	Create and use a fast-track approval system.	"As stated in the 2010 Aeronautics R&D Plan (Goal 5 of Mobility), a near term objective is to "Develop dynamic, need-based 'fast track' Federal approval process for airframe and avionics changes." This should be applied to all technology development. This would allow a faster, and likely greater, return on the National Aeronautics R&D investment."	0	1	0	0
	Certification procedures should be coordinated across agencies.	"Of specific near-term concern is the coordination of all government efforts associated with the certification of bonded composite structures."	0	1	0	0
	Government should provide more funding to facilities and infrastructure to support technology testing.	"All industry has been helped greatly by having use of these facilities, and their products are much better because of this capability. Priority needs to be given to resource the operation of these important capabilities."	1	0	0	0
	Government should maintain flight testing capabilities.	"We support the intent to restore flight demonstrations to NASA's portfolio to compliment fundamental capabilities and technologies, as flight demonstrations provide the validation and a pathway to encourage further maturation and adaptation into general aviation."	0	0	1	1

Barrier Category	Recommendation	Example	No. of Federal Responses	No. of Industry Responses	No. of Pre-Roundtable Interviews	No. of Other Sources
“Fog and friction” barriers that hinder technology transfer	Emphasize system integration.	“Recognizing that many of the recent aeronautics achievements and future gains are due to hardware and software associated with information collection, processing, and distribution, add explicit emphasis leading to funded R&D on system integration of technologies beyond traditional aircraft technologies.”	0	1	0	0
	Ensure technology transfer personnel have proper backgrounds.	“You can get the right people; that would be an improvement.”	0	0	0	1
	The government should provide more funding.	“Government can facilitate technology development by providing a portion of the funding and helping to address barriers to commercialization.”	4	1	0	0
	The government should focus on fundamental technologies.	“Where NASA can be focused in the future is on fundamental technologies and multidisciplinary processes that can accelerate product development, test and evaluation through analysis and simulation to provide rapid validation and verification for quicker certifications with regulatory agencies.”	0	1	0	0
	There is not a need for recommendations.	“Once non-Federal stakeholders are aware of what we offer, access is not an issue.”	2	0	0	0
	Use mutual review structures.	“The bulk of the companies are presenting to government; but could also have the government could have labs present about what the government is doing.”	1	0	0	0
	Use specially-negotiated licenses.	“You need to look to specially-negotiated license rights more often. It’s the best way to let a contractor protect their [intellectual property], especially across risks in multiple domains.”	0	0	0	1
	Laboratories should retain specialists in intellectual property.	“Other recommendations to maximize benefits include retention of attorneys that specialize in intellectual property and licensing”	1	0	0	0

Barrier Category	Recommendation	Example	No. of Federal Responses	No. of Industry Responses	No. of Pre-Roundtable Interviews	No. of Other Sources
	Allow for flexibility in partnerships.	"Flexibility in how to enable such mutually beneficial arrangements, for all types and sizes of companies, would be helpful. Each company may wish to participate differently depending on their unique position and competitive advantages or disadvantages."	0	1	0	0
	Create an all-transportation consortium for the issues that span across multiple industries.	"Create an all transportation consortia (agency spanning) on transportation for electric propulsion, autonomy, hybrid power, fuels (all energy), materials, manufacturing, and networking."	0	0	0	1
	Create a user-based prioritization of R&D goals.	"Because budget priorities must often change, a transparent, user-based prioritization of the R&D goals would help industry better plan internal investments."	0	1	0	0
	Ensure policies don't dead-end technologies.	"There needs to be a look again at how policy can affect making sure there's adequate R&D in some of the vendor areas where technology is very important to bring that together."	0	1	0	0
	Establish concrete goals.	"Establish goals that support the next generation aviation workforce and include opportunities for them to become familiar with the Federal laboratory assets as well as collaborative networks (i.e. Federal tuition reimbursement for post and graduate level work)."	1	0	0	0
	Once technologies reach a certain maturity, the research focus should be on the eventual transition.	"Research areas that are at Technology Readiness Level 3 or higher should be focused on the end used candidate; that is, the expected technology transition candidate."	0	1	0	0
	Use more specific measures in the assessments.	"Increase the number of specific measures in the Assessments (many areas already have specific measures) and link these measures to the end user's commercial or military value propositions and to transition plans;"	0	1	0	0

Barrier Category	Recommendation	Example	No. of Federal Responses	No. of Industry Responses	No. of Pre-Roundtable Interviews	No. of Other Sources
	Use innovation prizes to incentivize innovation.	“You could provide a platform to different teams, teams compete for time on the platforms, self-select in and self-select out. FAA example. Once you provide the platform, the teams compete to get on the platform. Then it becomes a competitive environment by nature.”	0	0	0	1
	Allow contractors to directly license to each other instead of having laboratories manage the rights to collaborative projects.	“The preference would be to establish contractor-to-contractor licensing approaches or something along the lines of specially-negotiated licenses.”	1	0	0	0
	Allow for temporary exclusivity on new products.	“Allow government to give exclusive rights for a period of time.”	0	0	0	1
	There should be boilerplate agreement templates for joint projects.	“OSTP should develop default templates for approaches to Intellectual Property Agreements that maximize the potential of Federal/non-Federal partnerships.”	0	0	1	0
	Give industry the patent for joint projects and allow the government to license it.	“Follow the DOD licensing path, in which industry holds the patent but licenses the technology to DOD. In cost-sharing, they need to get something out of a partnership to make it worth putting something in.”	0	1	0	0
	Decrease obstacles in intellectual property and technology transfer issues between industry and academia.	“We strongly suggest that [intellectual property] and technology transfer must become less of an obstacle for companies to work with universities –such that Federal funding to universities would be limited unless this happens.”	0	1	0	0
	Standardize intellectual property rights across projects.	“There needs to be a standard way to identify what information can be released to whom.”	0	1	0	0
	Reward the aeronautics workforce based on performance.	“Look for ways to reward for performance and value added, and not entitlement because of our competitiveness and wages.”	0	0	1	0

Barrier Category	Recommendation	Example	No. of Federal Responses	No. of Industry Responses	No. of Pre-Roundtable Interviews	No. of Other Sources
	Engage in cost-sharing between Federal laboratories and industry.	"In exchange for the license agreement, the commercial company pays for the maintenance and support cost of the code. This alleviates advertising cost and sustainment effort-thereby increasing the availability of research dollars."	7	0	1	0
	Laboratories should leverage local resources.	"Some labs leverage a lot of local resources—there's a lot of opportunity there for labs to exercise local stuff."	0	0	0	0
	The Federal Government should make better use of existing facilities.	"Much of the technology being created needs to have a quick avenue to orbit (satellite) or high altitude (UAV). Where launches may be scheduled out for a year or more, quick launch capabilities will allow experiment results to be fast-track integrated into larger projects as either a "capability enhancement" or a "lessons learned" integration. Therefore, make use of the Kodiak Island launch facilities of Alaska Aerospace for such Quick Launch Capabilities at high altitudes."	0	1	0	0
	Leverage Federal investments in technology transfer by requiring laboratories to match funds from partners.	"Require Federal Labs to match funds with universities, industry, and other government organizations for the establishment and operation of collocated research parks. This leverages Federal Lab investments with other entities in a more formal way that incentivizes the other entities to invest in research."	1	0	0	0
	Charge user fees to make up the costs of transferring technologies.	"By charging the user a nominal maintenance fee the researcher has the funds he needs to keep the code viable, easy to use and relevant to advanced rotorcraft."	1	0	0	0
	Allow for the "build a little, test a little" method of testing.	"Build something up quickly and start testing it quickly in field environments."	0	0	1	0
	Laboratory portfolios should balance long- and short-term needs, as well as the needs of the laboratories and the needs of industry.	"Develop, document, and articulate a balanced portfolio strategy where NASA is constantly developing disruptive ideas for the future while also maintaining openly planned research activities to address and resolve immediate national needs."	1	3	1	0

Barrier Category	Recommendation	Example	No. of Federal Responses	No. of Industry Responses	No. of Pre-Roundtable Interviews	No. of Other Sources
	Prioritization should be given to projects that are likely to have a long-term impact.	"Projects should be encouraged that have long term impact. Next generation of students should be involved early on so that our future in aeronautics sector could be secured."	0	1	0	0
	Examine historical paths of innovation to find replicable models.	"It may be helpful to examine the historical paths and time to infusion of technologies, with the goals of: (a) determining time at each step from original research through application; (b) determining root cause as to why it took as much time as it did at each step; (c) identifying best practices; (d) determining how to adopt these best practices more broadly or wring out delays at each step."	1	0	0	0
	Laboratories must select the technologies to transfer to industry.	"We must first be methodical about selecting technologies that are suitable for transfer to non-Federal entities."	1	0	0	0
	Allow government laboratories to reconfigure themselves as necessary.	"Allow the labs to rationalize their workforce (downsizing in some areas and renewing in others). They have the wrong skills for the future and have the mix of the past."	0	0	1	0
	Current barriers for government partnering with non-traditional entities should be reduced.	"Most importantly, exploitation of technology will improve through streamlining the processes required to engage Federal technology and reducing the barriers to partnership for non-traditional entities."	1	0	0	0
	Reduce government oversight.	"The government does know how to manage projects right in certain cases. You get a program from certain officers and the requirements are just what they need to be, the oversight is just right, they're really there as partners; some programs start at that world and it's moving as fast as greased lightning. And when it gets moved into normal acquisition it's like moving through molasses. If government can pick up its own mechanisms, that would be helpful."	0	0	0	1

Barrier Category	Recommendation	Example	No. of Federal Responses	No. of Industry Responses	No. of Pre-Roundtable Interviews	No. of Other Sources
	Streamline the organizational processes in laboratories for technology transfer.	“A simple way to make the SAA process faster is to delegate approval to local and lower levels in the chain of command while still requiring checks by legal counsel and procurement officials for compliance with law and policy. Agency-wide ‘guidance’ can still be provided by NASA Headquarters on permissible actions and spot checks / audits can be performed to check on compliance.”	2	0	0	0
	Involve students early on in aeronautics projects.	“Next generation of students should be involved early on so that our future in aeronautics sector could be secured.”	0	1	0	0
	Create or require technology transfer training for Federal laboratory personnel.	“Require all Federal agencies with major aerospace hardware and software developers to include subject specific technology transfer training as part of the engineering employees’ annual training requirements.”	1	1	0	0
	Encourage industry to make better use of existing Federal programs.	“Not all SBIR performers participate in TAP. There is some “homework” required. This could be more strongly encouraged.”	2	0	0	0
	Encourage use of CRADAs as a partnership mechanism.	“In addition, full advantage of the CRADA should be taken to provide industry the opportunity to gain access to Federal Laboratory facilities and to share research results.”	1	0	0	0
	Laboratories should use more Space Act Agreements to engage in partnerships with industry.	“Cooperative space act agreements are another way to jointly develop technology and transition it to industry.”	1	0	0	0

Table A-3. Role of U.S. Government

Role	Description	Example	No. of Federal Responses	No. of Industry Responses	No. of Pre-Roundtable Interviews	No. of Other Sources
Facilities and infrastructure	The role of the U.S. government is to fund facilities and infrastructure.	"He'd love to have the U.S. government somehow support the advancement of the technology by funding the testing that they want to do at NASA, to bring NASA in at the ground floor."	1	0	1	0
Fundamental or Basic Research	The role of the U.S. government is to fund basic or fundamental research.	"As a part of their contribution we see the need for NASA to conduct extensive research on fundamental technology that will need to be integrated into future solutions for air traffic management."	3	3	3	0
Prototyping	The role of the U.S. government is to fund prototyping.	"But prototyping used to happen in the DOD more, and that was used to communicate with the fighter pilot and the engineers. Where you affect the prototyping can help. So what is DOD doing now instead of prototyping?"	0	0	1	0
Provide enterprise-level guidance	The role of the U.S. government is to provide enterprise-level guidance.	"What they'd like to see in general is NASA taking the lead on performing the sorts of scientific research that's going to support the aerospace industry as a whole."	0	3	4	0
Transformative or Risky Research	The role of the U.S. government is to fund transformative or risky research.	"The role of the government should not be to compete with private industry; it should look beyond that and fund the types of things that are impossible for companies to fund."	0	1	1	0

Role	Description	Example	No. of Federal Responses	No. of Industry Responses	No. of Pre-Roundtable Interviews	No. of Other Sources
Other	Emphasize system integration.	“Recognizing that many of the recent aeronautics achievements and future gains are due to hardware and software associated with information collection, processing, and distribution, add explicit emphasis leading to funded R&D on system integration of technologies beyond traditional aircraft technologies.”	1	0	1	0

Table A-4. Mechanisms

Category	Mechanism	Example	No. of Federal Responses	No. of Industry Responses	No. of Pre-Roundtable Interviews	No. of Other Sources
Dissemination	The use of direct one-on-one contact between laboratory and industry personnel, through contact at conferences, site visits, and so on.	"Visits to industry and academia to discuss and or create awareness of potential collaborations. The aforementioned provides an opportunity to describe National Aeronautics and Space Administration (NASA) Vision and Mission, ARMD's projects and programs, GRC contributions to NASA and the nation, our core competencies and capabilities."	7	4	1	0
	Use of outreach activities (visitor centers, inviting K-12 school groups, etc.) to give industry visibility into Federal R&D activities.	"The NASA GRC Visitor Center relocated to the Great Lakes Science Center with the following outcomes, 330,000 visitors/yr (5X previous onsite location), 950 school groups/yr (4X previous), 75,000 students/yr (7X previous). We have populated the GLSC space with aeronautics' related products and exhibits."	3	0	0	0
	Publications by laboratory personnel as a method of giving industry visibility into Federal R&D activities.	"…publishing papers in archival journals…"	6	4	0	1
	Use of publicly available data.	"Generally, we are left to access research products through searching publically available data and interacting with agency personnel at conferences and other public forums such as peer research organizations."	0	1	0	0

	Use of technical briefs or reports as a method for industry to gain visibility into Federal R&D activities.	"The Federal Aviation Administration (FAA), Advanced Concepts and Technology Development Directorate's Human Factors Division publishes an Annual Technical Review describing R&D which supports both the agency's Aviation Safety Line of Business in its regulatory and certification role, and the Air Traffic Organization (ATO) relative to integration of human factors in operations and acquisitions."	6	1	0	0
	Lab engagement with the press as a method for industry to gain visibility into Federal R&D activities.	"Throughout the year we respond to multiple requests for interviews and or collaborations to articles by technical magazines, local and out of state newspapers"	2	1	0	0
	Use of web sites, web portals, and web databases as a method for industry to gain visibility into Federal R&D activities.	"The Defense Technical Information Center database is a formal mechanism used to provide visibility to non-Federal stakeholders on aeronautics R&D activities."	7	4	0	0
Events/Activities	Use of competitions (such as NASA's Centennial challenges) as a mechanism to increase visibility.	"Improving visibility: An opportunity for the Centers to be involved with the planning of NASA Centennial Challenges as well as for NASA to invest in competitions that addresses aviation and aeronautical problems or challenges."	1	0	0	0
	Attendance by laboratory and/or industry personnel at events sponsored by third parties (such as technical societies).	"Attendance at forums, technical conferences, and technology showcase are some of the many mechanisms."	10	5	3	0
	The use of government-funded studies.	"Government funded studies where the objective is to develop technology needs, roadmaps and plans are perhaps the best formal mechanism for industry to provide input."	0	2	0	0
	Use of independent assessments of industry needs.	"We receive formal and informal feedback regarding the relevance and effectiveness of our technology efforts through our advisory groups, independent assessments, and technical interchange forums."	1	0	0	0

	Use of personnel exchanges.	"Langley Lead Researcher detailed to FAA to facilitate the transfer to FAA and industry through joint discussions, rules-making activities, and flight standards meetings."	2	0	0	0
	Use of presentations to industry by laboratory personnel (at conferences or at meetings sponsored by the laboratory).	"Typically, these connections are made during presentations at symposia."	10	2	0	0
	Meetings, workshops, or symposia hosted or organized by the laboratory or agency as a method of giving industry visibility into Federal R&D activities.	"Several agencies also hold dedicated conferences to preview their research plans which help with the understanding of the direction taken by the agency."	11	4	0	0
	Use of Requests for Information/Comment and surveys of industry.	"NASA FAP recently issued an RFI to solicit industry input to guide future technology programs for FAP."	2	1	0	0
Laboratory Procedures	The use of programs at laboratories that are explicitly dedicated to technology transfer.	"Small businesses involved in SBIR projects are very well supported by the [sic] "Transition Assistance Program" (TAP) which provides guidance in preparing transition plans and briefings and offers an opportunity to present at the annual Navy Opportunity Forum."	8	3	2	1
	Defining the commercial value of a technology early in the transition process.	"The mechanisms that have best enabled transition to products are the early definition of a clear value to the user and the identification and engagement of user champions who create a pull for the technology-enabled capability."	0	1	0	0
	Engagement of an individual who is willing to champion the technology.	"The mechanisms that have best enabled transition to products are the early definition of a clear value to the user and the identification and engagement of user champions who create a pull for the technology-enabled capability."	0	1	0	0
	Use of a specific government liaison position.	"They have a specific Collaborative Partnerships position."	0	0	1	0

	The use of NASA Research Announcements to give industry visibility into Federal R&D activities.	“NASA Research Announcements (NRA) process.”	2	0	0	0
	Organizational features as mechanisms for enhanced technology transfer.	“Created multidisciplinary activities integrating materials and modeling.”	4	0	0	0
	Beginning negotiation between laboratories and industry early on in the process in joint projects.	“Priorities are determined based on the schedule of the project milestones negotiated with project leadership during the cost-share negotiations with the industry. If needed, the project milestones are rescheduled with consent from the program/project leadership.”	1	0	0	0
	Federal research plans as a method of giving industry visibility into Federal R&D activities.	“A high-level report of AEE technology development in the previous fiscal year is provided in the annual National Aviation Research Plan (NARP) as well as the NextGen Implementation Plan (NGIP).”	1	0	1	0
	Use of requests for proposals and other solicitations as a method for giving industry visibility into Federal R&D activities.	“Government BAAs and RFPs.”	3	2	0	0
	Use of social media such as Twitter and Facebook as a method for giving industry visibility into Federal R&D activities.	“[U]sing social media to communicate results”	2	1	0	0
	The use of specific positions within an institution to gain visibility into Federal R&D activities.	“Through the Vice Provost for Research at [ ], and the Vice Chancellor for Research at [ ]”	0	1	2	0
	Creation of programs aimed at student populations.	“In addition, student intern programs are used to provide learning and development opportunities and work experience for non-Federal individuals in undergraduate and graduate programs.”	1	1	0	0

