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NASA/DoD Aerospace Knowledge Diffusion Research Project

Paper Ten:

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The NASA/DoD Aerospace Knowledge Diffusion Research Project

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With its contribution to trade, its coupling with national security, and its symbolism of U.S. technological strength, the U.S. aerospace industry holds a unique position in the nation's industrial structure.[1] Although the U.S. aerospace industry continues to be the leading positive contributor to the balance of trade among all merchandise industries, it is experiencing significant changes whose implications may not be well understood.[2]

Increasing U.S. collaboration with foreign producers will result in a more international manufacturing environment, altering the current structure of the aerospace industry. International alliances will result in a more rapid diffusion of technology, increasing pressure on U.S. aerospace companies to push forward with new technological developments and to take steps that maximize the inclusion of those technological developments into the research and development (R&D) process.

To remain a world leader in aerospace, the United States must improve and maintain the professional competency of its aerospace engineers and scientists, enhance innovation and productivity, and maximize the integration of recent technology into the R&D process. How well these objectives are met, and at what cost, depends on a variety of factors, but largely on the ability of U.S. aerospace engineers and scientists to acquire and process the results of NASA/DoD funded R&D.

These circumstances emphasize the need to understand the aerospace knowledge diffusion process with respect to federally funded R&D; to recognize that STI emanating from federally funded aerospace R&D is a valuable strategic resource for innovation,

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problem solving, and productivity; and to remove the major barriers that restrict or prohibit the ability of U.S. aerospace engineers and scientists to acquire and process the results of federally funded aerospace R&D. However, as Solomon and Tornatsky point out, "while STI, its transfer and utilization, is crucial to innovation [and competitiveness], linkages between [the] various sectors of the technology infrastructure are weak and/or poor defined."[3]

The conditions also intensify the need to understand the production, transfer, and utilization of knowledge as a precursor to the rapid diffusion of aerospace technology and as a means of maximizing the aerospace R&D process. Maximizing the aerospace R&D process begins with an understanding of the information-seeking habits and practices of U.S. aerospace engineers and scientists. As Menzel states,

> The way in which [aerospace] engineers and scientists make use of the information systems at their disposal, the demands that they put on them, the satisfaction achieved by their efforts, and the resultant impact on their future work are among the items of knowledge which are necessary for the wise planning of S&T information systems and policy.[4]

The ability of aerospace engineers and scientists to identify, acquire, and utilize scientific and technical information (STI) is of paramount importance to the efficiency of the R&D process. Testimony to the central role of STI in the R&D process is found in numerous studies.[5] These studies show, among other things, that aerospace engineers and scientists devote more time, on the average, to the communication of technical information than to any other scientific or technical activity.[6] A number of studies have found strong relationships between the communications of STI and technical performance at both the individual[7,8,9] and group levels.[10,11,12] The "role of scientific and technical communication is thus central to the success of the innovation process, in general, and the management of R&D activities, in particular."[13]

In terms of empirically derived data, very little is known about the diffusion of knowledge in the aerospace industry, both in terms of the channels used to communicate the ideas and the information-gathering habits and practices of the members of the social system (i.e., aerospace engineers and scientists). Most of the channel studies have been concerned with the transfer of aerospace technology to non-aerospace industries.[14,15]

Most of the studies involving aerospace engineers and scientists have been limited to the use of NASA STI products and services and have not been concerned with information-gathering habits and practices.[16,17] Although researchers have investigated the importance of technical communications to engineers, it is not impossible to determine from the published results if the study participants included aerospace engineers and scientists.[18,19] An understanding of the process by which STI in the aerospace industry is communicated through certain channels over time among the members of the social system would contribute to increasing productivity, stimulating innovation, and improving and maintaining the professional competence of U.S. aerospace engineers and scientists.

