Issue Paper

RAND

Redirecting R&D in the Commercial Aircraft Supply Chain

Lance Sherry, Liam Sarsfield

Science and Technology Policy Institute

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Prepared for the
Office of Science and Technology Policy

IP-212-OSTP

Science and Technology Policy Institute

The research described in this issue paper was conducted by RAND's Science and Technology Policy Institute, under Contract ENG-9812731.

Cover photo courtesy of The Boeing Company

Published 2002 by RAND
1700 Main Street, P.O. Box 2138, Santa Monica, CA 90407-2138
1200 South Hayes Street, Arlington, VA 22202-5050
201 North Craig Street, Suite 102, Pittsburgh, PA 15213-1516
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Preface

About This Analysis

For the last 50 years, the United States has held a position of leadership in commercial aircraft and aircraft component manufacturing. However, recent market forces have changed the structure of the commercial aircraft industry supply chain, eroding the competitive advantage of the U.S. aeronautics research and development (R&D) system.

This issue paper describes changes in the commercial aircraft industry that have lead to an increased role of the supply chain in the R&D of aircraft components. This paper evaluates the allocation of federal R&D funding to the supply chain relative to the increased role of the supply chain in performing R&D. It also examines the roles that federal R&D agencies can play in overcoming inefficiencies in R&D that are inherent to a distributed supply chain.

This research was sponsored by the White House Office of Science and Technology Policy (OSTP).

About the White House Office of Science and Technology Policy

The Office of Science and Technology Policy was created in 1976 to provide the president with timely policy advice and to coordinate the federal investment in science and technology.

OSTP's Technology Division helps to develop and implement federal policies for harnessing technology to serve national goals, such as global economic competitiveness, environmental quality, and national security. The division's priorities include the following: sustaining U.S. technological leadership through partnerships to promote the development of innovative technologies, R&D and policy initiatives for advanced computing and communications technologies, advancing technologies for education and training, and the U.S. space and aeronautics program.

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Originally created by Congress in 1991 as the Critical Technologies Institute and renamed in 1998, the Science and Technology Policy Institute is a federally funded research and development center sponsored by the National Science Foundation and managed by RAND. The institute's mission is to help improve public policy by conducting objective, independent research and analysis on policy issues that involve science and technology. To this end, the institute

- supports the Office of Science and Technology Policy and other Executive Branch agencies, offices, and councils
- helps science and technology decisionmakers understand the likely consequences of their decisions and choose among alternative policies
- helps improve understanding in both the public and private sectors of the ways in which science and technology can better serve national objectives.

Science and Technology Policy Institute research focuses on problems of science and technology policy that involve multiple agencies. In carrying out its mission, the institute consults broadly with representatives from private industry, institutions of higher education, and other nonprofit institutions.

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Summary

For more than 50 years, the United States has held a position of leadership in aircraft and aircraft component manufacturing. This economic sector has been a major contributor to the U.S. economy in terms of revenue and balance of trade, and has been a cornerstone of national security. The success of this sector can be attributed to strong local demand for air transportation during this period and to the continuous stream of innovations generated by the U.S. aeronautics R&D system.

Today this leadership is being challenged by intense international competition in aircraft manufacturing. Also, a shift in the structure of the marketplace toward standardized products that are differentiated by cost has eroded the U.S. competitive advantage.

To remain competitive and be cost-effective, aircraft manufacturers have taken advantage of economies of scale and the risk/cost sharing benefits of outsourcing. A majority of the components in modern aircraft are designed and manufactured by vendors in the supply chain. For example, 60 percent of the value of Boeing airplanes are currently outsourced to supply chain vendors.

While outsourcing has reduced the cost of components, it has radically changed the origin and rate of flow of innovation and technology development in the industry. R&D, a key determinant of sustainable competitive advantage, is now performed by fragmented vendors in the supply chain.

This has raised several questions about the role of U.S. federal R&D agencies in stimulating, coordinating, and performing long-range, high-risk R&D critical to the future of the industry. Although responsibility for developing components has been passed down to supply chain vendors, this has not been accompanied by a shift in allocation of federal R&D funds. For example, only 30 percent of NASA's fiscal year (FY) 2000 aeronautical R&D research funds allocated to industry flow to supply chain vendors. Furthermore, there exists a new, unfilled role of developing mechanisms for creating industry-wide visions and technology roadmaps, and for coordinating the flow of requirements and technologies throughout the supply chain.

With national economic well-being and national defense at stake, there are several policy research issues associated with the competitive sustainability of

U.S.-based commercial aircraft manufacturers and supply chain vendors in the global marketplace:

1. Has the allocation of federal R&D funding shifted properly toward the supply chain where increased levels of R&D are now performed?
2. Are supply chain vendors sufficiently integrated into the federal R&D decisionmaking and planning process?
3. Is there sufficient coordination and communication throughout the tiers of the supply chain to maximize the efficiency of the supply chain without losing R&D capability?
4. Is R&D planning taking into account the likely structure of the supply chain in the future?

Acknowledgments

We are grateful to the following researchers for their contributions to this issue paper: Marl Lorell, Lowell Schwarz, Emile Ettedigu, Scott Hassell, and Scott Pace (at RAND), Joe Juarez (at Honeywell), and Dan Shunk and Mike Greiner (at Arizona State University).