	#N/A	#N/A	0	1	0	0
	Technology Transfer Offices, Offices of Research and Technology Applications (ORTAs), and similar organizations within laboratories as a method for industry to gain visibility into Federal F&D activities.	"[T]he Office of Research and Technology Applications (ORTA) attendance at applicable technology transfer events and meetings."	4	2	0	0
Legal Agreements	Cost-sharing research allows industry to see the products of Federal research.	"The Government cost-shares research with the Vertical Lift Consortium (VLC). These activities thus have excellent visibility to the [sic] major rotorcraft manufacturers."	7	0	1	0
	The use of Cooperative Research and Development Agreements (CRADAs) as a mechanism for industry to gain visibility into Federal R&D activities.	"…the cooperative research and development agreement (CRADA) which allows the Federal Laboratory to establish partnerships to jointly conduct R&D initiatives, share technical information, and jointly publish technical papers and present results at national and international conferences."	5	2	1	0
	Use of –firm-fixed-price contracts as a mechanism.	"Firm-fixed-price contracts."	0	1	0	0
	Use of unspecified grant or Cooperative Agreement mechanisms.	"Aviation grants/cooperative agreements to conduct aeronautics R&D at academic entities and not-for-profit organizations."	2	0	1	0
	Use of licenses to transfer technologies from Federal laboratories to industry.	"Formal mechanisms include licensing our patented technology"	4	1	0	0
	Use of Memorandums of Understanding and Memorandums of Agreement to transfer technologies.	"MOUs and MOAs."	0	1	0	0
	The use of New Business processes.	"New Business and Space Act Agreements (SAA) processes"	1	0	0	0

	Use of Other Transaction Authority processes.	“Anecdotally, a key partnership was established with a non-traditional entity through use of Other Transaction Authority, where no other vehicle was suitable.”	3	1	0	0
	Use of Partnership Intermediary Agreements.	“Some of the more commonly used authorities include: SBIR to extend access to diverse and emerging partners, CRADA for allow non-Federal entity access to unique government facilities and more flexible partnerships, and PIA to connect Lab R&D through commercially expert agents.”	1	0	0	0
	Use of a Software Use Agreement.	“[A]cquiring software through a Software Use Agreement.”	1	0	0	0
	Use of Space Act Agreements.	“SAAs are the means by which NASA centers work directly with industry on problems of interest to industry, often providing access to NASA’s unique test facilities or computer models to validate solutions or designs created in industry.”	4	1	2	0
	Use of testing agreements between Federal laboratories and industry.	“Some examples include partially reimbursable and fully reimbursable test agreements with GE, Honeywell, Pratt & Whitney, Air Force Research Labs, IARPA, and DOE.”	3	1	0	0
	Use of Technology Investment Agreements.	“A direct exchange of technology is accomplished by Cooperative Research & Development Agreements (CRADAs) and Technology Investment Agreements (TIAs).”	1	0	0	0
	Use of Work for Private Parties agreements.	“CRADAs and Work-for Private Parties agreements”	2	0	0	0

Partnerships	Use of Centers of Excellence as a mechanism to increase visibility.	"In addition to these forums, university R&D activities that are conducted through our Partnership for AiR Transportation Noise and Emissions Reduction (PARTNER) Center of Excellence (CoE) have visibility to non-Federal stakeholders through their semi-annual PARTNER Advisory Board meetings as well as by posting of R&D products on the PARTNER Website."	3	0	0	0
	Academia gains insight into Federal R&D activities by partnering with industry.	"Partnerships with corporations."	0	1	0	0
	The use of industry consortia and advisory committees as a method of giving industry visibility into Federal R&D activities.	"In addition, formal groups such as Versatile, Affordable, Advanced Turbine Engine (VAATE) and Propulsion Safety and Affordable readiness (PSAR) are formed where progress/program information is shared with all stakeholders."	9	5	9	3
	Specific mention of Versatile, Affordable, Advance Turbine Engine (VAATE).	"The two most prominent examples are the Versatile, Affordable, Advanced Turbine Engine (VAATE) Steering Committee and the Fixed Wing Vehicles (FWV) Executive Council. Both involve regular occurring meetings with representation from DOD, national agencies, and key industrial partners that develop shared priorities and coordinate planning and funding."	2	2	6	3
	The use of initiatives across many different sectors to give industry visibility into Federal R&D activities.	"The FAA is collaborating with other government agencies and industry through the Commercial Aviation Alternative Fuels Initiative (CAAFI) to develop and deploy alternative fuels that are a drop-in replacement to fuels derived from petroleum. CAAFI is comprised of approximately 300 stakeholders from government, the aviation industry, fuel suppliers, and universities."	1	1	0	0

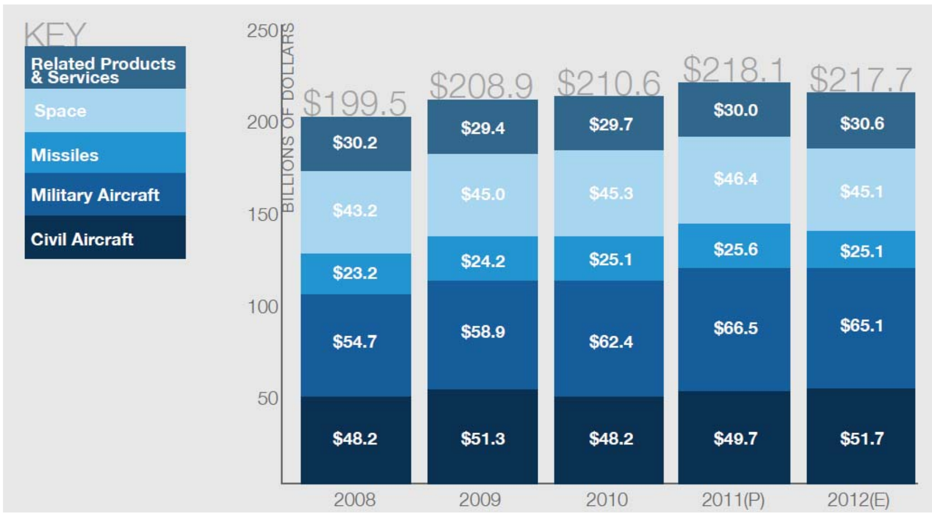
	Peer review processes, standard-setting bodies, and other oversight bodies or processes as a method for giving industry visibility into Federal R&D activities.	"Participation on aviation standards bodies and Aviation Rulemaking Committees"	6	1	2	0
	Involvement of laboratory personnel in technical societies and their associated activities as a method for industry to gain visibility into Federal R&D activities.	"Membership in aeronautics-related technical societies, including active committee and subcommittee participation. By bringing our current and specialized knowledge to the technical community in this way, we sharply accelerate awareness and adoption of technologies, research tools and research results.	4	2	0	0
Other	Expression that the respondent cannot identify specific mechanisms that are used by industry to access or transfer technologies.	"This is difficult to gauge because most of our work that is pertinent to non-Federal entities is fundamental. Therefore, the prevalent tech transfer mechanisms are informal and not easily traced."	1	0	1	0

Table A-5. Metrics

Category	Metric	Example	No. of Federal Responses	No. of Industry Responses	No. of Pre-Roundtable Interviews	No. of Other Sources
Content Goals and Targets	Use of content goals and targets as a metric.	"They have fuel burn reduction goals and targets; if technologies are implemented what would be the impact."	1	0	0	0
CRADAs (metric)	Use of number of CRADAs as a metric for technology transfer.	"As a metric, number of related Cooperative R&D Agreements (CRADA's)"	1	0	0	0
Diversity of partnership types	Measure of the distinct methods of partnerships used in portfolio	"diversity of partnership instruments used"	1	0	0	0
Federal Funding to Leveraged Funding Ratio	Measure comparing the Federal funding in a partnership to the funding from other stakeholders.	"fraction of Federal funding leveraged with partnership funding."	1	0	0	0
Fraction of portfolio in tailored partnerships	Proportion of projects in portfolio that are in tailored partnerships.	"fraction of portfolio in tailored partnerships"	1	0	0	0
Infusion of technology	Measure of how much transferred technology has infused into other sectors.	"GRC defines innovation as the actual use of inventions or technologies and as such these are not just patents or 'new technology reports'. Thus actual 'infusion' of new ideas, models, and hardware is the validation of the investments that have been made in research, development, and demonstration."	1	0	0	0
Mission use documents	Number of mission use documents.	"mission use documents"	1	0	0	0
Number of inquiries to TTO	Number of inquiries that have been made to the Technology Transfer Office or Office of Research and Technology Applications.	"ORTA offices could maintain metrics of number of inquiries, and number satisfied through provision of some product."	1	0	0	0

Category	Metric	Example	No. of Federal Responses	No. of Industry Responses	No. of Pre-Roundtable Interviews	No. of Other Sources
Number of publications	Number of publications resulting from funded research.	In terms of the success for how they disseminate the technology, one of the basic ways is at technical conferences—they keep track of the number of technical papers they produce, with general categories (conference papers, peer-reviewed publications, et cetera).	1	0	0	0
Patents (Metric)	Number of new patents arising from technology transfer activities.	“new patent applications”	4	0	0	0
Software Usage Agreements (Metric)	Number of Software Usage Agreements.	“software usage agreements”	1	0	0	0
Tech Reports (Metric)	Number of tech reports.	“new technology reports”	2	0	0	0
Partnerships	Number of partnership opportunities.	“metrics for success for the Federal Laboratory include the generation of at least three new technical partnership opportunities annually through outreach activities”	1	0	0	0

Appendix C.
Aerospace-Related R&D Funding



Source: Aerospace Industries Association (2011).

Figure C-1. Two-Thirds or More of Aerospace Industry Sales Are Likely Related to Aeronautics Products

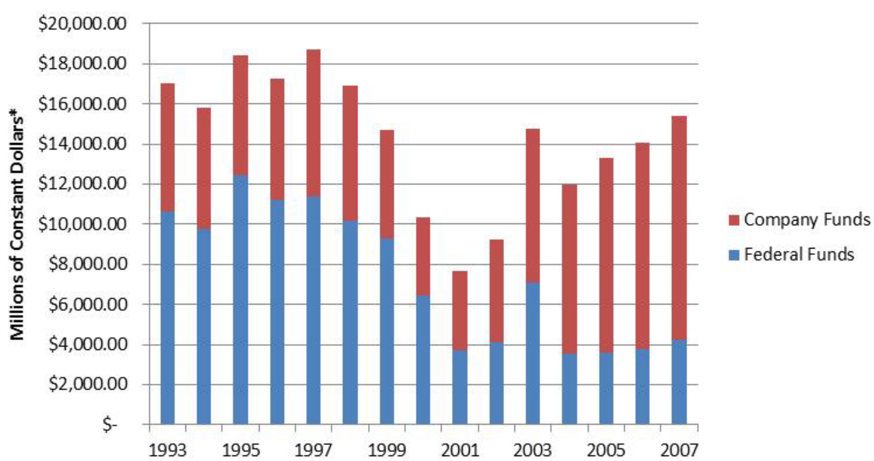
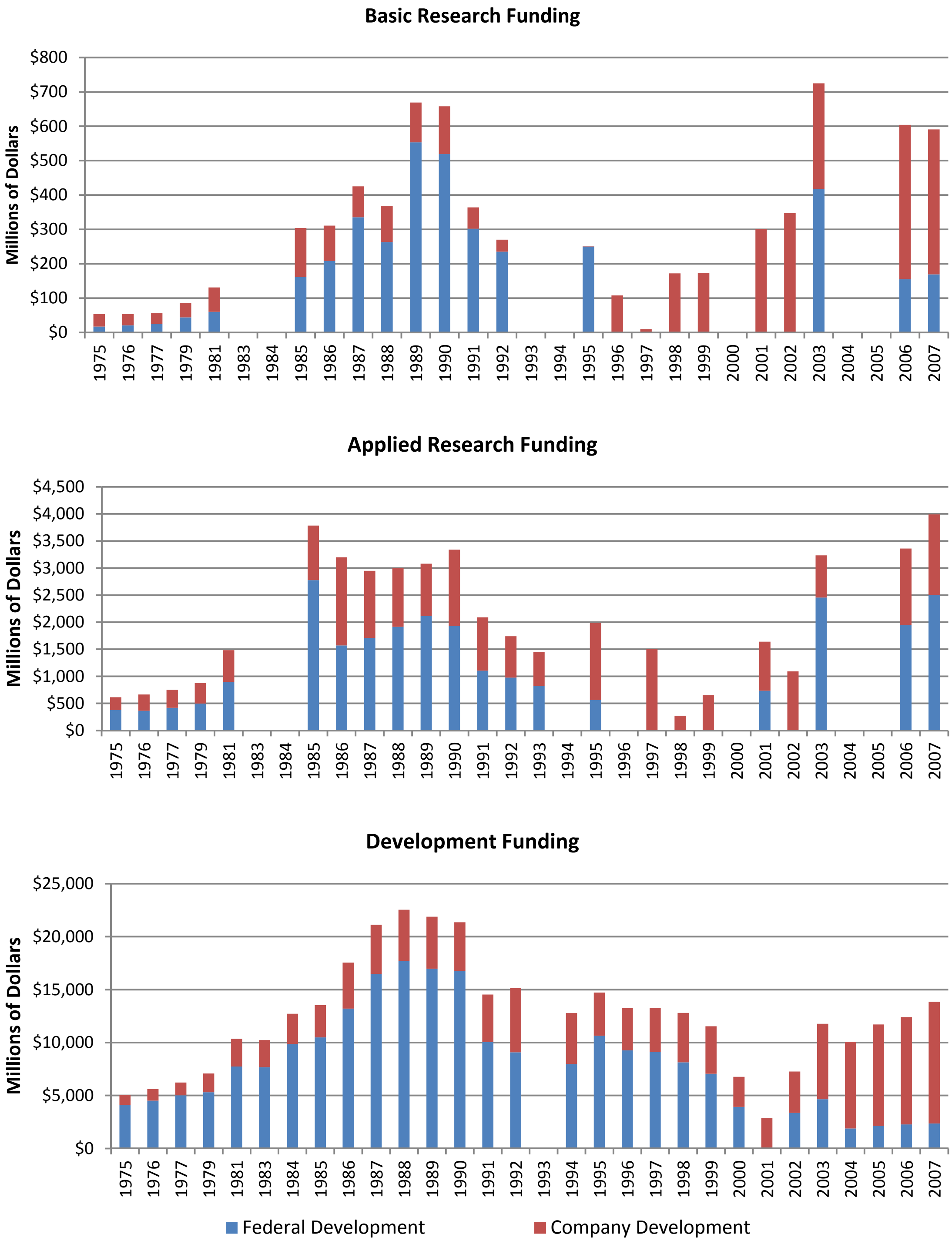


Figure C-2. Aerospace Industry R&D Funding by Source

Source: Aerospace Industries Association (2011)..

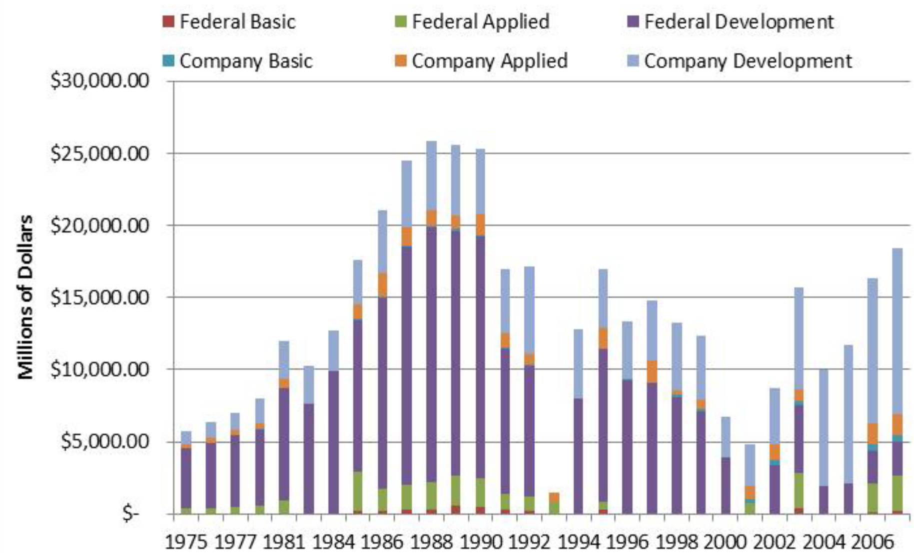
Notes: No data provided or collected for years 1978, 1980, 1982. Data purposefully and inconsistently left off across the three funding domains for years 1983 and 1984, 1993 and 1994, 1998–2002, and 2004–2005 by the National Science Foundation to avoid disclosing sensitive information.



Source: National Science Foundation, Annual Survey of Industrial Research and Development.

Notes: No data provided or collected for years 1978, 1980, 1982. Data purposefully and inconsistently left off across the three funding domains for years 1983 and 1984, 1993 and 1994, 1998–2002, and 2004–2005 by the National Science Foundation to avoid disclosing sensitive information.

