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The Use of Computer Networks in Aerospace Engineering

Ann P. Bishop
University of Illinois at Urbana-Champaign
Urbana, Illinois

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CHAPTER 1:
INTRODUCTION TO THE RESEARCH

1.1. Introduction

The purpose of this research is to explore and describe the use of computer networks by aerospace engineers. Computer networks, also called electronic networks, are defined in this study as telecommunication links that connect computers to each other or to other devices, allowing users access to remote resources through such applications as electronic mail, file transfer, and remote log-in. Aerospace engineers, the community of interest in this research, are engaged in research, development, design, testing, and manufacturing related to a wide variety of aerospace technologies, from commercial aircraft to guided missiles to space equipment.

This research investigates computer networking from a user perspective. This means that it seeks to describe the manner in which electronic networks are currently used by aerospace engineers to facilitate communication and assist in the performance of their work tasks. Further, the study explores factors associated with network use, and impacts of network use, from the perspective of members of the aerospace engineering community. The ultimate goal of the study is to increase understanding of the work, communication, and networking needs and behavior of aerospace engineers so that more effective networking systems, services, and policies can be developed for members of the aerospace engineering community. Results may be applicable to other scientific and technical work as well.

1.2. The Research Context: Aerospace Engineering and Computer Networks

The aerospace industry is of vital importance to the economy of the United States. It employs 1.3 million people, and its total annual sales amount to over $117 billion. Over $24 billion was spent on aerospace research and development in 1990, most of that by the Federal government, who is the largest customer for aerospace products (Aerospace Industries Association, 1991). Aerospace belongs to the high technology sector of American industry. It encompasses military and commercial segments and is dominated by a handful of large companies. Competition is fierce, and the billion dollar investments that these firms make are fraught with risk. The development of a new product may take decades and sales depend more on meeting rigid performance and schedule requirements than on product pricing (Bluestone, Jordan, & Sullivan, 1981).

Aerospace engineers work in all stages of product development and are employed in industry, government, academia, and other not-for-profit settings. The major work specialties comprising aerospace engineering include structural design, avionics, aerodynamics, propulsion, electronic systems, and material and processes. Aerospace engineering work also varies according to primary job responsibility (e.g., management, science, or engineering) and engineering subfield (e.g., chemical, mechanical, or electrical). Finally, aerospace engineering work can also be described in terms of the kinds of tasks and activities which the typical engineer performs on a day-to-day basis. There is tremendous variety in the work day of most aerospace engineers. As is the case with engineers in other industries, many aerospace engineers define problems, come up with new ideas, solve problems, review the work of others, produce reports, perform calculations, conduct experiments, and negotiate with customers and co-workers. In order to perform these tasks, aerospace engineers require a variety of business and technical information that includes fundamental design concepts, criteria and specifications, quantitative data and practical know-how. Much of this information comes from co-workers and in-house documents.

Currently, a number of aerospace engineering organizations are exploring the ability of computers and electronic networks to improve the performance of engineers. They hope that by facilitating communication, improving coordination, and allowing shared access to important data and tools, electronic networks will decrease both the costs and time needed to bring products to market and will facilitate the production of higher quality products that better meet customer needs. Due to proprietary and security concerns, and the need to maintain and transfer large volumes of critically important data, many engineering organizations have implemented their own private, high-speed networks that are used only by their own employees.

Today, aerospace engineers can use networks for distributed access to rapidly-changing information about project requirements and progress. They can receive electronic data collected by remote instruments and use networks to analyze those data with the help of remote computers. Networks facilitate the shipment of documents and designs and are used to automate the manufacturing process. Electronic data interchange (EDI) is used to exchange orders and invoices with vendors and suppliers, and contracts with clients and customers. Aerospace engineers can also use networks for information retrieval in connection with both in-house and commercial or government databases. Finally, some engineers in the aerospace industry use electronic networks for a variety of communication purposes. Computer-based message systems such as electronic mail (e-mail), bulletin boards, and conferences can be used to call on the expertise of others, locate resources, schedule and coordinate work, and exchange information. Such systems can be used to contact project team members, managers, people in other departments or divisions, colleagues in outside organizations, customers, and funders.

Many of the benefits of networking that individual aerospace organizations seek are also important on a national scale. Proponents of national networking assert that Federal investments in high-speed networks will pay off in terms of improved national productivity, scientific and technical advances, and economic competitiveness. The use of networks in engineering has itself received increasing attention. In introducing the High Performance Computing Act of 1991 (Congress. Senate, 1991), for example, then Senator Albert Gore of Tennessee remarked that networked supercomputers are used by engineers to design better airplanes. The bill itself asserted that the development and use of high-performance computers and networks is essential for maintaining and enhancing industrial productivity in the United States (Section 2.a.2). The High Performance Computing Program (HPCC) initiated in the Executive branch also aims at improving national engineering outcomes. The HPCC "is driven by the recognition that unprecedented computational power and capability is needed to investigate and understand a wide range of scientific and engineering 'grand challenge' problems" such as aerospace vehicle design and microsystems design and packaging (Office of Science and Technology Policy, 1991, p. 2). The Clinton/Gore administration has continued to foster policies in support of national networking, first under the rubric of the National Research and Education Network (NREN) and, more recently, in connection with the development of the National Information Infrastructure (NII). And anticipated engineering uses and outcomes from computer networking continue to receive Federal attention.

Although the use of electronic networks in the aerospace industry is increasing, the financial stakes are high, and many benefits are expected on both an organizational and national level, no empirical studies of the use of electronic networks have dealt exclusively or extensively with aerospace engineers (or any other group of engineers). Reports of what the technology can do have appeared in the popular and technical literature. Several aerospace firms have described some of their experiences with network implementation. The Federal government invests millions of dollars to study and improve the technical capabilities of national high-speed networks. But very little is known about the users of these systems, including aerospace engineers. What kinds of aerospace engineers use networks? Which network applications do they use? To perform which job functions? Under what circumstances? What problems and constraints do they encounter? What effects do they perceive and experience? In spite of large financial investments and promises of strategic competitive advantages, very little is actually known about the use and impact of electronic networks in the aerospace industry.

1.3. Scope of the Current Research

Based in part on expectations of improved engineering effectiveness and efficiency, both individual aerospace engineering organizations and the Federal government are making large investments in computer networking to support R&D, economic competitiveness, and technology transfer. Federal policy makers, network system designers and service providers, and workplace managers are struggling to implement effective systems and develop appropriate policies to govern network implementation and use. But little empirical information has been gathered that can be used to help in understanding the impact of network investments, designs, and policies on aerospace engineering work. Thus, many major investment, design, and policy decisions are being made solely on the basis of educated guesses about the contribution of electronic networking to the aerospace engineering work and communication.

In general, technical and financial issues related to networking initiatives receive the bulk of attention from network implementers, while social and behavioral issues that also impact the degree to which networks will effectively support the activities of the intended user communities are inadequately examined (McClure, Bishop, Doty, & Rosenbaum, 1991). Aerospace engineering efficiency and effectiveness, at both the organizational and national level, will not be optimally enhanced by the implementation of electronic networks until the manner in which networks facilitate aerospace engineering communication and work tasks is better understood. The success of institutional and national networking endeavors will depend on the development of network features, policies, and support programs based on solid knowledge of aerospace users' needs and habits and substantiated links between network use and engineering outcomes. Without such data it will be difficult to develop and implement effective policies and services or predict the results of networking investments.

This gap is addressed by the current study, which gathers data that describe the current uses of electronic networks by aerospace engineers and explore the relationship between electronic networks and engineering communication and work. The data collected address the following research questions:

1) What types of computer networks and network applications are currently used by aerospace engineers?

2) What work tasks and communication activities do aerospace engineers use computer networks to support?

3) What work factors are related to the use of computer networks by aerospace engineers?

4) What are the impacts of network use on aerospace engineering work and communication?

Empirical data on perceptions and behavior related to work, communication, and network use have been gathered from aerospace engineers through site visits, interviews, a national telephone survey, and a national mail survey. Engineers represented in the study occupy different types of jobs in a variety of settings. Following national employment trends in the aerospace industry (National Science Foundation, 1987), most of the study's subjects are employed by industrial organizations, and few are employed primarily in such activities as research, marketing, and manufacturing.

All networking applications relevant to engineering work are considered. These include, for example, electronic mail, information retrieval, remote access to computing resources, and file transfer. Wherever feasible and appropriate, network use is tied to particular work tasks and communication activities. Network impacts and factors affecting network use are derived primarily from the reports of aerospace engineers participating in the research, and both positive and negative factors and impacts are explored. Work-related factors influencing use were expected to encompass such things as primary job responsibility, type of organizational unit, aerospace subfield and product, and the degree to which computers are a part of one's work, as well as situational characteristics such as the need for secrecy, accuracy, extensive interpersonal interaction, or reference to physically-encoded knowledge. Networking impacts emerge as both perceptions and behaviors, in such forms as degree of use, perceived importance of various network applications, perceived increases or decreases in work and communication efficiency and effectiveness, and changes in work or communication patterns.

1.4. The Research Approach

The conceptual and methodological approach of this research begins from the premise that in order to maximize the value and utility of electronic networks, they must be designed with the needs and goals of their users in mind. The user-based conceptual and methodological approaches exemplified by the current study are described below.

1.4.1. User-Based Approaches to the Study of Information and Communication Activities

Information seeking and use is a cognitive activity that takes place within a complex social matrix. In recognition of this, a number of researchers from a variety of disciplines have applied user-based approaches to the investigation of information and communication activities. These approaches have been used to investigate the information needs and uses of particular communities of users and are often intended to improve the design and evaluation of particular information systems and services. In such work, special attention is often given to individuals' needs, goals, actions, and settings. Understanding the user context is important because it not only uncovers problems with existing systems and services, it elucidates underlying needs in a way that can guide the development of new generations of systems. It also points to improvements in policies--as opposed to technology features per se--that could significantly enhance the effectiveness of systems and services. Finally, user-based approaches tend to reveal ways in which new technologies are changing the way people work and learn, as opposed to simply recording ways in which new technologies are automating people's standard activities.

The current study is not based exclusively on any single theory or method developed in past research. The phenomena of interest--engineering work and communication, network use, factors associated with network use, and networking impacts--have been studied from the perspectives of a variety of social science disciplines, including library and information science, communications, sociology, psychology, management. Even within each of these disciplines there is no unified theory of computer-based communication and its relationship to knowledge transfer and the conduct of work; nor is there complete consensus on appropriate definitions for concepts or methodological approaches. Across disciplines, there is even greater variation in the conceptual and theoretical base for studying network use in work communities. While user-based research arises in all of these disciplines, and shares the general characteristics and concerns described above, results have not yet led to conclusive evidence about the nature and impact of network use, and theory remains underdeveloped.

Thus, this study draws its assumptions, goals, and methodological techniques from several relevant sources, integrating them in a manner appropriate to its own particular purposes. It also builds on the approaches and techniques that the researcher has used successfully in earlier work on scientific and technical information transfer. Previous research that has been most influential in shaping the conceptual and methodological approaches of the current study is highlighted below and discussed more fully in Chapter 2, which also describes relevant results from previous research on engineering work and networking.

In an earlier study, the researcher explored the impact of electronic networks on scientific work and communication from a user perspective (McClure et al., 1991). This study reported on the use of different network applications to support particular research activities, on technical and non-technical problems and issues experienced by users, and on perceived impacts of network use on the conduct of research and on formal and informal scientific communication. This study produced results that were used by Federal policymakers and network service providers to inform the development of network services and policies and predict the impact of networking on scientific research; these are also the goals of the current study.

The work of other networking researchers also contributes significantly to the current study. Sproull and Kiesler argue for the importance of considering social and behavioral factors in the investigation of networking. Their influential work in the area of electronic communication (see Sproull & Kiesler, 1991 for an overview) is based on the assertion that although organizations may implement networked systems in the hope that they will increase the speed or decrease the costs of work, the broader impact of networks depends on how they affect the nature of work and the environment in which work is performed. Hiltz's pioneering work on the use of electronic networks in scientific environments (see, e.g., Hiltz, 1984) has demonstrated the importance of examining, in tandem, individuals' behavior and perceptions in order to arrive at an understanding of networking use and impacts that is both practically and theoretically useful. The current research is also related to previous studies of networking impacts that address the relationship of computer-mediated communication (CMC) to task and social aspects of work (e.g., Foulger, 1990; Steinfield, 1986a).

A number of pioneering studies of information needs and use also inform the approach adopted by the current research. Taylor's (1991) theoretical investigation of "information use environments" emphasized the importance of understanding the context in which information is sought, conveyed, and applied. Context for professional groups, including engineers, is defined by Taylor as a combination of the nature of work problems, solutions, and settings associated with particular types of jobs. Taylor assumes, in other words, that members of a profession share tasks, goals, and needs in a way that influences their use of information. The current study is also close, conceptually, to empirical research on scientific and technical communication and information exchange conducted by Allen (1984) and Garvey (1979). These researchers identified and described communication sources and channels used by engineers and scientists, respectively, and connected them with various work tasks and outcomes.

A shift in emphasis toward the study of cognitive and situational variables surrounding information needs and uses, and away from users' personal characteristics and specific system features, has been advocated by a number of communications and information science researchers, most notably Dervin and Nilan (see Dervin & Nilan, 1986 for their discussion of this approach). Following their arguments, the current study also devotes special attention to understanding what there is about a particular situation that encourages an individual to use networks in fulfilling an information need. In terms of the four programs of research in scientific communication identified by Lievrouw (1988), the current study is closest conceptually to what she terms "user studies" (where information is treated as a commodity whose value depends on user needs) and "lab studies" (where information is treated as a construction, and value resides in the meanings and perceptions of individuals).

Many information and communication system designers ignore three important aspects of user-based design: the personal characteristics of users, the particular tasks and activities that networks are to support, and the social matrix in which these tasks and activities are carried out. There are, however, a number of researchers who advocate user-based approaches to system design. Galegher and Kraut (1990) argue that understanding the user's work and work environment is a critical factor in the design of information and communication systems. They note that "the history of experience with telecommunications and computer-based information systems contains many instances of expensive technological failures that are at least partly attributable to designs that do not mesh well with the social and behavioral systems in which they are to be used" (p. 4). Wixon, Holtzblatt, and Knox (1990) also insist on the importance of understanding how new technology "supports, extends, and transforms users' work" and of adopting research techniques "that yield an *understanding* of real customers [i.e., users] solving real problems in the real world (p. 330). Similarly, Gould, Boies, and Lewis (1991) emphasize the importance of first understanding the work and work environment of those people for whom productivity-enhancing information systems are designed.

Finally, the current study also draws on a number of important sociological studies of scientific and technical work and communication for its conceptual approach. Such studies demonstrate that scientific and technical work and communication does not take place in a vacuum but is embedded in a web of personal and political motivations (Charlesworth, Turnbull, & Stokes, 1989; Gilbert & Mulkay, 1984; Latour & Woolgar, 1979).

In summary, a number of user-based approaches have been applied to the study of information and communication activities and technologies. The current research applies appropriate assumptions and techniques from this body of work to the study of the use of electronic networks by aerospace engineers. Based on the demonstrated utility of this body of work and on the lack of user-based investigations of networking, this study argues that it is vital that network service providers and policy makers undertake systematic empirical evaluation of networking from a user perspective. It also asserts that decisions about network implementation should not be based exclusively on technical, economic, or political considerations. We know relatively little about the users and uses of networks in terms of how networks are integrated into the work lives of those people whose activities they are meant to support. Few user-based evaluations of networks have been done that are systematic, empirical investigations of network users' behavior and perceptions, and that provide insights into critical success and failure factors in networking.

1.4.2. Developing a User-Based Model of Networking in Aerospace Engineering

Broadly speaking, the goal of this research is to describe and explore the ways that electronic networks are being integrated into the work lives of a particular community of users. It is based on the premise that the use and impact of electronic networks on aerospace engineers is related to the nature of their communication and work. Thus, the emphasis of the study will be on the identification of characteristics of work and communication activities, environments, and situations that are associated with network use. Since network use is examined within the context of work and communication, social and behavioral determinants and effects of new communication technology will be given special attention.

Figure 1-1 presents a model of the aerospace engineer's use of electronic networks that is used to identify and organize concepts and issues important in this study. The model represents the study's focus on those network uses, impacts, and factors associated with use that operate within the context of the aerospace engineering work environment. According to the conceptual model, an aerospace engineer may use electronic networks--given a particular set of circumstances that are combined in the work environment--to access the variety of resources required to accomplish a particular work task. The model depicts the environment within which individuals use networks as a complex blend of social, behavioral, technical, and situational factors.

The conceptual model is based on descriptions of engineering work and communication that have appeared in the literature. This literature is reviewed in Chapter 2. Reports of the information seeking and use behavior of engineers (e.g., Allen, 1984; Gould & Pearce, 1991; Kaufman, 1983; Kremer, 1980; Pelz & Andrews, 1966; Pinelli, 1991a; Rosenbloom & Wolek, 1970; Shuchman, 1981) describe the engineering resources needed by engineers to perform their work. These resources include people, such as colleagues, engineers in other organizational units, customers, vendors, and consultants. They also include a wide range of print and online information resources such as trade journals, technical reports, parts lists, technical specifications, budgets and schedules, designs and design histories, laboratory notebooks,manuals, and textbooks. Finally, engineering resources include tools for experimentation, analysis, and performing calculations.