1. Importance of the Aviation Industry to the United States

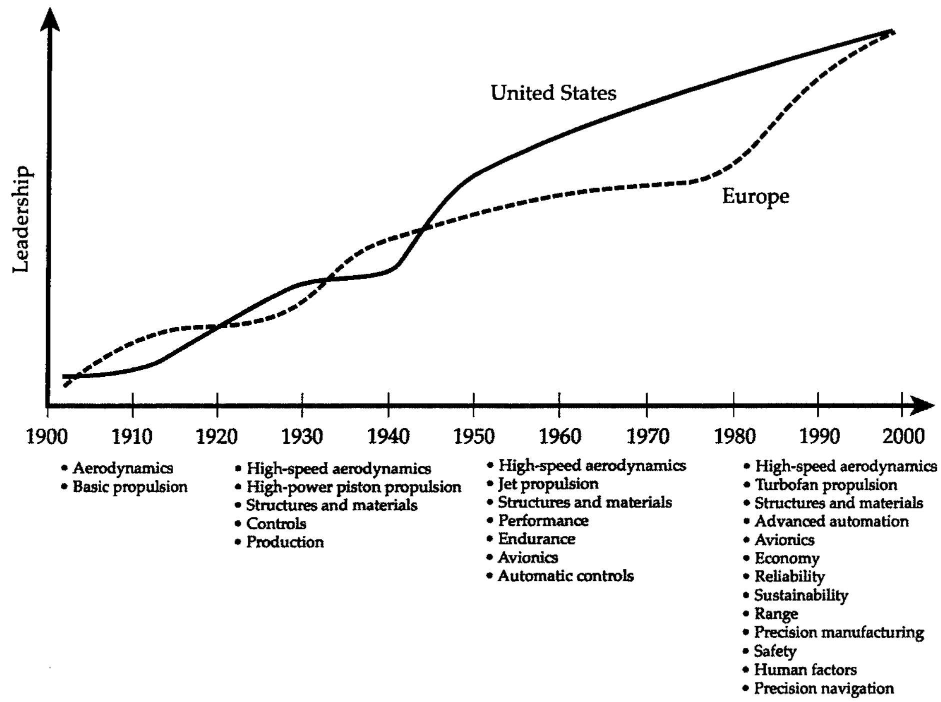
The commercial aircraft industry has been one of the most consistently productive and sustainable U.S. industries in the latter part of the 20th century. The sale of commercial aircraft generated revenues of $31 billion for the U.S. economy in FY 2000 (AIA, 2000). Sales of engines and other aircraft parts generated revenues of $15 billion. The export of commercial aircraft and the export of engines and aircraft parts generated $23.6 billion and $18.5 billion, respectively, making this sector the largest contributor of all U.S. industries to the positive balance of trade (AIA, 2000).

The worldwide market for civil aircraft is expected to continue to provide demand for sales of commercial aircraft with forecast sales in excess of $810 billion over the period 1999 to 2008 (Anderson, 1999). As of September 2000, the U.S. aircraft manufacturer of large transport aircraft had a backlog of 1,620 commercial transport aircraft orders.

In addition to the direct contribution to the economy, employment (456,000 employees), and the tax base, the aircraft industry provides several secondary benefits. The industry is a source of new technologies that are transferred to other sectors of the economy (e.g., gas turbines used for ship propulsion and emergency electrical generation and global positioning system navigation used in surveying and automobiles). The industry is also a critical component of the industrial and technology base for enhancing and maintaining national security (Lorell and Levaux, 1998).

R&D Determines Leadership in the Aviation Industry

Leadership in the commercial aircraft industry has historically been determined by the well-timed introduction of new aircraft (and products) to meet airline needs (Lorell and Levaux, 1998). A continuous stream of innovations, generated through research and development, is a critical element in attaining and sustaining this leadership (Phillips, 1971). History demonstrates that government investment in research (military and commercial) and competition within the industry is essential to establishing competitive advantage (Lorell and Levaux, 1998; NSTC, 1999, p. 11). The ability to rapidly change and refocus research directions is also critically important (Levine, 1963). These concepts are illustrated in the pictogram in Figure 1. Aeronautics leadership changes have occurred as a result of increased investment in aeronautics R&D and by focusing (and refocusing) aeronautics R&D to meet market demands.



NOTE: The above changes in aeronautics leadership are defined by military supremacy and by share of the military and commercial marketplace over the last century.

Figure 1—Changes in Aeronautics Leadership

Despite the success of the U.S.-based Wright brothers, Europe was responsible for much of the advancement of early aerodynamic research. This advantage was demonstrated by the superiority of German, French, and British aircraft over U.S. aircraft during World War I. To overcome this disadvantage, the U.S. government established the National Advisory Committee for Aeronautics (NACA) in 1915 to actively manage R&D and develop the air transportation industry. The infusion of R&D funding along with the strong demand for air service for government mail delivery fueled a regional "golden age" of aviation in the United States. A similar demand for air service, subsidized by British, French, and German governments, spurred the growth of aviation on the European continent (Heppenheimer, 1995).

U.S. leadership in aerodynamics was reestablished during the 1920s and 1930s through the significant gains made by U.S. aviation researchers and manufacturers. However, as time passed, leadership shifted. By the start of World War II, U.S. aircraft were once again inferior compared with German and British aircraft. During the period leading up to World War II, the Europeans had expanded their research to include aircraft structures, materials, and propulsion. These turned out to be significant factors in the next generation of airplanes built by the Europeans (Levine, 1963).

Once again the United States was obliged to embark on a crash research program to overcome the deficit. This military-sponsored research sparked advances in the science of aerodynamics, propulsion (i.e., jet engines), structures and materials, manufacturing, and control. These innovations and the tremendous manufacturing infrastructure developed during the war made possible the "golden age" of intercontinental aviation.

The U.S. leadership in aviation has remained largely unchallenged until around 1980 when Airbus Industrie, a consortium of European manufacturers, successfully penetrated a niche segment of the aircraft marketplace with the A300, a wide-body short-haul aircraft. Airbus followed this achievement with the introduction of the advanced technology A320 series aircraft in the narrow-body short-haul market, and then the A330/A340 aircraft in the wide-body, long-haul markets. Airbus's success, sponsored in large part by European governments, is fundamentally based on the utilization of advanced technology (e.g., fly-by-wire) made possible by a vibrant R&D system (Lynn, 1998; Heppenheimer, 1995).