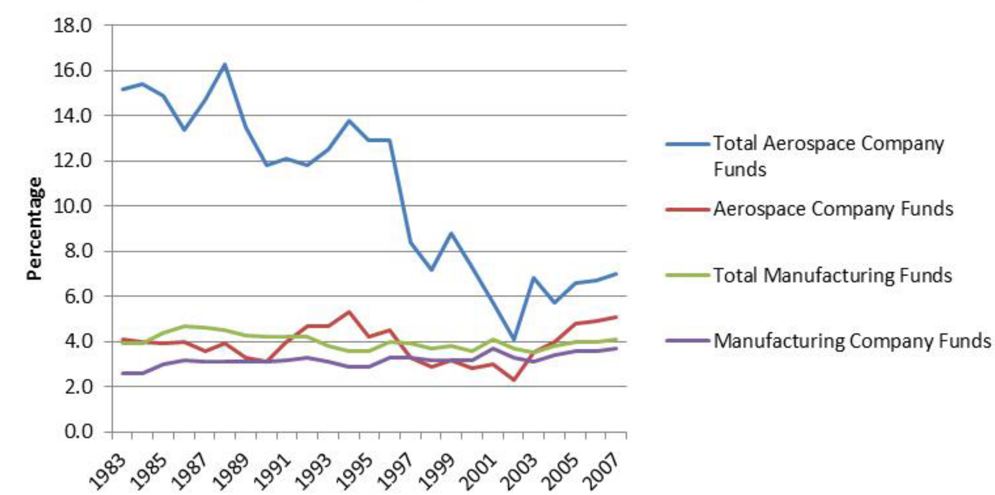
Figure C-3. U.S. Aerospace Industry Basic, Applied, and Development Funding



Source: National Science Foundation, Annual Survey of Industrial Research and Development.

Notes: No data provided or collected for years 1978, 1980, 1982. Data purposefully and inconsistently left off across the three funding domains for years 1983 and 1984, 1993 and 1994, 1998–2002, and 2004–2005 by the National Science Foundation to avoid disclosing sensitive information.

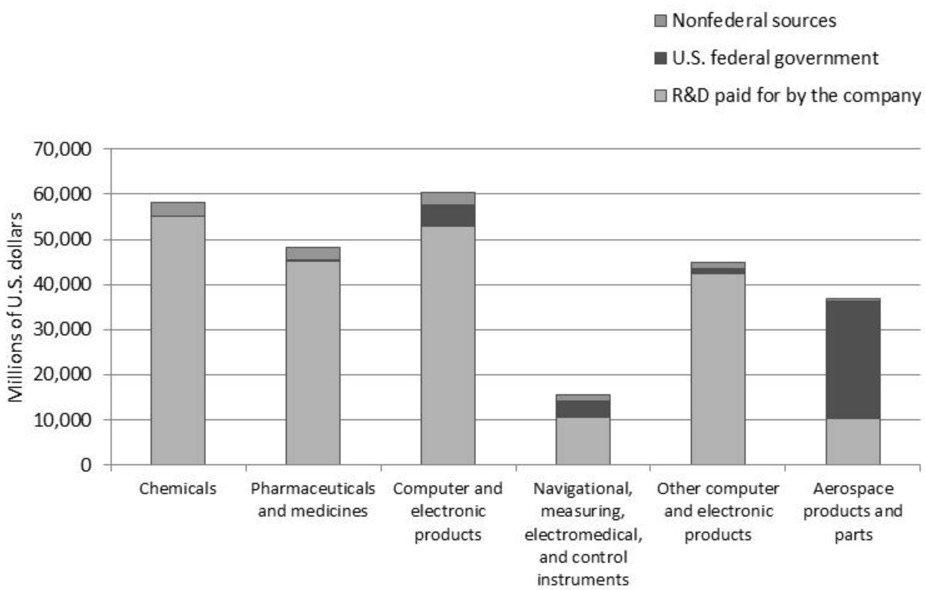
Figure C-4. U.S. Aerospace Industry Total R&D Funding



Source: National Science Foundation, Annual Survey of Industrial Research and Development.

Notes: No data provided or collected for years 1978, 1980, 1982. Data purposefully and inconsistently left off across the three funding domains for years 1983 and 1984, 1993 and 1994, 1998–2002, and 2004–2005 by the National Science Foundation to avoid disclosing sensitive information.

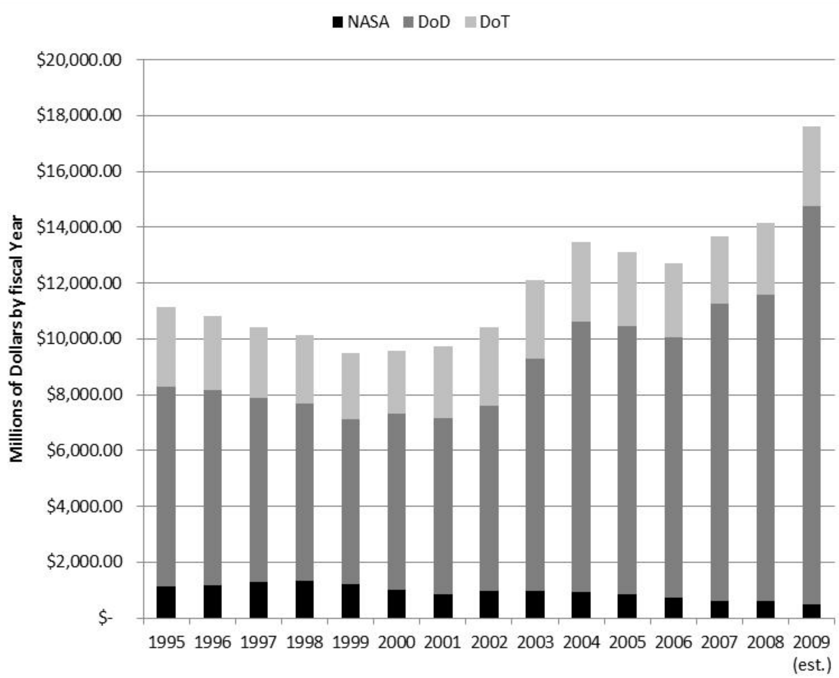
Figure C-5. R&D as a Percentage of Net Sales for U.S. Aerospace Companies



Source: Table 4-7, National Science Foundation, National Center for Science and Engineering Statistics, Survey of Federal Funds for Research and Development: FY 2009–11. Science and Engineering Indicators 2012, http://www.nsf.gov/statistics/seind12/c4/tt04-07.htm.

Note: Aeronautics is NAICS Code 3364.

Figure C-6. Sources of Funds for Domestic R&D Performed by the Company, by Selected Industry, 2008



Source: NASA Aeronautics and Space Report of the President, FY 2008 Activities, http://history.nasa.gov/presrep2008.pdf.

Figure C-7. Federal Aeronautics R&D Budget Authority, 1995–2009

Appendix D.
Century of American Aeronautics[1]

The vantage of over one hundred years of powered, winged flight offers a unique opportunity to reflect on the air and space revolution and the part played in it by the United States. Certainly, the pace of transportation reflects the dramatic results that the introduction of the airplane achieved. Humanity entered the 19th century moving at the speed of an animal-drawn vehicle, about 6 miles per hour. It entered the 20th at the speed of a steam locomotive, about 60 miles per hour. It entered the 21st at the speed of a trans-or-intercontinental jet airliner, about 600 miles per hour. Might American aeronautics enter the 22nd at 6,000 miles per hour, the speed of a hypersonic commercial air and space liner? Critics say no—but similar dismal predictions have been made many times before as well, and in time such negative prognostications have proven shortsighted.[2] Will such be the case in the future? One, of course, cannot know. Equally uncertain is the future of American aeronautics in the second century of heavier than air flight.

The Roots of Flight

The flight revolution was largely a product of technology, not so much science. Its practitioners followed the tradition of the craftsman and mechanician who, informed by the experimental method of Sir Francis Bacon and others, were the proto-engineers of the great expansion of technology and engineering that took place from the time of the

[1] This appendix, written by historian and author Richard P. Hallion, is an elaboration of earlier presentations he has made to the National Aeronautical Systems & Technology Conference of the National Defense Industrial Association, the Annual Aerospace Sciences Meeting of the American Institute of Aeronautics; as a Sigma Lecture to the NASA Langley Research Center and as a briefing to ACC/XP, Headquarters USAF Air Combat Command; and to the Capitol Hill Exchange Club. Chapter 2 of the main report is an abbreviated version of this standalone piece.

[2] For a catalogue of failed forecasting, see Lee D. Saegesser, "Quotes that Failed: A Chronology of Unhelpful Utterances," NASA Draft Publication HHN 112, June 1971, copy in the archives of the NASA History Office. For a thought-provoking (and fiery) example of anti-SST and HST prognostication, see R. E. G. Davies, *Supersonic (Airliner) Non-Sense: A Case Study in Applied Market Research* (McLean, VA: Paladwr Press, 1998), esp. pp. 45-53.

Industrial Revolution onwards.[3] Its first great accomplishment was the invention of the balloon and lighter-than-air flight in 1783. By the mid-1790s, the balloon had already been turned to practical benefit, as an observation system; it appeared as a scientific lifting platform shortly afterwards. The quest for steerable flight led to the creation of practical, small airships by the end of the 19th century, and the larger rigid airship appeared at the beginning of the 20th, almost simultaneously with the appearance of the airplane.[4]

Creating heavier-than-air flight—the airplane—was a far more difficult task than inventing the balloon or airship, and it is not surprising that it took longer. For one thing, airplane developers had to have a profound understanding (and capability to master) propulsion, maneuvering flight, and aerodynamics, all of which were of less significance, or at least less challenging, with a "stall-proof" lighter-than-air system that was already floating in the air. In particular, the airplane, which, of necessity, had to move through the air above stall speed at all times—had to await the development of a suitable "prime mover," something achieved with the introduction of the internal combustion engine. (It is often unappreciated that some early pioneers, notably Hiram Maxim, Samuel Langley, and Clement Ader, developed highly refined lightweight steam engines having flight-worthy power to weight ratios).

The Wrights deserve full credit for the invention of the airplane, for they thoroughly understood its requirements, mastered them completely, and then demonstrated them in full-scale flight. In doing so, they followed a succession of pioneers who had contributed to a generalized knowledge base they consulted before they began their own work. In fairness to the brothers, the accomplishment of the first powered and controlled airplane flight was theirs alone. Success for them was not accidental, not the blind luck of fortuitous tinkers. Rather than the "bicycle mechanics turned airplane builders" of popular myth, the brothers were insightful and creative (if largely self-taught) engineers who followed a research and develop path that could be used as a model even today.

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[3] See Berthold Laufer, *The Prehistory of Aviation,* Publication 253 in the *Anthropological Series*, v. 18, n. 1 (Chicago, IL: Field Museum of Natural History, 1928); Lynn White, Jr., "Technology in the Middle Ages," in Melvin Kranzberg and Carroll W. Pursell, Jr., eds., *Technology in Western Civilization*, v. I: *The Emergence of Modern Industrial Society: Earliest Times to 1900* (London: Oxford University Press, 1967); Lynn White, Jr., "Eilmer of Malmesbury: An Eleventh Century Aviator: A Case Study of Technological Innovation, Its Context and Tradition," *Technology and Culture*, v. II, n. 2 (Spring 1961); Clive Hart, *The Dream of Flight: Aeronautics from Classical Times to the Renaissance* (New York: Winchester Press,1972); David C. Lindberg, *The Beginnings of Western Science: The European Scientific Tradition in Philosophical, Religious, and Institutional Context, 600 BC to AD 1450* (Chicago: The University of Chicago Press, 1992); and Edward Grant, *God and Reason in the Middle Ages* (New York: Cambridge University Press, 1992).

[4] The best survey on the invention of both the balloon and the airplane remains Charles H. Gibbs-Smith's *Aviation: A Historical Survey from its Origins to the End of World War II* (London: Her Majesty's Stationery Office, 1970.

They knew far more about flight than any of their predecessors and, indeed, most of their successors as well. They made certain they were thoroughly cognizant of what had been done, evaluated it critically, rejected much, and accepted some.[5]

The work of the Wrights must be recognized as work that built upon a strong and emerging technical base—a base so advanced that, had the Wrights not existed, it is probable that the airplane would have been invented anyway, in Europe (most likely France), by 1910. That is something to be kept in mind this year, when so much attention will be focused on the two brothers and so little attention to those who went before. Pioneers such as Sir George Cayley, Alphonse Pénaud, William Henson and John Stringfellow, Francis Wenham, Horatio Phillips, Lawrence Hargrave, Otto Lilienthal, Samuel Langley, Hiram Maxim, Octave Chanute, and Augustus Herring (to mention just a few) had generated a supportive underpinning of insights in aerodynamics, structures, propulsion, and (in the case of Lilienthal and Chanute-Herring) actual full-scale flight testing that enabled the Wrights to quickly assess what they needed to do. This freed them to focus their primary attention upon the greatest challenge of all—controllability (which other pioneers had largely neglected). The Wrights' accomplishment, in short, was neither a "singularity" nor uniquely American (though the social, cultural, industrial, and economic circumstances of the United States at the turn of the century favorably influenced their work). Rather, as stated earlier, it was rooted in an older European tradition of inquiry and accomplishment transplanted in the United States and nourished by individuals such as Chanute and Herring following the death, in 1896, of the greatest European pre-Wright pioneer, Otto Lilienthal.[6] In short, the Wrights won an international race, among the first of many such air and space races that have continued to the present day.

The Wrights were generous in acknowledging both the work of earlier pioneers, and their debt to them. Of Cayley, for example, Orville noted "He knew more of the principles of aeronautics than any of his predecessors, and as much as any that followed him up to the end of the 19th century. His published work is remarkably free from error and was a most important contribution to the science."[7] Wilbur selected six of Cayley's

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5 Literature on the Wrights is voluminous; the best sources are Marvin W. McFarland's *The Papers of Wilbur and Orville Wright*, 2 volumes (New York: McGraw-Hill, 1953) (hereafter WP I or II); Peter L. Jakab, *Visions of a Flying Machine: The Wright Brothers and the Process of Invention* (Washington, D.C.: Smithsonian Institution Press, 1990); and Tom D. Crouch, *The Bishop's Boys: A Life of Wilbur and Orville Wright* (New York: W. W. Norton & Company, 1989).

6 For the seminal work of Lilienthal, see Werner Heinzerling and Helmuth Trischler, eds., *Otto Lilienthal: Flugpionier, Ingenieur, Unternehmer—Dokumente und Objekte* (Munich: Deutsches Museum, 1991).

7 Quoted in J. Laurence Pritchard, *Sir George Cayley: The Inventor of the Aeroplane* (London: Max Parrish 1961), p. 34. The best most recent treatment on Cayley is Professor J. A. D. Ackroyd's "Sir George Cayley: A Bicentennial Review," the 46th Cayley Lecture of the Royal Aeronautical Society, 19 April 2000. I thank Professor Ackroyd for making a copy available to me.

successors, Lilienthal, Chanute, Langley, Maxim, Ader, and Hargrave, for special recognition as "very remarkable men who in the last decade of the 19th century raised studies relating to flying to a point never before attained. [They] formed by far the strongest group of workers in the field that the world has seen."[8] Even of their closest and best known "rival," Smithsonian Institution Secretary Samuel Langley, the Wrights would write (after his death) that he had offered "a helping hand at a critical time and we shall always be grateful. . .His work deserved neither abuse nor apology."[9]

Ironically, before the Wrights flew at Kitty Hawk, few of the most knowledgeable individuals in the fields of science and technology recognized just how close humanity was to fulfilling the dream of constructing a winged "flying machine." In 1896, the great scientist Lord Kelvin scathingly rejected an offer of membership in the Aeronautical Society of Great Britain (now the Royal Aeronautical Society), writing "I have not the smallest molecule of faith in aerial navigation other than ballooning or of expectations of good results from any of the trials we hear of."[10] At the time of Langley's first failure in 1903, the astronomer Simon Newcomb intoned "May not our mechanicians…ultimately forced to admit that aerial flight is one of that great class of problems with which man can never cope?"[11] Even advocates of flight were surprisingly cautious in their predictions. H. G. Wells, only slightly over a year before Kitty Hawk, wrote "Few people, I fancy, who know of the work of Langley, Lilienthal, Pilcher, Maxim, and Chanute but will be inclined to believe that long before the year AD 2000 and very probably before 1950, a successful aeroplane will have soared and come home safe and sound."[12]

How America Lost Its Advantage

Though the invention of the airplane was a genuine triumph for the United States, the exploitation of the airplane was not. Indeed, in less than a decade, the United States had lost not only its lead in aeronautics, but also its market share in aeronautics. As with many such "Hare and Tortoise" stories, the root of this decline began with complacency. Such smugness is somewhat understandable if not forgivable: by the end of 1905, by which time the Wrights had a fully controllable practical airplane capable of remaining aloft for the better part of an hour and flying several dozen miles, not a single European

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8 WW to Charles L. Strobel, 27 Jan. 1911, WP II, 1018.

9 WW to Octave Chanute, 8 Nov.1906, WP II, p. 737.

10 Letter, Kelvin to Baden F. S. Baden-Powell, 8 Dec. 1896, from the letters files, folder 13, in the library, Royal Aeronautical Society, London (hereafter RAeS Library). I thank librarian Brian Riddle for making it available for my examination.

11 Simon Newcomb, "The Outlook for the Flying Machine," *The Independent* (22 Oct. 1903), p.2509.

12 H. G. Wells, *Anticipations* (New York: Harper and Brothers, 1902), p. 208.

powered airplane existed. The Wrights promptly gave up flying and further technical development of their craft for *almost three years*, turning instead to the challenge of marketing their craft, convinced they possessed an insurmountable advantage over any possible rivals. In October 1906, Wilbur Wright wrote to Octave Chanute "We do not believe there is one chance in a hundred that anyone will have a machine of the least practical usefulness within five years."[13]

In this judgment, he was disastrously wrong; within just three years, in fact, European aviation would have caught up with and surpassed that of the United States, and within five, it would have already gone to war. Looked at in detail, the Wright trips to Europe in 1908 and 1909 certainly did not, as is often suggested, "give" the Europeans the "secret" of flight or "teach them to fly." Indeed, European aircraft that would supersede the Wrights in design excellence—notably the Farman, Antoinette, and Blériot, for example—were *already* flying, and had even flown abroad (and in the case of Farman, even in the United States) before the first Wright European trip. At best, the Wrights demonstrated to the Europeans the importance of lateral control and rational design. This served as a goad to further action, in effect "teaching them to fly *better*." In less than a year Blériot would fly the Channel, and Europe would hold its great aviation meet at Reims, showcasing its parity—and indeed advancement—over the United States.