THE FEDERAL AEROSPACE KNOWLEDGE DIFFUSION PROCESS

A model (Figure 1) that depicts the transfer of federally funded aerospace R&D is composed of two parts—the *informal* that relies on collegial contacts and the *formal* that relies on surrogates, information products, and information intermediaries to complete the "producer to user" transfer process. The producers are NASA and the DoD and their contractors and grantees. Producers depend upon surrogates and information intermediaries to complete the knowledge transfer process.

When U.S. government technical reports are published, the initial or primary distribution is made to libraries and technical information centers. Copies are sent to surrogates for secondary and subsequent distribution. A limited number are set aside to be used by the author for the "scientist-to-scientist" exchange of information at the individual level.

Surrogates serve as technical report repositories or clearinghouses for the producers and include the Defense Technical Information Center (DTIC), the NASA Scientific and Technical Information Facility (NASA STIF), and the National Technical Information Service (NTIS). These surrogates have created a variety of technical report announcement journals such as TRAC (Technical Report Announcement Circular) and STAR (Scientific and Technical Aerospace Reports) and computerized retrieval systems such as DROLS (Defense RDT&E Online System) and RECON (REmote CONsole) that permit online access to technical report databases.

Information intermediaries are, in large part, librarians and technical information specialists in academia, government, and industry. Those representing the producers serve as what McGowan and Loveless[20] describe as "knowledge brokers" or "linking agents." Information intermediaries connected with users act as "technological entrepreneurs" or "gatekeepers."[21] The more "active" the intermediary, the more effective the transfer process becomes.[22] Active intermediaries take information from one place and move it to another, often face-to-face. Passive information intermediaries,

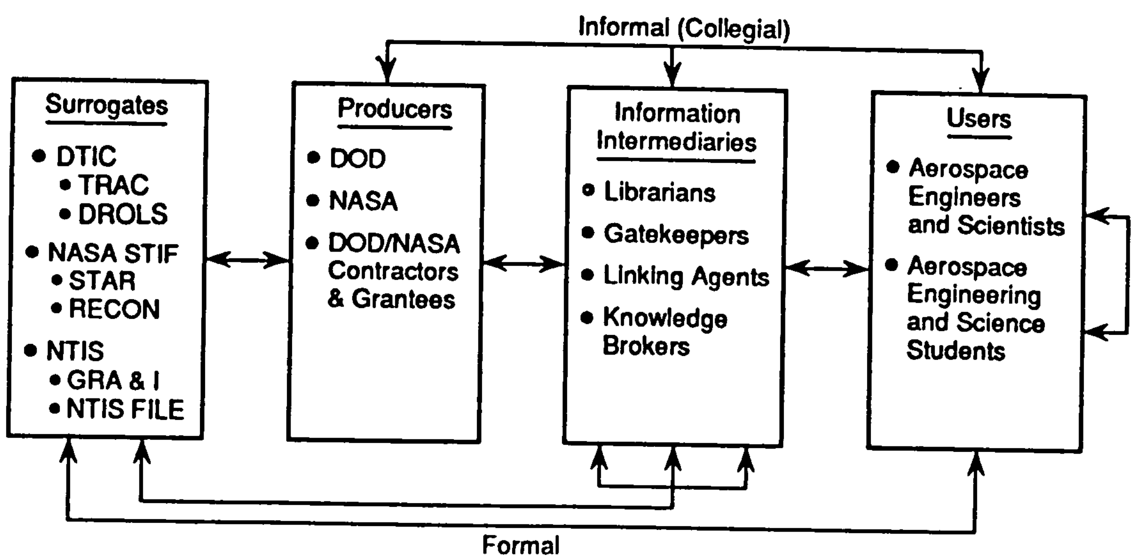

Figure 1. A Model Depicting the Transfer of Federally Funded Aerospace R&D

on the other hand, "simply array information for the taking, relying on the initiative of the user to request or search out the information that may be needed."[23]

The problem with the total Federal STI system is "that the present system for transferring the results of federally-funded STI is passive, fragmented, and unfocused." Effective knowledge transfer is hindered by the fact that the Federal government "has no coherent or systematically designed approach to transferring the results of federally-funded R&D to the user."[24] In their study of issues and options in Federal STI, Bikson et al.[25] found that many of the interviewees believed "dissemination activities were afterthoughts, undertaken without serious commitment by Federal agencies whose primary concerns were with [knowledge] production and not with knowledge transfer;" therefore, "much of what has been learned about [STI] and knowledge transfer has not been incorporated into federally-supported information transfer activities."