Engineering resources are used in the performance of a wide range of engineering tasks and activities. These are described in information science and communication sources, in

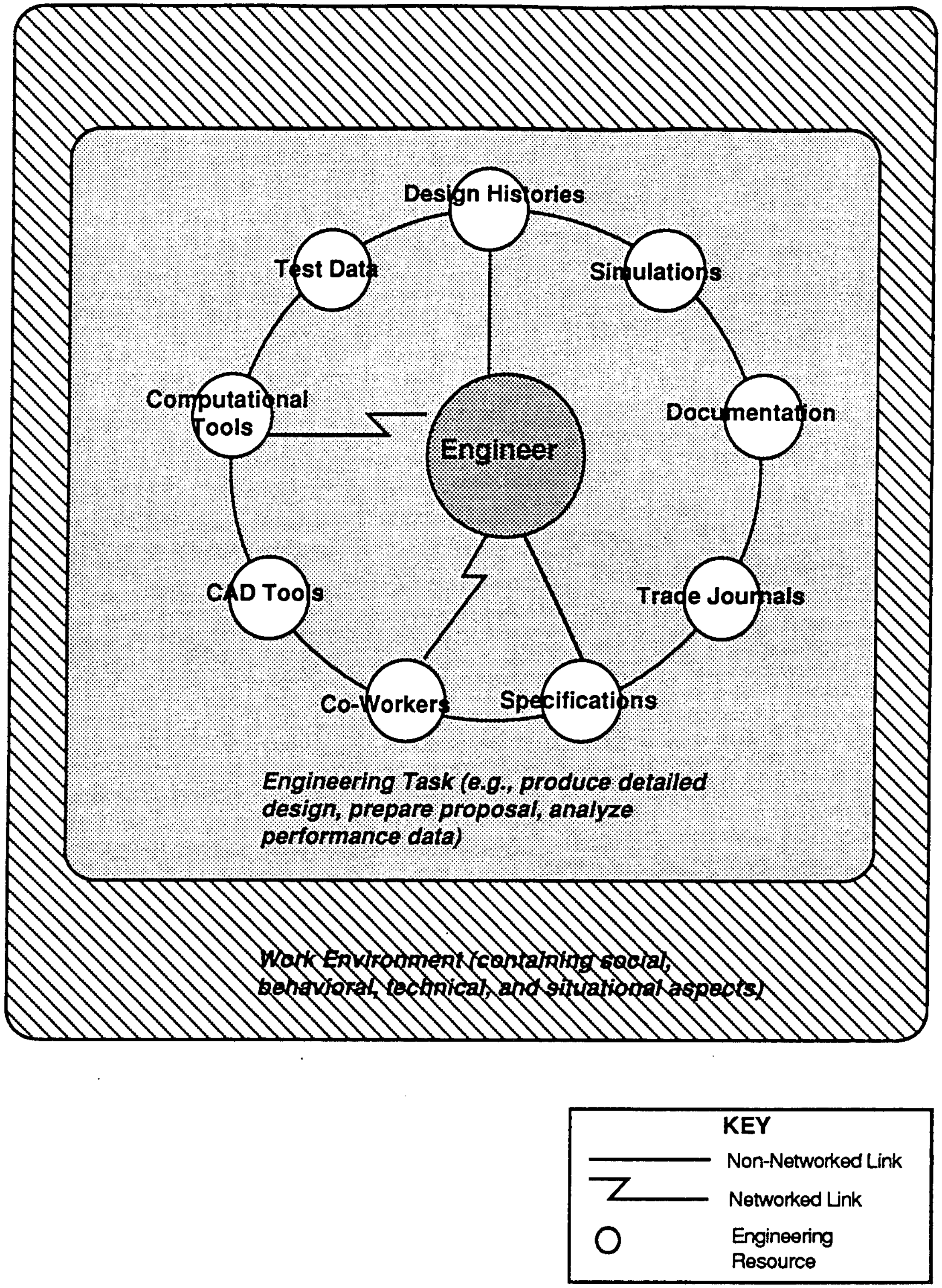


Figure 1-1.
Network Use within the Context of Engineering Work

popular and professional descriptions of the work of engineers, and in sociological and historical scholarship devoted to the study of technology (see, e.g., Adams, 1991; Buhl, 1969; Florman, 1987; Kamm, 1989; Kemper, 1990; Ritti, 1971; Taylor, 1991; Vincenti, 1990). According to these sources, the kinds of tasks and activities that engineers perform include identifying problems, conducting experiments, writing proposals, analyzing performance data, scheduling and reviewing work, building prototypes, and writing documentation and technical reports. These sources also describe various social, behavioral, technical, and situational aspects of the engineering work environment. They suggest that the use of engineering resources and technology and the performance of engineering tasks and activities cannot be separated from the work environment in which they occur. Engineering work, for example, is typically conducted within strict time and resource constraints, involves extensive and intensive teamwork, and is subject to personal and political influences.

This study asks questions and adopts techniques appropriate to its user perspective and to the concepts and issues it explores. It employs a user-based approach to investigate the relationships between networking and aerospace engineering communication and work. This means that it does not focus on technology or organizational issues, but investigates network use from the perspective of individual engineers. The research relies on their own descriptions of their work tasks and communication behavior rather than on existing classification schemes or on the opinions of people other than those engineers who actually participated in the investigation.

The data collection activities pursued in this study are inductive and cumulative. Preliminary activities included site visits, a telephone survey, and individual interviews with aerospace engineers. Experience gained in each activity was used to select specific methods and refine instruments used in subsequent data gathering stages. While the research questions are answered primarily with data collected in the national mail survey, the in-depth, semi-structured interviews with aerospace engineers are used to enhance the depth of the study's user perspective. The interviews are used, in other words, to identify network uses, impacts, and factors affecting network use that are most meaningful from the point of view of aerospace engineers. Thus, the interviews are important in improving both the validity of the survey results and one's ability to interpret them.

1.5. Study Sponsors and Advisors

This study is sponsored by the National Aeronautics and Space Administration (NASA) and the Department of Defense (DoD), under the umbrella of their Aerospace Knowledge Diffusion Research Project (Pinelli, Kennedy, & Barclay, 1991). The Center for Survey Research (CSR) at Indiana University was under contract to provide technical advice and production assistance; technical advice was provided by the Project's NASA investigator as well. The researcher selected all approaches and techniques used in the study, designed and developed all the instruments, and oversaw the coding and statistical analysis of survey data. CSR staff conducted the preliminary phone survey; produced, mailed, and collected the mail questionnaires; coded and entered survey data, and performed requested statistical analyses. Staff at the Library Research Center at the University of Illinois at Urbana-Champaign also performed statistical analyses associated with the mail survey results. Computer software was used in the telephone interviews to automate data collection and analysis and was also used in the statistical analysis of mail survey results.

1.6. Benefits of the Research

This study contributes to existing knowledge about both the use of electronic networks and the nature of engineering work and communication. Systematic study of these domains is relatively recent, so findings from the study may be used to stimulate the development of theory. The study also provides examples of user-based techniques for studying information and communication technologies that may be useful to other researchers. As networks evolve and as the size and heterogeneity of the networking community increases, it will become increasingly important to gain experience with the conduct of user-based research in the study of computer networking, in order to gain insights into the needs and activities of different communities of users (Bishop & Bishop, 1994). The current study will help to identify, develop, and refine of user-based methods for the investigation of electronic networking.

Findings from this investigation are also intended to be of practical value. Electronic networks seem to offer many opportunities for facilitating and improving engineering work. But the medium and its use require careful scrutiny in order to realize projected benefits. Results of this research will provide baseline data on the current use of electronic networks by aerospace engineers. Perhaps more importantly, results will suggest reasons why networks are used, or not used, by aerospace engineers in the performance of particular work tasks. It is only recently that networking has become widespread enough for these data to be meaningful, i.e., indicative of future use patterns. This information can be used by Federal policy makers, network system designers, network service providers, and engineering managers as a basis for informed decision-making related to network investments, design features, implementation strategies, and management and use policies. Although the context for the current study is aerospace engineering, many of the results obtained, hence many of the study's benefits, are also expected to be relevant beyond the domain of aerospace. This is because the research will describe many needs, activities, goals, and constraints that are generic to engineering work, communication, and network use. Findings unique to the aerospace industry are fairly easily interpretable as such.

This study also produces benefits for professional engineering societies and for the library community. Findings can help information service providers and intermediaries who work with aerospace engineers better understand the information seeking and use behavior of their clients. Recent years have seen an upsurge in the number and variety of electronic information resources available to aerospace engineers. Many new systems incorporate mechanisms for the exchange of both formal and informal information. In these systems, information professionals have a new opportunity to improve service to their clients. But to do so, it will be important to become more familiar with the nature of work and communication in aerospace engineering and with the range of uses that engineers are finding for electronic networks. Thus, findings from the study should help in the strategic planning of new information systems and services in aerospace engineering environments.

Finally, the benefits of this research will be extended by disseminating the results as widely as possible. As noted above, one of the goals of user-based research is to bring users' needs and problems to the attention of those people who are in a position to resolve them. Thus, it will be important to bring results of this study to the attention of both institutional and national policy makers and service providers in engineering, networking, and information communities. Study participants will receive a synopsis of research findings and conclusions. Study sponsors (NASA and DoD) will receive a final report. Opportunities will also be sought to present results to a broader and more diverse audience.

CHAPTER 2:
UNDERSTANDING THE USE OF ELECTRONIC NETWORKS IN THE CONTEXT OF AEROSPACE ENGINEERING WORK

2.1. Introduction

The major goals of this study are to describe the current use of electronic networks by aerospace engineers and to explore relationships among network use and aerospace engineering work and communication. Reviewing what is known about the aerospace industry, engineering work and communication, and the use of electronic networks in science and technology environments sets the stage for the investigation by:

1) Providing background information needed to achieve an understanding of the major phenomena of interest in this study, i.e., aerospace engineering work, communication, and network use;

2) Providing an overview of research approaches that have been used to investigate these phenomena; and

3) Describing the current state of knowledge related to these phenomena and revealing gaps that the current study hopes to fill.

This investigation can be broadly classified as social science research. It seeks to understand the way that aerospace engineers work and communicate and the way that electronic networks --an emerging technology that facilitates both information processing and communication--are currently perceived and used by aerospace engineers. Further, this understanding may be used by network designers and managers at all levels to develop systems and policies that are better suited to the tasks and needs of the engineering community and, hence, more effective. The phenomena and issues that are relevant to the aims of the current study have been investigated by a variety of disciplines, including information science, communications, management, and sociology. This investigation draws from and hopes to contribute to knowledge in these areas.

Thus, the literature reviewed in this chapter is derived from all of these disciplines and incorporates social, behavioral, and policy perspectives.

Some work has appeared in the literature that explores the nature of engineering work and communication, but only a small portion of this focuses on the aerospace industry specifically. Further, no user-based empirical studies of networking appear to have been conducted that deal extensively or exclusively with engineers in any field. Thus, this chapter must cast a somewhat wider net in seeking what is known about the major phenomena of interest to this study: the chapter includes both popular and scholarly work on networking and on the nature of scientific and technical work, knowledge, and communication, drawing out that which appears particularly relevant to the aerospace engineering environment.

This chapter begins with a brief overview of the aerospace industry and aerospace engineering jobs. The next section describes the nature of engineering work and knowledge, focusing on findings and issues most applicable to aerospace engineers. The chapter then provides an overview of findings from studies of scientific and technical communication that were conducted before the use of electronic networks became widespread, but which may have implications for understanding the use of networks by aerospace engineers. It concludes with an overview of descriptions and studies of computer networking in the scientific and technical community, focusing on findings related specifically to network use and impact.

2.2. The Aerospace Industry

2.2.1 Introduction

The purpose of this section is to define the study's use of the terms "aerospace industry" and "aerospace engineering" and to identify characteristics of the industry that may play a role in the use of electronic networks. It is also important to understand the nature and structure of the aerospace industry and the nature of aerospace engineering in order to assess the applicability of study results to engineering work in other industries.

2.2.2. Nature and Structure of the Aerospace Industry

The aerospace industry encompasses firms which produce aircraft, space vehicles, guided missiles, or particular parts and accessories of any of those products; it also includes individuals and organizations conducting research in any of a broad range of areas related to flight in or outside the atmosphere (Pinelli, 1991b). The Standard Industrial Classification (SIC) system developed by the U.S. government can be used to broadly enumerate the range of products and activities typically considered to comprise the aerospace industry (Aerospace Industries Association,1991, p. 12). Major parts and accessories related to propulsion include propellers, engines, and propulsion units. Aerospace equipment and systems produced include those used in flight for communication, search and detection, and navigation and guidance. The general term "avionics" is often applied to such systems, which are virtually all computerized. Other equipment and electronic systems are used on the ground, for training and simulation. Another group of aerospace industry products are those collected under the rubric "dynamics and control." These include aeronautical and navigational instruments and measuring and controlling devices. These classifications suggest the incredible diversity of products manufactured by aerospace firms, which may vary from a single type of seal to an entire aircraft.

The aerospace industry is unusual in a number of ways, as compared to other U.S industries. The nature and structure of the industry have been described in a number of sources (e.g., Adams & von Braun, 1962; Bluestone, Jordan, & Sullivan, 1981; Goldman, 1985; Phillips, 1971; Rae, 1968; Steckler, 1965). The aerospace industry includes both military and commercial segments. The U.S. government is the largest customer for aerospace products. Due to the incredible complexity, major investment, and extreme risk associated with the production of major aerospace systems and products, the industry is dominated by a small number of commercial firms (Bluestone et al., 1981). Two firms, Boeing and McDonnell Douglas, account for almost one half of the industry's production, which is estimated to value about $127 billion in 1991 (Dept. of Commerce, 1991, pp. 22-3). Other major U.S. firms are Northrup, General Dynamics, Lockheed, and Grumman. These firms typically "bet the company" each time they embark on the development of a new airplane or space vehicle (Newhouse, 1982). Other firms of various types and sizes act as suppliers to these major players by contributing particular components, parts, and accessories that are used to assemble the final product. These include major corporations such as General Electric, IBM, and United Technologies, in addition to a wide range of smaller firms. A number of aerospace engineers in academia, not-for-profit R&D labs, and private firms act as consultants to the firms that manufacture these aerospace technologies.

The aerospace sector is faring well in terms of international competitiveness, with the trade surplus expected to equal about $32 billion in 1991 and is, on the other hand, increasingly characterized by international industrial cooperation (Dept. of Commerce, 1991, p. 22-1). Nonetheless, the industry's financial performance is lower than the combined average for all manufacturing firms (p. 22-3), pointing to a need to improve operating efficiency.

The aerospace industry leads all other industries in terms of R&D expenditures, which were estimated at about $25 billion in 1988 (Aerospace Industries Association, 1991, p. 102). The U.S. government funds the majority of this work, but funding has dropped somewhat in recent years due to cuts in the U.S. defense budget, and is expected to continue to decline over the next five years. The major government funding sources are the National Aeronautics and Space Administration, the Department of Defense, the Department of Commerce, and the National Science Foundation (National Science Board, 1989). Due to cuts in U.S. defense spending, many major firms have recently experienced layoffs and are engaged in restructuring their operations toward nonmilitary products.

Aerospace is generally characterized as a high technology industry, in terms of both its means of production and its output. Computer systems are used to control aircraft, space vehicles, and missiles; many components and subsystems are also computerized. In addition, computer systems are used to train aerospace personnel, to design and manufacture aerospace technologies, and to conduct research. As a whole, therefore, aerospace firms seem to adopt information technology earlier than do firms in a number of other industries (Shuchman, 1981).

This brief overview of the nature and structure of the aerospace industry highlights several key points about the industry that may have an impact on aerospace engineering work and communication patterns and, therefore, on the use of electronic networks by aerospace engineers. For example, because aerospace firms engaged in manufacturing major systems and components are large, complex, high-risk, and diverse organizations, extensive intraorganizational communication is needed. Extensive interorganizational communication is required where the primary contractor relies on a number of smaller firms to produce particular parts and accessories. Because the government plays a major role in setting R&D agendas, regulating the industry, and purchasing aerospace products, strong communication links exist between the industrial and government sectors. A large part of this communication is devoted to negotiating and documenting compliance with complex and formal procedures related to government reporting schedules, specifications, and documentation production. Extensive formal reporting requirements are needed because of the complexity, uniqueness, and lengthy development time of many aerospace products. They are also needed because product failures can lead to the serious losses in terms of both human life and equipment in which millions of dollars have been invested.

The aerospace industry is highly competitive and engages in extensive military work. Thus, both proprietary and security concerns will drive the communication behavior of aerospace engineers and the development of communication systems intended for use in the aerospace industry. R&D expenditures in the aerospace industry are enormous. This points to the importance of studies aimed at understanding communication efficiency and effectiveness, since R&D is largely a communication activity. The extent of R&D in aerospace also indicates the industry's reliance on both scientists and engineers. The extensive use of advanced technology in aerospace signals that aerospace engineers may have greater need for and access to advanced computing and communications infrastructure than do other kinds of engineers.

2.2.3. Aerospace Engineering

This section defines "aerospace engineering" as used in this study and describes the basic work activities of the aerospace engineer. In practical terms, aerospace engineering is a label that is applied to a very heterogeneous group of activities, and "is sometimes used more to designate all engineering activities in the broad industrial sector known as aerospace than to apply to a specifically defined field of engineering" (Kemper, 1990, p. 257). That is the scope of the term that will be adopted in this research. A degree in aerospace engineering implies a focus on aerodynamics, but the industry also employs significant numbers of individuals whose education and training is based in mechanical, civil, electrical, materials or other types of engineering. According to the *Occupational Outlook Handbook* prepared by the Department of Labor (1990, p. 64):

> Aerospace engineers design, develop, test, and help produce commercial and military aircraft, missiles, and spacecraft. They develop new technologies in commercial aviation, defense systems, and space exploration, often specializing in areas like structural design, guidance, navigation and control, instrumentation and communication, or production methods. They also may specialize in one type of aerospace product, such as passenger planes, helicopters, spacecraft, or rockets.

This succinct description highlights the great diversity of aerospace engineering work.

Practicing engineers in the aerospace industry can be located in industry, government, academia or other not-for-profit labs. Many aerospace engineers are engaged in management activities. Kemper (1990, p. 257) and others note that because the aerospace industry is on the cutting edge of technical knowledge, it has always been closely associated with scientific research; thus, a comparatively large number of aerospace engineers are engaged in scientific activities. The National Science Foundation reports that in 1986, there were about 110,500 aerospace engineers employed in the United States. This figure represents about 5% of all engineers (National Science Foundation, 1987).

2.2.4. The Aerospace Industry: Summary and Conclusions

This section identified basic characteristics of the aerospace industry and aerospace engineering. The current research describes the way that electronic networks are used to support aerospace engineering work and communication. Clearly, the university aerospace engineer involved in research on the aerodynamic properties of wing foils will be involved in activities which differ from those of the corporate aerospace engineer who manages the manufacturing division of a large aerospace firm that produces jet engines. The work of the aerospace engineer who designs circuit boards for guided missiles will, in turn, differ from that of the engineering researcher or manager. Because of this diversity and its impact on communication patterns, it was important to analyze the results of the current research in terms of various work-related dimensions, such as respondents' primary area of work specialization, type of employer, type of engineering product or process, and major job function. The diversity inherent in the work of aerospace engineers, if combined with the ability to isolate the peculiar characteristics of the aerospace industry and to analyze network use along various work-related dimensions, also means that results of the current study will allow inferences about the use of networks by engineers employed in other industries who perform functions similar to those of the aerospace engineer.