The dominance of U.S. commercial aircraft manufacturers in this market has been eroded by this competition. In addition, during the last decade there have been significant changes in the structure of the marketplace and the way aircraft are designed and manufactured that have eroded advantages previously held by U.S.-based manufacturers. These changes are fundamentally altering the way R&D is performed. Without a vibrant R&D system for generating the kind of innovations that lead to long-term sustainable competitive advantage, the future leadership position of U.S.-based aircraft manufacturers and supply chain vendors is in jeopardy.

The Shift to Emphasis on Cost

The aviation marketplace has been characterized as "a sporty game" with low profit margins, staggering nonrecurring costs, and high risk (Newhouse, 1988). For example, the cost of development of the proposed Airbus A380 is estimated to be $11.7 billion (Sparaco, 2000).

Although the industry generates significant revenues, low profit margins—less than five percent—are the rule (Newhouse, 1988; Lynn, 1998). For example, the price of a 100-seat aircraft has been held to 1989 levels or less, and greater than 50 percent price concessions are demanded on new engine sales (Stanley, 1999).

Currently there are two remaining competitors: (1) Airbus Industrie and its European Union–based supply chain, and (2) Boeing and its global supply chain. Unlike other duopolies that hold market power, these two competitors face a number of forces that have conspired to create a very competitive, cost-sensitive marketplace (see Figure 2).

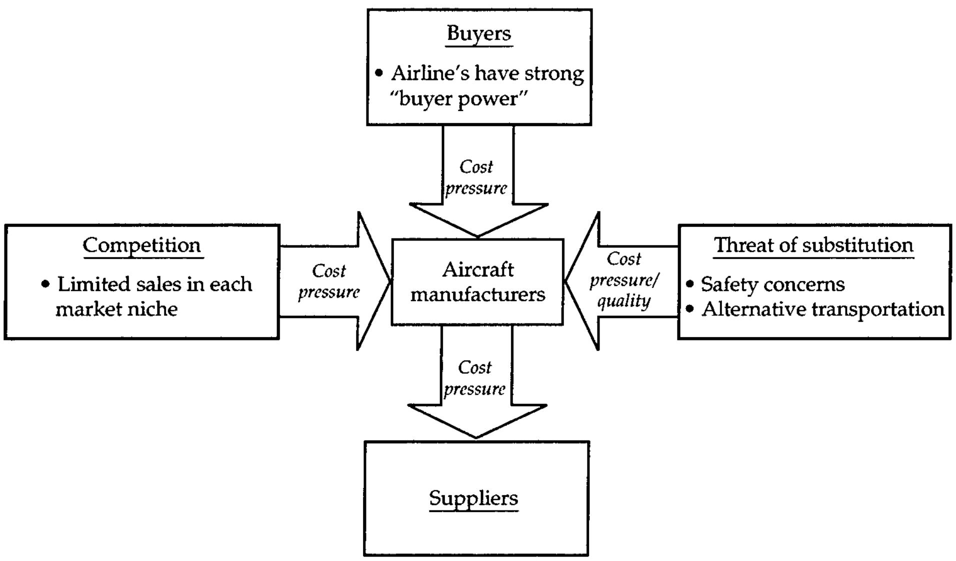


Figure 2—Industry Structure Creates Cost Pressure

Competition in each niche in the marketplace is fierce. Aircraft manufacturers are obliged to consider each sale a "must win," not only for the sake of revenue generated by the sale and market share, but for the sustained revenue from spares and maintenance over the life of the aircraft. Each successful sale also increases the probability of future sales to that airline by virtue of the economies of scale that the airline can achieve by operating a fleet of aircraft with the same (or similar) engines and other aircraft system components. As a result, the aircraft manufacturers follow the maxim of the industry, "don't abandon a market to the other guy," seeking creative ways to finance and serve each airline's needs at almost any cost.

The strong "buyer power" exhibited by the airlines compounds the sales pressure on cost. Although there are a large number of commercial airlines and aircraft leasing agencies, airlines do not operate as independent buyers. Airline demand for equipment is heavily influenced by energy prices and economic growth. As a result, airlines' requirements tend to be quite similar in terms of what aircraft each one needs and when each needs them. These shifts in the demand for types and quantities of aircraft tend to be synchronized and effectively mimic the behavior of a single buyer.

A few large airlines are responsible for the majority of sales that set trends for the rest of the industry. In the U.S. domestic airline market, ten airlines accounted for 93 percent of revenue passenger miles in 1994 (Kaplan, 1995). Furthermore, there are only a dozen airlines that update their fleets with large enough quantities to support the launch of a new aircraft.[1]

The trend of alliances among airlines has the effect of concentrating buyers into loosely formed buying cooperatives. In the very near future, global airline alliances could force aircraft manufacturers to sell to five potential customers—three alliances and two leasing companies—which will include over 80 percent of aircraft purchases (Stanley, 1999). For example, 40 world airlines and aircraft leasing companies convened in November 1998 to petition Airbus and Boeing to build less-expensive "no-frills" aircraft. The objective was to provide for aircraft from both aircraft manufacturers that can be configured to suit each airline's needs. This aircraft could then be operated without retraining and recertification of personnel and could share spares and other equipment (Lorell and Levaux, 1998).

Reducing Costs Through Outsourcing to the Supply Chain

These changes in the marketplace have spurred aircraft manufacturers to modify their operations with an emphasis toward reducing aircraft costs (Lorell et al., 2000). In addition to performance specifications, aircraft manufacturers have now developed models of the cost share of each system, subsystem, and component (see Figure 3). Under this "must-cost" design

[1]As a rule of thumb, the launch of new aircraft requires commitments to purchase 60 aircraft. Typically two or three airlines agree to purchase 20 or 30 aircraft each.

paradigm, price targets are an explicit and fundamental element of the engineering decisionmaking. It is much more difficult to pass on incremental cost increases to the overall airframe, and ultimately, to the airlines.