The problem with the *informal* part of the system is that knowledge users can learn from collegial contacts only what those contacts happen to know. Ample evidence supports the claim that no one researcher can know about or keep up with all the research in his/her area(s) of interest. Like other members of the scientific community, aerospace engineers and scientists are faced with the problem of too much information to know about, to keep up with, and to screen—information that is becoming more interdisciplinary in nature and more international in scope.

Two problems exist with the *formal* part of the system. First, the formal part of the system employs one-way "supply side" transfer procedures that do not seem to be responsive to the user context.[26] Rather, these efforts appear to start with an information system into which the users' requirements are retrofit.[27] The consensus of the findings from the empirical research is that interactive, two-way communications are required for effective information transfer.[28]

Second, the *formal* part relies heavily on information intermediaries to complete the knowledge transfer process. However, a strong methodological base for measuring or assessing the effectiveness of the information intermediary is lacking.[29] In addition, empirical findings on the effectiveness of information intermediaries and the role(s) they play in knowledge transfer are sparse and inconclusive. The impact of information intermediaries is likely to be strongly conditional and limited to a specific institutional context.

Furthermore, most Federal approaches to research utilization have been ineffective in stimulating the diffusion of technological innovation.[30] According to Roberts and Frohman, numerous Federal STI programs are "highest in frequency and expense yet lowest in impact" and that Federal "information dissemination activities have led to little documented research utilization." Roberts and Frohman note that "governmental programs start to encourage utilization of research only after the R&D results have been generated" rather than during the idea development phase of the innovation process.

NASA/DoD AEROSPACE KNOWLEDGE DIFFUSION RESEARCH PROJECT

This cooperative effort is sponsored by NASA, Code RF and Code NTT, and the DoD, Office of the Assistant Secretary of the Air Force, Deputy for Scientific and Technical Information. The research project is a joint effort of Indiana University's Center for

Survey Research and the NASA Langley Research Center. As scholarly inquiry, the project has both an immediate and a long-term purpose. In the first instance, it provides a practical and pragmatic basis for understanding how the results of NASA/DoD research diffuse into the aerospace R&D process. Over the long term, it provides an empirical basis for understanding the aerospace knowledge diffusion process itself and its implications at the individual, organizational, national, and international levels.

Despite the vast amount of scientific and technical information (STI) available to potential users, several major barriers to effective knowledge diffusion exist.[31] First, the very low level of support for knowledge transfer in comparison to knowledge production suggests that dissemination efforts are not viewed as an important component of the R&D process. Second, there are mounting reports from users about difficulties in getting appropriate information in forms useful for problem solving and decision making. Third, rapid advances in many areas of S&T knowledge can be fully exploited only if they are quickly translated into further research and application. Although the United States dominates basic R&D, foreign competitors may be better able to apply the results. Fourth, current mechanisms are often inadequate to help the user assess the quality of available information. Fifth, the characteristics of actual usage behavior are not sufficiently taken into account in making available useful and easily retrieved information.

These deficiencies must be remedied if the results of NASA/DoD funded R&D are to be successfully applied to innovation, problem-solving, and productivity. Only by maximizing the R&D process can the United States maintain its international competitive edge in aerospace. The NASA/DoD Aerospace *Knowledge Diffusion Research Project* will provide descriptive and analytical data regarding the flow of STI at the individual, organizational, national, and international levels. It will examine both the channels used to communicate information and the social system of the aerospace knowledge diffusion process. The results of the project should provide useful information to R&D managers, information managers, and others concerned with improving access to and utilization of STI.