2.3. Engineering Work

2.3.1. Introduction

The basic features of the aerospace industry and jobs performed by aerospace engineers have been described above. This section explores the nature of engineering work in greater detail, but to do so it must step outside the aerospace realm. Whereas the previous section highlighted unique characteristics of aerospace engineering, this section discusses aspects of engineering work that are common to all fields. What is engineering work like? What tasks and activities are performed by engineers on a day-to-day basis? These questions are explored in the management, information science, and science and technology policy literature, and also in literature that deals, broadly speaking, with the nature of the engineering profession. These questions are important because the primary aim of this study is to describe relationships among work tasks, communication activities, and network use as they occur in engineering environments. Therefore, it is critical to describe engineering work as realistically and specifically as possible and to explore the way that communication facilitates various work tasks.

This section describes engineering work processes on both "macro" and "micro" levels and highlights the diversity inherent in engineering work. Florman, an engineer who has written extensively on the nature of the profession, proclaims that (1987, p. 64) "the essence of engineering lies in its need and willingness to embrace opposites. Empiricism and theory, craftsmanship and science, workshop and laboratory, apprenticeship and formal schooling, private initiative and government venture, commerce and independent professionalism, military necessity and civic benefit--all of these and more have their place." For a variety of perspectives on the history and nature of engineering work, see Adams (1991), Kamm (1989), Noble (1982), Pletta (1984), and Schön (1967). The next section describes the engineering process at a macro level and relates this to the tasks and activities that the individual engineer is likely to perform on a day-to-day basis. It also describes some of the goals and constraints inherent in engineering work.

2.3.2. A Macro View: The Engineering Process

The characteristic activity of engineers is making things. Expressed more formally, engineering is usually defined as the application of scientific knowledge to the creation or improvement of technology for human use (Kemper, 1990, p. 3). The term "technology" as used in the context of describing engineering work encompasses tangible products, systems, and structures. It also includes intangible entities, such as processes. Because engineering is essentially the construction of manmade objects, engineering work is often described, at the macro level, as a process that originates with the first idea for a new or improved technology and ends when the technology is put into use.

The National Research Council (1991, p. 17) describes what it calls "the product realization process" as extending "over all phases of product development from initial planning to customer follow-up." Phases included in this process are: definition of customer needs and product performance requirements, planning for product evolution, planning for design and manufacturing, product design, manufacturing process design, and production. The technology transfer process is also often described as encompassing stages that move from research to commercialization (see, e.g., Ballard et al., 1989; Bishop & Peterson, 1991; Marquis & Gruber, 1969; Pinelli, 1991b). In his book on the engineering profession, Kemper (1990) describes the major functions that are traditionally regarded as parts of "the engineering spectrum" (p. 23), including: research, design and development, testing, manufacturing/construction, and sales. Similarly, Roadstrum (1967, p. 12) notes that people doing engineering work may be occupied in research and development, design, manufacturing, testing, and marketing.

Based on nearly four decades of experience in private-sector engineering, Hughes (1990, p. 170) describes the "generic new product introduction cycle" as beginning with market evaluation and the development of competitive tactics and progressing through the development of technical specifications, product/process definition, testing and refining, field testing, production, and delivery. This description of engineering work provides the foundation for Hughes' recommendations for improving the management of the engineering process. Other models in the management literature focus on particular stages of the engineering process, such as R&D, design, or manufacturing. To provide a context for her discussion of engineering information systems, Mailloux (1989, p. 239) notes that "conceiving, planning, estimating, designing, prototyping, testing, evaluating, and implementing are steps in a continuum from the first idea to the final physical object, " and that "these steps are necessarily carried out within and as part of a managed, complex effort that usually represents a significant financial outlay."

These descriptions of the major stages in the engineering process apply generally to all kinds of engineering, including aerospace engineering. Pinelli (1991b, p. 12) uses a model of what he calls "the aerospace innovation process" to describe the information processing system of aerospace scientists and engineers. His model resembles those described above. It depicts five basic stages: research, design and development, manufacturing and production, marketing and sales, and service and maintenance.

A great deal of emphasis in recent literature is placed on integrating, or simultaneously completing, the various stages of the engineering lifecycle, from research and development to design, manufacturing, and marketing. Efforts to accomplish this usually go by the name "concurrent engineering," which aims to make the engineering process less sequential and more interactive. Concurrent engineering is the attempt to implement a systematic approach to the integrated, simultaneous design of technologies and the processes related to their manufacturing and support. This approach hopes to cause the designers to consider the requirements (e.g., financial, schedule, user, quality) associated with all phases of the product life cycle--from conception through use--from the outset. Stoll (1990, p. 86) explains the rational for taking a more integrative approach to product development or improvement: "Perhaps the most serious [sic] drawback of the serial approach is that it often leaves life-cycle cost, quality, and development lead time to chance. By the time problems in these areas are recognized, iteration to fix them is often expensive and time consuming. The result is numerous redesigns, suboptimal and costly total designs, poor response to market and technological change, and excessively long design cycles."

Rachowitz, Maue, Angrisano, & Abramson (1991, p. 66) describe concurrent engineering (called "task teaming") at Grumman, a major aircraft firm: "Task teaming facilitates design changes when they are most manageable and easy to make. The result is product optimization--quality products manufactured with fewer errors in shorter time and at a lower cost." The key to concurrent engineering is communication and, increasingly, communication technology. As discussed below, many engineering firms are implementing electronic networks in direct support of concurrent engineering goals.

These high-level models of the engineering process are recognized as idealistic, over-simplistic, and too linear, but they provide a basic framework for describing engineering work and for analyzing possible management, policy, and information interventions to improve engineering effectiveness and productivity. The complexity of the engineering process leads in some cases to ambiguous, conflicting, and overlapping definitions for particular stages of work. But the complexity of the process and the financial risks involved in bringing products to market--on both organizational and national levels--demands that attempts at definition and understanding be made. Taylor (1991, p. 235) notes that another limitation of these models is that the engineering process includes not only innovation and the development of new technology but also small improvements and adjustments to existing products, processes, and systems.

This section has provided a few examples of what is variously reported in the literature as "the innovation process," "the R&D process," "the technology transfer process," or "the product realization process." These reports differ according to their authors' field of study and aim, but they have a basic purpose which makes them relevant to this research: they seek to describe and explain the process by which new or improved products and processes are developed. Policy analysts and other stakeholders in the Federal government seek an understanding of the innovation process in order to implement effective R&D, technology transfer, and industrial policies and programs. Their ultimate aim is to improve the advance of science and technology and enhance the nation's productivity and economic competitiveness. The management literature contains studies of the R&D process that aim to guide firms in the development of policies and practices to encourage innovation, speed up product development cycles, and improve productivity. Information science literature uses such models as a framework for investigating scientific and technical communication within and among the various stages. Current emphasis on concurrent engineering has refocused attention on the importance of defining the various stages of product development in order to integrate them in a manner that will make the process more effective and efficient; more and better communication is often seen as a primary mechanism for accomplishing this integration. What these models have in common, and why they are reviewed here, is that they provide a useful framework for the discussion of engineering tasks and communication, one that makes sense within the context of institutional and national policy.

2.3.3. A Micro View: Engineering Tasks and Activities

Engineering work is also described in the literature in terms of the kinds of tasks and activities which the typical engineer performs on a day-to-day basis. Because engineering centers on the creation of new things, most engineers perform a wide variety of tasks. Engineering work involves both cognitive activities and physical tasks that can be characterized as technical and non-technical, routine and inventive, rational and serendipitous. The typical engineer invents, manages, makes things, and solves problems related to all of these activities.

There is general agreement in the literature that an individual engineer is likely to perform a wide range of technical and non-technical work tasks, including many that may be classified as information or communication tasks. Kemper (1990, p. 2) notes that there is "enormous variety in the kinds of things engineers do." He specifies a range of tasks that the typical engineer performs, regardless of their stage in the engineering process. Such tasks include defining problems, coming up with new ideas, producing designs, solving problems, managing the work of others, producing reports, performing calculations, and conducting experiments. Hollister (1966, p. 18) also describes the work of the engineer as multi-faceted: "He begins with an idea, a mental conception. He conducts studies and, when necessary, research into the feasibility of this idea. He directs the building and operation of what he has planned."

Mailloux (1989, p. 239) reports that about "20% of an engineer's time is spent in the intellectual activities of engineering-- conceiving, sketching, calculating, and evaluating-- with the remaining 80% spent on activities associated with creating, accessing, reviewing, manipulating, or transferring information." According to Ritti (1971), engineering work consists of scientific experimentation, mathematical analysis, design and drafting, building and testing of prototypes, technical writing, marketing, and project management.

Murotake (1990) used participant observation at two computer systems companies to develop a taxonomy of engineering tasks and activities that is quite detailed and comprehensive. Five of the major areas he outlines represent basic engineering process stages. These areas are listed below, along with the tasks they include:

- Environmental scanning: Market analysis, requirements analysis, technology scanning.
- Analysis: Problem identification, idea generation, experimentation, mathematical analysis/simulation, cost analysis, trade-off analysis.
- Design: Mechanical design, electrical and electronic design, software design, overall system design.
- Development: Mechanical prototyping, electrical and electronic prototyping, software coding and debugging, overall system integration.
- Production: Production and process engineering, quality control, maintenance and troubleshooting.

The other major areas of work described by Murotake (1990), communication and management, take place throughout the engineering process:

- Management: Administrative or group management, project management, technical management, planning.
- Technical communication: Writing and editing, drafting and drawing, information search, reading.
- Other communication: Meeting and seminar attendance, briefing preparation and presentation, education and training.

Murotake's taxonomy includes descriptions of each of the tasks within these major areas. After developing the taxonomy, Murotake surveyed 73 engineers at the two companies about their activities. Each engineer completed a questionnaire by indicating the total hours worked at each task during that day. Aggregate results indicated that engineers spent about 45% of their time in analysis, design, and development and about 35%-40% percent of their time in communication activities (p. 30). Murotake's detailed description of engineering work demonstrates the variety of tasks and the diverse nature of the cognitive activities that are undertaken. His results indicate that there is a great deal of variety in engineering work, on both individual and aggregate levels, and that communication is a critical aspect of engineering work.

Whinnery (1965) presents a description of engineering work that elaborates the essential features of the engineering process (p. 13, citing O'Brien):

(1) The identification of a feasible and worthwhile technical objective and definition of this objective in quantitative terms;

(2) Synthesis of knowledge and experience to conceive a design that meets the technical objective; quantitative analysis of the design concept to fix the necessary characteristics of each component and to identify unresolved problems;

(3) Performance of exploratory research and component tests to find solutions to the problems;

(4) Development of concept for the design of those components which are not already available;

(5) Re-analysis of the design concept to compare the predicted characteristics with those specified;

(6) Preparation of detailed instructions for fabrication, assembly, and testing;

(7) Production or construction; and

(8) Operational use, maintenance, field service engineering.

Note that in this description of engineering work, specific activities are described only for the conceptual and design components, not for production or maintenance. Design is usually considered the characteristic feature of engineering work; thus, tasks and activities that make up the design process are most frequently studied and described.

Roadstrum (1967, p. 7) describes the design process as "Conceive: get new ideas. Experiment: try them out. Design: work out the details and record on paper. Make: build one or more from the design. Test: try out. Recycle: repeat and improve as needed." Alger and Hays (1964, p. 10) describe the engineering design process as encompassing "recognizing, specifying, proposing solutions, evaluating alternatives, deciding on a solution, implementing," and discuss the nature of the specific activities that design engineers perform in completing these steps. Buhl (1960) elaborates a model of the engineering design process that suggests the diversity of the cognitive activities involved:

- Problem recognition: finding a problem situation or mess; problem is formless.
- Problem definition: bring form or orderliness out of problem situation by determining specific problem to be solved--basic function, reliability, producibility, operation, etc.--and requirements which any solution must meet. Define in familiar terms and symbols; dissect into subproblems and goals; place necessary limitations and restrictions.
- Preparation: by compilation of all past experience in the form of data, ideas, opinions, assumptions, observations, measurements, past solutions, previous analytical procedures.
- Analysis: analyze all the preparatory material in view of the defined problems, interrelation, comparison, evaluation of all information which may have bearing upon a solution. Bring understanding and form out of prep data by analyzing it to find out those few basic ideas which have some potential bearing on the problem.
- Synthesis: of a solution from analyzed information. Assemblage of the various items analyzed to produce possible solutions. Solutions are combinations and arrangements of the analyzed data and the specific problems.
- Evaluation and selection: evaluate possible solutions and select best. Verification and checking of various facets of the solution and coordination of all sub-problem solutions into an integrated whole. A decision. Compare, judge, select, adopt solution(s).

- Presentation and execution: presentation of necessary information to others in order to execute the solution. Activation of the solution to satisfy the need recognized. Need to understand motivations and goals of others.

In Buhl's analysis, engineering design is depicted as a problem-solving activity. In fact, engineering work, especially design, is often characterized as a problem-solving activity. Laudan (1984, p. 84) notes that "change and progress in technology is achieved by the selection and solution of technological problems, followed by choice between rival solutions." Murotake (1990, p. 18) notes three problem-solving activities in design: breaking a problem into manageable subcomponents; analogy to similar, previously solved problems; and browsing/ serendipity. Guindon (1990) describes the early stages of design in computer software engineering. He offers an in-depth analysis of the technical problem-solving process in design work, based on relating the results of his empirical study to other research. He concludes that top-down rational models of the decomposition of design problems apply only to the special case of very well-structured problems whose correct decomposition is already known. Most decompositions are opportunistic. They involve "the immediate recognition of a partial solution in another part of the problem, immediate handling of inferred or added requirements, drifting through partial solutions, and interleaving of problem specification with solution development" (Guindon, 1990, p. 327). This characterization of engineering problem-solving highlights the diversity of the cognitive tasks performed by engineers and the need for flexible access to many different sources of information.

These descriptions of the work tasks and activities of engineers indicate that the work performed by engineers is often diverse and multi-faceted, involving a blend of physical and cognitive activities. The descriptions of engineering tasks offered in the literature suggest the importance of a variety of engineering resources, including colleagues, print sources, and analytical tools to engineering work. Further, they suggest that the use of these resources and way are integrated into engineering work may be planned in some cases and very ad hoc in other situations. Thus, these descriptions of engineering tasks and activities suggest that the kind of quick and flexible access to information, analysis tools, and people that networking can provide may be an important factor in facilitating engineering work.

Although engineers perform many tasks independently, most products result from team effort, requiring engineers to share their knowledge and the results of their work with others (Holmfeld, 1970, p. 156). For complex products, teamwork is required at each stage of the engineering process. Obviously, no single engineer, for example, designs a jet engine. Design engineers often need to coordinate their work with the efforts of other design engineers so that various subcomponents of the system being designed fit together. The literature on concurrent engineering indicates that teamwork is a natural requirement of the need to progress through and integrate the various stages of the engineering process. Literature on engineering communication, from a variety of perspectives, will be discussed below. This literature (e.g., Allen, 1984; Ancona & Caldwell, 1990; Barczak & Wilemon, 1991; Kremer, 1980; Shuchman, 1981) confirms the importance of teamwork in engineering work. It indicates that bringing a product to market requires, for example, that design engineers communicate with management, legal staff, marketing, and manufacturing to ensure compliance with changing requirements and constraints and that, further, engineers need to communicate with people outside their organizations, such as clients, funders, and suppliers.

Another important aspect of engineering work that must be kept in mind is that it is not simply a technical endeavor. Murotake (1990, p. 20) describes the group nature of engineering work and emphasizes the importance of its nontechnical elements. He concludes that "the process of engineering work is not only a technical one, but a social one in which management, communication, and motivation influence the efficiency, quality, and innovativeness of the project team's work."

Engineering work takes place in a variety of environments, depending not only on the nature of the product being developed, and the stage of product development, but also on the nature of the employing organization. Organizations employing engineers include universities, research centers, government laboratories and agencies, and private sector manufacturers and consulting firms. The basic goal of engineering is to produce usable products at the lowest possible cost. This goal drives the work and communication activities of virtually all engineers, but it is manifested to a different degree in different employment settings.

2.3.4. Engineering Work: Summary and Conclusions

This section described the nature of engineering work at several levels, by presenting models of the engineering process and discussing the tasks and activities that individual engineers perform. According to the literature, engineering work is fundamentally both a social and a technical activity. It is a social activity in that it often involves teamwork, as individuals are required to coordinate and integrate their work. Engineering is defined as the creation or improvement of technology; as such, it clearly encompasses both intellectual and physical tasks, i.e., both knowing and doing. The characterization of engineering work presented here suggests immediately the importance of communication to the accomplishment of work tasks at both the macro and micro levels. It also suggests that engineers require access to a variety of tools and resources in order to accomplish their work. Thus, one would conclude that electronic networks, to the extent that they facilitate communication and extend access to needed analytic tools and information resources, have the potential to greatly improve the conduct of engineering work. The next section explores the nature of engineering knowledge in order to arrive at a deeper understanding of engineering work, which may be viewed as the creation of knowledge, and engineering communication, which may be viewed as the transfer of knowledge.

2.4. Engineering Knowledge

2.4.1. Introduction

What kinds of knowledge do engineers need to perform the tasks and activities described above? How is this knowledge acquired? These questions must be answered in order to understand the substance of engineering communication and its relationship to engineering work. Research in the sociology and history of technology strives toward a better understanding of the nature of technological work, the way that new technologies are developed, and the growth of technological knowledge. Although this body of work is less well developed than is work devoted to the investigation of scientific knowledge, it has yielded useful findings. This section describes findings, from a sociological and historical perspective, on the nature of engineering knowledge, its relationship to engineering work, and the role of the engineering community in knowledge creation and transfer. These topics are so closely intertwined, in fact, that it is difficult to discuss one without the other. As noted by Vincenti (1990, p. 257) "... engineering knowledge cannot--and should not--be separated from engineering practice. The nature of engineering knowledge, the process of its generation, and the engineering activity it serves from an inseparable whole. What we eventually need to comprehend is the whole of engineering behavior--what it is that 'engineers really do.' "

2.4.2. Anatomy of Engineering Knowledge

As noted above, engineering practice involves both knowing and doing. Literature on the nature of engineering work describes an activity that incorporates art and craft, science and technology. Because engineering work is directed to the achievement of social and economic goals, engineers also require knowledge about the world around them, especially the costs and benefits (social, technical, and financial) of their activities and results. Even the popular literature suggests the wide variety of knowledge needed by engineers due to the diversity of their work (Hollister, 1966, p. 18):

> [The engineer's] task is not alone that of contrivance with material things, for which he must possess an extensive working knowledge of scientific principles and facts. He must also thoroughly understand the functions to be performed by the projected work when it is completed, the methods of its manufacture and construction, and the economics that govern its use. He must have an understanding of the crafts that are to be used and of the organization of the work. It is his responsibility to coordinate and guide the contributions of labor, machines, money, and ideas, and to exert the control necessary to attain his objectives within the prescribed limits of time, cost, and safety.