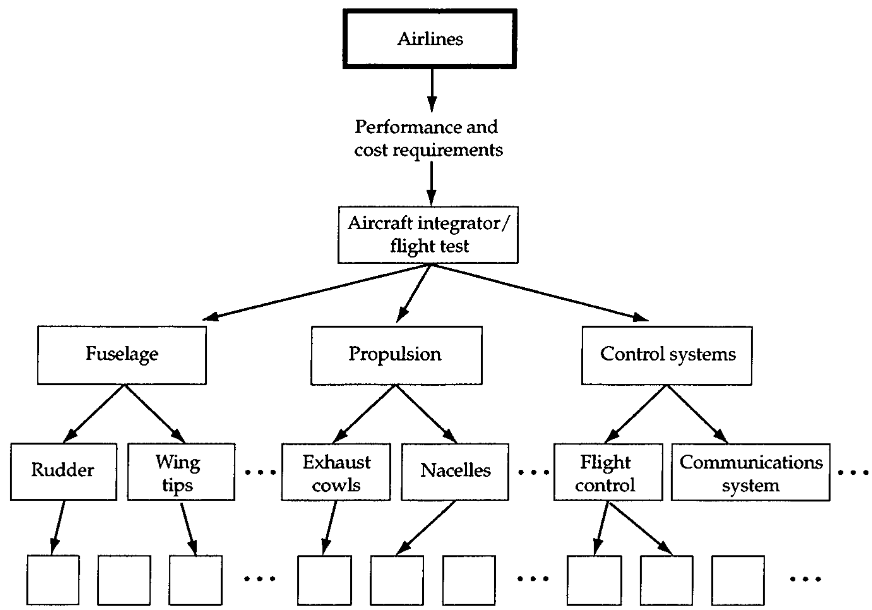


Figure 3—Aircraft Manufacturers Assign Cost Targets for Each System, Subsystem, and Component of the Aircraft

With cost targets for each component, manufactures have been able to better evaluate their ability to design and produce these components. In the majority of cases, the ability of supply chain vendors to produce a particular component at a reduced cost has led to the decision to outsource the component. For example, Boeing—historically a highly vertically integrated organization—now outsources, on average, 60 percent of the value of each airplane to vendors in the supply chain (Stowers, 1999). The Boeing goal is to migrate to outsourcing 75 percent of the value of each airplane by 2016.

Aircraft manufacturers gain several cost advantages by outsourcing components (see Table 1). The primary cost advantage is the leverage of the economies of scale that a vendor, supplying other customers in the same market (and/or customers in similar, noncompeting markets), can generate. For example, jet-engine manufacturers supply engines to commercial aircraft manufacturers as well as to military aircraft manufacturers.

Table 1

Summary of Cost Benefits Accrued by Aircraft Integrators via Outsourcing

Advantages to Manufacturer	Accrued Benefits
Supply chain economies-of-scale	
Supply chain specialization and leveraging of "world-class" processes and technologies	Reduced cost of component
Concentration of core competencies	Reduced cost of management and production
Reduced capital requirements	Reduced development costs and shared risks
Outsourcing to potential aircraft customer countries	Global outreach/market access

Outsourcing the design and manufacture of components to enterprises that are focused on a specific product or technology also creates economies of specialization. In this way, airframe integrators can leverage world-class technologies and processes of focused supply chain vendors into their final products. Building and maintaining this expertise in-house is expensive and a utilization of resources that may have very little in common with the sales, design, manufacture, and customer support for airplanes (Prahalad and Hamel, 1990).

Outsourcing components to supply chain vendors also improves the cash flow of aircraft manufacturers. By removing the costs of inventory and work in progress from their books, manufacturers improve their financial situation and can help maintain viable stock prices for generating necessary capital.

Another benefit of outsourcing is the opportunity to share the risk of development of new products and technologies. Instead of simply outsourcing the development of components, aircraft manufacturers have forged long-term relationships with suppliers that involve a share of the risk and the potential profit. For example, the B777 aircraft included substantial international outsourcing. The Japan Development Corporation (JADC), a consortium of three of the largest Japanese manufacturers, built 21 percent of the aircraft (sections of the fuselage, tail and wing, the fuel tanks, and the landing gear doors). Under a "program partnership," JADC provided funding for nonrecurring development—$18.2 million from Japan's Ministry of International Trade and Industry and part of a $1.1 billion loan from the Japanese Development Bank (NIST, 1998).

Outsourcing is also a critical element in the sale of aircraft, particularly to airlines with close ties to, or owned by, national governments. Boeing's foreign outsourcing is considered to be an integral part of its marketing strategy (Lynn, 1998). Countries that consistently purchase Boeing aircraft have historically also participated in the Boeing supply chain.

2. Policy Research Issues that Need to Be Addressed

Outsourcing of components in the commercial aircraft industry has delivered safe and reliable aircraft to the airlines at extremely competitive prices. However, the increased role of the supply chain has resulted in a reformulation of the vertical value chain (i.e., the sequence of steps for the conversion of raw materials to integrated systems). This calls for a change in the way federal R&D funds are allocated and the roles and responsibilities for performing R&D.

Is Federal R&D Funding Supporting Supply Chain R&D?

The long-term sustainability of U.S. aircraft and component manufacturers requires a large, capital-intensive infrastructure. Most of the truly big innovations in aviation, such as supersonic aircraft or high-bypass turbojet engines (or even jet engines themselves) were developed by R&D organizations with almost complete control of the vertical value chain. Furthermore, these kinds of R&D were financed in whole or part by the government. Because of the large-scale, generic nature of aeronautical facilities and the very long payback period, the federal government must continue to maintain the lead role in the provision and funding of the research and the infrastructure (Office of Science and Technology Policy, 2000).