Project Assumptions

- Rapid diffusion of technology and technological developments requires an understanding of the aerospace knowledge diffusion process;
- Knowledge production, transfer, and utilization are equally important components of the aerospace knowledge diffusion process;
- Understanding the channels; the information products involved in the production, transfer, and utilization of aerospace information; and the information-seeking habits, practices, and preferences of aerospace engineers and scientists are necessary to understand aerospace knowledge diffusion;
- The knowledge derived from federally funded aerospace R&D is indispensable in maintaining the vitality and international competitiveness of the U.S. aerospace industry and essential to maintaining and improving the professional competency of U.S. aerospace engineers and scientists;
- The U.S. government technical report plays an important, but as yet undefined, role in the transfer and utilization of knowledge derived from federally funded aerospace R&D; and

- Librarians, as information intermediaries, play an important, but as yet undefined, role in the transfer and utilization of knowledge derived from federally funded aerospace R&D.

Project Objectives

- Understanding the aerospace knowledge diffusion process at the individual, organizational, and national levels, placing particular emphasis on the diffusion of federally funded aerospace STI;
- Understanding the international aerospace knowledge diffusion process at the individual and organizational levels, placing particular emphasis on the systems used to diffuse the results of government funded aerospace STI;
- Understanding the roles played by the NASA/DoD technical reports and aerospace librarians in the transfer and utilization of knowledge derived from federally funded aerospace R&D;
- Achieving recognition and acceptance within NASA and the DoD and throughout the aerospace community that STI is a valuable strategic resource for innovation, problem solving, and productivity;
- Providing results that can be used to optimize the effectiveness and efficiency of the Federal STI aerospace transfer system and exchange mechanism.

Project Design

The initial thrust of the project is largely exploratory and descriptive; it focuses on the information channels and the members of the social system associated with the Federal aerospace knowledge diffusion process. As scholarly inquiry, the project has both an immediate and a long-term purpose. In the first instance, it provides a pragmatic basis for understanding how the results of NASA/DoD research diffuse into the aerospace R&D process. Over the long term, the project will provide an empirical basis for understanding the aerospace knowledge diffusion process at the individual, organizational, national, and international levels. An outline of the descriptive portion of the project is contained in Table 1 as "A Five Year Program of Research on Aerospace Knowledge Diffusion."

Phase 1 of the 4-phase project is concerned with the information-seeking habits and practices of U.S. aerospace engineers and scientists, with particular emphasis being placed on their use of federally funded aerospace STI products and services. A number of studies have indicated that researchers' information input and output activities are related or, at least, associated. Their communication behavior can be viewed as a system of information input and output activities and characterized as a series of complex interactions affected by a variety of factors. These factors influence the use and production of information and can be used to understand and explain the use and production of information sources and products (e.g., NASA/DoD technical reports).

The conceptual model shown in Figure 2 assumes a consistent internal logic that governs the information-seeking and processing behavior of aerospace engineers and scientists despite any individual differences they may exhibit. This logic is the product of several interacting structural and sociometric factors, the purpose for which the