Florman (1987, p. 64) emphasizes that engineering involves both routine and creative thought: "Although engineering is serious and methodical, it contains elements of spontaneity. Engineering is an art as well as a science, and good engineering depends upon leaps of imagination as well as painstaking care" (p. 75). Scholarly literature on the nature of engineering knowledge reinforces such popular accounts. Donovan (1986, p. 678) asserts that the range of scientific and technical knowledge used by engineers includes "not only the more formal types of experimental and theoretical knowledge but also all forms of practical skill and tacit understanding as well ..."

Schön (1983) deals extensively with engineering in his book on the nature of professional knowledge and work. His work will be presented in some detail here because it portrays both what engineers do and the nature of the knowledge they need to perform their work. Schön rejects the model of technical rationality which is typically applied to scientific and technical professions. This dominant model portrays professional knowledge as "the application of scientific theory and technique to the instrumental problems of practice" (p. 30). He argues instead that the situations encountered by practicing professionals are increasingly characterized by "complexity, uncertainty, instability, uniqueness, and value conflicts (p. 14); such situations require intuitive, artistic, and ethical responses in addition to purely technical and rational ones. Schön labels this model of professional work "tacit knowing-in-action" (p. 49).

To illustrate his argument, Schön describes the development of a new process to produce a desired gunmetal color. He represents the activities of the mechanical engineers involved in this project as "a reflective conversation with the materials of the situation ... [that] wove its way through stages of diagnosis, experiment, pilot process, and production design" (p. 175). Throughout this process, experiments are used to explore puzzling phenomena, test the applicability of potentially useful theories, or achieve particular technological effects. These experiments, however, often produce unanticipated phenomena and outcomes, which then trigger new hypotheses, questions, and goals (p. 177). Schön's analysis of this and other examples suggests that the knowledge required to reach a technological solution is derived from the integration of intuition, past experience, creativity (often in the form of analogy development), theory, experimentation, and reflective thinking that occur in a particular problematic situation. He also argues that engineering solutions incorporate social and ethical considerations.

The notion of tacit knowledge permeates discussions of engineering work. Polanyi (1966, pp. 6-7) describes tacit knowledge--part experience, part intuition, part tactile sensation--as combining "knowing what" and "knowing how" and declares that it is expressed in such actions as expert diagnoses, the performance of skills, and the use of tools. Laudan (1984, pp. 6-7) discusses the tacit component of engineering work and considers it to be a contributing factor in the inaccessibility of technology and its practice to scholarly study.

Tacit knowledge is, by definition, not encoded in verbal form. Another important type of engineering knowledge, visual information, shares this characteristic. The importance of visual information in technological work is the subject of a paper by Ferguson (1977) and is also discussed by Breton (1981). Layton (1974, p. 37) describes this phenomenon, too: "technologists display a plastic, geometrical, and to some extent non-verbal mode of thought that has more in common with that of artists than that of philosophers." The importance of these two nonverbal modes of thought is rooted in the essence of engineering as production of physically-encoded knowledge. Engineers must know how to make things, and the results of this knowledge are encoded in the objects produced. A number of authors have noted this as a critical distinction between the nature of scientific and engineering work (e.g., Allen, 1984; Pinelli, 1991a) and have suggested its implications for information transfer. Both scientists and engineers consume and produce knowledge. But whereas scientists consume and produce text (with the journal article as the archetypal form), engineers rely much more heavily on nontextual information, such as informal communication, drawings, and the investigation of physical objects to acquire the knowledge they need to perform their work. Similarly, the output of engineering work is often nontextual in nature (e.g., designs, physical devises). Although this distinction between scientific and engineering knowledge is valid, it should not cloud the fact that many engineers perform a number of tasks that are typically considered to belong to the realm of science, such as experimentation, and that many engineers require a knowledge of scientific theories to conduct their work.

The nature of the relationship between science and technology has often been discussed in the literature, and the nature of engineering work and knowledge is often explored from within this context. A number of early theorists held that engineering work was a purely technical or craft activity and that engineering knowledge derived from scientific knowledge. The dominant view today seems to be that technology represents an autonomous body of knowledge which interacts with science in complex ways. Gutting (1984, p. 63), for example, asserts that: "Technology is (like pure science) a cognitive enterprise, producing its own distinctive body of knowledge about the world. Technology is also (unlike pure science) a practical enterprise, concerned with the most immediately pressing needs of the society in which it exists." Weingart (1984, p. 115) argues that "both science and technology are systems of knowledge evolving in structures of social action." Layton (1974) concludes that technology is not merely applied science or the use of techniques, that science is not the source of all technical knowledge, and that technology produces its own new knowledge.

On the other hand, a number of writers also point to similarities in the methodologies of science and engineering. Florman (1987, p. 64) describes engineering work as encompassing both theory and empiricism. Ziman writes that (1984, p. 130): "Technological development itself has become 'scientific': it is no longer satisfactory, in the design of a new automobile, say, to rely on rule of thumb, cut and fit, or simple trial and error. Data are collected, phenomena are observed, hypotheses are proposed, and theories are tested in the true spirit of the hypothetico-deductive method."

Research in the sociology and history of technology has shed light on the nature of engineering knowledge, often by a close examination of the development of individual technologies. Holmfeld (1970), Constant (1980), and Vincenti (1990) offer just such detailed studies. Moreover, all three of these studies are based on investigations in the field of aerospace engineering.

Holmfeld (1970) produced a sociological study of the communication behavior of 70 scientists and engineers working on the problem of combustion instability in liquid propellant rocket engines. The study was based on in-depth interviews conducted in a number of organizations. One focus of the study was on elucidating the nature of engineering knowledge. Holmfeld found that "technological knowledge is based to a high degree on intuition grounded in extensive individual experience" (p. 121). Many of the engineers interviewed emphasized that an important aspect of engineering knowledge resided in the "feel" that one has for the objects of work. Holmfeld concluded (p. 127) that part of this feel is implicit, existing only in the mind and hands of the individual. The rest, however, was made explicit and resided in local records of test results, design variations, and other kinds of data. The content of this knowledge includes calculations based on empirical work, widely agreed upon rules of thumb and practices, and the vague statements that are used to try to express the tacit knowledge embodied in having a good feel for one's work.

Holmfeld also found three other common mechanisms for generating needed knowledge in engineering work. Engineers rely on the "cut and try" method to refine and fine tune (p. 129). They also frequently search their memories for familiar concepts and designs in order to increase their confidence in some new variation (pp. 134-135). Finally, they make use of that scientific knowledge which they deem to be relevant and readily applicable. This knowledge is often in the form of a simple fact, such as the optimum hole size or speed rotation, derived from scientific work (p. 148).

Constant (1980) presents a detailed history of the origin of the modern jet engine. His study was undertaken in order to explore "the nature of widely shared technological traditions, the characteristics of and interrelations among the people who work with those technologies, and the ways in which those technologies change, specifically the roles and relative importance of incremental versus discontinuous or revolutionary changes, and the roles of advances in theoretical science and of testing and experiment in technological change" (p. 3; see also Weingart, 1984 for a discussion of the nature and structure of technological change.) Constant presents a "variation-retention" model of technological change that is based on the process of random variation and selective retention that occurs in biological organisms. Technological conjecture, which can occur as a result of knowledge gained from either scientific theory or engineering practice, yields potential variations to existing technologies. These variations are subsequently tested, and successful variations are retained (pp. 6-7). In the case of the turbojet revolution, technological conjecture was based on engineers' knowledge of scientific theories; the design, development, and testing of systems that resulted in the retention of the most successful variation involved, on the other hand, the technical and craft knowledge needed to carry out those tasks.

In characterizing the nature of engineering work and knowledge, Constant notes that the basic activities of technological work mirror those of scientific work in that both follow the procedures inherent in the scientific method. He characterizes this method as "the bold conjecture of theoretical systems--their basic entities and the relationships among them--followed by the rigorous testing and refinement of those conjectured systems" and asserts that "the application of this scientific method to technology would seem to have become increasingly pervasive and effective since, at the latest, the beginning of the nineteenth century" (p. 20).

Vincenti (1990) traces five "normal" (as opposed to revolutionary) developments in the history of aerospace engineering to detail what he calls "the anatomy of engineering design knowledge." His examples reveal that technological developments require a range of scientific, technical and practical knowledge as well as information about social, economic, military, and environmental issues. Vincenti also conducts three important analyses of engineering knowledge.

The first involves his own elaboration of the variation-selection model of the growth of technological knowledge, an analysis that recalls the descriptions of the engineering design process presented in Section 2.3 above. Vincenti concludes, after examining numerous examples from history, that the mechanisms for producing variations in engineering design include three types of cognitive activities (p. 246): searching past experience to find knowledge that has proved useful, including the identification of variations that have not worked; incorporating novel features thought to have some chance of working; and "winnowing" the conceived variations to choose those most likely to work. Vincenti notes that these activities occur in an interactive and disorderly fashion. Selection occurs through physical trials such as everyday use, experiments, simulations (e.g., wind tunnels), or analytical tests such as sketches of proposed designs, calculations, and other means of imagining the outcome of selecting a proposed variation (pp. 247-248).

Vincenti (pp. 197-198) also proposes a schema for engineering knowledge that categorizes knowledge as either descriptive (factual knowledge), prescriptive (knowledge of the desired end), or tacit (which he defines as knowledge that cannot be expressed in words or pictures but is embodied in judgment and skills). Descriptive and prescriptive knowledge are explicit; tacit knowledge is implicit. Both tacit and prescriptive knowledge are procedural and reflect a "knowing how." Finally, Vincenti (pp. 208-222) enumerates and defines specific engineering knowledge categories: fundamental design concepts, criteria and specifications, theoretical tools (i.e., mathematical methods and theories and intellectual concepts), quantitative data, practical considerations, and design instrumentalities (i.e., procedural knowledge and judgmental skills). He then presents a matrix that details how each type of knowledge is acquired. The possible sources of engineering knowledge that he describes include: transfer from science or generation by engineers during invention, theoretical and experimental engineering research, design practice, production, and direct trial and operation (p. 235).

2.4.3. Knowledge and the Engineering Community

The concept of "community" is important for understanding both work and communication. As members of a profession, engineers share a common knowledge base and set of espoused values. The profession prescribes its own approach to work behavior. As emphasized above, engineering is a social activity; especially in aerospace, most work is accomplished as a result of group effort. Further, communication always takes place within a social context; to understand the nature and meaning of communication, one needs to understand its social context.

Studies of scientific communities look at the values, norms, knowledge, methods, reward system, and culture shared by community members (see, e.g., Barber, 1952; Doty, Bishop, & McClure, 1990; Kuhn, 1970). Further, the role of informal communication in cementing the community is frequently noted. Gaston (1980, p. 495) notes that "[the problem of the internal workings of the technological community] is virtually unexplored.... In contrast to the sociology of the scientific community, little is known about the sociology of the technological community." Constant (1980, p. 8) also notes the lack of research on technological communities. He writes that "While extensive research has been done on 'invisible colleges,' research fronts, and the community structure of science, there has been little analogous [sic] sociological or historical investigation of technological practice." Rothstein (in Petrucci and Gerstl, 1969) argues that the model of a profession as a community is inadequate to describe engineering behavior. He argues that the huge variety of occupations and disciplines in engineering demonstrates that there is no such thing as a single engineering community. Further, he contends that most discussions of professional communities fail to direct enough attention to the nature of professional knowledge and its influence on behavior. The heterogeneity, rate of change, and degree of specialization of engineering knowledge also leads to the emergence of specific communities in engineering.

Some work, however, has begun to explore the extent to which members of an engineering community share similar work tasks, goals, and methods; are governed by shared social and technical norms; and engage in extensive informal information exchange among themselves. Laudan (1984, p. 3) finds justification for this approach in that "cognitive change in technology is the result of the purposeful problem-solving activities of members of relatively small communities of practitioners, just as cognitive change in science is the product of the problem-solving activities of the members of scientific communities." Layton (1974, p. 41) also claims that " ... the ideas of technologists cannot be understood in isolation; they must be seen in the context of a community of technologists ..." Donovan (1986, p. 678) notes that "the study of engineering knowledge must not be divorced from the social context of engineering" and suggests that "the interplay of social values and theoretical understanding in the evolution of scientific disciplines certainly has its analogues in engineering, although the values and knowledge involved are often quite different."

Rosenthal (1990) discusses the design-manufacturing team in new product development. He says that such teams represent "a community of interest" with a shared commitment to the group effort. The group shares information and advice, as well as instructions and decisions (p. 45). He describes the difficulties in merging these two subcommunities or cultures, because designers and manufacturers have developed their own "tacit understandings built up through years of working on particular problems with special points of view" (p. 44).

The notion of community has also been addressed in connection with aerospace work. Vincenti (1990, pp. 238-240) describes informal communities of practitioners as the most important source of knowledge generation and means of knowledge transfer in aerospace. He defines a community as those involved in work on a particular aerospace development or problem (e.g., fasteners, airfoils, or propellers). Vincenti attributes several functions to these engineering communities. Competition between members supplies motivation, while cooperation provides mutual support. The exchange of knowledge and experience generates further knowledge, which is disseminated by word of mouth, publication, and teaching and is also incorporated into the tradition of practice. The community also plays a significant role in providing recognition and reward.

Vincenti (1990) also describes the particular roles of important types of aerospace engineering institutions, such as government research organizations, university departments, aircraft manufacturers, military services, airlines, professional societies, government regulatory agencies, equipment and component suppliers. He concludes, however, that "As with individual engineers, formal institutions do a complex multitude of things that promote and channel the generation of engineering knowledge. They do not, however, constitute the locus for that generation in the crucial way that informal communities do. Their role [...] is to supply support and resources for such communities" (p. 240).

Constant (1980, 1984, p. 29) also describes aerospace communities as the central locus of technological cognition. He notes that the aeronautical community is, in fact, composed of a multilevel, overlapping hierarchy of subcommunities (1980, pp. 9-10). He argues that technological change is better studied at the community level than at the individual, firm, national, or industry levels. Constant describes the community as the embodiment of traditions of practice (1980, p. 10):

> [Technological traditions of practice] define an accepted mode of technical operation, the conventional system of accomplishing a specified technical task. Such traditions encompass aspects of relevant scientific theory, engineering design formulae, accepted procedures and methods, specialized instrumentation, and, often, elements of ideological rationale. A tradition of technological practice is proximately tautological with the community which embodies it; each serves to define the other. Traditions of practice are passed on in the preparation of aspirants to community membership. A technological tradition of practice has, at minimum, a knowledge dimension, including both software and hardware, and a sociological dimension, including both social structure and behavioral norms.

Constant discusses the nature of community norms in engineering. He alleges that, at least in connection with complex systems, there are (1980, p. 21) "fundamental social norms governing the behavior of technological practitioners which are very close in structure, spirit, and effect to the norms governing the behavior of scientists." Such norms guide the development of techniques and instruments and the reporting of data. Constant also argues for the existence of "counternorms" (see Mitroff, 1974, for a discussion of counternorms in scientific communities): "Technological practitioners are required to be objective, emotionally neutral, rational, and honest. Yet technological practitioners often are--and protagonists of technological revolution usually are--passionate, determined, and irrationally recalcitrant in the face of unpleasant counterevidence bearing on their pet ideas" (Constant, 1980, p. 24).

2.4.4. Engineering Knowledge: Summary and Conclusions

The diversity of engineering work is closely associated with the diverse nature of engineering knowledge. The literature reviewed in this section describes engineering knowledge as being comprised of scientific laws, engineering principles, community rules of thumb, experience, intuition, and creativity. This section also describes the role of the engineering community in knowledge production and transfer. In the next section, the focus of this literature review shifts from the nature of engineering work and knowledge to an exploration of the nature of engineering communication.

2.5. Engineering Communication

2.5.1. Introduction

The goal of the current study is to investigate the use of electronic networks by aerospace engineers, focusing on relationships between network use, engineering work, and engineering communication. Previous sections of this literature review provided an overview of the aerospace engineering environment and then discussed the nature of engineering work in greater detail. Engineering knowledge, an essential link between engineering work and communication, was also discussed. Literature reviewed in these previous sections suggests that aerospace engineers perform both scientific and technical tasks. Aerospace engineers also appear to conduct their work as members of both formal organizations and informal communities. This section describes and discusses literature on the nature and purpose of engineering communication and its impact on engineering work. It also describes empirical findings on the use of a variety of work tools and information resources by engineers. This sections brings together literature from a variety of fields, including information science, communications, management, and sociology. In order to set the context for subsequent discussion of electronic networks, it begins with an overview of the nature and purpose of human communication networks in science and technology environments. It then moves on to review empirical studies of engineering communication.

2.5.2. Social Networks in Science and Technology

Studies of social (or "human resource") networks and their utility for information exchange and other forms of support have been conducted in a number of domains. These studies discuss the importance of human networking in both informal communities and formal organizations. In describing the links between community membership and communication, they generally conclude that informal social networks increase the diversity of available contacts and provide a valuable means for acquiring information and resources, solving problems, and receiving social and moral support. A thorough review of this literature is beyond the scope of this dissertation, but selected discussions of the role of informal networks in formal organizations are highlighted because they provide a useful context for the study of interpersonal communication, both traditional and electronic, in scientific and technical communities.

Dosa, Farid, and V'as'arhelyi (1989) review literature on social networks in health, scientific, business, and policy settings. They define a human resource network as "the mutual support mode of sharing knowledge, observations, documentation, data or opinions by people who are well informed" in some area (p. 6) and describe the transactions in an information sharing network as including "information acquisition, referral, information sharing, resource identification, resource acquisition, verification, [and] opinion exchange" (p. 7). Reporting on the results of a health information sharing project, Dosa (1985) describes the differences between people acting as individuals (i.e., as members of informal networks) and those acting as official members of their organizations (i.e., as members of formal networks) in regard to the types of information exchanged and the motives and constraints of information sharing. Among the types of information that are exchanged by individuals acting as members of an informal community are expertise, ideas, methods, processes, opinions, personal files, memoranda, unpublished papers, proposals, research data, field observations, engineering designs, collections of specimens, and compounds (p. 111). Thus, the social network was found to be the primary means for exchanging information that is informal, visual, or encoded in physical objects.