In addition to simple complacency, there are several notable reasons why the United States fell behind Europe, not least of which is that our geostrategic position at the time did not generate the same kind of pressures for incorporating new technology into the military that worked to accelerate European aviation. European aviation was also quicker to take advantage of a strong and growing industrial and academic laboratory tradition, characterized by the creation of the first genuine aeronautical research laboratories in France, Germany, Russia, Italy, and England from 1904 onwards.[14] When, at last, American airmen recognized the growing superiority of European practice, the natural tendency was to import foreign machines and airmen, and emulate European technology and institutions. Indeed, when in 1915 the United States at last created its own equivalent to a European aero-research body, the National Advisory Committee for Aeronautics, it copied the *exact* legislative language and even the institutional title of a comparable British committee. Further, government experts had traveled to Europe to study the European laboratory structure at close hand before returning to America to attempt to convince Congress to furnish a similar American institution. Even so, the fight for an

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13 WW to OC, 10 Oct. 1906, WP II, pp. 729-730.

14 For European developments, see N. H. Randers-Pehrson, "Pioneer Wind Tunnels," *Smithsonian Miscellaneous Collections,* v. 93, n. 4 (19 Jan. 1935), pp. 4-18; and Albert F. Zahm, "Report on European Aeronautical Laboratories," *Smithsonian Miscellaneous Collections*, v. 62, n. 3 (27 July 1914), pp. 1-23.

American laboratory took several years and involved overcoming both active and passive opposition as well as continued complacency.[15]

But there were other reasons for America's decline as well. The Wrights knew how to make the first airplane. They did not know how to make its successors. In particular, they underestimated how desirable and appealing the positively stable airplane—particularly the tractor airplane-was. They had built a totally unstable and extremely difficult to fly aircraft with a complicated means of takeoff and landing. Yet though they could fiddle with it, relocating its canard elevator to the rear, making it marginally stable, and replacing the takeoff catapult with a wheeled undercarriage, it, at heart, remained at best a derivative of the original 1903 machine. Worse, even as the value of the technology they possessed declined (compared to world standard), they tried to ensure market dominance through a series of lawsuits against foreign and American competitors, charging patent infringement over their means of lateral control. The lawsuits accomplished virtually nothing against the Europeans, and little else except the hamstringing of American aeronautical development. In particular, they accomplished even less against the wily and aggressive Glenn Curtiss, the Wrights' major rival. By the end of 1918,Curtiss designs would account for the vast majority of American military aircraft, with Wright or Wright-Martin airplanes accounting for a much smaller percentage.[16]

Some measure of the dominance of European aircraft less than a decade after Kitty Hawk can be found in this: in 1912, the French demonstrated the Deperdussin Monocoque monoplane racer in the United States, winning the Gordon-Bennett Trophy with an average speed of 105 mph over a 124 mile course outside Chicago.[17] No American airplane competed and, indeed, the latest production Wright aircraft, the Wright Model D "Speed Scout," had a top speed of only slightly greater than 60% that of the Deperdussin. This dominance continued unabated throughout the remainder of the prewar years and until well after the end of the First World War as well, and was marked by a pronounced outburst of creative energy within European aeronautical circles.

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[15] Jerome Hunsaker, "Europe's Facilities for Aeronautical Research, *Flying*, v. III, n. 3 (April 1914); Statement of PM Herbert Asquith in *Hansard's Parliamentary Debates*, 5th series, v. IV (26 April-14 May 1909), cols. 1047-1048; Public No. 271, 63rd Congress, 3rd session, HR 20975 (1915); the debate over creation of a national American laboratory is discussed in Richard P. Hallion, "To Study the Problem of Flight: The Creation of the National Advisory Committee for Aeronautics, 1911-1915 (Washington, D.C.: National Air and Space Museum Department of Science and Technology, 1976), an unpublished manuscript in the collections of the NASM Library and the NASA History Office.

[16] Computed from data in Tables 1, 2, and 4 of Herbert A. Johnson's *Wingless Eagle: U.S. Army Aviation Through World War I* (Chapel Hill: University of North Carolina Press, 2001), p. 111-112.

[17] "How About America in 1913?" *Aerial Age*, v. I, n. 5 (Oct. 1912), p. 9; Don Vorderman, *The Great Air Racers* (Garden City, N.Y.: Doubleday, 1969), pp. 39-42.

For example:

- In 1909, Laurent and Louis Séguin introduced the Gnôme rotary engine, the most significant of all pre-war aero engines which, in the words of Louis Blériot, "enabled the industry to advance by leaps and bounds."[18] So advanced was the Gnôme that, eight years later, it was the first powerplant ordered into production by the United States after it entered the First World War.[19]
- In 1910, Hugo Junkers' patented an all-metal flying wing, which, if not achieved for over the next 35 years (until the first flight of the Northrop XB-35), and not ultimately fulfilled for nearly 80 years (until the first flight of the Northrop B-2), nevertheless pointed the way towards the cantilever all-metal aircraft of the late war and interwar periods.[20]
- In 1911, René Lorin conceptualized a reaction-powered supersonic aircraft anticipating such later concepts as the supersonic aircraft of the late 1940s and the Sänger-Bredt orbital boost-glider scheme.[21]
- In 1912, as discussed, Louis Béchéreau introduced the practical monocoque streamlined monoplane, the Deperdussin Monocoque racer.[22]
- In 1913, Igor Sikorsky demonstrated the world's first multiengine air transport, following it with an even more impressive successor the following year.[23]

And these are but a few. Perhaps the best example of European dominance is the obvious one: production and utility. When the European nations went to war in 1914, they numbered, respectively by country, 244 Russian, 232 German, 162 French, and 113 British, aircraft. The United States possessed but 23.[24] In short, the United States, the

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[18] Quoted in Grahame-White and Harry Harper, p. 200; see also C. Fayette Taylor, *Aircraft Propulsion: A Review of the Evolution of Aircraft Piston Engines* (Washington, D.C.: Smithsonian Institution Press, 1971), pp. 22-26.

[19] Col. G. W. Mixter and Lt. H. H. Emmons, *United States Army Aircraft Production Facts* (Washington, D.C.: Government Printing Office, 1919), p. 13.

[20] Reichspatentamt Patentschrift Nr. 253778, Klasse 77A, Gruppe 5 (granted 14 Nov. 1912).

[21] René Lorin, "La sécurité par la vitesse," *L'aérophile*, v. XIX, n. 17 (1 Sept. 1911), pp. 409-412.

[22] Henri Mirguet, "Le 'Monocoque' Deperdussin," *L'aérophile*, v. XX, n. 28 (15 Sept. 1912), pp. 410-411.

[23] Igor I. Sikorsky, *The Story of the Winged-S: An Autobiography* (New York: Dodd, Mead & Company, 1967 ed.), pp. 69-117; Dorothy Cochrane, Von Hardesty, and Russell Lee, *The Aviation Careers of Igor Sikorsky* (Seattle: University of Washington Press in association with the National Air and Space Museum, 1989), pp. 20-42; and V. B. Shahrov, *History of Aircraft Construction in the USSR*, v. I: *To 1938* (Moscow: Mechanical Engineering Publishers, 1978), pp. 63-65, 85-88, 121-145, 187-203.

[24] Relative force structure figures from: Kriegswissenschaftlichen Abteilung der Luftwaffe, *Mobelmachung, Aufmarsch und erster Einsatz der deutschen Luftstreitkräfte im August 1914* (Berlin: Ernst Siegfried Mittler und Sohn, 1939), p.8-9, Table 3, p. 106;Von Hardesty, "Early Flight in Russia," in Robin Higham, John T. Greenwood, and Von Hardesty, *Russian Aviation and Air Power in the*

birthplace of powered heavier than air flight, accounted for at best only 2.5% of the military aircraft then in service with leading nations! Even the language of flight was European, particularly French: *aviation, aviator, aeroplane, longeron, fuselage, aileron, nacelle, chandelle, hangar, empennage, monocoque*, etc. And of course, during the war itself, when Americans saw their airmen in conflict, they saw Eddie Rickenbacker in front of a French SPAD, Doug Ingells in front of a British Camel, and Fiorello LaGuardia in front of an Italian Caproni.…The evident frustration felt by many Americans was perhaps best expressed by former President Theodore Roosevelt in a letter to the Aero Club of America. "This country, which gave birth to aviation," Roosevelt wrote, "has so far lagged behind that now, three years after the Great War began, and six months after we were dragged into it, we still have not a single machine competent to fight the war machines of our enemies."[25]

Indeed, even America's best-remembered aircraft contribution to the First World War effort, the much-loved Curtiss Model JN "Jenny," was the product of European practice. While on a study tour of England and France, Glenn Curtiss hired an émigré Sopwith engineer, B. Douglas Thomas, to design a multipurpose biplane. Thomas designed this plane, the Model J, while still in England, sending the drawings to Curtiss, who cabled him to come to America. The J, and a successor Thomas designed in the U.S., the N, bore a distinct similarity to existing Sopwith, Avro, and Nieuport design practice, using as well French and British airfoils. The merger of the best features of both aircraft resulted in the ubiquitous JN, America's best-known airplane of the First World War era.[26]

Clearly, then, within fifteen years of the invention of the airplane, the United States had lost control of its own creation. The European "fast seconds," thanks to their own innovative insight, and aided by American complacency, sequential disinterested administrations, a cost-obsessed Congress, and, worst of all, an enervating series of patent suits, had raced ahead to secure dominant leadership of the aeronautics revolution. Attempts during the war to catch up simply by throwing money at the problem failed miserably. America's wartime efforts to match the latest state of the art in aeronautical

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Twentieth Century (London: Frank Cass, 1998), p. 22; Captain Paul-Louis Weller, "L'aviation française de reconnaissance," in Maurice de Brunoff, ed., *L'aéronautique pendant la guerre mondiale, 1914-1918* (Paris: Maurice de Brunoff, 1919), p. 63; Alfred Gollin, *The Impact of Air Power on the British People and their Government, 1909-14* (Stanford: Stanford University Press, 1989), p. 307; Jerome Hunsaker, "Forty Years of Aeronautical Research," *Smithsonian Report for 1955* (Washington, D.C.: Smithsonian Institution, 1956), p. 243 (though his European figures are clearly in error).

25 TR to Augustus Post, 27 July 1917, in Elting E. Morison et. al., *The Letters of Theodore Roosevelt,* v. VIII (Cambridge, MA: Harvard University Press, 1954), p. 1214.

26 Louis S. Casey, *Curtiss: The Hammondsport Era, 1907-1915* (New York: Crown Publishers Inc., 1981), pp. 176-177, 188-189; Peter M. Bowers, *Curtiss Aircraft: 1907-1947* (London: Putnam, 1979), pp. 63-65.

design failed both in design excellence, and in achieving basic production goals. Capable designers, seeing the chaos around them were left, in the words of pioneer Grover Loening, "aghast at the debacle in the making."[27] As late as 1923, the Wrights' hometown newspaper, the *Dayton Daily News*, would note "The Old World, singularly enough, has utilized the airplane for many more purposes than America, though here in our country we invented it and first gave it to the world. Mail routes and transportation lines in France, England, Italy and Germany are commonplace elements in the lives of the people. Here in America we have been a bit laggard about claiming for our own that to which we are entitled."[28]

The Road to Recovery

Clearly, overcoming the European lead would take considerable time, and require the complete revamping and rebuilding of America's aeronautical base. This the United States accomplished over approximately the next fifteen years. Several notable developments made the recovery of American aviation possible:

- *The establishment of the NACA and the beginning of an indigenous program of rigorous laboratory research*, thanks to the importation of classically trained European engineers and scientists such as Germany's Max Munk, and Norway's Theodore Theodorsen.[29]
- *The creation of The Daniel Guggenheim Fund for the Promotion of Aeronautics*, which greatly expanded American aeronautical engineering education, undertook basic research on the problems of blind flight and safe aircraft design, and undertook as well demonstrations of airline operation complete with the establishment of a West Coast "Model Air Way" having real-time weather and radio communication and state-of-the-art Fokker trimotor transports. Most significant, however, was the Fund's importation of Theodore *von* Kármán, arguably the greatest aeronautical scientist and educator of the 2oth century, to

[27] Grover Loening, *Takeoff Into Greatness* (New York: G. P. Putnam's Sons, 1968), pp. 106-107.

[28] *Dayton Daily News* (17 Dec 1923).

[29] See, for example, James R. Hansen's *Engineer in Charge: A History of Langley Aeronautical Laboratories, 1917-1958* (Washington, D.C.: National Aeronautics and Space Administration, 1987), pp. 97-99, 105-122; Pamela E. Mack, ed., *From Engineering Science to Big Science: The NACA and NASA Collier Trophy Research Project Winners*, SP-4219 (Washington, D.C.: NASA, 1998); and R. T. Jones, "Recollections From an Earlier Period in American Aeronautics," *American Review of Fluid Mechanics*, Paper 8094 (1977), pp. 1-11.

serve as director of the Guggenheim Aeronautical Laboratory at the California Institute of Technology.[30]

- *A Russo-European aeronautical migration similar to the 1960s-70s "brain drain" that witnessed some of the best and most capable individuals in European aeronautics and related fields depart (for various reasons) to the United States*. In addition to the well-known cases of Munk, Theodorsen, and von Kármán, were many others, including: Alexander de Seversky, Alexander Kartveli, Felix Pawlowski, Igor Sikorsky, Assen Jordanoff, Anthony Fokker, Samuel Heron, Paul Kollsman, Frank Courtney, Jean Roché, Carl-Gustaf Rossby, Edgar Schmued, Armand Thieblot, John von Neumann, and Edward Teller.[31]

- *The adaptation by American designers of state-of-the-art European thinking*—the thinking of individuals such as Junkers, Adolf Rohrbach, Claude Dornier, and A. P. Thurston—in the field of all-metal design and streamlining, which served as a departure point for subsequent American work.[32]

- *The regulatory and administrative infrastructure that resulted from key legislation*, particularly the Kelly Act of 1925, the Air Commerce Act of 1926, and the Army and Navy Five Year Plans of the same time period.[33]

- *The rise of "air mindedness" among Americans in general and children in particular*, and the development and implementation of aviation curriculums in primary and secondary schools, together with the widespread proliferation of model airplane building as a youth activity.[34]

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[30] For the Fund and the importation of von Kármán, see Richard P. Hallion, *Legacy of Flight: The Guggenheim Contribution to American Aviation* (Seattle, WA: University of Washington Press, 1977), and Paul A. Hanle, *Bringing Aerodynamics to America* (Cambridge, MA: MIT Press, 1982).

[31] For a discussion of this migration, see Roger E. Bilstein, "American Aviation Technology: An International Heritage," in Peer Galison and Alex Roland, eds., *Atmospheric Flight in the Twentieth Century* (Dordrecht, NI: Kluwer Academic Publishers, 2000).

[32] Edward P. Warner, *Technical Development and its Effect on Air Transportation* (Northfield, VT: Norwich University, 1938); Ronald Miller and David Sawers, *The Technical Development of Modern Aviation* (New York: Praeger Publishers, 1966); T. A. Heppenheimer, *Turbulent Skies: The History of Commercial Aviation* (New York: John Wiley & Sons, Inc., 1995); and Peter W. Brooks, *The Modern Airliner: Its Origins and Development* (London: Putnam, 1961).

[33] Nick A. Komons, *Bonfires to Beacons: Federal Civil Aviation Policy Under the Air Commerce Act, 1926-1938* (Washington, D.C.: Smithsonian Institution Press, 1989 ed.).

[34] Model building as a goad to future aeronautical careers has not received the attention it deserves. For an introduction to this issue, and the whole issue of a "gospel of aviation, " see Joseph J. Corn, *The Winged Gospel: America's Romance with Aviation, 1900-1950* (New York: Oxford University Press, 1983), esp. pp. 17-62. For a classic example of the kind of excellent technical literature that was widely available for anyone possibly interested in aeronautics to study in this time period, see Assen Jordanoff, *Your Wings*

- *The development of powerful new aero engines*, both liquid and air-cooled, together with advances in engine *supercharging*, fuels, and variable-pitch propeller and engine cowling/nacelle design.[35]
- *The use, in the 1920s of high-speed government-sponsored (and, to a lesser extent, privately sponsored racing aircraft as technology demonstrators* blending leading-edge advances in aerodynamics, structures, propulsion, and controls. Virtually all the significant technical developments in the 1920s and 1930s appeared on various air racing aircraft. As early as 1924, Major R. H. Mayo, the technical advisor to Imperial Airways noted "the splendid achievements of American designers in the development of high-speed [racing] aircraft have been due entirely to the fact that the American Government has properly appreciated the significance of research and experiment, and has allocated the available funds accordingly. . . . By her vigorous technical policy, America has placed herself well ahead of any other nation in the design of high-speed aeroplanes and the development of suitable engines, and her position as the leading air power is secure for some time to come."[36]

Taken together, these acted to quickly reshape and redirect American aviation down an approximately 15-year path of recovery.[37] Here the "fast second" syndrome assisted the United States, which quickly surpassed Europe in the design of commercial aircraft. In 1928, for example, when Northrop's Vega was already in service with a top speed of 185 mph, an Imperial Airways Armstrong-Whitworth Argosy (a large slab-sided high-drag trimotor biplane) lost a race between London and Edinburgh to the *Flying Scotsman*,

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(New York: Funk & Wagnalls, 1937). Jordanoff, incidentally, had been one of the earlier Bulgarian airmen, having flown in the Balkan Wars before Sarajevo.

[35] Robert Schlaifer and S. D. Heron, *Development of Aircraft Engines and Fuels* (Boston: Division of Research, Graduate School of Business Administration, Harvard University, 1950), esp. pp. 57, 223-228, 328-329, 501-507, 628-630.

[36] Major R. H. Mayo, "The Development of High-Speed Aircraft," *The Journal of the Royal Aeronautical Society*, v. XXVIII, n. 159 (March 1924), pp. 175-176. For a detailed engineering examination of the racers of this period, see Birch Matthews, *Race with the Wind: How Air Racing Advanced Aviation* (Osceola, WI: MBI Publishing Co., 2001); and Thomas G. Foxworth, *The Speed Seekers* (Garden City, N.Y.: Doubleday & Company, 1975).