	Phase 1 1989–1991	Phase 2 1990–1992	Phase 3 1990–1991	Phase 4 1991–1994
Level	•National •Individuals •U.S. Aerospace Engineers and Scientists	•National •Individuals and Organizations •Aerospace librarians in gov't and industry •U.S. gov't and aerospace industries	•National •Individuals and Organizations •U.S. academic faculty, students, and engineering libraries	•International •Individuals and Organizations
Focus	•Knowledge production and use	•Knowledge transfer and use	•Knowledge transfer and use	•Knowledge production, transfer, and use
Emphasis	•Use, importance, and production of NASA/DOD STI (e.g., technical reports) •Impediments to access, transfer, and use of NASA/DOD STI •Use and importance of AGARD and non-U.S. STI •Use and importance of information technology •Information sources used in problem solving	•Use, importance, and production of NASA/DOD STI (e.g., technical reports) •Impediments to access, transfer, and use of NASA/DOD STI •Use and importance of AGARD and non-U.S. STI •Use and importance of information technology •Effectiveness of system used to transfer U.S. gov't funded STI	•Use, importance, and production of NASA/DOD STI (e.g., technical reports) •Impediments to access, transfer, and use of NASA/DOD STI •Use and importance of AGARD and non-U.S. STI •Use and importance of information technology •Effectiveness of system used to transfer U.S. gov't funded STI	•Use and importance of NASA/DOD STI •Use of AGARD and non-U.S. STI •Impediments to access, transfer, and use of aerospace STI •Use of information technology •System used to transfer results of gov't funded aerospace STI non-U.S. aerospace STI, and systems, policies, and practices
Subjects	•AIAA membership •SAE membership	•U.S. aerospace librarians in gov't and industry •Selected U.S. gov't facilities and aerospace companies	•U.S. aerospace faculty, academic engineering libraries, and U.S. aerospace students (seniors) in USRA capstone design courses	•RAeS •aerospace faculties and •DGLR students •JSASS •aerospace librarians
Method	•Pilot study •Self-administered mail questionnaires •Telephone follow-ups	•Self-administered mail questionnaires •Personal interviews •Telephone follow-ups	•Self-administered mail questionnaires •Personal interviews •Telephone follow-ups	•Pilot study •Self-administered mail questionnaires
Desired Outcomes	•Understanding of individual information-seeking behaviors of U.S. aerospace engineers and scientists •Explain use/non-use of U.S. gov't funded STI products and services by U.S. aerospace engineers and scientists	•Understanding of the internal flow of aerospace STI in gov't and industry •Understanding of the system used to transfer results of U.S. gov't funded aerospace STI	•Understanding of the internal flow of aerospace STI in academia •Understanding of the system used to transfer results of U.S. gov't funded aerospace STI	•Understanding of individual information-seeking behavior •Understanding of the system used to transfer results of gov't funded aerospace STI •Understanding of non-U.S. aerospace STI systems, policies, and practices