Hellweg (1987) reviews studies of "organizational grapevines." She provides a typical definition of formal and informal communication networks. The formal network is represented by the organizational chart and "systematically established for the transmission of officially sanctioned messages," while the informal network is "emerges spontaneously and is situationally defined" (p. 214). Hellweg concludes that organizational grapevines allow for the interpretation of management messages, provide a means for employees to socialize and make comments off the record, allow management to gauge employees' feelings and obtain their input in decision making, are an effective mechanism for the dissemination of some types of information, and are especially valuable for communicating in times of crisis. Informal networks can also produce negative effects when the information disseminated is prematurely leaked, inaccurate, or distorted.

Clampitt (1991, pp. 86-89) notes that every organization has both a formal and an informal network. He cites a 1990 survey of 40 companies and over 45,000 employees showing that the organizational grapevine is the second most frequent source of information for employees, even though it is the least preferred. Clampitt analyzes other studies to suggest possible reasons for the use of informal channels in organizations. He notes that the grapevine is fast; it provides an outlet when the formal network is "clogged"; it reduces uncertainty in exceptional situations and satisfies affiliation needs; it carries a great amount and variety of information; and it tends to be accurate. Dangers associated with informal networks in organizations are also cited. If "poor quality" information suffuses an organization through the informal network, the result can be anxiety, poor decisions, low morale, perceived favoritism, and reduced productivity (p. 89).

Farace, Monge, and Russell (1977) also discuss organizational network structures and roles, and review research approaches and results. The in-depth analysis of communication functions that they provide is particularly valuable. They enumerate the functions of organizational networks (pp. 179-180) as: communication, coordination and control, achievement of production goals, incorporation of new ideas and practices, and member socialization and maintenance. They describe the informal network as "the network of interaction that can (and does) range broadly across different content areas, use various communication modes, and perform much broader functions than the formal network" (p. 179). Farace et al. (1977) note that individuals use different pathways (both formal and informal) to exchange messages serving different communication functions. The authors offer an analysis of the differing networks for communication about work-related matters ("the work network") and communication that diffuses new information ("the innovation network"). Their chief point is that identifying and understanding the various communication networks used by employees can be used to improve organizational functioning and productivity. Schön (1971) also notes the existence of different kinds of networks in organizations. He describes "shadow networks" as filling the gap between fragmented services and a more highly aggregated functional system. Such networks smooth institutional transitions and reduce uncertainties, helping people to get things done when formal networks fail (p. 191).

Mueller (1986) presents a wide-ranging discussion of human resource networks in corporations. He interweaves research results, personal experiences, and anecdotes. Informal networking experiences in the corporate world are compared to everything from lonely hearts clubs to tribal customs to the Flying Wallendas. Mueller synthesizes this unusual mixture of material to arrive at his view of the essence of networking, which is that it allows individuals to obtain information, influence, expertise, and support. Mueller's view of organizational grapevines corresponds with those presented above (1986, p. 79):

> ... we tend to forget the value of social networking, the informal gossip channels, and verbal and written grapevines that persist in all organizations like crabgrass in a well-trimmed lawn. Stamping out these informal channels is not possible, nor should it be a goal. Actually, grapevines can provide a check and balance on poorly conceived plans, the rise of favoritism, and emotional situations and decisions. Grapevines provide management with uncontrolled feedback about the climate, morale, and social health of the firm, and about what is really happening in the organization.

Mueller also notes that "Norms, values, beliefs, and codes are transmitted by networks" (p. 10). His central argument is that institutional hierarchies of authority and control limit the ability of individuals to act and should be balanced by social networks, which are "self-organizing, overlapping, open-ended, and fluid" (p. 114). Mueller argues that networks are an important factor in improving organizational innovativeness and productivity, citing his 1984 study that revealed "an organizational style with easy communication and human networking" as the common attribute of ten innovative companies. He also argues that social networking can be transformational, leading to personal empowerment and individual growth. Mueller advises organizations to overlay such "networking concepts and practice with the hierarchical, bureaucratic paradigm of traditional organizational functioning" (115). His vision of the networked organization of the future relies not only on new organizational attitudes but also on new technology; he notes that electronic networks "can multiply the effectiveness of a decentralized human network in speed, capacity, and accuracy" (p. 74). Mueller warns that "If we don't transform our conventional, hierarchical structures into cross-level networking systems, many of our institutions will continue to decrease in effectiveness" (p. 13).

The literature presented above focuses on the role of informal communication in formal organizations. It suggests that social networks, while they have drawbacks, can also fulfill both individual and institutional goals. Informal networks facilitate the exchange of expertise and other information--beyond that available through formal channels--that provide social support and empower individuals to be more efficient, innovative, and productive. Discussion now turns to whether or not these findings are applicable to engineering work; literature that describes the functions of interpersonal communication networks in science and technology environments is reviewed.

Connolly (1983) discusses organizational communication theory as it applies to scientists and engineers. He notes that in order to bring technical solutions into being as actual products or processes, engineers are required to communicate effectively with clients, colleagues, and other co-workers, and that problems may occur when communication partners do not share the same "codebook," or because messages carry both overt and symbolic meanings. Connolly devotes special attention to a discussion of communication networks in R&D labs. He asserts that for scientists and engineers performing development work, communication tends to follow the formal organizational hierarchy, but "for those involved in more basic research, the pattern tended to be both less centralized and less hierarchical, with people sharing ideas and discussion with whomever seemed relevant to their current problems, regardless of rank or department" (p. 105).

A number of sociologists have described the nature of the information needed by people performing scientific and technical work and have concluded that informal social networks are important for conveying the ideas, hints, tacit knowledge, and expertise that people performing scientific and technical tasks need. Most of this work is aimed at analyzing the production of knowledge; it is basically inductive, arrived at by thinking about particular cases from history or personal experience. Interpersonal communication is placed within the context of the practice of research, which is often described as an "art" or "craft" activity. These studies do not deal specifically with engineers--they usually describe scientists or researchers--but they relate interpersonal communication to the same kinds of specific tasks and activities that have been attributed to engineering work.

Ravetz (1971) presents perhaps the most complete analysis of the nature and importance of what he terms "craft knowledge" in R&D work, and of its conveyance through informal communication channels. Ravetz portrays the researcher as a "craftsman" who (p. 75):

> works with particular objects [including both material and intellectual constructs]; he must know their properties in all their particularity; and his knowledge of them cannot be specified in any formal account [...] he must develop a personal, tacit knowledge of his objects and what he can do with them, if he is to produce good work.

Researchers must gain craft knowledge, through their own experience or through informal communication with more experienced researchers, to avoid pitfalls in their work and to satisfy the technical norms prevalent in their particular community for collecting and analyzing data and for assessing the adequacy of one's solution to a research problem.

According to Ravetz, one of the most important uses of interpersonal communication is for the transmission of craft knowledge related to research methods (p. 77):

> The transmission of methods is accomplished almost entirely within the interpersonal channel, requiring personal contact and a measure of personal sympathy between the parties. What is transmitted will be partly explicit, but partly tacit; principle, precept, and example are all mixed together. There is no substitute for such personal communication; messages whose transmission requires a prior formulation and clarification of ideas (as even in a letter to a colleague), will necessarily be impoverished in their content of private craft knowledge.

Ravetz sums up (p. 179):

> In conclusion, we may consider the two channels of communication and their contents as a pair of interpenetrating opposites. The one distributes and preserves the results of the work, while the other governs the work itself; one is public and explicit, while the other is informal and interpersonal. The contents of the public channel are in principle permanent, and exist independently of the circumstances or ultimate fate of the work which produced them; while the body of methods, bound to a very particular personal experience (both technical and social) directly control the future contents of the public channel. The results of scientific inquiry are in principle based on controlled experience and rigorous argument; but the methods governing the inquiry itself are a particularly subtle craft knowledge, different in nature from scientific knowledge.

Ravetz also emphasizes the importance of both social and technical factors in the conduct of research and, specifically, in research communication.

Ziman has written extensively on the nature of science as a social activity and the role of informal communication as part of this social fabric. He recognizes that scientific investigation "is a practical art" that is "not learnt out of books, but by imitation and experience" (Ziman, 1968, p. 7). This characterization applies to much engineering work as well. It describes a context in which informal communication plays a significant role as a means of conveying the results of personal experience and intuition from one researcher to another. Ziman credits "unofficial channels" such as "private correspondence ... conferences and meetings, interchange of manuscripts and data, sabbatical leaves, consulting visits, seminars, conversations around the coffee table" with providing "a grapevine of hints and ideas, observations and opinions" (p. 108). He concludes that "the informal system of scientific communication is quite as important as the formal system, although having a different function" (p. 116).

Garvey (1979, p. 266) found that the use of journals and local colleagues, the two types of information sources used most often by researchers (his use of the term seems to encompass both scientists and engineers), were complementary, for the most part fulfilling different needs. Local colleagues provided information for selecting a design or strategy for data collection, selecting a data-gathering technique, designing equipment and apparatus, and choosing a data analysis technique. Journals were most important for placing work in the proper context, and integrating findings into current knowledge. The two sources coincided in their importance for problem definition, formulating a solution, and interpreting data.

Wilson and Farid (1979, p. 130) note that "behind the public story finally formulated and presented to the world lies the private story of what went wrong as well as what went right, of successive attempts and corrected versions, of mistakes and lucky guesses, of detours and discouragements." Vincenti (1990) presents aerospace engineering work in a very similar light. He notes that "Errors and misconceptions inevitably arise and must be detected and surmounted; the number of these that end up in even the unpublished archival record can never constitute more than a small part of those encountered. The [individual] learning, in short, while it is going on is messy, repetitious, and uneconomical" (p. 11).

Beveridge (1957) produced an early, classic treatise on the art of scientific investigation. He proposes informal discussion as an important stimulus to the scientific mind. More specifically, he notes that the discussion of problems with colleagues may be helpful in several ways (p. 85):

- The other person may be able to contribute a useful suggestion.
- A new idea may arise from the pooling of information or ideas from two or more persons.
- Discussion provides a valuable means of uncovering errors.
- Discussion is usually refreshing, stimulating and encouraging.

- Discussion helps one escape from an established habit of thought which has proved fruitless.

Beveridge's analysis seems to prefigure some of the conclusions about the role of informal communication in science and engineering that were subsequently established empirically by Garvey (1979), Allen (1984), and others.

In reviewing the literature on invisible colleges, Cronin (1982) enumerates the advantages of interpersonal communication among people engaged in work on similar problems, stating that they:

- Encourage feedback and increase researcher motivation;
- Play a part in helping to establish priority and discovery;
- Allow for reality-testing; for sounding out ideas and theories;
- Have an important current-awareness function;
- Can facilitate boundary spanning, i.e., help transmit ideas across disciplines;
- Have a bonding effect on groups with more or less shared research orientation; and
- Increase the match between information needs and information delivery by being direct and personalized

Cronin asserts that informal communication improves one's productivity and status because (1982, p. 215):

> ... it ensures that participants in (even loosely defined) networks are able to keep abreast of current developments (it also allows for the transmission of procedural or technical/equipment-related data which cannot always be satisfactorily conveyed via the primary publication media), and [...] it reinforces the group's sense of identity and purpose.

Once again, this description is very similar to descriptions of the functioning of aerospace engineering communities presented above (e.g., Constant, 1980; Vincenti, 1990).

Granovetter (1973) recognizes a benefit of informal communication for both individuals and scientific progress as a whole, one that gains in import as research becomes increasingly interdisciplinary. He finds that weak ties (i.e., communication among people that are not members of the same work group and may not even be formally acquainted with each other) facilitate more extensive communication flow and carry ideas across discipline boundaries.

Recent years have seen the emergence of ethnographic studies of the working life of researchers. These studies (e.g., Knorr-Cetina, 1981; Latour, 1987; Latour and Woolgar, 1979; Lynch, 1985), although not monolithic in their theoretical bases, are conducted like anthropological field studies and draw attention to the personal, political, and other social factors that guide the behavior of researchers and, in particular, the production and transfer of scientific and technical knowledge.

Gilbert and Mulkay (1984, p. 53) report that "scientists stressed that carrying out experiments is a practical activity requiring craft skills, subtle judgments, and intuitive understanding." They use discourse analysis to identify and characterize two main "repertoires" used by researchers to explain their activities. The empiricist repertoire appears almost exclusively in the formal literature. It "portrays scientists' actions and beliefs as following unproblematically from the empirical characteristics of an impersonal natural world" (p. 56). The contingent repertoire, on the other hand, is frequently exhibited by researchers in informal communication. It portrays actions and beliefs as idiosyncratic, "heavily dependent on speculative insights, prior intellectual commitments, personal characteristics, indescribable skills, social ties and group membership" (p. 56).

Summarizing the implications of this literature on social networks and the nature of work for the current study, it provides further support for the proposition that informal communication networks are important for cementing the social structure of engineering work and for improving the ability of engineers to produce technically competent work. Informal communication allows access to the craft and tacit knowledge and private versions what happened during the course of a particular project. This type of knowledge often does not appear in formal information sources and yet is vital to the conduct of scientific and technical work.

2.5.3. Empirical Studies of Engineering Communication

The information needs and communication habits of scientists and engineers have been studied by researchers in the fields of information science, communications, and management. Reviews of this research appear most frequently in the library and information science literature (e.g., Menzel, 1966; Pinelli, 1991a; Poland, 1991). Poole (1985) compares and analyzes the results of approximately one hundred empirical studies of information use by scientists and engineers, distilling common principles from this work.

A significant amount of the literature on scientific and technical communication is oriented chiefly toward scientists, especially in policy, communications, and sociology studies (see, e.g., Nelson & Pollack, 1970; Garvey, 1979; Hagstrom, 1965; Meadows, 1974). It is traditionally acknowledged that scientists and engineers differ in regard to the kind of information they need and the manner in which information is acquired and produced, even though they perform similar tasks. These differences in information seeking and use behavior are attributed to differences in the nature and goals of work, institutional settings, and reward structures. Discussions of these differences appear in Allen (1984, pp. 2-5), Holmfeld (1970), Pinelli (1991, pp. 88-91), and Taylor (1986, pp. 39-40).

The studies that explore the information needs and communication patterns of engineers may be divided into several groups. For example, a number of studies of information and communication behavior have either been devoted exclusively to the information needs and communication habits of engineers or present separate results for engineers (Allen, 1984; Kaufman, 1983; Kremer, 1980; Pelz & Andrews, 1966; Pinelli, 1991b; Rosenbloom & Wolek, 1970; Shuchman, 1981). A significant number of studies focus on the impact of STI exchange on the innovation process, often intending to offer recommendations to improve the management of R&D communication and enhance R&D productivity (e.g., Allen, Lee, & Tushman, 1980; Ebadi & Utterback, 1984; Orpen, 1985; Tushman, 1978, 1979). These studies typically include both scientists and engineers, often without distinguishing one group from the other. Some investigate variations in the contribution of scientific and technical communication to different R&D tasks and differences between scientists and engineers in the selection and use of information sources and channels (e.g., Chakrabarti et al., 1983; Gerstberger & Allen, 1968; Gerstenfeld & Berger, 1980). Barczak and Wilemon (1991) look specifically at the different communication patterns of innovating and operating groups in new product development. The tendency to concentrate on those engaged in R&D work as opposed to those conducting "normal" or "mainline" engineering work has been criticized by Shuchman (1981, p. 1) and Taylor (1991, p. 234), who contend that mainline engineering is of equal importance to concerns of industrial productivity.

Generally speaking, all of the studies that investigate the information needs and habits of engineers have concluded that interpersonal communication is an important source of information and ideas for engineers and a significant factor in improving engineering productivity. They also provide descriptions of the wide variety of information sources used by engineers. None of these studies of engineering communication direct more than passing attention to the role of electronic networks. Several studies of information use and communication among engineers report a significant amount of data derived from the aerospace community (e.g., Allen, 1984; Holmfeld, 1970; Pinelli, 1991b; Shuchman, 1981).

The most commonly used method in these studies was the written survey (e.g., Brown& Utterback, 1985; Chakrabarti et al., 1983; De Meyer, 1985; Pelz & Andrews, 1966). A number of the surveys used some form of critical incident technique to elicit responses about information sources and channels used in particular incidents (e.g., Gerstenfeld & Berger, 1980; Kaufman, 1983; Kremer, 1980; Pinelli, 1991; Rosenbloom and Wolek, 1970; Shuchman, 1981). These studies asked a series of questions that proceeded either about a particular information incident or a particular work incident. Allen's classic study (1984) included results of his empirical study of "twin" R&D projects. In this study, engineers working on parallel Federal contracts completed solution development records that kept track of any changes that occurred in the team's work and the source of any information that prompted each change. In this manner, Allen collected detailed data on information sources and was also able to relate information use to project success.

In-depth interviews that made substantial contributions to the investigation were conducted by a few investigators (e.g., Holmfeld, 1970; Kremer, 1980; Schrader, 1991; Shuchman, 1981). A few studies used diaries (e.g., Tushman, 1979) and some investigators produced sociometric maps of communication networks as part of their data analysis (e.g., Kremer, 1980).

These investigations of information exchange and use in engineering settings leave no doubt that engineers obtain the information needed to accomplish their work from a wide variety of sources. Among the information resources mentioned in these studies are:

- Technical reports (in-house and external)
- Trade journals (both technical and non-technical articles)
- Scholarly journals
- Patents
- Memos
- Tables
- Specifications and standards
- Vendors' catalogs
- Manufacturers' advertisements
- Handbooks
- Textbooks
- Government laws and regulations
- Own notebooks
- Records of past company projects, including data and designs.

It appears that trade journals, in-house reports, manuals, and standards and specifications are often judged the most highly valued print sources. Shuchman (1981, p. 45) found that print sources were used by engineers to (in descending order of importance) keep current in one's field, keep current in other fields, discover new markets, answer specific technical questions, monitor the competition, and flag articles to pass on to others. There is less consistency in study findings related to information sources other than interpersonal communication, because different studies include different print sources as objects of investigation.