[37] For interwar developments and the American aircraft industry in general (in addition to those works cited previously), see: Roger E. Bilstein: *Flight Patterns: Trends in Aeronautical Development in the United States, 1918-1929* (Athens: The University of Georgia Press, 1983); John B. Rae, *Climb to Greatness: The American Aircraft Industry, 1920-1960* (Cambridge, MA: The MIT Press, 1968); William M. Leary, ed., *Aviation's Golden Age: Portraits from the 1920s and 1930s* (Iowa City: University of Iowa Press, 1989); Brig. Gen. Benjamin S. Kelsey, *The Dragon's Teeth? The Creation of United States Air Power for World War II* (Washington, D.C.: Smithsonian Institution Press, 1982); and Jeffrey S. Underwood, *The Wings of Democracy: The Influence of Air Power on the Roosevelt Administration, 1933-1941* (College Station, TX: Texas A&M University, 1991).

Britain's crack train.[38] American engine manufacturers quickly took to the variable-pitch propeller, far faster than their European contemporaries, despite its having been conceived overseas; "Use of the controllable pitch propeller in the United States," S. D. Heron recalled, "produced learned theoretical discussions in Europe which proved that such complicated propellers were either unnecessary or disadvantageous."[39]

In 1934, a small, highly refined two-man British De Havilland D.H. 88 Comet racer won the England-to-Australia MacRobertson race. . .but just behind it was a KLM Douglas DC-2 airliner carrying a small number of passengers and airmail, and in third place was a United Air Lines Boeing 247D. "It has been realized with astonishment," the London *Morning Post* intoned, "that America now has in hundreds standard commercial aeroplanes with a higher top speed than the fastest aeroplane in regular service in any squadron in the whole of the Royal Air Force." [40] In 1935, when Donald Douglas presented the 23rd Wilbur Wright lecture at London's Science Museum before the membership of the Royal Aeronautical Society, American airliners, typified by the Boeing 247 and, particularly, the new DC-2 and soon-to-fly DC-3, led the world. At the end of his talk, C. R. Fairey, one of the most distinguished names in British aviation, commented that "It was to be hoped that in the hands of our designers this lecture would have some effects on the future of British air transport."[41] The shoe was firmly on the other foot, and would remain so until the jet era.

But there was another factor as well that had tremendously benefited the transformation of American aviation: the economic climate of the United States after the First World War. The strength of the American economy, compared to the war-ravaged economies of the European nations (both winners and losers) enabled a level of expansion and aeronautical investment—particularly commercial and general aviation aircraft production—impossible for others to match. After the First World War, the United States, by itself, was responsible for fully 42% of the world's annual industrial output.[42] One European observer of the growing American colossus noted[43]

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[38] Sandy Mullay, "The Air/Rail Race to Edinburgh," *The Gresley Observer*, n. 124 (2001), pp. 2-9; I thank Col. Rick Lach, USAF (ret.) for making this available to me.

[39] Schlaifer and Heron, p. 629.

[40] London *Morning Post* (24 Oct. 1934); see also "The Empire Air Routes," *Flight* (1 Nov. 1934); and Sir Geoffrey de Havilland, *Sky Fever: The Autobiography of Sir Geoffrey de Havilland C.B.E.* (Shrewsbury, UK: Wrens Park Publishing, 1999 ed..), p. 151; and Roger E. Bilstein, *The American Aerospace Industry: From Workshop to Global Enterprise*, n. 16 in the *Twayne's Evolution of Modern Business* series (New York: Twayne Publishers, 1996), p. 58.

[41] Donald W. Douglas, "The Developments and Reliability of the Modern Multi-Engine Air Liner (With Special Reference to Multi-Engine Airplanes After Engine Failure)," 23rd Wilbur Wright Lecture, RAeS, 30 May 1935, and attached post-lecture commentary, RAeS Library.

[42] For more on this, see Thomas Parke Hughes, *American Genesis: A History of the American Genius for Invention* (New York: Penguin Putnam, Inc, 1990), pp. 2-3, 14-15; Donald W. White, *The American*

> [I]n Europe mass production and civilization do not go together…wherever mass production by perfected machinery and scientific organization are required, the American cost of production is so low in spite of high wages that they can easily compete in the world markets…[America possesses] a home market that is so large and so uniform that it is admirably suited to standardized or, in this case, economical production.

Certain American accomplishments—the air mail service for example, drew envious appreciation from European aviation observers, as did the extraordinarily rapid development of American airlines and passenger services after the Lindbergh flight of 1927. A total of 18,697 Americans flew as passengers that year. In 1930, this figure rose to no less than 385,000 (representing 85 million passenger-miles), and a decade later, in 1940, this would jump to 2.8 million passengers flying over one billion passenger miles.[44]

What lessons, then, can be discerned from the first three decades of the aeronautical revolution—from the sands of Kitty Hawk to, say, the first flight of the Douglas DC-3, which revolutionized global air transport? It may not be fair to say America was more lucky than good, but after about 1905 Americans were certainly more adapters and emulators than innovators and creators. This shows in two of the most important areas of aeronautical development: structures and aerodynamics. American structures were rooted in European work; as late as 1940, for example, the vast majority of drawings in Lockheed's official company reference sketch book on aircraft design technology—intended (according to a preface from Lockheed chief engineer Hall Hibbard) "to give to the designer a collection of ideas, in sketch form, that will stimulate his own creative and inventive mind"—were details of European, not American, aircraft.[45] Aerodynamics was as well (indeed, the "crown jewel" of NACA research tools, the Langley Variable Density Tunnel, was a direct product of the NACA bringing Max Munk to America).

Century: The Rise and Decline of the United States as a World Power (New Haven: Yale University Press, 1996), p. 55; Daniel Boorstin, *The Americans: The Democratic Experience* (New York: Random House, 1973), pp. 43-52, 193, 188-213.

[43] André Siegfried, *America Comes of Age: A French Analysis* (New York: Harcourt, Brace and Company, 1927), pp. 170, 183, and 209.

[44] Richard P. Hallion, "Commercial Aviation: From the Benoist Airboat to the SST, 1914-1976," in Eugene M. Emme, ed., *Two Hundred Years of Flight in America: A Bicentennial Survey* (San Diego: American Astronautical Society, 1977), p. 159; see also Komons, pp. 210-211; and William Leary, "Safety in the Air," in William Leary and William Trimble, eds., *Airships to Airbus*, v. I: *Infrastructure and Environment*, a volume in the *Proceedings of the International Conference on the History of Civil and Commercial Aviation* series (Washington, D.C.: Smithsonian Institution Press, 1995), p. 97.

[45] LAC, *Aircraft Design Sketch Book* (Burbank, CA: Lockheed Aircraft Corporation, 1940). The sketches were copied (with permission) from Britain's *Flight, The Aeroplane,* and *Jane's All the World's Aircraft*, France's *L'aéronautique,* and America's *Aviation.*

American theory of airfoil design was so tied to German work that a senior NACA official, Ira Abbott, in a classic text-reference issued in 1949, stated:

> The tests made at Göttingen during the First World War contributed much to the development of modern types of wing sections. Up to about the Second World War, most wing sections in common use were derived from more or less direct extensions of the work at Göttingen.[46]

(Indeed, the famous "Clark Y," America's best-known airfoil of the interwar period, was, in fact, a smooth, flat-bottom derivative of the Göttingen 398 airfoil used on late-war Fokker fighters). Good and creative work took place in controls (including cockpit displays, for example blind flying instrumentation) and propulsion, but that work could not offset a general pattern of development that depended, in large measure, upon European inspiration.

Ironically, of course, the European nations themselves were not able to take fullest advantage of their mastery of aeronautics in the interwar years, thanks to their own economic circumstances and the demands of rearming for their next war, which competed, fatally, with the needs of commercial air transport.47 Such was not a problem for the United States, which could afford to emphasize commercial aviation over military need throughout much of the 1930s. By the end of the 1930s, America had already emerged as the leading air power (both commercial and military) exporter, selling nearly 40% of its production overseas. Under the Roosevelt administration, exports rose from $9.2 million in 1933 to $627 million in 1941 (equivalent, respectively, to $115 million and $7.6 billion today) —and this despite the fact that the United States was locked in the throes of a severe and enduring economic depression.[48]

The building of that national aeronautical industrial base dramatically benefited the country during the Second World War. In that war, American air power would prove of overwhelming significance, and, as well, the American industrial colossus would furnish tens of thousands of aircraft to the Allied cause. A look at total aircraft production

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[46] Ira H. Abbott and Albert E. von Doenhoff, *Theory of Wing Sections, Including a Summary of Airfoil Data* (New York: McGraw-Hill Book Company, 1949), p. 112; Albert C. Piccirillo, "The Clark Y Airfoil: A Historical Retrospective," Paper 2000-01-5517, Society of Automotive Engineers. I thank Colonel Piccirillo for making a copy available to me.

[47] For the competing and conflicting demands of military and civil aviation, see Sir W. Sefton Brancker, "The Lesson of Six Years Experience in Air Transport," a presentation to the Royal Aeronautical Society, 6 Oct. 1925, RAeS Library.

[48] Jacob A. Vander Meulen, *The Politics of Aircraft: Building an American Military Industry* (Lawrence, KS: University Press of Kansas, 1991), Table 7.2, p. 186. $1.00 in 1933 = $12.49 in 2001; $1.00 in 1941 = $12.15 in 2001.

statistics for the major industrial combatants clearly reveals the wartime industrial power of the United States, as well as the maturation of the American aircraft industry:[49]

- United States: 299,293
- Soviet Union: 142,775
- Great Britain: 117,479
- Nazi Germany: 111,787
- Imperial Japan: 68,057
- Fascist Italy: 11,508

As well, this reflected first, the general ability of American technologists and companies to rapidly integrate various cutting edge technologies to a far greater degree than their foreign opposite numbers, and, second, the ability of the United States to build what would today be termed a "system of systems" approach.

An example of this would be the American air transport system of the late 1930s, which blended the following: airframes (particularly the DC-2/3) integrating the highest standards of practice in the classic fields of aerodynamics, structures, propulsion, and controls; ground-based radio navigation and weather aids "netted" to related cockpit instrumentation; transcontinental standardized airways accompanied by standardized in-flight procedures; standardized airport and facilities design; increasing numbers of specialized workers (pilots, mechanics, meteorologists, radio technicians, dispatchers, flight attendants, etc.), trained to uniform standards and required to pass standardized licensing and certification procedures. (In contrast, at the same time that the Douglas DC-3 was securing the domination of air transport begun with the earlier Boeing 247 and Douglas DC-2, European airlines, for all the expertise of their aircraft industries and for all the scientific excellence of their research and development establishments, were still deep in the midst of the biplane and trimotor era, with little systematic airways development, and a lack of all-weather and blind flying training and expertise of airmen that would sorely hurt their various military air arms in the first two years of the air war to come).[50]

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[49] Irving B. Holley, Jr., *Buying Aircraft: Materiel Procurement for the Army Air Forces* (Washington, D.C.: U.S. Army, 1964), p. 555; Alfred Goldberg, "The Production Record," in Wesley Frank Craven and James Lea Cate, eds., *The Army Air Forces in World War II,* v. VI: *Men and Planes* (Chicago: University of Chicago Press, 1955), pp. 352-353; Soviet production from John Greenwood, "The Aviation Industry," in Higham et. al., *Russian Aviation*, Table 6.4, p. 146; Italian production figures are from http://www.comandosupremo.com/Facts.html, and reflect wartime production through the armistice of 8 Sep 1943.

[50] Monte Duane Wright, *Most Probable Position: A History of Aerial Navigation to 1941* (Lawrence, KS: The University Press of Kansas, 1972), esp. chapters 5-7. German researchers had made considerable

Another would be the vast system of support for military expansion, production, and utilization during the Second World War, which ranged from comprehensive introductory training programs for servicemen and war workers, through realigning industry to support the war effort, and then the fielding of tens of thousands of aircraft overseas so that, by 1943, a single routine combat mission might involve upwards of a thousand airplanes, maintained, flown, and supported by tens of thousands of personnel.

This knack for industrial organization and output might, in fact, be considered the great strength that American aviation possessed, and that it has largely continued to possess to the modern era.

Confronting the Turbojet and High-Speed Revolutions

Although the American research establishment and military services showed commendable vigor in their approach to wartime research, this burst of energy could not in full measure make up for deficiencies in prewar organization and activity.

For one example, the United States lagged badly in the development of radar, a subject of immense importance to aeronautics, despite having first recognized its value as early as 1922. Instead, it was Great Britain and Germany who pursued it most assiduously; Britain, fortunately, was quicker, placing its first coastal early warning radar in operational service in mid-1937. Its "Chain Home" network of radar stations played a critical role in the Battle of Britain; without them, the RAF's victory over the *Luftwaffe* would have been impossible. Once war broke out, a vigorous scientific exchange took place between British and America, and the agreement to transfer British radar technology to America was one of the most important of all wartime scientific decisions.[51] For another, American engine development in the interwar years had favored the radial engine used largely in transports and bombers; after the 1920s, liquid-cooled inline engine technology lagged behind the latest European state of the art, so much so that in 1939, the Kilner-Lindbergh board, a board formed to investigate the readiness and future needs of the U.S. Army Air Corps, placed inline engine development at the top of the AAC's priorities. Again, reverse lend-lease played an important role: the transfer of the Rolls-Royce Merlin engine to the United States and its subsequent license

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progress in the interwar years with directional beam navigation, and applied this quickly to their bomber operations against England. For the roots of German work, see R. Stüssel, "The Problem of Landing Commercial Aircraft in Fog," a lecture presented to the Royal Aeronautical Society, 26 April 1934, RAeS Library.

[51] David Zimmerman, *Top Secret Exchange: The Tizard Mission and the Scientific War* (Montreal: Alan Sutton Publishing Limited and McGill-Queen's University Press, 1996), p. 16-24; Brian Johnson, *The Secret War* (New York: Methuen, Inc., 1978), pp. 63-81; and James Phinney Baxter III, *Scientists Against Time* (Cambridge: The MIT Press, 1968 ed.), pp. 136-145.

manufacturing made possible the refinement of the North American P-51 Mustang into the finest of all American wartime fighters.[52]

Most seriously of all, the United States lagged badly behind Europe in the field of turbojet propulsion and high-speed flight. This is surprising, considering the mastery the United States showed over both fields after the war. Even in the years prior to war—in fact as far back as 1920—American researchers were both aware of transonic phenomena such as drag rise and decreasing lift, and actively pursuing the turbosupercharger—the direct predecessor of the turbojet—as a means of boosting engine performance at altitude. By late 1941, the turbosupercharger was a standard element of new aircraft designs, used in both major American bombers, the B-17 and B-24, and two new fighters, the P-38 and P-47).

Yet the truth remains that, unfortunately, no sooner did the United States catch up and then surpass European practice than Europe advanced again beyond the U.S., this time in the area of high-speed flight and, particularly, turbojet propulsion. In fact, the United States was third, behind both Germany and England, while its leading technical establishment, the NACA had little interest in any form of reaction propulsion aside from a short burst of interest over a Secundo Campini-inspired ducted fan propulsion system. Only after the importation of Whittle engine technology, and its joining to an American airframe (the Bell XP-59A), would America enter the jet age, in October 1942, nearly eighteen months after England, and over three years after Germany. Thus, when the German Messerschmitt 262 appeared in European skies in mid-1944, no equivalent American fighter existed in service that could contest it. Lockheed's P-80, which could have, did not enter widespread service until after the Second World War. Overall, America's debt to British engine development was great. That the NACA had missed the significance of the jet engine was one of the compelling reasons General Henry H. "Hap" Arnold established the postwar Air Force Scientific Advisory Board—so that the service would never again be caught napping.[53]

As well as the jet engine, America lagged badly in pursuing high-speed aerodynamics, particularly the technology of high-speed aircraft design. Again, wartime research went a long ways to overcoming deficiencies in prewar research emphasis and direction, but could not completely close the gap. In 1935 and afterwards, American

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[52] Schlaifer and Heron, pp. 246-320; Rae; 107.

[53] The jet engine story is covered in detail in Schlaifer and Heron, esp. pp. 480-508; for a good historical analysis, see James O. Young, "Riding England's Coattails: The Army Air Forces and the Turbojet Revolution," in Jacob Neufeld, George M. Watson, Jr., and David Chenoweth, eds., *Technology and the Air Force: A Retrospective Assessment* (Washington, D.C.: Air Force History and Museums Program, 1997), pp. 3-39; the NACA venture with Campini propulsion is discussed in Macon C. Ellis, Jr., and Clinton E. Brown, "NACA Investigation of a Jet-propulsion System Applicable to Flight," NACA Technical Report No. 802 (1943); see also Hansen, pp. 238-245.

engineers (including von Kármán) missed the significance of the high-speed sweptwing postulated by Adolf Busemann at the Volta Congress on High Speeds in Aviation in 1935. Only after the independent rediscovery of it by Robert T. Jones of the NACA and the subsequent discovery of tremendously comprehensive German work amid the rubble of the Third Reich was the sweptwing taken seriously. (Indeed, on January 24, 1945, a sweptwing variant of the Nazi V-2 missile, the A-4b, became the first aircraft-like winged vehicle to exceed the speed of sound).[54] High-speed wind tunnel development lagged in the United States as well. By 1945, few American supersonic wind tunnels existed. In contrast, Nazi Germany had no less than eight, six exceeding Mach 3 and one exceeding Mach 4. (Out of this would come the impetus to build the postwar Arnold Engineering Development Center at Tullahoma, as well as new tunnels for the NACA.[55]

The transformation that took place in aviation between September 1939 and the end of December 1945 was extraordinary; at the beginning of that time period, all the major air arms, the United States included, still possessed operational open-cockpit fabric-covered wire-braced biplane fighters. Just five years later, the first jets had appeared in combat, supersonic ballistic missiles had attacked London, Paris, and Antwerp after transiting the upper atmosphere into space, and the first supersonic research airplanes—the Nazi DFS 346, the British Miles M.52, and the Bell XS-1 were in advanced design and, indeed, fabrication. In short, as with the invention of the airplane, as with the development of the jet engine, yet another race—the race to fly a piloted aircraft faster than sound—was underway.