Table 1. A Five-Year Program of Research on Aerospace Knowledge Diffusion

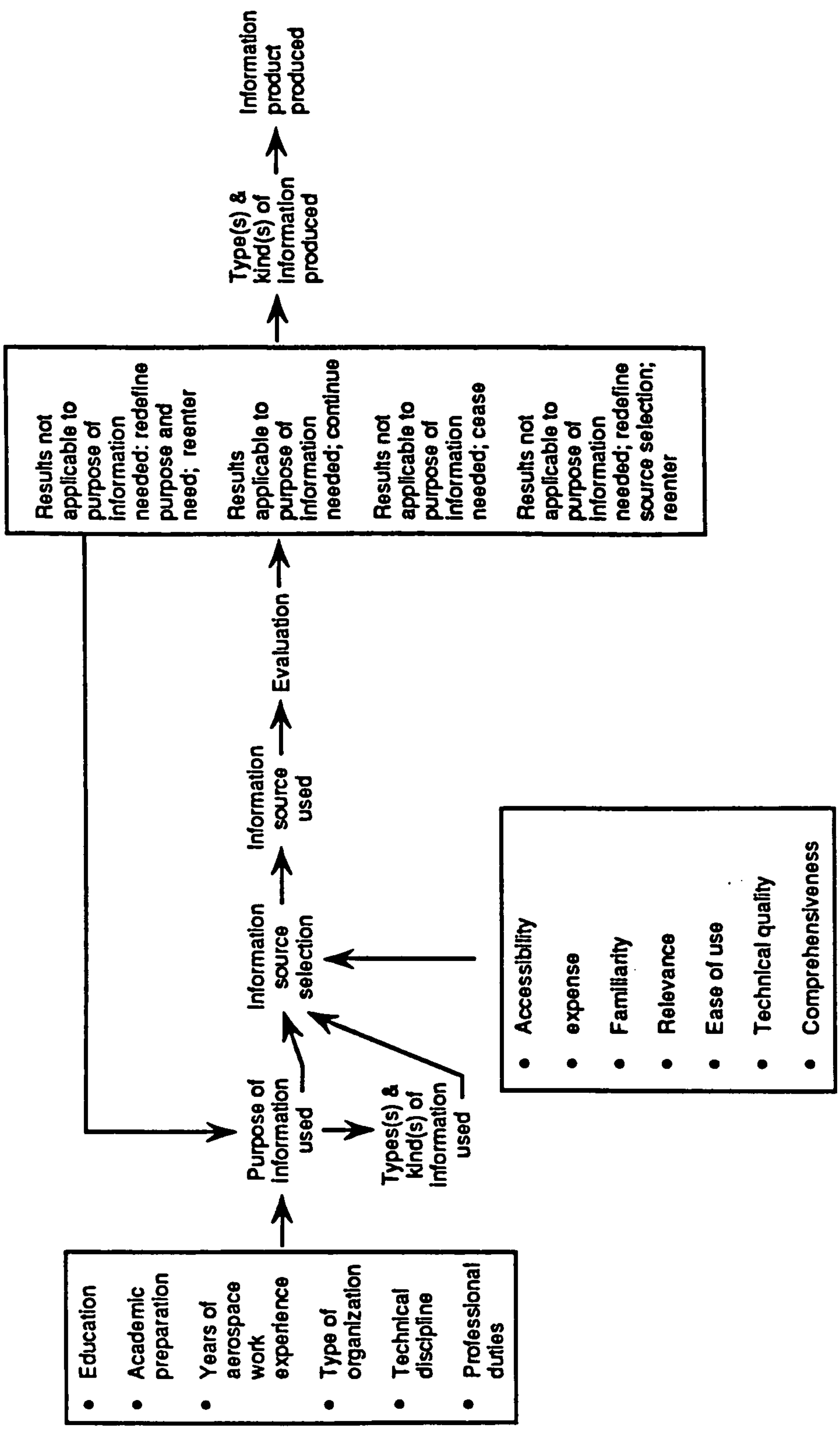

Figure 2. A Conceptual Model for the Use, Transfer, and Production of Scientific and Technical Information by U.S. Aerospace Engineers and Scientists

information is needed, and the perceived utility of various information sources and products. The model is shown as a flow chart consisting of several functions and actions, including an evaluation function and a reinforcement function that provide feedback.

The results of the *Phase 1 pilot study* indicate that U.S. aerospace engineers and scientists spend approximately 65 percent of a 40-hour work week communicating STI. The types of information and the information products used and produced in performing professional duties are similar, with basic STI and in-house technical data most frequently reported. STI *internal* to the organizational is preferred over *external* STI, which includes NASA/DoD technical reports, journal articles, and conferences/meeting papers. Respondents identified informal channels and personalized sources as the primary method of STI seeking, followed by the use of formal information sources, when solving technical problems. Only after completing an informal search, followed by using formal information sources, do they turn to librarians and technical information specialists for assistance.

Phase 2 focuses on aerospace knowledge transfer and use within the larger social system, placing particular emphasis on the flow of aerospace STI in government and industry and the role of the information intermediary (i.e., the aerospace librarian/technical information specialist) in knowledge transfer. In Phase 2, the process of innovation in the U.S. aerospace industry is conceptualized as an information processing system which must deal with work-related uncertainty through patterns of technical communications.

Information processing in aerospace R&D (Figure 3) is viewed as an ongoing problem-solving cycle involving each activity within the innovation process, the larger organization, and the external world. For purposes of this study, the innovation process is conceptualized as a process of related activities or units beginning with research on one end and service and maintenance on the other.