Supply chain vendors receive direct funding and tax credits for R&D. Direct funding is received from government agencies such as NASA, the Federal Aviation Administration, and the Department of Defense. For example, the NASA aeronautics budget has funded R&D at roughly $1,200 million (2000 constant year dollars) for the last decade. Supply chain vendors also directly benefit from innovations and technologies developed at government laboratories and universities that are funded by the National Science Foundation.

The allocation of government R&D funding, however, has not adapted to the increased role of vendors in the supply chain. Thirty percent of the NASA aeronautics budget funding industry research is allocated to supply chain vendors (see Figure 4), the remaining 70 percent remains with aircraft manufacturers. For example in FY 1999, commercial domestic aircraft manufacturers were allocated $119 million in R&D funds by NASA. In contrast, in FY 1999, supply chain vendors were allocated $47 million in R&D funding from NASA.

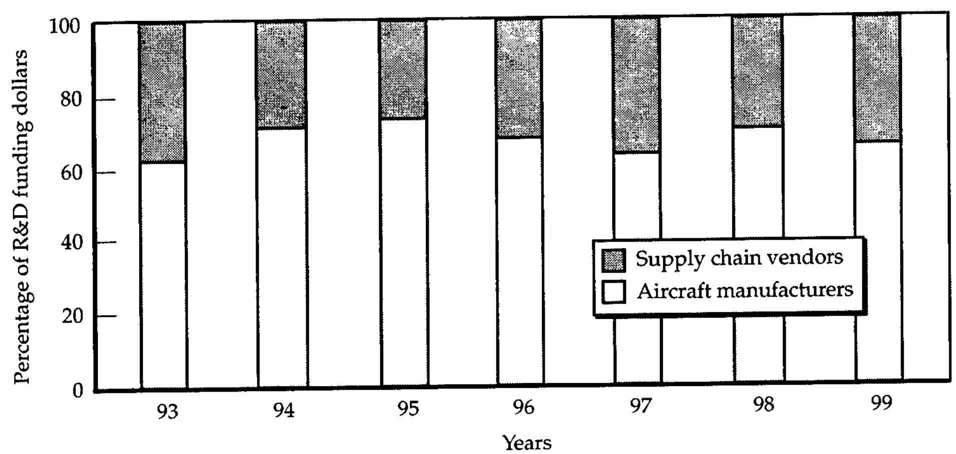


Figure 4—Supply Chain Vendors Are Allocated 30 Percent of the NASA Aeronautics Budget

It has long been an assumption that product innovations are only developed by manufacturers of the product. In a study of innovation in industry, von Hippel (1988) found that innovations in a product are generated by end users (e.g., airliners), manufacturers (e.g., aircraft manufacturers), and/or supply chain vendors (e.g., tire manufacturers). In some industries, innovative end-users develop innovative products and processes. In other fields, suppliers of related components and materials are the typical sources of innovation. In others, conventional wisdom holds, and the manufacturers are the typical innovators.

Von Hippel (1988) demonstrated that the origin of innovation is a function of the derived benefits to the organization, the organization's level of product know-how, and its ability to protect the innovation. End users of products have the most to gain from improvements in operational capability. When these users have the know-how to modify the product or use a product in a new way, they are most likely to innovate. By the nature of these innovations, end users are also in the best position to protect their innovation by using it as a trade secret and keeping it proprietary.

Manufacturers, those that supply end users, gain improved sales and market share from innovations in operational capability derived from improvements in product features and improvements in the implementation technology. These innovations are the hardest to protect from imitation because, by definition, they are revealed to end users. Manufacturers are known to frequently ignore these innovations until there is broad demand across the marketplace or until competitive forces drive the change.

Supply chain vendors are also motivated to innovate in both operational capability and implementation technology to improve sales and reduce costs. Like those of manufacturers, their innovations are difficult to protect from imitation.

The ratio in allocation of funding between aircraft manufacturer and supply chain vendor is not a simple decision. Because of the importance of the flow of operational requirements from the aircraft manufacturer down the supply chain, it is imperative that the manufacturer remain funded and active in performing research (e.g., identification of operational requirements). At the same time, cost pressures passed down the supply chain necessitate assurance that the supply chain is funded and performing R&D to use existing technologies to fulfill new operational requirements as well as to develop new technologies.

Determining the optimum ratio of funding between aircraft manufacturer and supply chain vendor is an area for future work.

Is the Supply Chain Adequately Represented in Federal R&D Decisionmaking?

Several studies have made recommendations for the creation of new government agencies, interagency committees, or industry-government consortia, and other organizations to oversee and coordinate research in industry (NRC, 1992, 1994, 1996, 1997; NSRC, 1995; Sarsfield, 1998). These proposals have all called for greater interaction between government, industry, and academia. None of these studies explicitly recommend the inclusion of supply chain vendors.

Several government agencies, however, have already addressed this issue by including supply chain vendors on executive steering committees and in industry advisory groups. Analysis of the composition of ten randomly selected NASA aeronautics steering committees found that supply chain representation was, on average, 50 percent of the industry representation on these committees. This percentage is deceptively high because it reflects the duplication of representation by each of the supply chain manufacturers for a given component. For example, program steering committees with an avionics element will have representatives from all three of the U.S. major avionics manufacturers.

Determining the role and most efficient means of supply chain representation in federal R&D decisionmaking is an area for further research.

What Role Could Technology Roadmaps for Components Developed by the Supply Chain Have in Coordinating R&D?