This was a race that the United States won. But here, too, it had been a "close run thing." The Bell XS-1 had been completed in December 1945; readying it for the first supersonic flight took another 22 months before, on October 14, 1947, test pilot Chuck Yeager attained Mach 1.06 at 43,000 feet over Muroc Dry Lake, California. That it was first largely stemmed from a mix of bad decision-making and ill-luck involving its rivals. Britain's M.52 was abandoned in a (in retrospect) foolish decision by the British

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[54] Adolf Busemann, "Aerodynamische Auftreib bei Überschallgeschwindigkeit," *Luftfahrtforschung* (3 Oct. 1935), pp. 210-220; Robert T. Jones, "Properties of Low-Aspect Ratio Pointed Wings at Speeds Below and Above the Speed of Sound," NACA Technical Report No. 835 (11 May 1945), and his "Wing Planforms for High-Speed Flight," NACA Technical Note No. 1033 (March 1946, but issued at Langley Laboratory on 23 June 1945); see also Richard P. Hallion, "Lippisch, Gluhareff, and Jones: The Emergence of the Delta Planform and the Origins of the Sweptwing in the United States," *Aerospace Historian*, v. XXVI, n. 1 (March 1979), pp. 1-10.

[55] Theodore von Kármán, *Where We Stand,, and* reprinted in Michael H. Gorn, ed., *Prophecy Fulfilled: "Toward New Horizons" and Its Legacy* (Washington, D.C.: Air Force History and Museums Programs, 1994), pp. 19-267, 17; Alex Roland, *Model Research: The National Advisory Committee for Aeronautics, 1915-1958*, NASA SP-4103 (Washington, NASA, 1985), pp. 213-221; and Donald D. Baals and William R. Corliss, *Wind Tunnels of NASA*, NASA SP-440 (Washington, D.C.: NASA, 1981), pp. 65-66.

government that eventually set back British high-speed aviation by about 10 years. Only the collapse of the Third Reich had prevented the completion of the DFS-346; the plans and technical staff working on this project were taken into the Soviet Union and there the aircraft was completed, drop-tested from an American B-29 that had force-landed in Eastern Siberia following a bombing raid on Japan. Only transonic flutter and lateral control problems caused by an odd aileron design prevented this German-Russian project from possibly exceeding Mach 1 ahead of the XS-1.[56]

The success of the XS-1 led to expansion of the X-series, and resulted in a range of aircraft, missile, and robotic systems that continue to the present day; notable early examples were the XS-1, the X-5 variable sweep testbed, the X-15 (the first hypersonic airplane), the X-17 reentry testbed, and the proposed—but cancelled—X-20 Dyna-Soar, a projected lofted hypersonic boost-glider. These research aircraft systems served to validate ground research test methodologies, prove out new configurations, act as focusing points for drawing together new technologies and ideas, and demonstrate technology themselves. The data base generated was quickly applied to other, service-oriented systems: the adjustable horizontal tail of the X-1, for example, was applied to later production F-86E Sabres, enhancing their transonic MiG-killing potential; the X-5 proved the practicality of in-flight variable wing-sweeping; the X-15 gave aviation its first experience with winged, controlled flight into and from space, and pioneered concepts later applied to the Space Shuttle; and the X-17 generated a data base of great importance to ballistic missile reentry studies.[57]

Exploiting the high-speed revolution brought about by the jet engine and an increasing understanding of transonic and supersonic aerodynamics resulted in a reshaping of the airplane, characterized by reduction in aspect ratio and wing thickness-chord ratio, increasing fuselage fineness ratios, and introduction of various design refinements including (eventually) the all-moving tail and "wasp-waist" area ruling (the latter of three key contributions by the NACA-NASA's Richard Whitcomb, the other two

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[56] "The Miles Supersonic," *The Aeroplane* (13 Sept. 1946); Charles Burnet, *Three Centuries to* Concorde (London: Mechanical Engineering Publications, 1979), pp. 43-52; Derek Wood, *Project Cancelled: British Aircraft that Never Flew* (Indianapolis: Bobbs-Merrill, 1975), pp. 28-32; J. R. Smith and Antony L. Kay, *German Aircraft of the Second World War* (Baltimore, MD: Nautical and Aviation Publishing Company of America, 1989 ed.), pp. 636-638; Henry Matthews, *Samolyot 346: The Untold Story of the Most Secret Postwar Soviet X-Plane* (Beruit: HSM Publications, 1996); for the impact of the M.52 cancellation on British aviation, see Sir Roy Fedden, *Britain's Air Survival: An Appraisement and Strategy for Success* (London, 1957).

[57] For further discussion of these, see Richard P. Hallion, "Technology for the Supersonic Era," in Philip Jarrett, ed., *Faster, Further, Higher: Leading-edge Aviation Technology since 1945* (London: Putnam Aeronautical Books, 2002), pp. 29-51; and Richard P. Hallion, "American Rocket Aircraft: Precursors to Manned Flight Beyond the Atmosphere," XXVth Congress, International Astronautical Federation, Amsterdam, the Netherlands, 4 Oct.1974.

being his supercritical wind and his wingtip winglet). But the most visible change was, of course, the sweptwing. The discovery of German sweptwing work, coupled with Jones' independent discovery of it at the NACA, resulted in two very significant postwar American aircraft programs, the North American F-86 Sabre fighter and the Boeing B-47 Stratojet bomber. Both had started as straight-wing projects, but the discovery of sweptwing data by Allied technical intelligence resulted in their redesign as sweptwing machines. The Sabre entered service slightly ahead of a Russian equivalent, the Mikoyan and Gurevich MiG-15; had it been produced as a straight-wing airplane, the United States clearly could not have maintained superiority over the Korean peninsula, with possible disastrous consequences during the pivotal battles of early 1951. The B-47 became a mainstay of the Strategic Air Command and, as well, the progenitor of all subsequent large American sweptwing aircraft.

As with the results of the First World War, the post-Second World War economic environment was such that the United States continued, and, indeed, even expanded its position as the dominant economic power in the Free World. Such a position put particular demands upon the United States, which launched ambitious multinational defense and aid programs to help Western European and Far Eastern nations, particularly as they faced Communist expansionism in both Europe and Asia. Interestingly, despite their position of relative economic weakness, England and, to a lesser extent, France, showed a surprising robustness in their aircraft programs and ventures after the war.

In this environment, complacency again threatened American international competitiveness in both commercial and military aviation. In July 1949, Britain first flew the De Havilland D.H. 106 Comet, the world's first jet airliner, and, a month later, Canada followed with a jet airliner of its own, the Avro C-102. While the Canadian aircraft remained a prototype only, the Comet quickly succeeded in securing both great publicity and firm orders. Even so, the American aircraft industry, government, and most airlines preferred to exist with incremental performance improvements to the existing "normative paradigm" aircraft, building upon the DC-4 and original Lockheed 049 Constellation to generate the later DC-6 and DC-7/7C and subsequent Constellations and a Constellation spin-off, the Starliner. In July 1952, Viscount Swinton (Sir Philip Cunliffe-Lister, who had been appointed as the first British Minister of Civil Aviation in 1944) stated in the House of Lords "I feel that we have such a lead in civil jet aircraft. . .that we may not only get orders from all over the world but will possibly 'collar' the market for a generation."[58]

[58] Quoted in Air Commodore L. G. S. Payne, *Air Dates* (New York: Frederick A. Praeger, 1957), p. 453; Heppenheimer, pp. 156-157.

By this time, it was too late to introduce a design prior to the in-service introduction of the Comet, and, in any case, industry interest was at best lukewarm: for example, three months after Swinton's statement, Juan Trippe of Pan American (America's flag carrier) placed a small order for Comets, after having earlier fruitlessly offered to purchase any American-built jet transport, without receiving any response from industry. American carriers Trans World Airlines, Overseas National Airways, and Eastern Airlines expressed interest in the Comet as well. At this point, British attempts to have the Comet certified for American operation fell afoul of Civil Aeronautics Administration and State Department reluctance to do so pending development and certification of an American jetliner as a predecessor—reluctance the British logically saw as an attempt to keep the Comet out of the American market. Meanwhile, Boeing, far more interested in developing a sweptwing jet tanker-transport of greater performance that could serve both as an aerial tanker and military transport with airline potential, authorized development of a prototype in mid-1952. Out of this came the 367-80, the "Dash 80" that, forcefully championed by the charismatic General Curtis LeMay, served as a prototype for both the KC-135 and the 707 airliner families, flown two years later.[59]

Had events proceeded in uninterrupted fashion, the early Comet would undoubtedly have been fully developed into a mature system by the mid-1950s, undoubtedly achieved an American certification, and, with a strong base of airline customers, the stage might have been set for the fulfillment of Swinton's prediction. But such did not happen, for a series of tragic decompression accidents to the Comet caused its lengthy grounding, the abandonment of all early models, and a redesign that removed it from the airline scene for several years and forever tarnished its reputation. Boeing (and Douglas) were free to catch-up with their own jet airliner projects (reputedly, inspecting the Dash 80 in the mid-1950s, the head of Rolls-Royce said to Boeing's George Schairer, "This is the end of British aviation").[60] The resulting 707 and DC-8, achieved market dominance and ensured the continued supremacy of American commercial aviation well after the 1950s.

In the field of military aviation, the spectre of an atomic war against the Soviet Union drove American acquisition towards a mix of nuclear bombers and attack aircraft, nuclear-armed strike fighters, and interceptors intended to defend against Soviet nuclear bombers, and exotic reconnaissance aircraft. The design of the Lockheed U-2, and the subsequent design of the Lockheed A-12 Blackbird family, was so challenging and yet so significant in terms of their operational impact, as to earn for Lockheed's Clarence

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[59] William H. Cook, *The Road to the 707: The Inside Story of Designing the 707* (Bellevue, WA: TYC Publishing Co., 1991), pp. 211-252. The Trippe story is on p. 236. See also Janet McGee, "The De Havilland Comet and CAA Protection of American Aircraft Manufacturers," *Journal of the American Aviation Historical Society*, v. 47, n. 4 (Winter 2002), pp. 242-251.

[60] Ibid., pp. 239-240.

Johnson deserved recognition as the outstanding postwar American designer. No aircraft system could better indicate just how thoroughly the United States had mastered the supersonic regime, across the range of technical disciplines, than the Mach 3+ A-12, an aircraft system that spawned several derivatives, the best known being the SR-71A. The A-12 family was one of only three aircraft systems built to date—the others being the Anglo-French Concorde and the Lockheed-Martin F/A-22A Raptor—that could cruise in the supersonic arena.

The success of the Blackbird family, another genuine American aeronautical triumph unmatched by foreign equivalency, was not matched by most other American supersonic military aircraft of the postwar period. Of the so-called "Century series" fighters (the F-100, F-101, F-102, F-104, F-105, F-106, and F-111) only one, the North American F-100 Super Sabre, could be truly considered a swing-role multipurpose fighter in the tradition of the Second World War's P-47. Instead, these were aircraft largely intended for the nuclear war-fighting roles of strike and interception. Of the pre-Vietnam fighters developed after the F-100, only the McDonnell F-4 Phantom II was an extraordinary standout—a very capable, very powerful "systems" airplane that could—and did—fulfill multiple roles, though even it suffered some serious deficiencies, notably visibility, armament, and human factors (cockpit layout) problems. For their part, Soviet technology generally succeeded in matching, and in some cases exceeding, that of the United States. For example, the U.S. first exceeded Mach 1 in 1947, the Soviets in 1948. The first supersonic Soviet jet fighter, the prototype MiG-19, exceeded Mach 1 in June1952; the prototype YF-100 did so eleven months later, in May 1953. Bomber development, as typified by the supersonic B-58 and the projected B-70 (and other more exotic concepts as well) followed this same trend, though the development of the workhorse B-52—again, an aircraft that began life as a propeller-driven design study in the late 1940s—constituted a genuine accomplishment; already a half-century old, the B-52 is expected to remain in service for another 30 years.[61]

The Vietnam air war constituted a shock to the United States, for many of the combat aircraft systems employed in that conflict suffered from real deficiencies in utility, survivability, and role fulfillment. In Korea, F-86s had shot down ten MiG-15s for every Sabre lost. In Vietnam, the victory-loss rates were disturbingly less: while Mach 1.5-2.0 American fighters such as the Vought F-8 Crusader and the McDonnell F-4 Phantom II had a nearly 6-1 kill advantage over Korean era MiG-17s, they enjoyed only a little over a 3-1 advantage over the MiG-19, and not quite a 2-1 advantage over the MiG-

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[61] William Green and Gordon Swanborough, *The Complete Book of Fighters* (London: Salamander Books Ltd., 2001), pp. 394 and 454; Adam J. Herbert, "When Aircraft Get Old," Air *Force Magazine* v. 86, n. 1 (Jan 2003), p. 35.

21. The risk posed to conventional strike packages of aircraft was so great that by 1968, the ratio of escorting fighters to attackers was fully 2-1.[62]

While much of this performance reflected a combination of poor strategy, political meddling in military planning, poor tactics, and poor training, it reflected as well the price of having overemphasized one model of warfare—nuclear war—at the expense of more conventional conflict. (Today, in the wake of 9/11 and the wars in Iraq and Afghanistan, the United States faces a similar challenge, in possibly overemphasizing special operations and low intensity conflict at the risk of losing its ability to wage wars against high-technology opponents operating increasingly sophisticated systems).

Vietnam had a profound impact upon all of America's military services, and, particularly, on military acquisition and training. It was the direct result of this experience that led to the American combat aircraft of the modern era, the tremendous investment in precision attack, the emphasis upon electronic combat, and, of course the stealth revolution (the latter inspired, ironically, by a 1967 Soviet paper on wave diffraction that was read by a Lockheed engineer and recognized by him as the key to cracking an enemy's integrated air defense network).[63] What made these possible in many ways were the great multiple technological revolutions that took place after the Second World War in the fields of computers, sensor development, new materials, advanced gas turbine propulsion, and advanced electronic flight controls.

Computers, key to command and control over nuclear defense and strike forces, gave U.S. the first "systems" airplanes such as the air-defense F-102/F-106, and the surface-attack A-6 and F-111; new generations of electro-optical sensors such as TRAM, Pave Tack, and LANTIRN greatly enhanced the ability to strike precisely; new composite materials enabled lighter, more agile, yet more rigid and stronger aircraft, taking U.S. from the era of the exclusively (or near exclusively) all-metal airplane; advanced gas turbine propulsion produced high thrust-to-weight ratios exceeding 1:1, and, in the airlift and commercial sector, led to the era of 100,000 lb.-thrust turbofan engines; advanced electronic flight controls enabled the design of "non-traditional" completely unstable aircraft such as the X-29, F-16, F-117, and B-2, unhindered by the "necessity" of having an inherently stable planform.

The dominance the United States had in the 1970s is illustrated by two events: the decisive marketing victory in 1975 of General Dynamics over Dassault for the "Sale of

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[62] Information from Dr. Wayne Thompson, Air Staff History Office, Headquarters USAF, Washington, D.C.

[63] The paper was Pyotr Ufensev's "Method of Edge Waves and the Physical Theory of Diffraction," translated by the Air Force Foreign Technology Division. See Paul G. Kaminski, "Low Observables: the Air Force and Stealth," in the previously cited Neufeld, et. al., p. 300.

the Century," NATO's selection of the F-16 over the Mirage F-1 as the alliance's standard fighter; and the total dominance of Syria's air defense forces (and their Soviet advisors) by the Israeli air force, flying the F-15 and the F-16 over the Bekaa Valley in 1982. The introduction of new aircraft and weapon systems such as the Pave Tack, Paveway Laser-guided bomb family, E-3 AWACS, and the development of the F-117 (and the B-2 that followed) were all examples of how effectively America had mastered the air and space sciences in the early to late 1970s.[64] The Gulf war of 1991 exemplified the powerful force projection inherent in joint service precision air and space power, which has continued to be dominant in conflicts to the present, right through the eventual destruction of Saddam Hussein's odious regime.

Overall, American aviation from 1945 to the early 1970s might be considered to have enjoyed a "Golden Age." Projects proliferated, and numerous companies (now gone or merged) enjoyed healthy, independent existences. Military services operated hundreds, and occasionally thousands, of essentially competing airplanes, and airlines had large and diverse fleets of their own. While there were some glitches—the collapse and then slow recovery of the postwar general aviation market, for example, the tortuous development of the TFX/F-111, or the SST debacle of the early 1970s—the pace of aeronautical research and development ensured that plenty of work was left to do. Aside from the brief threat of the Comet, and a briefer threat from turboprop foreign airliners such as the Viscount and Britannia, America's airline market was securely in the hands of Seattle and Santa Monica and, to a lesser extent, Burbank. Again, this was largely due to the strong national industrial process America had first pioneered in the aviation business in the 1930s (a legacy, it may be said, of a strong industry-airline-military partnership of the kind that rapidly grew out of social favor from the 1960s onwards). But as well it reflected some weaknesses in our international economic rivals: nations such as Britain and France, despite the brilliance of concepts such as the Viscount or the Comet or the Caravelle, simply were not in a position to compete successfully against the United States. Neither, too, was the Soviet Union, except in the field of military systems—and space.

The Impact of *Sputnik*

It is no surprise to state that the launching of *Sputnik* shocked America's faith in its air and space leadership—indeed, so great was the change in thinking that Sputnik, in fact, spawned the word "aerospace," a recognition that the world had moved beyond merely the consideration of aeronautics. Though the rocket dated to ancient China, the modern liquid-fuel rocket was the product of Dr. Robert H. Goddard, a single-minded

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[64] The previously cited Neufeld, et. al., has a series of case studies on many of these developments.

physicist with a passion for spaceflight in all its aspects. Goddard had difficulty securing support for his research, until adopted by the far-seeing Guggenheims and Charles Lindbergh. Even so, visitors to his New Mexico test site were often unimpressed, for his rockets were small and his natural tendency to secretiveness hurt the image of his work. Official government attitudes were that rocketry had little potential value. Before the Second World War, Jerome Hunsaker turned MIT away from rocketry, remarking to Caltech's Theodore von Kármán, "You can have the Buck Rogers job." Von Kármán was only too happy to take it; Hunsaker instead chose to devote MIT's considerable talents to studying deicing windshields.[65] If the United States failed to pursue the rocket, Nazi Germany did not. In reality, the German V-2 effort was tremendously misguided and a waste (fortunately) of that nation's increasingly scarce wartime resources. But the wedding of the ballistic missile and the atomic warhead, and the increasing accuracy of the ballistic missile thanks to developments in inertial navigation technology, clearly had the potential to reshape postwar strategic thinking—which they did very quickly.