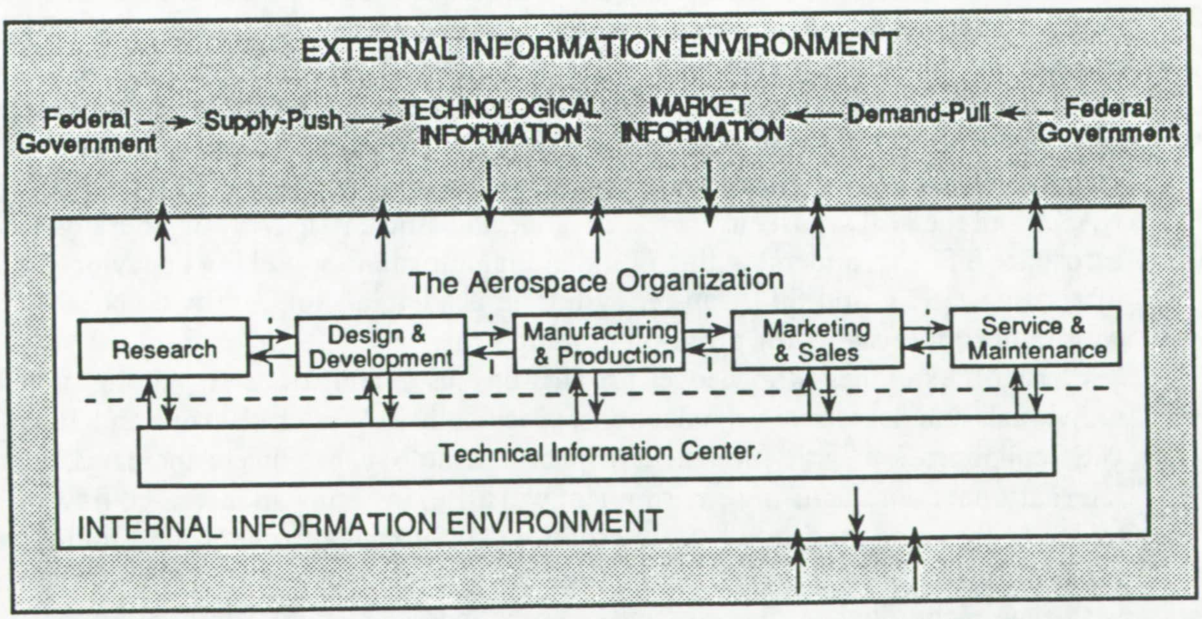

Figure 3. The Aerospace Innovation Process as an Information Processing System

These activities or units are highly differentiated, however. They operate on different time frames, with different goals, and with varying professional orientations.[32] These differences in norms and values also carry with them different internal coding schemes which suggest that each unit may possess specific and unique information requirements and information processing patterns. In addition, each unit is likely to have different sources of effective feedback, evaluation, and information support.[33]

For any given task, each activity or unit within the innovation process "must [based on open system theory] effectively import technical and market information from the external information world."[34] New [external] and established [internal] information must be effectively processed within the work area; decisions, solutions, and approaches must be worked on and coordinated within each activity and within the organization; and outputs, such as decisions, processes, products, and information, must effectively be transferred to the external environment. The outputs of this process create conditions for another set of activities, thereby initiating another information processing cycle. Throughout the process, organizations must be sensitive to the differences between the activities or units that comprise the innovation process. Specialized feedback, evaluation, and support may be required to process new information from internal and external sources.[35]

It is, however, the nature of organizations engaged in innovation to isolate themselves from the outside world, to erect barriers to communication with their external environment, and to rely on information internal to the organization.[36] This behavior occurs because of the need for organizations to exercise control over those situations in which they interact with the "outside" and to reduce uncertainty, and because these organizations are frequently involved in activities of a proprietary nature.[37,38] Numerous studies have found a strong relationship between successful innovation, idea formulation, and information external to the organization.[39,40,41] The danger, then, for organizations engaged in innovation is to become isolated from their *external* environment and from information *external* to the organization.[42]

Phase 3 focuses on knowledge use and transfer at the individual and organizational levels in the academic sector of the aerospace community. Faced with shrinking enrollments, particularly at the graduate level, university aerospace programs must find ways to maintain the talent pool that will advance aerospace technological development and guarantee U.S. competitiveness. To prepare future aerospace engineers and scientists, academic programs must have access to "state of the art" STI. Consequently, NASA and the DoD must ensure the effective and efficient delivery of federally- funded aerospace STI. An understanding of individual information-seeking behavior, the flow of aerospace STI, and STI transfer system in academia should provide NASA/DoD with important insights for program development.