To maintain a full spectrum of design, technical, and manufacturing activities, it is imperative for all parties in the U.S. aircraft industry to work together. In policy terms this implies the need for a mechanism to build consensus and implement an ongoing strategy, as well as to remove unnecessary obstacles to cooperation that exist in the United States. Several industries have developed visions and technology roadmaps that have served to focus resources in the supply chain in meaningful ways, eliminate gaps in R&D in the supply chain, and create synergies among vendors (Semiconductor Industry Association, 1994; Kostoff and Schaller, 2000; Groenveld, 1997).

Has the Full Potential of Information Technology Been Used to Facilitate Communication in Supply Chain R&D?

Several industries have demonstrated improvements in overall productivity through communication and information sharing using modern information technology (IT) and the web (Hassell, Bernstein, and Bower, 2000; Neu, Anderson, and Bikson, 1999). This technology has the potential to improve communication and collaboration among vendors throughout the commercial aircraft industry supply chain.

The airline community has already established several examples of information sharing. The Global Aviation Information Network (GAIN) is a Federal Aviation Administration (FAA) program that collects and disseminates safety-related information (www.gainweb.org). NASA also funds a similar type of safety program, the Aviation Safety Reporting System (ASRS), which collects anonymous pilot incident reports on the web (http://asrs.arc.nasa.gov/). Trends and statistics are made available to airlines and researchers.

Supply chain vendors could also access and utilize this information to improve their products and services.

Segments of the supply chain have also been collecting and utilizing data to improve the performance of their products. Engine manufacturers routinely record engine performance data, which are used to monitor engine performance and schedule maintenance, develop warrantee programs, and improve the reliability of engines under development. Vendors in these supply chain branches may be able to better understand the consequences of their design decisions with access to noncompetitive, nonproprietary industry data.

Another area that begs for the utilization of information technology for transmission and status of documentation is in the certification of aircraft components by regulatory authorities. A study of FAA rule-making processes found that a rule takes, on average, four years to pass through the system. A significant portion of that time is spent in queues at bottlenecks.[2]

The priority of cost containment can be met only if the airframe manufacturer allows suppliers to choose how to design, manufacture, and service their own particular system, subsystem, or component. Instead of detailed technical specifications, airframe manufacturers are obliged to define products in terms of generic performance requirements, form-fit-and-function specifications, and the FAA safety standards required for new aircraft certification. This approach gives suppliers sufficient flexibility to respond to unexpected cost increases as well as to introduce new and more cost-effective technologies. The transmission of these specifications throughout the supply chain also requires the development of specification standards and transmission protocols for electronic data exchange. Several consortia are already working on these issues, e.g., the AIA Supplier Management Council.

The following are questions for further research: Is there sufficient coordination and communication throughout the tiers of the supply chain to maximize the efficiency of the supply chain without losing R&D capability? What is the role of IT in communicating requirements throughout the supply chain and in coordinating R&D? What type of system would be required and what are the potential benefits and costs?

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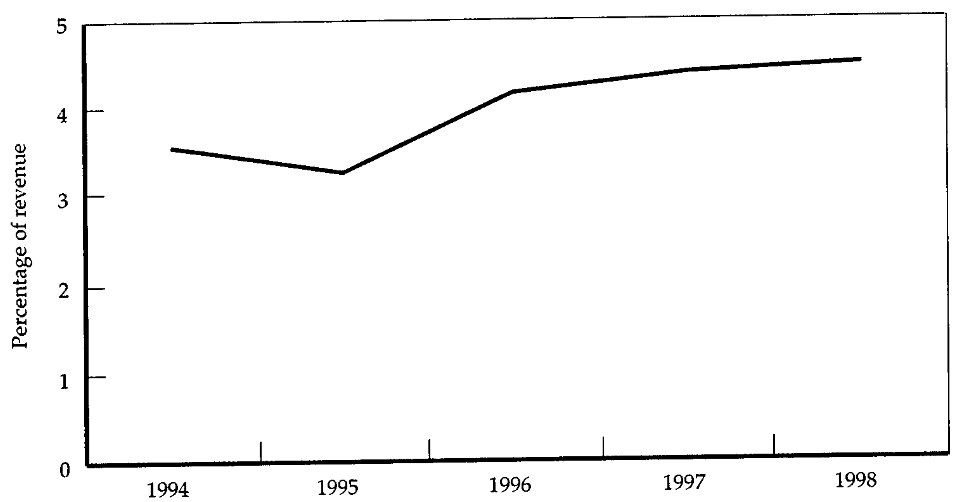
[2]Information from RAND colleague John Friel.

Have Supply Chain Vendors Adapted to Increased R&D Responsibility?

The shift in technical responsibility to supply chain vendors has been accompanied by a parallel shift in financial responsibility. Suppliers now pay an increasing share of the R&D and certification costs for new aircraft. This cost pressure has affected R&D activity in the supply chain.

The increased role of the supply chain has resulted in a slight change in the internal R&D (IR&D) budgets of supply chain vendors. For example, the average IR&D budget for the top six Fortune 500 supply chain vendors (engine, avionics, and airframe components) increased from 3.5 percent of revenue in 1994 to 4.4 percent of revenue in 1999 (see Figure 5). Despite this increase of 25 percent, the value remains well below the average IR&D expenditures in the aerospace industry of 7 percent (AIA, 2000).



SOURCES: U.S. Security and Exchange Commission reports, www.sec.gov.

Figure 5—Trends in IR&D for Six Fortune 500 Aircraft Component Vendors

Does R&D Planning Take into Account Future Structures of the Supply Chain?