Information is acquired not only on the job, but at conferences, trade shows, and bidders' meetings. In addition to these information sources, engineers rely on a wide variety of people for needed information, including: co-workers, supervisors, technical staff, subordinates, sales representatives, customers, consultants, friends and colleagues in other organizations, and government representatives. A few investigators (e.g., Allen, 1984; Holmfeld, 1970; Kaufman, 1983) present results that describe the role of experimentation and the engineer's own knowledge and experience--as opposed to other people and literature--in providing needed information.

Shuchman (1981, p. 58), provides an extensive list of the reasons information is needed by engineers. Her data show that engineers need a wide variety of information to perform their work, including basic scientific knowledge, data, practical and procedural information about design methods, and non-technical information such as codes of practice. Kremer (1980, p. 61) delineates the range of reasons why engineers need information, including to find a solution to a scientific or technical problem, to solve administrative problems, to identify clients' requirements, to define a problem, and to keep abreast of current developments. Barczak and Wilemon (1991) found a similar range of communication purposes: to discuss product features, technical issues, customer needs, manufacturing issues, schedules and timing, financial issues, managerial issues, and resource issues. These results are valuable in that they validate the findings, described above, about the nature of engineering tasks and knowledge. Kremer and Shuchman, however, do not relate these specific information needs and uses to particular information sources and channels. They do not, in other words, describe the role of interpersonal communication or reliance on other engineering tools and resources, in satisfying specific information needs.

A few of the studies present results that link particular information needs or sources to specific work tasks. Several studies discuss particular uses of interpersonal communication, but results are not very detailed along this dimension. Rosenbloom and Wolek (1970) found that interpersonal communication was the primary source of information used by engineers to solve a particular work problem. Allen (1984) found that interpersonal contacts were the primary means of generating ideas and solutions for problem-solving (p. 63), as well as for defining problems (i.e., generating criteria and setting limits of acceptability) and testing potential solutions against critical dimensions (p. 65). Kaufman (1983) found that interpersonal communication was most important for finding a solution to a problem and learning new techniques, and was also of significant value in helping to define a problem and in finding leads to information sources (p. 17).

The literature reveals consensus on the factors associated with the use of particular sources and channels by engineers. These are accessibility, technical quality or reliability, ease of use, relevance, and degree of prior experience with a particular source or channel (Allen, 1984; Chakrabarti et al., 1983; Gerstberger & Allen, 1968; Kaufman, 1983; Kremer, 1980). Accessibility is consistently concluded to be the most important determinant of use.

De Meyer (1985) offered a unique view, suggesting that whether the product being developed was in its infancy or mature affected the nature and manner of engineering information resources consulted. Shuchman (1981) found that job activity and type of industry were the most important variables in determining the value placed on particular information sources. Allen (1984), Shuchman (1981), and Holmfeld (1970) all note that proprietary concerns inhibit external communication (p. 41). Allen (1984) also concludes that engineers are able to communicate more easily with internal colleagues because a shared knowledge and cultural base reduces the likelihood of semantic noise and misinterpretation (p. 139). Holmfeld (1970, p. 158) remarks on other communication constraints faced by engineers, namely time, budget, performance, and manufacturability requirements.

Key findings on the communication patterns of engineers are presented below. Findings are related to particular types of information needed, particular work tasks (such as idea generation or problem-solving), work categories (such as research or development), or task characteristics (such as degree of complexity, interdependence, or uncertainty):

- Interpersonal communication is an extremely important source of information for engineers (Allen, 1984; Chakrabarti et al., 1983; Kaufman, 1983; Kremer, 1980; Pelz & Andrews, 1966; Shuchman, 1981; Tushman, 1979).

- Most of this interpersonal communication is internal (Allen, 1984; Goldhar, Bragaw, & Schwartz, 1976; Kaufman, 1983; Kremer, 1980; Pelz & Andrews, 1966; Shuchman, 1981).

- Interpersonal communication is significant means of acquiring information categorized as unpublished material (Allen, 1984), or information not deliberately sought (Kremer, 1980; Rosenbloom & Wolek, 1970; Shuchman, 1981).

- Interpersonal communication is used primarily for problem-solving (e.g., Allen, 1984; Gerstenfeld & Berger, 1980; Shuchman, 1981; Tushman, 1979).

- Interpersonal communication is an important factor in engineering productivity and quality (e.g., Allen, 1984; Barzak & Wilemon, 1991; Tushman, 1979). Diversity of communication is more important than frequency (Allen, 1984; Pelz & Andrews, 1966). The exact nature of the impact of communication on productivity is complex (e.g., Allen, Lee, & Tushman, 1980; Shuchman, 1981; Tushman, 1978) and varies according to a number of interacting factors, such the nature of the engineering project and whether communication is internal or external.

- Use of interpersonal communication channels is linked to perceived accessibility and technical quality (Allen, 1984; Chakrabarti et al., 1983; Gerstberger & Allen, 1968; Kaufman, 1983; Kremer, 1980). Relevance of information is important factor in choice of source (Rosenbloom & Wolek, 1970).

- Use of interpersonal communication is linked to task uncertainty, interdependence, complexity (e.g., Tushman, 1978, 1979).

- Interpersonal communication is linked to primary engineering category or activity. It is used more in design and development (e.g., Kaufman, 1983; Rosenbloom & Wolek, 1970) and in applied research (e.g., Gerstenfeld & Berger, 1980) than in basic research.

Although De Meyer (1991) points out that there are conflicting results if one goes below a certain level of generality, the importance of interpersonal communication is a major conclusion of virtually every study that investigates the information behavior of engineers. Shuchman (1981, p. 40) says:

> Most engineers rely on a very limited group of sources for technical information, making an engineer's informal contacts the critical element in solving technical problems, maintaining competence, and disseminating new information. Engineers without access to the informal network are apt to have difficulty in getting necessary technical information.

Interpersonal communication is important to engineers because it conveys needed information not found in published work and because it is perceived as more efficient than searching though published literature. These studies, thus, confirm that the conclusions reached by sociologists about the importance of interpersonal communication to the conduct of scientific and technical work are, indeed, specifically applicable to the work of engineers. On the other hand, the exact nature of the relationship between different kinds of tasks, different types of interpersonal contact, and productivity is complex and not completely understood, although it is clear that different types of information, as well as different information channels and sources, are needed at different stages of engineering work.

A few studies offer unique results that are of particular interest to the current study. Allen (1984) presented results related to informal social networks in engineering organizations. He found very close agreement in the selection of individuals for social contact and technical discussion, although he was unable to determine the direction of causality. He concluded that, given the importance of the informal communication network, organizations should create conditions that foster informal exchanges. Although he only suggests here that electronic networks, which facilitate informal exchanges, would be valuable in engineering organizations, Allen explicitly discusses the potential of new communications technologies in a later paper. Here he asserts (Allen, 1986) that a "project" or matrix organizational structure facilitates task coordination, while a "functional" structure connects engineers more closely with others who have the same relationship to the technology being produced that they do. This means that organizations are faced with a trade-off, one that Allen suggests may be eased by the introduction of new information and communication technologies. Information retrieval systems might be used in project-oriented organizations to achieve some functional goals, while in functionally-structured organizations, electronic communication systems might allow a virtual matrix to exist.

Schrader (1991) conducted an empirical study of "informal technology transfer" among R&D workers in industry that has interesting implications for the issue of proprietary concerns in the networked environment. He found that most external communication exchanges were better characterized as "information trading" than "information leaking," and that they resulted in substantial gains to individuals, their firms, and industry as a whole. Further, he found that previous acquaintanceship was not required to initiate or maintain such trading relationships. One implication of this is that electronic bulletin boards, which would allow engineers to come into contact with external, unknown people who might have needed information on a posted topic or problem of interest, might be valuable in facilitating this kind of useful contact.

Virtually all of the studies reviewed in this section were conducted before the advent of substantial computer networking implementation in science and technology settings. Shuchman (1981) found that engineers made little use of information technologies, although aerospace engineers were more likely to do so than other kinds of engineers. Pinelli (1991b), who investigated information transfer in the aerospace industry through a survey of 1,800 scientists and engineers, offers one of the only studies of scientific and technical information transfer that collected data on the use of electronic networks. The percentage of respondents reporting use of various networking technologies was as follows:

- Electronic networks 44%
- Electronic mail 54%
- Electronic bulletin boards 30%
- Electronic databases 57%
- Videoconferencing 21%.

Pinelli did not, however, relate this data to any other data collected in his study in a manner that would suggest associations between network use and particular work tasks, communication activities, or factors encouraging or discouraging network use.

2.5.4. Engineering Communication: Summary and Conclusions

This section reviewed literature on the use of various engineering resources--including people and other tools and information resources--by scientific and technical workers. It emphasized the relationship between informal communication channels and specific information needs, work categories, work activities, task characteristics, and work impacts. Studies of the nature and role of communication networks and information exchange in scientific and technical work have been conducted by researchers in information science, communications, and management. Although a number of empirical studies have examined the information seeking and use behavior of engineers, it is scientists who have received the bulk of attention. Further, studies of engineers tend to focus on those engaged in R&D work as opposed to those conducting "normal" or "mainline" engineering work, which is of equal importance to concerns of industrial productivity. Generally speaking, these studies have concluded that communication is an important source of information and ideas for engineers and a significant factor in improving engineering productivity.

In summary, both the popular and scholarly literature can be used to gain an understanding of the relationship between engineering work and communication. The nature of the work performed by engineers demands a great deal of communication. In fact, it is estimated that engineers spend about 30% of their time in communication-related activities

(Murotake, 1990). The uses of social networks in engineering work can be summarized as follows. They:

- Convey personal or private knowledge, e.g., mistakes, detours, lucky guesses, opinions, and values, which does not appear in published versions of research;
- Convey how-to information such as hints about preparation of compounds and quirks of apparatus;
- Contribute and generates new ideas through serendipitous, interactive contact with external sources;
- Are used for planning and coordinating, problem-solving, and collecting and analyzing data; and
- Serve social as well as technical functions, e.g., stimulate and encourage engineers and reinforces their sense of group identity and purpose.

All of these findings seem to imply some substantial benefits from the use of electronic networks for informal communication in engineering environments. To the extent that important formal information (e.g., experimental data, published literature, parts lists, specifications) are made available online, networks should be valuable in supporting access to these resources, as well. The next section of this chapter turns to a review of literature on the use of electronic networks by engineers.

2.6. Engineers' Use of Information and Communication Technology

2.6.1. Introduction

With the recent proliferation of computer networks, a number of discussions and studies of the potential impact of networking on science and technology have begun to appear in the literature. This section provides an overview of this work, which has been conducted from policy, information science, management, communications, and social psychology perspectives. The purpose of this section is to describe the information and communication technology environment of engineering today and to review what is known about both the use of networks by engineers and the impact of networks on engineering work. This review of selected literature provides an overview of:

- Thoughtful analyses of the potential impact of networks on science and technology, especially those conducted from a policy perspective;

- Descriptions of the use of information and communication technology in engineering environments that have appeared primarily in the trade, professional engineering, and management literature; and

- Empirical investigations of network use that have been conducted in science and technology environments, primarily by researchers in the fields of communications, information science, management, and social psychology.

The literature reviewed in this section is useful to the current study in that it identifies current expectations and concerns regarding electronic networking in science and technology, provides some information about current uses of electronic networks by engineers, and identifies research findings and approaches related to electronic networking. A major gap in the literature is the lack of integration of these three areas of work. No extensive, cross-institutional, empirical studies that focus on the use of networks to support engineering work and communication appear to have been conducted. Results obtained in the present study address this gap.

2.6.2. Critical Analyses of Networking Impacts on Science and Technology

With the increasing proliferation of electronic networks, a number of analyses and discussions of the potential impact of networking on science and technology have been conducted. The Federal government has held a series of hearings on this topic, has commissioned several studies, and has produced its own reports. An overview of this material will be followed by a brief review of other scholarly analyses of networking impacts on various aspects of science and technology. The emphasis in these analyses has been on the use of networks to support science and R&D, although the Federal government has begun to consider the implications of national networking for engineering productivity (Congress. Senate, 1991).

The work reviewed in this section is relevant to the current study because it encompasses engineers and many of the tasks performed by engineers, but there is also a clear need to learn more about engineers specifically. Much of the literature reviewed here is contemporaneous with the inception of the current study. Over the course of the study (from 1991 to 1994), Federal attention has shifted from the National Research and Education Network (NREN) to the National Information Infrastructure (NII) and has moved toward greater attention to the needs of end users of network technology and to the use of networks in industry (Bishop, 1993; Bishop & Bishop, in press). Especially relevant Federal policies and reports that have appeared since the completion of the current study are discussed in Chapter 5.

The Federal government has, historically, been concerned with the development of effective policies related to scientific and technical information (STI). This concern waxes and wanes in light of specific historical and technological developments, i.e., as problems and opportunities related to science and technology, and hence to scientific and technical information, present themselves. Federal involvement increases when world events (such as the launch of Sputnik, U.S. entry into World War II, and emerging Japanese leadership in high technology) threaten national security, U.S. superiority in certain areas of science and technology, and international economic competitiveness. Federal attention is also spurred by general concerns about improving technology transfer and improving return on the Federal government's multibillion dollar investment in R&D. Finally, it also increases when new information technologies are developed that suggest potential improvements to scientific and technical work productivity and to STI transfer. Major policy studies that include discussions of new information and communication technologies include those produced by the President's Science Advisory Committee (1963), the Committee on Scientific and Technical Information (Federal Council for Science and Technology, 1965), the Committee on Scientific and Technical Communication (1969), the Federal Council for Science and Technology (1972), Giuliano and colleagues (Arthur D. Little, 1978), and Bikson, Quint, and Johnson (1984). An analysis of major

Federal STI policy studies is presented by Bishop and Fellows (1989); Pinelli, Henderson, Doty, and Bishop (1992) provide an overview of policies, studies, and events related to U.S. scientific and technical information. For other discussions of government support of science and computing, see Cohen (1988), Dupree (1986), Etzkowitz (1988), and Licklider (1979).

Government interest in, and support of, computer networking can be traced to the development of ARPANET, a national network intended for use by researchers involved in Department of Defense work in the 1960s (Quarterman, 1990). Then, as now, there is concern at the Federal level that R&D is an essential national enterprise and must be supported. There is also the recognition that electronic networks, which link researchers to each other, to powerful analytic and computational tools, and to important information resources, are a key component of increased scientific and technical productivity and competitiveness. NSFNet, which came online in 1985, connected six government-supported supercomputing centers, and became the backbone of the current Internet. More recently, the Federal government has supported the development of high-speed national networking, first in the form of the National Research and Education Network (NREN) and, currently, as part of the overall development of the National Information Infrastructure (NII).

The original NREN legislation was introduced in 1988 (Congress, Senate, 1988a) and served as the catalyst for a series of government hearings, studies, and reports related to the potential impact of national networking on the conduct of research (see McClure et al., 1991 for an extensive review of this material). The Office of Science and Technology Policy (OSTP) issued two reports (1987, 1989) that outline a national agenda for the implementation of high-speed networks. These reports argue that the development and implementation of advanced computing and networking systems are critical because they provide the "means to develop large scale distributed approaches to the collaborative solution of computational problems in science, engineering, and other application areas" (Office of Science and Technology Policy, 1987, p. 18). Subsequent statements of Executive branch intent with regard to national networking (see, e.g., Office of Science and Technology Policy, 1991) describes the "grand challenges" in science and engineering that need to be supported and outline the government's strategy for supporting and implementing high-speed networks. The Office of Technology Assessment (1989) issued a background paper that explores key issues related to Federal support of national high-speed networking.

A report issued by the National Research Council in 1988 explicitly linked national networking with the need to maximize national productivity and competitiveness and recommended strategies for government support of high-performance computing and high-speed networking initiatives (National Research Council, 1988a). The Council also issued a report providing an in-depth and thoughtful treatment of major topics and concerns surrounding the role of national networking in the conduct of research (National Research Council, 1988b). More recently, the Council's report on "national collaboratories" (1993) describes the extent to which various scientific and engineering communities use information technology to support large-scale distributed work; the report also offers recommendations for further development of systems to support such efforts.

In addition to these reports, which outline the Federal government's goals and plans, a number of Congressional hearings were held on topics and issues related to the role of computer networks in science and technology and, in particular, the development of NREN. The topics of those hearings included the current status of the U.S. supercomputer industry, the need for high-performance computing and high-speed networking to support advanced research, and the appropriate role for government and for specific Federal agencies in national network development (see McClure et al., 1991, pp. 25-29 for a description of key NREN hearings). More recently, Federal attention as been directed to revising telecommunications regulations (see Browning, 1994, for an overview of legislative initiatives in this area) and intellectual property laws (Information Infrastructure Task Force, 1994, July 7). The outcome of current policy initiatives in both intellectual property and telecommunications regulatory reform will undoubtedly affect access to computer networks and networked information resources for U.S. engineers.

A report issued by the Panel on Information Technology and the Conduct of Research (1989) is unique because it takes a user perspective. The report describes the information technology needs, uses, and problems of researchers in different disciplines. It concludes that, although new computing and communications technologies have led to definite improvements in a number of areas, problems remain. Further, the report stresses that "complex institutional and behavior constraints" (p. 1) underlie current difficulties.

The coming of the electronic "information age" has also generated much commentary in the scholarly community and popular press. Brand (1987), Wenk (1986), Turkle (1984), Roszak (1986) are classic works that discuss developments in new information and communication technologies and raise technical, social, political, and behavioral issues related to the expanding use of computers and networks. A special issue of *Scientific American* (Communications, Computers, and Networks, 1991), occasioned perhaps by the perception that individuals, institutions, and society at large are actually beginning now to feel the revolutionary impacts of new technologies, provides a collection of articles related to the use of computer networks for research, business, education, and recreation.

The scholarly community has also begun to address concerns specifically related to the growing use of electronic networks by researchers in all disciplines. Denning (1985) offered an early description of research networking in science. Schrage (1990) describes and discusses the potential of various new networked technologies to enhance research collaboration. Lievrouw and Carley (1991) and authors in a collection edited by Aborn (1988) discuss the implications of "telescience" for individuals and institutions. Fienberg, Martin, and Straf (1985) give particular emphasis to the use of electronic media for sharing research data. Lapidus (1989) draws attention to the social and ethical implications of networking in research environments. Arms (1988) presents case studies of the development of electronic networks in and for academic research communities. Implications of networking for the formal system of research communication, i.e., for libraries and publishers, have also been discussed (see, e.g., Larsen, 1990; Osburn, 1989; Shaughnessy, 1989; Woodsworth, Allen, & Hoadley, 1989).