Phase 4 examines knowledge production, use, and transfer among non-U.S. individuals and aerospace organizations, specifically in Western Europe and Japan. As U.S. collaboration with foreign aerospace technology producers increases, a more international manufacturing environment will arise, fostering an increased flow of U.S. trade. At the same time, however, international industrial alliances will result in a more rapid diffusion of technology, prompting the U.S. aerospace industry to forge ahead with new technological developments. To cooperate in joint ventures as well as to compete successfully at the international level, U.S. aerospace industries will need to develop methods to collect, translate, analyze, and disseminate the best of foreign aerospace STI. Therefore, an understanding of the process by which non-U.S. aerospace engineers and scientists communicate at the individual and organizational levels becomes essential.

CONCLUSION

The President's Commission on Industrial Competitiveness concluded that "we must be able to compete [internationally] if we are going to meet our national goals."[43] Since 1965, however, seven of our ten U.S. high technology industries have lost world market shares.[44] The major exception to this rule is the aerospace industry which continues to be the leading positive contributor to the United States balance of trade among all merchandise industries.[45]

In his study of the commercial aviation sector of the aerospace industry, Mowery concludes that R&D investment resulted in dramatic productivity increases. Mowery further states that "total factor productivity in this [commercial aviation sector] industry has grown more rapidly than in virtually any other U.S. industry during the postwar period."[46]

Indeed, the U.S. aerospace industry leads all other industries in expenditures for R&D. The National Science Foundation estimates that total R&D expenditures on U.S. aerospace projects reached $24 billion in 1988.[47] However, the U.S. aerospace industry, in particular the commercial aviation sector, is in the midst of profound change and now faces a significantly more challenging competitive and global environment.[48] The MIT Commission on Industrial Productivity reinforces this position, stating that "federal regulatory policy and foreign competition has dramatically altered the marketplace for the U.S. commercial aviation sector."[49]

Numerous factors contribute to the economic growth, prosperity, and performance of a nation. Studies performed by economists reveal that from 40 to 90 percent of the increase in economic growth can be attributed to technological innovation, gains in knowledge, diffusion of technology, or similar innovation-related factors.[50,51] Although the precise amount of their contributions to economic growth, prosperity, and performance remain unresolved, the consensus is that technological innovation has contributed significantly to the economic growth of post-World War II United States, in general,[52] and the U.S. commercial aviation industry, in particular.[53] Economists, such as David, point out that "technological innovation is the primary, if not the only means of improving industrial productivity. It is the force propelling the American economy forward and a process [that is] inextricably linked to knowledge transfer and diffusion."[54]

The importance of the U.S. aerospace industry to the American economy is illustrated in the following commentary offered by the Aerospace Industries Association:

In 1987, U.S. aerospace exports totaled nearly $32 billion. Imports of similar goods were approximately $10 billion for a positive sector trade balance of $22 billion. This was a net improvement of $4 billion over 1988. In fact, the U.S. sectoral trade balance in aerospace products has improved every year since 1984. The contrast to other U.S. manufacturing industries is striking. The trade trend for high-tech U.S. industries, such as computers and automobiles, has been steadily negative. For such industries the goal is reversing these persistent negative trends; for U.S. aerospace, the goal is to maintain its positive trade balance.[55] In spite of its importance to the U.S. economy and the balance of trade, very little is known about technological innovation and the diffusion of knowledge in the aerospace industry, either in terms of the channels used to communicate the ideas and the information-gathering habits and practices of the members of the aerospace social system. Therefore, it is likely that an understanding of the process by which aerospace STI is communicated through certain channels over time among the members of the aerospace social system would contribute to stimulating technological innovation, maximizing the R&D process, increasing R&D productivity, and improving and maintaining the professional competence of U.S. aerospace engineers and scientists.

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