In this quest, the United States was fortunate to have several strong "czar" figures who, together, ensured the development of both weapons and space lift systems and the supporting infrastructure to maintain them: General Bernard Schriever and Admiral William Rayborn, Admiral Hyman Rickover, John von Neumann, Edward Teller, and, of course, Wernher von Braun. What these individuals gave to the United States—particularly Schriever—were the military and civilian space lift and weapon capabilities it continues to enjoy: systems such as the Atlas, Thor, Titan, and Minuteman, and the Redstone and Jupiter, which, in many cases, led directly to both military and civilian space launch systems. It was an indication as well of the value of having strong administrators in a position of continuing authority and direction over national scientific and technological programs, particularly those involving national defense issues; this, too, has changed dramatically since that time, as such figures are no longer as evident as they once were.[66]

America could have launched an earth satellite in 1954 but chose not to do so, a decision, in retrospect, that was most unfortunate. What is worth noting is how rapidly Soviet launch capabilities progressed; even though initially deficient in the most

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65 I thank the late Frank J. Malina, a co-founder of the Jet Propulsion Laboratory, for bringing this quote to my attention. See also Frank J. Malina, "Origins and First Decade of the Jet Propulsion Laboratory," in Eugene M. Emme, ed., *The History of Rocket Technology: Essays on Research, Development, and Utility* (Detroit: Wayne State University Press, 1964), p. 52.

66 See Wernher von Braun, "The Redstone, Jupiter, and Juno;" Robert L. Perry, "The Atlas, Thor, Titan, and Minuteman,", and Wyndham D. Miles, "The Polaris," in the previously cited Emme, pp. 107-121, 142-188. See also Richard P. Hallion, "The Development of American Launch Vehicles Since 1945," in Paul A. Hanle and Von Del Chamberlain, eds., *Space Science Comes of Age: Perspectives in the History of the Space Sciences* (Washington, D.C.: National Air and Space Museum, 1981, pp. 115-134.

important reason at that time to develop long-range rockets—as nuclear-tipped ballistic weapons—they more than sufficed to place significant payloads into space. In short order, the Soviet Union orbited a satellite, and then, within several years, a cosmonaut (Yuri Gagarin). Thus America, the birthplace of modern rocketry, was surpassed at its own craft.

The result was a complete restructuring of America's aeronautical research establishment; aeronautics was out, astronautics was increasingly in. The low-profile laboratory-focused NACA gave way to the high-profile research center-focused NASA (the difference, wags said, was between NA¢A and NA$A). Then came the Kennedy mandate to go to the Moon in a decade, and the explosive Apollo program, which succeeded, at the price of three very brave men killed in Apollo I, in placing multiple teams of astronauts in orbit around, and on the surface of, the Moon. But along the way, promising programs were considered and discarded at a rapid rate. The Boeing X-20 Dyna-Soar, a lofted hypersonic boost-glider under development since 1957, was one such victim, cancelled in 1963 and replaced by the Gemini-based Manned Orbiting Laboratory (MOL), which was itself cancelled a half-decade later. Both of these programs, in retrospect, were deserving of strong support, and might well have dramatically influenced the future course of American near-earth orbital operations and capabilities.

In retrospect, had America not been goaded by Russia's successes in the early days of the space program, it is highly unlikely Kennedy would have then launched the Apollo program, given the social and national security problems of the 1960s. Indeed, once the Moon had been attained, it quickly lost its allure both to the public and to the national political leadership as well. It has been 40 years since the last American left the surface of the moon; put in other terms, a NASA employee could have joined the agency, and had a full government career to retirement, without once having witnessed astronauts walking on the moon while in government service.

After the shelving of any plans for an immediate space station, and a brief sojourn with a rudimentary space laboratory (the Skylab project), NASA turned to developing and then operating a reusable space launch system, the Space Shuttle. Although touted as a "DC-3 for the space age," the Shuttle could at best be only a supplement to existing launch systems, not a replacement. More seriously, the investment in the Shuttle (and the International Space Station subsequently) would come increasingly at the expense of aeronautics.

NASA's inheritance of the NACA's aeronautics mission—including key facilities and personnel—meant that the legacy of aeronautics work within the agency was very powerful. It was this "legacy engine" that, though slowing winding down, fueled some of the most important contributions NASA made to aeronautics in this time period, including definition of advanced high lift-to-drag wing platforms for sustained supersonic cruise aircraft, configurations for hypersonic winged vehicles, the supercritical wing

(SCW), the wingtip drag-reducing winglet, and digital flight and propulsion controls. Some of these were transferred into civil and military practice—most notably the SCW, winglet, and fly-by-wire systems. But as more and more of the "aeronautics" centers' work was increasingly devoted to supporting NASA's space mandate, a growing number of NASA engineering professionals (most of whom were NACA veterans) began expressing serious reservations about the ability of the agency to fulfill its aeronautics mandate.

This concern first manifested itself in 1976, after NASA research pilots at the Dryden Flight Research Center had the opportunity to evaluate the prototype Northrop YF-17 lightweight fighter, an aircraft of then-radical aerodynamic configuration. Afterwards, the chief engineer of the center warned NASA Headquarters that "We must recognize the fact that we may not have as much to contribute these days as we had in the past," adding: [67]

> NACA was in that time period an acknowledged leader in the fields of aerodynamics, stability and control, aerodynamic loads, buffet, flutter, propulsion performance, and possibly others. *NASA no longer enjoys that esteemed position in the aeronautics world largely due to default*. NASA was actually unable to provide any substantial guidance or assistance to the desigher of the YF-12 and SR-71. Thus, NASA is now in an etreely weak position to bargain for participation in any new aircraft program [however] *NASA should be flight testig new aircraft if for no other reason than to keep abreast of technology."* [Emphasis added.]

Toward the Future

In the early 1980s the American Institute of Aeronautics and Astronautics published a special edition of *Astronautics & Aeronautics,* its flagship journal, with a gold cover featuring a computer-generated plot of the airflow around a sharply swept delta waverider, surmounted by the bold-type legend THE FUTURE IS NOW.[68] Indeed, the 1980s did look bright: Shuttle was flying at last, and promising an era of cheaper, routine access to space. New generations of military aircraft of unprecedented performance were

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[67] Memo, Milton O. Thompson to Center Director David Scott, 2 Jan. 1976, quoted in Richard P. Hallion, *On the Frontier: Flight Research at Dryden, 1946-1981,* SP-4303 (Washington, D.C.: NASA, 1984), pp. 232-233. The designer of the A-12 and YF-12 was Lockheed's legendary Kelly Johnson. Lockheed used Ames wind tunnels to test the A-12 configuration, but NASA personnel were only used to run the facility, not to review or comment upon the design itself and its anticipated performance. To be fair, the YF-17 had benefited from some cooperative Northrop-NASA wind tunnel testing, particularly on its Northrop-designed distinctive leading edge extensions (LEX). But Thompson was correct that the level and degree of NASA input to the YF-17 (and other advanced military systems as well, including the stealth revolution, of which he was then unaware) was less than comparable NACA involvement in military aircraft design from the 1930s onwards.

[68] A&A (May 1981).

in service or about to enter service, including, for those in the know, a radical stealth attack airplane, the F-117. Around the corner were new projects as well: a joint service advanced tactical fighter (ATF), a new stealthy Navy attack airplane (ATA), Apache and Blackhawk helicopters, the C-17, experimental tilt-rotor technology, new jetliners from Boeing (the 757 and 767), and a projected super jetliner that would, in time, become the 777. McDonnell-Douglas pinned its hopes on derivatives of the DC-9 and DC-10. Lockheed was leaving the commercial air transport market, but had a proposed new derivative of the P-3 (the P-7) under study. Laboratory studies promised a possible air-breathing Mach 25 single-stage-to-orbit "trans-atmospheric vehicle" (the future X-30 NASP).

But NASA's bold visions of a Shuttle-induced space future were swallowed up, first by the *Challenger* accident, and then by the skyrocketing launch and maintainability costs of the Shuttle itself, and a surprisingly costly space station program. In the 1930s, at the height of the air transport revolution, the NACA had produced technology that military and civilian users turned to their own purposes: it did not supervise the design of airliners or bombers and develop and maintain them itself. But in the 1970s through the end of the Shuttle program in 2012, NASA behaved in a very different fashion: it was charged to develop the Space Transportation System, and then to operate it, and to do so on a largely fixed budget (at least in its early years). Then it took charge of the space station effort as well. The combination of the two robbed the agency of much funding that might otherwise have been more profitably applied to other aerospace research ventures, particularly in aeronautics.

The anticipated steady military market collapsed after 1989 as the various military services downsized by at least 40% and America entered a period characterized by some as a "procurement holiday." Many programs were slashed or outright cancelled: the Navy version of the ATF; the Lockheed P-7 patrol bomber, the General Dynamics A-12 (ATA), a series of Army, Navy, and Air Force missile and satellite programs; the "Orient Express," aka the X-30 NASP; the B-2 (from 132 airplanes to just 21), the F-22 (severely downsized).

The commercial aircraft industry faced acute and growing competition from Airbus, which succeeded in doing what no previous foreign commercial airliner project ever had: achieving a deep and lasting penetration of the American market for both domestic and international jetliners. Threatened with extinction, ompanies embarked on a frenzy of mergers, and classic names disappeared or were combined in awkward new titles.

All this occurred even as American air and space power proved critically important to the stability of the post-Cold War world, with virtually constant military operations ranging from Southwest Asia to the Balkans, and the long watch in Korea.

To get a more precise fix on America's position today, a decade into the second century of powered flight, it is instructive to contrast two years roughly a quarter-century apart: 1976 and 2003:

In 1976—the year the Smithsonian Institution opened the National Air and Space Museum—NASA had a frozen budget in "then-year" dollars of about $4 billion; the space station was on life support; the SST effort had collapsed, nearly taking Boeing with it; the military services were struggling to fund new aircraft acquisition of systems such as the F-14, -15, -16, and -17/18; and new aero engineering graduates were having problems finding work, even as engineering departments were advising undergraduate aero students to change their major. It was, to say the least, a challenging period for American aviation.

But overall, at that time America had an aeronautics and astronautics establishment possessing—certainly by the standards of a quarter-century later—extraordinary health and vitality. The United States then was a country:

- Whose transport aircraft dominated international long, medium, and short-range air commerce, as they had for nearly the previous 40 years;
- Whose airlines were the "gold standard" for travel, elegance, and safety;
- Whose general aviation industry was profoundly productive, dominant both domestically and internationally, delivering well over ten thousand airplanes per year;
- Whose new military aircraft were at least a generation, and perhaps two, ahead of any potential rival;
- That had bold plans for extending the frontiers of flight into the hypersonic arena;
- That dominated commercial space launch;
- That possessed a strong and diverse group of aerospace companies; and
- That possessed well-funded and robust centers of aerospace research and development.

By December 17, 2003, the time of the centennial of powered, winged flight, the United States was in a vastly different position than it had been in 1956, and, for that matter, in December 1953, at the time of the 50th anniversary of Kitty Hawk:[69]

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[69] Phillip S. Meilinger, "The Air and Space Nation is in Peril," *Air and Space Power Journal,* v. 17, n. 1 (Spring 2003).

- *Had lost its traditional dominance of long- and-medium-range commercial aviation*. Despite bold visions of future aeronautics, American's commercial industry was sorely taxed.[70] Of the world's top four airliner manufacturers, only one—Boeing—was American. Flying in 2003, a passenger had only a 50-50 chance of flying an American-built airliner on a transcontinental or transatlantic flight, a situation unknown to American aviation since the invention of the global-ranging airliner.[71]
- *Had abandoned the field of regional commercial aircraft design.* Shockingly, the United States was virtually a non-player as a regional jet competitor (and it has continued so since).By 2003, a passenger had almost zero chance of flying in an American-built regional airliner. Instead, imaginative, high-performance turbo-propeller and turbofan-powered aircraft produced by a wide range of manufacturers in Sweden, France, Canada, Germany, Brazil, and Great Britain, flourished in American skies—and have continued to do so since.[72]
- *Possessed a seriously weakened airline industry.* Post 9/11 passenger declines (upwards of 60% after the attacks on the World Trade Center and the Pentagon), cargo traffic reductions (nearly 10% worldwide) and costs associated with new security measures stressed many carriers (both American and foreign) to the breaking point.[73]

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[70] Office of Aerospace Technology, *The NASA Aeronautics Blueprint—Toward a Bold New Era of Aviation,* NP-2002-04-283-HQ (Washington, D.C.: National Aeronautics and Space Administration, 2002), p. 12

[71] The others, in rank order, were Europe's Airbus, Canada's Bombardier, and Brazil's Embraer. Airbus had already captured over 50% of the world commercial aircraft market, dethroning American manufacturers who once controlled an over 80% global market share in commercial aircraft. Indeed, in 2003, for the first time since America seized control of the air transport revolution, Boeing delivered less jet liners to customers than a foreign competitor—Airbus. The troubled developmental history of both firms' jetliners—the failure of the Boeing "Sonic Cruiser," the lengthy development time of the composite FBW 787, the failure of Airbus to adequately define its A-350, and the teething troubles of its without-equal A-380 offers little comfort to either, but particularly to Boeing.

[72] Indeed, aside from the well-publicized Boeing-Airbus rivalry, the most closely watched market competition at that time was between Canada's Bombardier and Brazil's Embraer for dominance in the field of regional and executive jets. See Tim Padgett, "Dogfight," *Time* (Global Business Bonus Section), v. 161, n. 16 (21 April 2003), pp. A17-A18.

[73] Air carriers themselves had deferred purchases of new equipment and sent 1,700 commercial aircraft they possessed into storage. Traditionally highly leveraged (the debt burden of the largest carriers traditionally being 90% of their value) and labor intensive (typically 40% of an airline's operating costs), the American airline industry lost $7.7 billion in 2001, and (not surprisingly) $10 billion in 2002. Already struggling in a desperate attempt to retain economic viability even before 9/11, the airline industry subsequently cut over 115,000 positions, and in a bid to save the industry, the Federal Government established an Air Transportation Stabilization Board funded with $10 billion in lending funds (the airline industry debt was $100 billion). Of 66,000 airline pilots employed on 9/11, 7,800 faced layoffs and airlines cut pension costs as well. See George F. Will, "Airlines' Soothing Ill Wind,"

- *Had an air traffic control system with an aging infrastructure and equipment beginning to hinder overall system effectiveness and performance, measured by delays and cancellations*. Modernization programs for ATC were already forced to compete for scarce funding with the very real security demands posed by the 9/11 hijackers and associated threats.

- *Had already experienced the collapse of its general aviation industry, largely due to predatory legal actions, delivering just 941 aircraft in 1992*. Thanks to the General Aviation Revitalization Act of 1994 it was just beginning to recover, but in any case had totally lost its market dominance.

- *Had seriously aging military aviation forces.* The average age of the bomber and tanker force was already over 40 years. Eleven Air Force aircraft types were over 30 years of age, and aging fleet problems extended into the "high performance" fighter world as well.[74] New aircraft programs were struggling to receive sufficient funding and numbers, even as foreign aircraft and missile threats proliferate, particularly as global aerospace entered the era of the Super Flanker, the Eurofighter, the Gripen, the Rafale, and the double-digit SAM.[75]

- *Already faced an uncertain space future.* Increasingly, new foreign boosters competed with older American ones, often for launching American payloads into orbit.[76] Shuttle's promise of reduced cost, and safe and routine access to space had not been met; worse, the future of reusable heavy lift was in doubt following a second tragic loss of a Shuttle, the venerable *Columbia,* during

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Washington Post (20 April 2003). See also Kirsten Downey, "Dreamers Find Themselves Grounded," *Washington Post* (13 April 2003); the furlough numbers reflect members of the Air Line Pilots Association, as reported by ALPA spokesman John Mazor, but do not include non-ALPA-represented airlines such as American.

[74] Twenty years had passed since the vaunted F-117 stealth fighter reached "IOC:" its Initial Operational Capability. And if the Air Force and Navy's frontline F-14, F-15, and F-16 fighters were automobiles they would already be wearing classic car plates. Older fighters such as the F-15 (over two-thirds of which were over 21 years of age) were already encountering dangerous age-related problems, including in-flight high-Mach structural failure leading to catastrophic break-ups and imposition of safety limitations.

[75] In an admission that no American military officer had previously had to make at any time after Pearl Harbor, General John Jumper, then Air Force Chief of Staff, stated bluntly that "From time to time we get our hands on these airplanes. We take our Fighter Weapons School's best pilots, put them into one of these airplanes and, after two or three hours, put them up against other Fighter Weapons School guys flying an F-15 or F-16. *The result is our guy flying their airplane beats our guy flying our airplanes every single time*." See Tom Philpott, "Rising to the Challenge: an interview with General John P. Jumper," *Military Officer*, v. 1, n. 2 (February 2003), p. 58.

[76] The United States had to rely on military or commercial derivatives of what were its first generation of ICBMs and IRBMs: Atlas, Thor, and Titan (systems already nearly a half-century old by 2003).

reentry from orbit.[77] Cost pressures resulted in programs being cancelled, and others placed under stringent review.[78] Here too, American market dominance had already been lost. [79]

- *Had witnessed the winnowing down of its aircraft industry and workforce.* From a high of 47 aircraft companies that built not quite 300,000 airplanes in the Second World War, the industry shrank to just three mega-manufacturers in 2003: Boeing, Lockheed-Martin, and Northrop-Grumman.[80] States that once symbolized the aircraft industry—for example, New York and California—either had a minimal industry left, or had lost their industry entirely. Increasingly, the aerospace industry looked to foreign partnering and even to inviting foreign manufacturers (such as Airbus) to build their products on American soil, with an American workforce.[81]
- *Increasingly sought aircraft from abroad.* The last four trainers procured by American services (the T-45, T-1, T-3, and T-6) have been of foreign origin. As noted, airlines increasingly do the same, particular with the proliferating Airbus family and products of regional airliner manufacturers. Foreign helicopters were increasingly acquired for business, police, off-shore, news, or casualty/emergency services purposes, even as a possible Presidential transport.[82]

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[77] Heavy lift to space then cost approximately $450 million per launch or higher for a fully expendable Titan III/IV class booster, and higher still ($600+ million) per partially expendable Shuttle flight.