Koch (1991) offers an especially cogent analysis of the use and potential impacts of electronic networks in science. She reviews literature in this area and concludes that "the most pressing problems to be faced by network managers, science administrators, and policy makers are likely to be organizational rather than technical in nature" (p. 70). Morell (1988) is one of the few commentators to mention engineers specifically. He suggests that new information and communication technologies may produce a variety of impacts on the way scientific and engineering research is conducted. Morell hypothesizes that the proliferation of computers and networks may affect the individual behavior of scientists and engineers, the organization of R&D laboratories, social policy concerning R&D funding, and the selection of R&D problems, methods, and even solutions. He also suggests factors that may explain the extent to which these effects are felt in particular scientific and engineering endeavors, including the degree of data intensity, the requirements for real-time analysis, and lay interest in a particular field.

The literature noted in this section demonstrates and describes the interest of the Federal government in national networking initiatives aimed at the support of science and technology. It also points to a growing interest in the scholarly community about social, behavioral, and policy issues related to new developments in information and communication technology. Finally, it identifies a number of discussions related to the potential impact of electronic networks on science and technology. To date, these analyses of networking in science and technology overwhelmingly deal with issues related to the conduct of science. In the language of the initial NREN legislation itself (Congress. Senate, 1991, Section 2.a.2) and Executive branch documents devoted to goals and plans for national networking (Office of Science and Technology Policy, 1991, p. 2), however, the Federal government acknowledges the potential of national networking to solve "grand challenges" in engineering and improve U.S. industrial productivity.

Thus, policy and scholarly attention has begun to shift to explorations of the use of electronic networks in engineering work. The General Accounting Office (1991) conducted an assessment of the degree of electronic network implementation in industrial settings; this represents one of the first substantive efforts on the part of the Federal government to begin exploring issues related specifically to the implications of national networking for engineers. Anne Wolpert, Director of Information Systems at A.D. Little, Inc., warned in a 1991 conference presentation that NREN was lacking an "I" for industry. She asserted that national networks would not be used by engineers and would not, therefore, produce desired impacts in terms of industrial productivity, until policy makers began to take account of the particular needs and constraints surrounding engineering work tasks and communication activities in industrial settings. Descriptions of network use in engineering settings have appeared in the literature; an overview of this material is presented below. These descriptions, however, have rarely been integrated with policy discussions; nor have they been greatly extended or reinforced by the kind of systematic empirical work on networking use and impacts that is reviewed later in this section.

2.6.3. Descriptions of Electronic Networking in Engineering Settings

As discussed in early sections of this chapter, engineers work in teams to research, develop, design, test, and manufacture a wide range of systems, products, and processes. Engineering is a complex activity that involves creativity in addition to scientific, technical and managerial problem-solving and the coordination of many independent efforts. It is not only information-intensive, but communication-intensive, and computation-intensive as well. Thus, advances in computing and communication technologies would appear to offer many opportunities for improving the efficiency and effectiveness of engineering work.

This section provides an overview of the use of computing and communications technology in engineering settings. The popular and professional literature describes engineers' use of computing and communications applications such as computer-aided design (CAD), computer-integrated manufacturing (CIM), engineering information systems (EIS), and electronic mail and conferencing systems. Most of this literature concentrates on the technical, financial, or management aspects of these systems, while little attention is focused on problems, issues, and impacts from the users' point of view.

A number of authors discuss the strategic importance of new information and communication technologies to organizational performance, and provide examples from a variety of settings. Walton (1989) presents numerous case studies, including one in an aerospace company, to draw out important concepts, strategies, and techniques for improving the implementation process associated with new information technologies. He stresses the importance of considering both the technical and social aspects of system implementation. Keen (1986) presents a variety of case studies to support his argument that telecommunications is an important feature of any organization's strategy to improve its competitive advantage. Morton (1991) presents a number of perspectives on the introduction and impact of information and communication technologies in today's global economy. The impact of computer networking on organizations is described by Reich (1991) and Davidow and Malone (1992). The gains achieved when networks are used to reinvent the organizational enterprise are emphasized by Hammer and Champy (1993). All of these authors argue that new technologies are revolutionizing the way people in organizations work and communication and that the changes that are occurring must be better understood.

Today, engineers use computers to perform calculations; to produce and evaluate drawings, designs, and prototypes (CAD/CAM); to maintain and archive the "corporate memory," i.e., all the contracts, designs, schedules, assumptions, constraints, procedures, data, etc., associated with each particular project; to write and edit documents and prepare presentations; to run project management software; and to control equipment. Gunn (1982) provides an early report on the use of computers and electronic networks to "mechanize" design and manufacturing. A collection of papers on the application of computers to engineering design, manufacturing, and management are offered by Lastra, Encarnacao, and Requicha (1989). Ettlie and Stoll (1989) present a collection of essays and case studies on managing the design to manufacturing process. This work is especially intriguing because it draws attention to the philosophical and cultural changes that must accompany the implementation of new computing and communications, if this new technology is to bring about the desired effects. Rockart & Short (1989) describe the organization's need to manage interdependence. They give a number of examples of engineering firms using electronic networks and computerized tools and databases to integrate the stages of product development, distribution, and service; support team work; and facilitate coordination and control.

The policies, principles, and techniques of "concurrent engineering," derived from the perceived need to improve industrial productivity and competitiveness, aim to improve engineering quality, reduce costs, increase the speed of product development, and improve customer satisfaction. Concurrent engineering calls for integrating engineering functions so that they may be performed in parallel, as opposed to sequentially. It strives to improve communication in order to coordinate the work and integrate the information contributed by all of the many people involved in the development, production, and marketing of a particular technology.

Many engineering organizations are exploring the ability of computers and electronic networks to facilitate concurrent engineering and improve the performance of engineers and the technical quality of their work. A report by Lewis (1990) provides an in-depth treatment of the methodology and tools for developing networked systems for concurrent engineering at General Electric's R&D headquarters. Kaplan (1991, p. 32) notes that "Today, teamwork and concurrent engineering are the important organizational issues, so workstations must be tied together into networks that optimize the use of shared resources."

Computer networks are playing an increasingly important role in engineering work because they link design and analysis tools with other important resources to create integrated engineering information systems (EIS) that can be used by engineers from their own desktops. Dirr and Stockdale (1989) describe 3M's transition from the use of CAD systems to a distributed computing strategy in which "All authorized users would have access to information anywhere in the network, and CAD and project management would be joined in a single integrated system" (p. 50). Heiler and Rosenthal (1989, p. 431) define an EIS as the combination of "software tools, database managers, databases, and hardware to provide integrated environments for engineering design and management." They also describe the rationale for such systems (p. 431):

> Engineering environments can be extremely complex. They must support long, complex, and interdependent tasks that produce and manipulate highly specialized data. Often multiple representations of the same information are required to support different tasks. Moreover, more than one engineer may work concurrently on different aspects of the same design, which may introduce inconsistencies into the data...

The use of computers and networks to automate the manufacturing process is becoming more widespread. Boll (1988) describes the role of the manufacturing automation protocol (MAP) in accomplishing the integration of the manufacturing process, which includes "machining, assembly, warehousing, quality assurance, packaging and dispatch." Schatz (1988) describes the increase in computer-integrated manufacturing (CIM) investments worldwide, noting that they are expected to double between 1988 and 1992, reaching about $91 billion.

Electronic data interchange (EDI) is used to exchange orders and invoices with vendors and suppliers, and to exchange contracts with clients and customers (see, e.g., Beckert, 1989; Purton, 1988). Thus, networks are also used in engineering environments to facilitate formal business communication outside the firm. Networks are used in some firms for information retrieval (IR) in connection with both in-house and commercial databases. Information retrieval systems have received mixed reviews from engineers. Christiansen (1991, p. 21) discussed results of an informal IEEE survey on how engineers obtain the information they need to do their jobs. He reports that engineers have difficulty performing online searches and often obtain inadequate results. He also interprets the tendency of engineers to "scan and save" large amounts of material as a response to their dislike of retrieval systems. Breton (1981, 1991) presents a more compelling argument for the underutilization of information retrieval systems. He concludes that the informal and visual material that is important to engineers is not included in most information retrieval systems and, further, that current indexing techniques fail to retrieve information according to those dimensions, such as "desired function" that are useful to engineers. Gould and Pearce (1991) describe results of an assessment, based largely on interviews, intended to relate information needs in engineering to current systems for storing, organizing, and disseminating that information. Mailloux (1989) reviews literature on EIS. She provides an overview of a variety of engineering systems and devotes considerable attention to a discussion of how EIS support engineering work and communication behavior.

Finally, the literature suggests that engineers also use electronic networks for a variety of interpersonal communication purposes. Borchardt (1990) includes electronic mail among his suggestions for improving in-house technical communication in order to facilitate the sharing of ideas, provide a more stimulating work environment, and prevent the duplication of efforts (p. 135). Beckert (1990, p. 68) notes that engineers can use electronic mail to send text, data, and graphics to their colleagues and to automate the notification and status change process between engineering, manufacturing, and external entities. She notes that electronic communication eliminates telephone tag and problems associated with time-zone differences, and also saves time in scheduling meetings and responding to technical questions. Mishkoff (1986) describes computer conferencing as the answer to the problem corporations face when they employ geographically-dispersed work groups. He reports that Hewlett-Packard employs thousands of engineers in over 70 divisions, of which one-third are located outside the United States. Mishkoff describes how computer conferencing is used in place of more expensive mechanisms to allow groups of engineers to share their knowledge efficiently and coordinate their work (p. 29).

The power of computer conferencing systems to form the base of "electronic expert networks" in organizations is described by Stevens (1987), although he does not focus exclusively on engineers. His discussion applies the assertions about the importance of informal communication in organizations, discussed above, to the electronic environment. He argues that electronic networks are an important source of expertise for employees because "The best answers frequently come from surprising sources. An unknown peer with a relevant experience can sometimes provide better help than a more famous expert, who may be less accessible or less articulate" (p. 360). Stevens also notes that "While expert networks can be used by traditional organizations to strengthen their effort to produce and provide products and services, expert networks also seem to represent almost a new form of organization" (p. 369).

Many organizations hope that by facilitating communication and improving coordination, electronic networks will decrease both the costs and time needed to bring products to market. Due to proprietary and security concerns, a number of engineering organizations have implemented their own private, high-speed networks that are used only by their own employees. The need for high-bandwidth, completely reliable electronic transfer of critical data also makes the use of most public commercial networks infeasible for some industries and applications. Werner and Bremer (1991, p. 46) note that even companies involved in industry-academia-government R&D cooperatives prohibit electronic links to external consortium members for fear of security leaks.

The National Research Council's Panel on Engineering Employment Characteristics conducted an informal survey of engineering employers (National Research Council, 1985) in which they obtained employers' views on the impact of new tools on engineering productivity.

Survey results (p. 68) indicated that about one-third of employers had widely available computer-aided drafting or design systems in place, few had computer-aided manufacturing systems, and about 50% had engineering information systems. Fewer than one half of respondents had formally evaluated their systems, although they estimated productivity gains of about 100% for drafting systems, 50% for design systems, and 35% for information systems. The Panel concluded that "these new computer-aided tools permit increasingly sophisticated products to be designed in less time with substantially greater accuracy and with greater cost-effectiveness" (p. 27) although they also noted that "their net effect on engineering and on industry as a whole cannot be forecast with confidence" (p. 26).

The aerospace industry possesses a number of characteristics that make it a natural environment for the implementation of electronic networks. It is a high technology industry, already extensively computerized. It involves significant R&D, which, as the studies in Section 2.5. demonstrate, is a communication-intensive activity. Further, its end products are highly complex, calling for a great deal of work task coordination and the integration of information created by diverse people. In describing the business and technology strategy in place at British Aerospace, Hall (1990) emphasized the need for increased computing and communications capabilities in aerospace firms aiming to design, develop, make and market complex systems while maintaining a technical competitive edge and reducing unit costs (p. 16-2). He noted that a number of typical information technology opportunities were particularly relevant to the aerospace industry, such as "improved productivity, better competitive edge, reduced timescales, closer collaboration, more streamlined management, better commonality of standards across sites, more operational flexibility, [and] constructive change of workforce skill levels" (p. 16-2).

Rachowitz et al. (1991) describe efforts at Grumman, a major U.S. aerospace corporation, to realize a fully distributed computing environment. Grumman's goal is to implement a system of networked workstations in order to "cost-effectively optimize the computing tools available to the engineers, while promoting the systematic implementation of concurrent engineering among project teams" (p. 38). The network includes PCs and software to be used for communication. Grumman assumes that their computer/information integrated environment (CIE) will result in "product optimization--quality products manufactured with fewer errors in shorter time and at a lower cost" (p. 66).

Black (1990) presents a brief overview of the uses and advantages of computer conferencing systems, noting that computer conferencing is a "very powerful tool for the transfer of information in all areas of research and development" and "a natural for the AGARD [Advisory Group for Aerospace Research and Development] community... " (p. 13-4). Molholm (1990) describes the application of the Department of Defense's Computer-aided Acquisition and Logistics Support (CALS) initiative to the aerospace community. CALS mandates the use of specific standards for the electronic creation and transmission of technical information associated with weapons systems development. Eventually all Department of Defense contractors and subcontractors will be required to create and distribute in digital form all the drawings, specifications, technical data, documents, and support information required over the entire lifecycle of a military project. The CALS initiative may be a significant impetus to networking for aerospace firms.

These reports reveal that a number of engineering organizations are using electronic networks for communication activities, distributed computing, and shared access to information resources. Networks are being implemented to serve organizational goals and business strategies, i.e., to achieve impacts in the areas of better and faster product development and reduced costs. The motivations for network investments noted in these reports suggest factors that may encourage network use in particular engineering organizations and obviate the need for them in others. These reports also hint at a number of factors that may hinder network use, such as security and proprietary concerns, the failure of indexing techniques to retrieve stored information in a way useful to engineers, and the substantial financial outlays required to implement networked systems.

Descriptions of networking needs, uses, problems, and impacts in engineering environments are scarce, and few have been brought to the attention of policy makers charged with making decisions about networking investments and policies at the national level. Further, piecemeal anecdotal descriptions are not entirely sufficient for informing policy development at either the organizational or national level. The current study investigates networking needs, uses, problems, and impacts on a broader scale and in a more systematic manner than the reports reviewed here. These reports were useful as background for the current study, however, in that they suggest particular networking needs, uses, and impacts that are relevant to engineering work and deserving of further exploration. Empirical studies of electronic networking are reviewed below. They also suggest concepts to be explored in the current study and, further, identify approaches that have been used in previous empirical investigations. Because few of these empirical studies have dealt with engineers, the descriptions that have been presented in this section provide a useful complement to them.

2.6.4. Studies of Electronic Networking in Science and Technology

There is a growing body of literature that explores trends, issues, and concepts related to new information and communication technologies. Before moving on to a discussion of empirical research related to the use of electronic networks in science and technology, a selected review of more general work that elucidates networking use, impacts, factors associated with use, and research issues is presented.

Licklider and Vezza (1978; reprinted in Greif, 1988) present an early, and very broad, overview of networking applications and issues. They define and describe applications ranging from electronic mail to home security systems, and discuss a variety of issues related to the political, social, and economic impacts of networking. Vallee (1984) provides an overview of the use of electronic message systems in industry. He describes the need for, and capabilities of, such systems and focuses on issues related to network implementation and management. Similarly, Sullivan and Smart (1987) present a model for matching organizational communication flows with the capabilities of various communications technologies; their model is intended to assist organizations in implementing and managing electronic networks.

Overviews of research in computer-mediated communication (CMC) are provided by Steinfield (1986b), Rosenbaum and Newby (1990), and Rice (1980, 1987a, 1992). These review articles summarize work investigating the capabilities of new communications media and how they differ from traditional media, factors that affect network use, and network impacts. They also discuss gaps in the CMC literature and identify a number of issues related to the study of networked communication. Culnan and Markus (1987), Rockart and Short (1989), and Huber (1990) present critical overviews of research on the effects of advanced information and communication technologies on organizations.

The capabilities often attributed to electronic networking are that it allows both synchronous and asynchronous communication, it supports time-independent communication, at greater speed, over a large geographic spread, and it allows messages to be edited, forwarded, and distributed to many people simultaneously. In other words, electronic communication, as noted by Rice (1992, p. 1), "can reduce or alter some of the temporal, physical and social constraints on communication."

Influential empirical work on the use and impacts of electronic networks includes that of Sproull and Kiesler (see, e.g., 1986, 1991), who have been leaders in exploring the ability of CMC to convey social and emotional cues and have also been advocates of the need to understand the full social impacts of computer networks on work. Aspects of their research that deal with workers in science and technology are discussed below.

Daft and Lengel (1984) introduced the concept of "information richness" as an important for distinguishing the utility of different communication media in different situations. In analyzing the characteristics and capabilities of various media, they argue that rich, personal media (i.e., face-to-face and telephone exchanges that allow for immediate feedback, multiple social cues, and natural language messages) are best for processing complex and subjective messages, while media that are impersonal and less rich (i.e., written rules and numeric documents that restrict feedback, contain few social cues, and contain standardized or formal terms) are best suited for exchanging well understood messages and standard data. Their underlying theme is that no single communication medium is best for all information processing requirements.

Of particular interest to the current study is Daft and Lengel's (1986) theoretical work that points to the need for organizations to fit the characteristics of communication media to task characteristics in order to achieve greater efficiency and effectiveness. They describe work tasks along a number of dimensions, and relate the information processing requirements of various kinds of tasks to the information processing capabilities of various media. Work is characterized according to the variety, analyzability, interdependence, and differentiation of the tasks involved. Merging their previous analysis of media richness with this assessment of task characteristics, they conclude that individuals performing work involving a great deal of variety, the need for judgment and expertise as opposed to routine procedures for solving problems, and interdependence with other departments whose work is very different from their own will require rich media and frequent and intense information exchanges. Steinfield (1986a) and Rice and Shook (1990) also present research that links job type and task type to the use and impacts of electronic networks.

Trevino, Lengel, and Daft (1987) further extend this work by including electronic mail in the types of media analyzed and by investigating media choice empirically. Managers were asked to describe the reasons behind their choice of specific face-to-face, telephone, electronic mail, or written messages. The investigators found that reasons for media choice fell into three broad categories: the content of the message, the medium's ability to signal symbolic (i.e., non-explicit) meaning, and situational determinants having nothing to do with the message itself.