The supply chain itself has undergone dramatic changes in the last decade, also affecting R&D. The increased financial commitment of supply chain vendors has required vendors to either "bulk up" through mergers or alliances, or to "niche." The bulk-up strategy has been widely adopted, resulting in a profusion of business partnerships of every sort, from simple risk-sharing arrangements, to full joint ventures, to outright mergers. This has resulted in an extensive consolidation of the U.S. commercial aircraft industry supply chain (Velocci, 1999e; Scott, 2001). For example, aircraft manufacturers anticipate that the number of suppliers for a given aircraft will decrease from more than 3,000 to approximately 500 (Velocci, 1999f).

This consolidation of supply chain vendors has decreased costs. From the perspective of aircraft manufacturers, the mergers reduced the number of suppliers, eliminating the costs of managing and executing contracts. The mergers also reduced the cost of the components by providing products already integrated by suppliers and by eliminating duplication of general administrative costs previously included in the cost of each individual component. Eliminating duplicate equipment and processes and utilizing shared parts inventories have also been cited as sources of cost reduction. An example of this type of consolidation is Crane Aerospace (see www.craneaerospace.com). This organization is composed of four former separate companies: Interpoint (power conversion microelectronics), Eldec (proximity sensors and power management), Lear Romec (fuel, coolant, and lubrication pumps), and Hydro-Aire (brake control systems and fuel pumps).

Supply chain vendor consolidation has had a positive effect on R&D. The consolidation of smaller organizations that do not have R&D laboratories, has created sufficient critical mass to fund internal R&D in the new larger organizations (see www.craneaerospace.com). Likewise, several larger organizations that have established R&D laboratories have acquired smaller organizations and included their products and technologies as part of the R&D portfolio.

As described above, federal R&D spending has had limited effects on R&D in the supply chain. However, there appears to be significant potential in coordinating R&D and communicating requirements throughout the supply chain.

To mitigate the effects of industry consolidation and long industry cycles and to compensate for development cost sharing and reduced profit margins, supply chain vendors have had to leverage their knowledge and technologies to seek other sources of revenue. One of the most successful strategies adopted by vendors is to enter in "cradle-to-grave" relationships directly with manufacturers and airlines by offering after-sales support. Maintenance and repair operations generally provide high profit margins. In some cases, suppliers have packaged their products and after-sales support with a fixed fee based on the number of hours flown. For example, engine manufacturers offer "power-by-the-hour" and "fly-by-the-hour" contracts for engines and other systems (Schneider, 1998).

This shift from product to service as a source of revenue has had a positive effect on R&D. Fixed-price contracts and after-sales service have provided the incentive for suppliers to improve the reliability and designs to reduce life-cycle costs and cost of warrantees. This trend, however, was not forecast by federal R&D funding agencies and has not been supported in a broad manner by basic research.

The future structure of the supply chain is an important element in the decisionmaking process of federal agencies sponsoring aeronautics R&D. Trends in the supply chain and their effects on R&D should be studied further.

3. Conclusions

The importance of the aircraft industry to the U.S. economy and to national security demands an active role by the government to ensure the vitality of R&D in the industry. Federally funded, high-risk, capital-intensive R&D is critical to ensure the flow of innovation that provides the basis for sustainable competitive advantage for U.S. vendors. The modern industry structure of aeronautics places a significant element of the vitality of the R&D enterprise with supply chain vendors.

This issue paper has raised several questions about how the supply chain has affected the manufacture of commercial aircraft:

- Are R&D funds allocated to the supply chain proportional to the volume of R&D now performed by the vendors?
- Are supply chain vendors sufficiently integrated into the federal R&D decisionmaking and planning process?
- Is there sufficient coordination and communication throughout the tiers of the supply chain to maximize the efficiency of the supply chain without losing R&D capability? Do the mechanisms for communication and coordination (e.g., technology roadmaps, information technology, and proprietary data mechanisms) exist to ensure the vitality of R&D in the fragmented vertical value chain?
- Is R&D planning taking into account the likely structure of the supply chain in the future?

Failure to adjust the R&D system to reflect the role of the aircraft supply chain can potentially affect the competitive position of the U.S. aeronautics industry. It could also result in the failure to develop new technologies for the next generation of aircraft. In addition, the consequences of inaction will not be limited to the aircraft industry, having possible consequences for other industries and national security.

Most actions necessary to maintain U.S. leadership in the aircraft industry are the responsibility of the U.S. aircraft industry itself, including aircraft manufacturers and supply chain vendors. However, the U.S. government also needs to create a favorable environment for these actions and to play a specific role in creating incentives and/or making selective, limited investments, especially for R&D.

Bibliography

AIA (2000) *Aerospace Facts and Figure 2000/2001,* Aerospace Industries Association of America, Inc., Washington, D.C.

Anderson, L. (1999) *Impact of Aviation on the Economy,* presentation by Lynn Anderson, NASA Glenn Research Center, to NRC Committee on Strategic Assessment of U.S. Aeronautics, June.

Groenveld, P. (1997) "Roadmapping Integrates Business and Technology," *Research Technology Management,* Vol. 40, No. 5., pp. 48–55.

Hassell, S., M. Bernstein, and A. Bower (2000) *The Role of Information Technology in Housing Design and Construction,* RAND, CF-156-OSTP, Santa Monica, Calif.

Heppenheimer, T. A. (1995) *Turbulent Skies,* John Wiley and Sons, New York.

Industrial Research Institute (2001) *R&D Trends Forecast for 2001,* Washington, D.C.

Kaplan, D. (1995) "The Pursuit of Competition: A Review of U.S. Public Policy in the Airline Industry," *Handbook of Airline Economics,* The McGraw Hill Companies, New York, p. 151.

Kostoff, R., and R. Schaller (2000) "Science and Technology Roadmaps," *IEEE Transaction on Engineering Management,* May, Vol. 48, No. 2, pp. 132–143.

Levine, A. (1963) *United States Aeronautical Research Policy 1915–1958: A Study of Major Policy Decisions of the National Advisory Committee for Aeronautics,* Ph.D. dissertation, Columbia University, New York.