[78] Such as the X-33, X-34, and X-38.

[79] In 2002, only 14% of the rocket engines used in space launch came from the United States; 18% came from Europe, and 61% came from Russia; the remainder were from smaller space launch providers, particularly China and Japan. "I have never seen the industry in a more precarious position," Byron Wood, the Vice President and General Manager of Boeing Rocketdyne stated in congressional testimony; "We have three major liquid propulsion companies in the United States, and not enough work to keep even one healthy. Frankly, all three of U.S. are on the verge of going out of business. See "Statement of Byron Wood, Vice President and General Manager, Boeing Rocketdyne Propulsion and Power, before the Senate Subcommittee on Science, Technology, and Space, 3 June 2003. I thank Colonel Michael Heil, Air Force Research Laboratories, for bringing this testimony to my attention. The three manufacturers were Boeing Rocketdyne, Aerojet, and Pratt & Whitney.

[80] Aerospace employment plummeted: from 1.3 million in 1989 to 689,000 at the end of 2002—a decline of 47%. See Stan Crock, "An Arms Industry Too Big for the Task at Hand," *Washington Post* (31 Aug. 2003).

[81] For example, the proposal by Airbus to build tankers for the U.S. Air Force which ultimately resulted in a chaotic source selection and even further delays. See Robert Dorr, "We're Losing the Edge with Growth of Aviation," *Air Force Times,* v. 63, n. 31 (24 Feb. 2003), p. 54; see also Meilinger, p. 28.

[82] Data from www.eurocopterusa.com. I have benefited from a conversation of 12 Sep. 2003 with Mr. Roy Resavage, the President of Helicopter Association International, Alexandria, VA.

- *Had a constantly declining investment in future aerospace research and development funding*. Overall, both Federal and private aerospace research and development funding had been in a steady decline.[83] From the heyday of aeronautical research in the 1950s and the most creative years of space research in the 1960s and 1970s, the air and space research and development establishment was increasingly troubled by internal competition for resources. The traditional partnership of industry, the military services, the old NACA, and the academic community, that so greatly benefited aeronautical development in the pre-and-post World War II era, was gone. Instead, increasingly the research community was pressed between the twin dangers of money taken to support future acquisition of existing programs, and money diverted into operational needs.[84] "Overall, reductions in aeronautics research and technology," a 2002 NASA report concluded, "may ultimately have *irreversable consequences* if the United States cedes to foreign competitors the leadership position we have held for the last half of the 20th century."[85]
- *Had growing negative trade balances in areas thought to be traditionally "American," such as semiconductor equipment, computer components, robotics, and advanced structural materials*. They eerily recollect earlier declines in such "traditional" American industries as steel, shipbuilding, and automobiles.[86]
- *Faced serious problems in introducing new or innovated products*. By 2003, programs such as the F-22 and even the F-35 Joint Strike Fighter were already seen as reflecting failures in the acquisition process to produce timely, cost-effective, and technologically advanced systems. Critics were already noting that aircraft development times were running counter to a general trend in industry to go from concept to production on an average new product in not

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[83] From 1987 to 2000, Federal and private aeronautical research investment fell from nearly $35 billion to $15 billion, a more than 50% decline.

[84] The classic case, perhaps, is that of Shuttle's impact upon NASA. But another is the breakdown of research dollars within research establishments—the internal competition for resources—and the decline in research investment by industry. Basic R&D investment, as a percentage of net sales, by American companies, ranges between 1 and 10%, and the all-manufacturing average is but 3%. See Gregory Tassey, "R&D Trends in the U.S. Economy: Strategies and Policy Implications," National Institutes of Science and Technology Briefing Note (Germantown, MD: NIST, April 1999), Figure 2 and supporting text.

[85] OAT, *NASA Aeronautics Blueprint*, NP-2002-04-283-HQ (2002), p. 12. Worse, since modern wars are typically won by the R&D investment made 15 years prior to conflict, the decline in R&D investment, and the tendency to centralize R&D outside the services within the academic and other-governmental community, called into question whether future conflicts in the 2020 time frame will go as well as those of the 1990s—a question that, today, in the era of possible sequestration, remains as unanswerable as it did a decade ago.

[86] Meilinger, p. 22; the auto market share declined 33% in 40 years, from 48% to 15%.

quite two years (23 months). As one thoughtful observer of the acquisition scene noted, "We cannot afford to have the air and space star hitched to a Model T acquisition system."[87]

- *Faced a critical shortage of trained scientists and engineers, particularly in the Federal Government*, something that continues to be a serious challenge if the stewards of American aeronautics are to ensure continued national competitiveness in the years ahead.[88]

Today these problems have arguably accelerated, rather than eased. In part, this stems from what might be considered social and cultural issues. Air and space no longer has the appeal for American students that it once had. (Today, the majority of students studying air and space related subjects in American colleges and universities are foreign, not American, in background). Instead, many young people—perhaps reflecting their exposure to intensive environmental conditioning in primary and secondary schools over the last several decades (what might be seen as the post-Rachel Carson, post-Jonathan Schell era)—are opting for more generalized life sciences and environmental programs, not technological or overtly engineering ones. Their choice, incidentally, is having an interesting impact, namely that universities understandably are now under significant pressure to meet the needs of their customers—the students—by replacing engineering and technological laboratories and facilities with biological/life sciences/environmental ones. And this, in turn, is having a significant impact on the conduct of air and space research: some agencies and companies now have to go abroad to conduct research once done easily at American university laboratories. Accelerating this trend is an industry perception—largely justified—that NASA no longer has the ability to conduct and execute research on behalf of the aeronautics industry that it once did.[89]

But lest one think lack of interest in air and space is simply the perspective of the young, consider this: before his death, Dr. Richard T. Whitcomb, arguably the greatest aeronautical scientist of the post-World War II era (the creator of area ruling, the

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87 Meilinger, p. 30.

88 Although we have seen marked declines in the numbers of air and space engineering and technology graduates before (for example, throughout the 1970s), the decline over the 1990s to 2003 was startling: fully *57%*. In the space of just one year—from 1999 to 2000, the number of engineering students receiving degrees in aerospace engineering declined 52%, from 4,269 to 2,042; see Crock, and Meilinger, p. 28. Workforce reductions among the science and engineering career fields in the United States were considered serious enough to possibly "threaten our ability to regain 21st Century Battlefield Superiority" if left unchecked.; see Lt. Gen. Stephen Plummer, SAF/AQ, "Introduction," *Scientist and Engineer Summit Briefing* (Washington, D.C.: SAF/AQ, 11 Dec 2000), slide 5 "Problem Statement."

89 One anonymous source related an overheard conversation between a senior American aerospace industrialist and a NASA senior executive, in which the industrialist forcefully stated that the agency had little to nothing that his firm needed, and that when they did need some technical input from outside, they typically went to Europe.

supercritical wing, and winglets), was asked by a leading technological journal "Do you ever advise young people to go into engineering?" "I shock people," he replied.[90]

> I say, if you want to make an impact or have an effect, don't go into aeronautics. It's pretty well stabilized. No big things have come up in aeronautics since my inventions, and it has been 20 years since I left. *Go into the life sciences. That is where very important things are going to happen.*…No one has come up with anything truly new [in aeronautics] in years. It's just a matter of details now, not new approaches. That is why I quit. [Emphasis added.]

Examining the state of air and space today, it is hard to argue with that kind of logic—but if America is to restore its aeronautical supremacy, challenges and goals must be set forth that excite the mind—of young and old alike.

7. Closing Thoughts

Over the last century Americans accomplished much in the air and space fields making it truly an "air and space nation." American air and space investment, technology, and examples have become known around the world. When Peter, Paul, and Mary sang of "leaving on a jet plane," there was no doubt that it was an *American-built* jet plane. When Gordon Lightfoot sang of standing "cold and drunk" in the "early morning rain" watching an airplane at the end of a runway, it was a "big [Boeing] 707 ready to go." American aircraft became iconic symbols: The U-2 and B-52 are at least as well known as the name of rock bands as they are as aircraft, and the B-52 is still the most memorable symbol of American air power and freedom. Today, when Western coalitions go to war, it is generally with American products: F-16s, E-3 AWACS, C-130 transports, Chinooks, etc. American aviators—the Wrights, Byrd, the Lindberghs, Doolittle, Earhart, Yeager, Glenn, and Armstrong—are known around the world.[91] American derived aviation expressions are part of popular culture: "pushing the envelope," "wing and a prayer," "on the right glide slope," "God is my co-pilot," to name but a few. Neil Armstrong's "One small step. . ." is at least as well-known as Martin Luther King's "I have a dream," or John Kennedy's "*Ich bin ein Berliner*" or "Ask not what your country can do…." The world's most popular museum remains the National Air and Space Museum, which, in its first 25 years, had over 225 million visitors.[92]

So there has been considerable accomplishment and influence. But today it would not be accurate to state that the United States will inevitably remain as the unsurpassed

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[90] Jim Quinn, "Hall of Fame Interview: Richard Whitcomb," *American Heritage of Invention & Technology*, v. 19 n. 2 (Fall 2003), p. 63.

[91] Arguably only three foreign aviators are as well known: Richthofen, the "Red Baron" of the First World War; Saint-Exupery, author of *The Little Prince*; and Gagarin, the first to orbit the earth.

[92] Jacqueline Trescott, "The Museum that Took Off," *Washington Post* (30 June 2001).

leader in the air and space world. Given the seriousness of the challenges, we should not be naively optimistic about the future, for to regain the position of leadership that America has already lost will require a "systems of systems" approach that calls for multiple fixes across multiple areas.

Analogies might be made to China and to Spain. At the beginning of the fifteenth century, China possessed a vast and technologically advanced deep-water fleet that ranged as it wished throughout the western Pacific and Indian Oceans, even as far as Africa. But, largely from smugness and complacency, the Ming dynasty turned its back on maritime power; within a generation, China's fleet had collapsed to a fraction of its previous size, and pirates freely raided the Chinese coast. The torch of maritime exploration passed firmly to the Europeans. Here, initially, Spain held sway, as exemplified by the support the Spanish crown offered to Christopher Columbus's voyage of discovery to the "New World" in 1492. For the better part of the next century, Spain predominated. But as a nation it failed to adapt to the times, and the second century of New World investment—one of *exploitation*, not just *exploration*—saw other nations move to prominence.[93] American aviation today is hardly immune from losing its own aeronautics (and space) advantage in similar fashion to how China and Spain lost their maritime advantage centuries ago.

Two statements of Hap Arnold and Theodore von Kármán are appropriate in closing. One was the commander of a global air force locked in a total war; the other a refugee from Hitler Germany and the most gifted aeronautical scientist of his time, perhaps of all time. In 1944, Arnold charged von Kármán to forecast the future of aeronautics, noting "The first essential of air power is pre-eminence in research." A year later, just before Christmas 1945, von Kármán had a caution of his own: "Those in charge of the future Air Forces should always remember that problems never have final or universal solutions, and only a constant inquisitive attitude towards science and a ceaseless and swift adaptation to new developments can maintain the security of this nation through world air supremacy." Those sentiments, followed imperfectly in the past, must be adhered to in the future if America is to thrive, not merely survive, in the second century of winged flight.

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[93] Paul Kennedy, *The Rise and Fall of the Great Powers: Economic Change and Military Conflict from 1500 to 2000* (London: Fontana Press, 1989), pp. 7-9; Daniel J. Boorstin, *The Discoverers* (New York: Random House, 1983), pp. 168-201; for more on the Chinese and Spanish experiences, see Luise Levath, *When China Ruled the Seas* (New York: Simon and Schuster, 1994); and Samuel Eliot Morison, *The European Discovery of America* 2 vols. (New York: Oxford University Press, 1971).

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Abbreviations

ACT	Agreement for Commercializing Technology
AIA	Aeronautics Industries Association
AIAA	American Institute for Aeronautics and Astronautics
APL	Applied Physics Laboratory
ARMD	Aeronautics Research Mission Directorate
ARPA-E	Advanced Research Projects Agency—Energy
ASTS	Aeronautics Science and Technology Subcommittee
ATA	Advanced Tactical Aircraft
ATC	Air Traffic Control
ATF	Advanced Tactical Fighter
ATK	Alliant Techsystems Inc.
AWACS	Airborne Warning and Control System
BAE	British Aerospace and Marconi Electronic
BTP	Building Technologies Program
CAAFI	Commercial Aviation Alternative Fuels Initiative
CDRH	Center for Devices and Radiological Health
CIA	Central Intelligence Agency
CLEEN	Continuous Lower Emissions, Energy, and Noise
COMAC	Commercial Aircraft Corporation of China
COMPETES	Creating Opportunities to Meaningfully Promote Excellence in Technology, Education, and Science
CRADA	Cooperative Research and Development Agreement
CTWG	Clinical Trials Working Group
DARPA	Defense Advanced Research Projects Agency
DeVenCI	Defense Venture Catalyst Initiative
DFARS	Defense Federal Acquisition Regulation Supplement
DOC	Department of Commerce
DOD	Department of Defense
DOE	Department of Energy
DSB	Dispute Settlement Body
DTIC	Defense Technical Information Center
E-RIC	Energy Regional Innovation Cluster
EERE	(Office of) Energy Efficiency and Renewable Energy
EFRC	Energy Frontier Research Center
EIH	Energy Innovation Hub
EIR	Entrepreneurs-in-Residence
EU	European Union
FAA	Federal Aviation Administration
FAP	Fundamental Aeronautics Program
FDA	Food and Drug Administration

FFP	Fixed Firm Price
FFRDC	Federally Funded Research and Development Center
FLC	Federal Laboratories Consortium (for Technology Transfer)
FNC	Future Naval Capability
FWV	Fixed Wing Vehicles
FY	Fiscal Year
GAMA	General Aviation Manufacturers Association
GAO	Government Accountability Office
GASL	General Applied Science Laboratory
GE	General Electric
GLSC	Great Lakes Science Center
GOCO	Government-Owned, Contractor-Operated
GOGO	Government-Owned, Government-Operated
GRC	Glenn Research Center
HEO	Human Exploration and Operations Mission Directorate
HIFiRE	Hypersonic International Flight Research Experimentation
IARPA	Intelligence Advanced Research Projects Activity
IDA	Institute for Defense Analyses
IEEE	Institute for Electric and Electronic Engineers
IHPTET	Integrated High Performance Turbine Engine Technology
IMEC	Interuniversity MicroElectronics Center
IOC	Initial Operational Capability
IPA	Intergovernmental Personnel Act
IR&D	independent research and development
ISRP	Integrated Systems Research Program
ITAR	International Traffic in Arms Regulations
ITEA	International Test and Evaluation Association
ITP	Industrial Technologies Program
IWGTT	Interagency Working Group on Technology Transfer
KLM	Royal Aviation Company
LERD	Limited Exclusive Data Rights
MIT	Massachusetts Institute of Technology
NACA	National Advisory Committee for Aeronautics
NAISD	National Security and International Affairs Division
NARD	National Aeronautics Research and Development
NASA	National Aeronautics and Space Administration
NASP	National Aerospace Plane
NCI	National Cancer Institute
NGIP	NextGen Implementation Plan
NIH	National Institutes of Health
NIST	National Institutes of Science and Technology
NRC	National Research Council
NRTC	National Rotorcraft Technology Center
NSTC	National Science and Technology Council
NTRS	NASA’s Technical Reports Server
OECD	Organisation for Economic Co-operation and Development

OMB	Office of Management and Budget
ONR	Office of Naval Research
ORTA	Office of Research and Technology Applications
OSD	Office of the Secretary of Defense
OSTP	Office of Science and Technology Policy
PARTNER	Partnership for AiR Transportation Noise and Emissions Reduction
PIA	Partnership Intermediary Agreement
PICMET	Portland International Center for Management of Engineering and Technology
PLA	Patent Licensing Agreement
PPP	public-private partnerships
PSAR	Propulsion Safety and Affordable Readiness
R&D	research and development
RFC	Request for Comments
RFI	Request for Information
RITA	Rotorcraft Industry Technology Association
SAA	Space Act Agreement
SBIR	Small Business Innovation Research
SCW	Supercritical Wing
SPAD	Society for Aviation and its Derivatives
SST	Supersonic Transports
STEM	science, technology, engineering, and mathematics
STPI	Science and Technology Policy Institute
STTR	Small Business Technology Transfer Program
TAP	Transition Assistance Program
TFX	Tactical Fighter Experimental
TRL	Technology Readiness Level
TTO	Technology Transfer Office
UAV	Unmanned Aerial Vehicle
UC	University of California
UCSD	University of California, San Diego
USAF	United States Air Force
VAATE	Versatile Affordable Advance Turbine Engine
VLC	Vertical Lift Consortium
VLRCOE	Vertical Lift Research Centers of Excellence
WJHTC	William J. Hughes Technical Center
WTO	World Trade Organization

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14. ABSTRACT
The leadership of the Aeronautics Science and Technology Subcommittee (ASTS) of the Committee on Technology of the National Science and Technology Council requested that the IDA Science and Technology Policy Institute (STPI) examine what the ASTS can do to help accelerate the transition of Federal aeronautics research and development (R&D) products in a manner that promotes U.S. national security, jobs growth, and economic competitiveness. Using a combination of literature review, surveys of stakeholders and interviews, STPI provided ASTS and OSTP with ten recommendations, which, if implemented, could help strengthen the nation’s aeronautics enterprise. Recommendations relate to the goals of improved implementation of strategic plans (stronger reflection of strategic plans in activities, better opportunities for industry to provide input and feedback); better communication and coordination across stakeholders (better access of government to industry IR&D, better design and use of PPPs, guidance related to WTO ruling), technology maturation (better use of T&E, incorporation of private sector practices in government-funded technology development), and elimination of “fog and friction” barriers (engagement between government and industry with respect to intellectual property, incentives to promote culture change at laboratories, and use of meaningful metrics).

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