Lorell, M., and H. Levaux (1998) *The Cutting Edge: A Half Century of U.S. Fighter Aircraft R&D,* RAND, MR-939-AF, Santa Monica, CA.

Lorell, M., J. Lowell, M. Kennedy, and H. Levaux (2000) *Cheaper, Faster, Better? Commercial Approaches to Weapons Acquisition,* RAND, MR-1147-AE, Santa Monica, CA.

Lynn, M. (1998) *Birds of Prey: A Battle for the Skies,* Four Walls Eight Windows, New York.

National Research Council (NRC) (1997) *Maintaining U.S. Leadership in Aeronautics: Scenario-Based Strategic Planning for NASA's Aeronautics Enterprise,* Steering Committee for a Workshop to Develop Long-Term Global Aeronautics Scenarios, Aeronautics and Space Engineering Board, Commission on Engineering and Technical Systems, National Academy Press, Washington, D.C.

National Research Council (NRC) (1996) *Recent Trends in U.S. Aeronautics Research and Technology*, Committee on Strategic Assessment of U.S. Aeronautics, Aeronautics and Space Engineering Board, Commission on Engineering and Technical Systems, National Academy Press, Washington, D.C.

National Research Council (NRC) (1994) *High-Stakes Aviation: U.S.-Japan Technology Linkages in Transport Aircraft*, National Research Council, National Academy Press, Washington, D.C.

National Research Council (NRC) (1992) *Aeronautical Technologies for the 21st Century*, Aeronautics and Space Engineering Board, National Academy Press, Washington, D.C.

National Science and Research Council (NSRC) (1995) *Goals for a National Partnership in Aeronautics Research and Technology*, Office of Science and Technology Policy, Washington, D.C.

National Science & Technology Council (NSTC) (1999) *National Research & Development Plan for Aviation Safety, Security, Efficiency, and Environmental Compatibility*, Committee on Technology, Subcommittee on Transportation Research & Development, Washington, D.C.

Neu, C. R., R. H. Anderson, T. K. Bikson (1999) *Sending Your Government a Message: E-mail Communication Between Citizens and Government*, RAND, MR-1095-MF, Santa Monica, CA.

Newhouse, J. (1988) *The Sporty Game*, Alfred A. Knopf, New York.

NIST (1998) *Endless Frontier, Limited Resources: U.S. R&D Policy for Competitiveness—Sector Study: Aircraft*, Gaithesburg, MD.

Office of Science and Technology Policy (2000) *Goals for a Partnership in Aeronautics Research and Technology*, The White House, Washington, D.C.

Phillips, Almarin (1971) *Technology & Market Structure: A Study of the Aircraft Industry*, DC Heath, Lexington, MA.

Phillips, Edward H. (2000) "Uninhibited Data Sharing Called Key to Improving Airline Safety," *Aviation Week & Space Technology*, October 23, McGraw Hill, New York, pp. 85–87.

Prahalad, C., and G. Hamel (1990) "The Core Competence of the Corporation," *Harvard Business Review*, Vol. 73, May–June, pp. 79–91.

Sarsfield, L. (1998) *Aviation in the Next Millennium—A National R&D Plan for Improving Air Transportation Safety & Security in the 21st Century*, White House Commission on Aviation Safety & Security Task Force on Research & Development Implementation, Washington, D.C., October 1 (Rev. 2B).

Schneider, J. (1998) *What Are the Primes up to? Prospects for Aviation Industry Suppliers*, JSA Partners, presentation to Speednews Aviation Industry Suppliers Conference, March 15.

Scott, William B. (2001) "Industry Consolidation Seen Shifting to Subcontractors, Suppliers," *Aviation Week & Space Technology,* January 1, McGraw Hill, New York, pp. 63–64.

Semiconductor Industry Association (1994) *The National Technology Roadmap for Semiconductors,* San Jose, CA (www.semchip.org).

Sparaco, P. (2000) "Europe Embarks on $11-Billion A380 Gamble," *Aviation Week & Space Technology,* January 1.

Stanley, D. (1999) "Military Technologies Finding Homes in Commercial Engines," *Aviation Week & Space Technology,* June 14.

Stowers, Bill (1999) *Boeing Supplier Management Council, 1999,* Boeing Commercial Airplane Group, Seattle, WA.

Teal Group (2000) *World Military & Aircraft Briefing—Airbus Industrie,* Fairfax, VA, pp. A319/A320/A321 (www.tealgroup.com).

Velocci, Anthony L. (1999a) "Aerospace Still Trails Commercial Electronics," *Aviation Week & Space Technology,* McGraw Hill, New York, September 13, pp. 69–73.

Velocci, Anthony L. (1999b) "Pattern of Broken LTAs Raising Supplier Angst," *Aviation Week & Space Technology,* McGraw Hill, New York, September 13, pp. 73–75.

Velocci, Anthony L. (1999c) "Voice of Lower Tier Suppliers Beginning to Be Heard," *Aviation Week & Space Technology,* McGraw Hill, New York, September 13, p. 76.

Velocci, Anthony L. (1999d) "Primes Pledge to Cut Excessive Audits," *Aviation Week & Space Technology,* McGraw Hill, New York, September 13, pp. 77–78.

Velocci, Anthony L. (1999e) "Better Managed Suppliers Posting Strongest Gains," *Aviation Week & Space Technology,* McGraw Hill, New York, September 13, pp. 80–81.

Velocci, Anthony L. (1999f) "Suppliers Pressed in Bizjet Value Equation," *Aviation Week & Space Technology,* McGraw Hill, New York, October 11, pp. 56–58.

von Hippel, Eric (1988) *Sources of Innovation,* Oxford University Press, New York.

IP-212-OSTP