Rice's body of empirical work has contributed much to current knowledge about CMC use and impacts, chiefly by testing concepts and relationships developed initially by other researchers (see, e.g., Love & Rice, 1985; Rice, 1989b; Rice, Grant, Schmitz, & Torobin, 1990; Rice & Love, 1987; Rice & Shook, 1988). His analyses, both conceptual and empirical, of the conduct of CMC research are perhaps even more important (see, e.g., Rice, 1980, 1989a, 1990, 1992; Rice & Bair, 1983; Rice & Shook, 1990; Williams, Rice, & Rogers, 1988). This work analyzes concepts explored and methods employed in CMC research. Much of Rice's work on CMC is rooted in the tradition of quantitative studies of the structure of social networks. Rogers, another major proponent of social network research, has also discussed the role of social network analysis in the age of electronic communication technologies (see, e.g., Rogers, 1987). These studies tend to look at the structure of networks as opposed to the meaning of particular communication messages or their impact on individuals in particular situations. Wigand (1988) presents a historical overview of this line of work. Both Rice and Rogers, while recognizing the contribution of social network analysis techniques to the study of electronic network use and impacts, have also advocated the use of more qualitative techniques that would shift attention to individuals and to social and behavioral factors associated with electronic networking.

It appears that there is still considerable doubt about appropriate uses of CMC in terms of the ability of computer networks to support task-related and socioemotional communication and the degree to which networks are able to transmit cognitively and emotionally complex messages. A range of impacts have been attributed to CMC, including changes in the quantity of information exchanged, greater diversity of communication partners, changes in group processes and decision making, changes in organizational structure, media substitution, and increased productivity. Some "quantitative" impacts of CMC on work and communication (e.g., time savings) are easier to measure than "qualitative" impacts (e.g., transformation of work processes), and appear to be moderate. Qualitative impacts are sometimes more difficult to assess, but may be more significant.

Attempts to identify factors affecting network use have not yielded strong results, but it would appear that access to computers, the nature of the task performed, the nature of communication needs, situational needs and constraints, and users' perceptions of the medium have been shown to influence network use. CMC research has suffered from a lack of cross-organizational studies, a lack of studies conducted in non-office settings, a lack of studies that examine both users and non-users of networks, and a lack of qualitative studies.

Recently, a number of empirical efforts dedicated to exploring the use of electronic networks in science and technology have been undertaken. The rest of this section is devoted to a review of this work. Most of this work focuses on the use of networks for CMC. It suggests that networks can facilitate engineering communication and work, although no networking studies have dealt exclusively or extensively with engineers. Further, new questions and issues have been raised, a number of conflicting findings have been presented, and few studies have compared network users to nonusers. Those studies that provide the most in-depth treatment of the use and impact of electronic networks from the point of view of those engaged in scientific and technical work are reviewed first. Then, relevant results from other studies are presented.

In connection with the government's NREN initiatives, McClure et al. (1991) conducted an empirical assessment of the impact of electronic networks on the research process and scholarly communication. Multiple data collection techniques were used to gather data from researchers in a variety of organizations and disciplines. The authors present results related to network use, impact, barriers, and issues, and discuss implications for network administrators and computing staff, R&D managers, and network users and potential users. In terms of use, they found that network applications related to both informal communication (e.g., electronic mail and bulletin boards) and data collection and analysis (e.g., remote log-in, file transfer) were used often and considered most valuable. Applications related to formal information transfer (e.g., online searching, and publication in electronic journals) were used less often.

The conclusions reached by McClure et al. (1991) about the impact of electronic networks on research work were:

- There seem to be few differences in use among academic, Federal, and private sectors;
- Perceived value is related to degree of use;
- Networks promote and facilitate collaboration;
- Networks reduce negative effects of being at a remote or small institution;
- Basic components of the research process have not changed, but the process is made more efficient and, in some cases, more effective, by electronic networks;
- Networks have strongest impact at data collection and analysis stages;
- Networks have some impact on project preparation, the formulation of a research design, and the interpretation of results; and
- Networks have the least impact on problem definition and the presentation of results.

In terms of research communication, they found that:

- Some components of the scientific communication process have changed as a result of network use;
- Networks make scientific communication more efficient and, in some cases, more effective;
- Networks facilitate the administrative and logistical aspects of arranging conferences, meetings, publications;
- Networks aid in the identification and provision of documents;
- Networks facilitate and improve the production of print journals;
- Networks broaden the scope of a researcher's community; and
- Networks facilitate communication about work in progress.

This work is important because is one of the few studies of networking in science and technology settings that explores the problems encountered by individual researchers in their use of networks and that, in addition, devotes considerable attention to social and behavioral issues that present barriers to network use. The technical problems most often noted by study subjects include complex networking procedures; insufficient network capacity, connectivity, and reliability; lack of standards and user-friendly applications; and lack of adequate documentation and directories. Important nontechnical problems included: inadequate training and support; confusing and dysfunctional network policies; "cultural" differences between network users, network managers, and organizational managers; and increased competition for network resources.

In a subsequent study by the same researchers, Doty et al. (1991) looked at the relationship between social and technical norms in the research community and network use. They found that researchers' use of and attitudes toward networks appeared to be guided, to some extent, by the degree to which networks could be integrated into the prevailing normative beliefs of the community.

Researchers in the interdisciplinary area of computer-supported cooperative work (CSCW) begin from the premise that in order to implement effective information and communication systems, one must begin with a thorough understanding of the work that the new technology is intended to support. A number of CSCW studies have appeared in recent years, with important collections provided by Olson (1989), Greif (1988), and Galegher, Kraut, and Egido (1990). Most of these studies investigate the nature of certain kinds of work and work communication and then discuss the implications of these investigations for the design and implementation of computing and communications systems. Several CSCW studies describe scientific and technical work and communication.

Ancona and Caldwell (1990) investigated the tasks and communication of new product development teams in high technology companies. The authors note that such teams "are responsible not only for the specific technical design of a product, but also for coordinating the numerous functional areas and hierarchical levels that have information and resources necessary to make the new product a success" (p. 174). Product teams are becoming common in firms ranging from Proctor and Gamble to General Motors to Lockheed (p. 173). Ancona and Caldwell found that new product teams progress through three phases of activity: creation, development, and diffusion. The communication- and information-intensive tasks that accompany these phases include (pp. 184-185):

- Getting to know and trust team members;
- Determining the availability of resources;
- Understanding what other functional groups think the product can and should be;
- Investigating technologies for building the product;
- Exploring potential markets;
- Solving technical problems;
- Coordinating the teams work internally and externally;
- Keeping external groups informed;
- Building relationships with external groups that will receive the team's output;
- Promoting the product with manufacturing, marketing, and service groups.

Ancona and Caldwell conclude that information and communication technologies designed to support these changing activities must be flexible and support the team's need to identify and contact relevant external groups, generate and evaluate ideas, and coordinate work. They note that electronic mail could be used to facilitate communication within the team and coordinate work with external groups. Computer conferencing systems would allow the team to provide regular updates on work progress and encourage ongoing discussion of particular issues with relevant individuals. Finally, networking--combined with computing applications like CAD/CAM--allows the direct exchange of work products and non-textual technical details. Some of the limitations of networking are also mentioned. Electronic mail and conferencing systems may result in information overload for product development teams and may not be adequate for conveying ambiguous information or building personal relationships, both of which are important in the development work.

Kraut and his colleagues have published a number of papers that describe their work on the nature of informal communication and its relationship to collaborative R&D work (Kraut, Egido, & Galegher, 1990; Kraut, Fish, Root, & Chalfonte, 1989 draft; Kraut, Galegher, & Egido, 1988, 1989 draft). Their work is based on surveys and interviews completed by scientists and engineers in a large industrial R&D laboratory and also on examining the archival publication record of researchers in psychology. Several aspects of this work are especially relevant to the current study: the characterization of informal communication that is based on communication qualities, the treatment of collaborative work tasks and communication functions, and the discussion of implications of their findings on collaborative scientific and technical work for new communication technologies.

Informal communication is defined in this work in terms of the set of qualities it possesses (Kraut, Fish, Root, & Chalfonte, 1989 draft). Formal communication is characterized as scheduled in advance, with arranged participants and a pre-set agenda, a one-way communication flow, impoverished content, and formal language and speech register. Informal communication, however, is unscheduled, involves random participants and an unplanned agenda, is interactive, possesses rich content, and uses informal language. Stohl and Redding (1987, p. 457) review literature on the nature and function of messages and message exchange processes, although they do not relate this work to the potential of new communication technologies. They typify the formal/informal dichotomy along a set of dimensions similar to that described by Kraut et al., characterizing informal communication as unofficial, spontaneous, nonroutine, tentative or exploratory, and conveyed with casual language. The authors describe the functions of informal communication as R&D scientists and engineers involved in collaborative work initiate, plan, execute and wind down projects (Kraut, Galegher, & Egido, 1989 draft). They note that collaborators initiating projects must get acquainted, identify common interests, assess compatibility, and do preliminary planning. In planning and conducting work, informal communication "brings researchers into contact with a pool of theory, research findings and procedures" (p. 18). It also provides a mechanism for browsing and interpreting published literature, refining ideas, sharing information, coordinating activities, supervising work, and monitoring work progress and performance.

Kraut, Galegher, and Egido (1989 draft) argue that physical proximity is the best technology for fostering successful group efforts in science and technology because it allows the spontaneous, casual, interpersonal conversations that are necessary for group maintenance, member support, and work production functions. They present evidence, based on a survey of R&D workers, that physical proximity increases the chances that collaboration will occur. In a survey of researchers in psychology, they found that physical proximity is strongly related to communication frequency, including the frequency of telephone and electronic mail use. Their results for this group also show that frequency of communication is positively associated with greater satisfaction with the process of conducting work and is negatively associated with the time needed to complete a project.

In other work, Kraut, Egido, and Galegher (1990) "define basic requirements that communication technologies must meet to support [...] any cooperative intellectual work that spans months and is at least partially based on a sustained personal relationship among the members of a work group" (p. 165). The major requirements are that they permit high quality interactions as low personal cost, i.e., that they possess the characteristics typically associated with informal communication. They contend that current technologies, including electronic mail and conferencing systems, are limited in the degree to possess these qualities.

Kraut and his colleagues have designed technologies, such as the Video Window, that support interactive video and audio links between geographically remote sites and are intended to mimic all the characteristics of informal communication that exist with physical proximity. Nonetheless, they conclude that "no single technology for supporting collaboration will adequately satisfy researchers' needs throughout the collaborative process" (Kraut, Galegher, & Egido, 1988, p. 764). Thus, the capabilities of different communication technologies may make each more or less appropriate to a given situation. For those occasions requiring the transmission of a simple piece of non-visual, unambiguous information, electronic mail may be preferable to a video/audio connection because it provides sufficient bandwidth and does not demand the mutual presence of both partners in the exchange. They also note (Kraut, Galegher, & Egido, 1989, draft, p. 41) that the benefits of informal communication that they cite may not scale up: large, heterogeneous teams may require more formal communication and control mechanisms.

Bizot, Smith, and Hill (1991) conducted an investigation of the use of electronic mail by managers, scientists, engineers, technicians, and support staff in five divisions of an Amoco R&D facility. They found that employees in an R&D organization found electronic mail most appropriate for (in descending order) exchanging information, asking questions, exchanging opinions, keeping in touch, and communicating with people who are not well known. It was not considered very appropriate for exchanging confidential information, generating ideas, problem solving, decision making, task allocation, resolving disagreements, and bargaining and negotiating. R&D managers found electronic mail most appropriate for calling group meetings, passing suggestions up the organizational ladder, sending and receiving progress reports, assigning individual tasks, and giving positive performance feedback.

Overall, respondents felt that electronic mail had changed their work in a positive way. A content analysis of messages revealed that over 90% were work-related. Messages were assigned to each of the following functional categories (in descending order): solicit or supply nontechnical information/advice/opinions; computer-related; perfunctory approval or acknowledgement; meetings and appointments; request or provide routine support service; technical; establish responsibilities; status report on work in progress; and social or nonwork related. They conclude that most messages dealt with administrative or nontechnical, as opposed to technical matters. From their examples of message functions (p. 83), however, it appears that "technical" was applied very narrowly to mean the exchange of actual pieces of technical data, e.g., "The current solvent composition is..." Discussion of technical matters, e.g., "The data we are getting from the field will have been summed and differenced," was categorized as nontechnical information/advice/opinion.

Hiltz, along with various colleagues, has produced perhaps the most extensive and highly regarded body of research related to the use of CMC by those engaged in scientific and technical work (see, e.g., Hiltz, 1988; Hiltz & Johnson, 1989; Hiltz & Turoff, 1978, 1981). Moreover, this body of work demonstrates the value of, qualitative approaches to the study of network use and impacts. Her most in-depth treatment of this topic appears in a monograph that describes studies of several different "online communities," i.e., different groups of scientific and technical users of a particular CMC system (Hiltz, 1984). The study of use, and perceptions of impact, revealed a wide range of positive effects. CMC was used to:

- Increase professional reading;
- Increase communication with local, offline colleagues;
- Reduce time needed to contact, communicate with people;
- Clarify theoretical controversies;
- Clarify methodological controversies;
- Reduce travel;
- Meet new people;
- Broaden perspectives;
- Increase communication and connectivity;
- Make workers less space and time bound;
- Increase quality of work ;
- Increase quantity of work;
- Increase stock of ideas;
- Provide leads, references, or other info useful in work ; and
- Increase familiarity of others with one's work.

Hiltz concluded that CMC changes the way people think and work, and expands the size and density of social networks. This research also indicated that CMC use can exacerbate any conflicts that may exist between one's organizational and community affiliations. Hiltz found that network use may damage one's organizational career, while it increases one's general status within one's scientific community. One limitation of Hiltz's work is that it has been restricted primarily to the study of a few particular CMC systems.

Foulger (1990) conducted a large-scale empirical investigation of users of IBM's in-house, international computer conferencing system (about 50% of whom were employed in R&D). One contribution of this work is its in-depth analysis of both the nature of various computer messaging applications and the differences between electronic communication and other forms of interpersonal and mass communication (see Heeter, 1989, for another model for classifying CMC systems). Subjects in Foulger's study reported many positive effects of the electronic communication system used at IBM, most of which, Foulger notes, had not been mentioned in existing literature on conferencing systems. This comment draws attention to the limitations of existing research, or, perhaps to problems inherent in studying a technology that is changing so rapidly. In descending order of importance, reported impacts included: "answer questions, better answers, change way job is done, job knowledge, increased peer contact, boosted morale, outside group contact, increased productivity, personal contribution, IBM knowledge, changed thinking, anticipate problems, vertical contact." One problem noted by respondents was isolation from nonusers. Foulger also found that people using the conferencing system felt a sense of community with other users, similar to that which they felt for people in their neighborhood communities.

Hesse, Sproull, Kiesler, and Walsh (1993) studied the use of electronic networks by researchers in oceanography. They found that oceanographers who use electronic networks employ them for (in descending order) electronic mail, data transfer, accessing remote databases, and accessing remote programs. In terms of impact, frequent use of networks was associated with institutional prestige, professional recognition, more publications, and more colleagues known. In terms of networking functions, frequent use is associated with planning and administrative tasks and data collection and analysis; infrequent use is associated with theoretical work.

Feldman (1987) conducted a study of several divisions of a Fortune 500 office systems corporation and found that the R&D divisions were the most extensive users of electronic messaging systems. She found that 65% of messages transmitted were work-related, that spatial and organizational distance did not have a systematic effect on message traffic, and that most messages were one-to-many communication, sent to groups of people via distribution lists. Perhaps the most significant finding of this study was that electronic mail and bulletin boards create communication links that would not otherwise exist between people who do not know each other or are spatially and organizationally distant; such "weak tie" messages were particularly important in supporting socialization and problem-solving. This finding is important because it suggests that the benefits described in connection with social networks may in fact be facilitated by electronic networks.

Key results of other recent studies of the use of electronic networks by scientists and engineers are summarized below:

- Electronic networks are most useful for logistical, administrative exchanges related to research projects. They are somewhat useful for engineers, less useful for scientists (Gerola & Gomory, 1984).
- Electronic mail is intimately involved in supporting cooperative R&D work; it is most important for enhancing existing interactions. There is a great deal of communication within, but not between, research programs (Eveland & Bikson, 1987).
- Electronic mail is most often used by researchers to contact people with similar interests at different locations, is used primarily for research work, is used most often to get information, and is usually used to contact individuals (Schaefermeyer & Sewell, 1988).

- For the seven software development teams studied, greater use of electronic mail is associated with improved performance. Electronic mail reduces use of other communication channels and is used most often for coordinating work (Finholt, Sproull, & Kiesler, 1990)

- For employees in R&D and product development divisions of a Fortune 500 office equipment firm, those in the development division had greater access to CMC, sent more messages, sent a greater proportion of work related messages, and knew their partners better (Sproull & Kiesler, 1986).

Some work has investigated the use of networks in science and technology settings, not by looking at individual users, but by conducting surveys targeted to a single individual representing an entire organization. While offering little insight into individual use and impact, they are able to describe network use on a broader scale than user-based studies of particular organizations and groups. Case and Pickett (1987) surveyed 74 Fortune 500 R&D companies about their use of information technology. They found that a majority of those organizations surveyed reported using information and communication technology for such things as, in decreasing order, scientific calculations, data collection, lab automation, CAD, modeling, process control, and project management. Between one-third and one-half of respondents reported the use of computer-aided engineering, prototyping, and CAM applications. Computer networks were employed in 62% of the companies surveyed and better networking was the most often cited area for improvement. Respondents indicated that information and communication technology contributed to enhanced productivity and performance in a variety of ways. It allowed R&D workers to do more thorough research, compile more accurate or complete information, perform more powerful or sophisticated analyses, save time, reduce errors, improve the coordination of project activities, and facilitate the production of written reports.

De Meyer (1991) surveyed 14 international R&D firms about the mechanisms they used to improve organizational communication and coordination. All of the firms studied used electronic mail and computer conferencing to some degree to encourage R&D communication, although some of the systems used were pilot programs or experiments. Most firms found electronic communication to be more effective in coordinating work; the use of electronic communication to share "innovative, problem-solving information" varied with the nature of the work being performed: "The higher the analyzability and the lower the complexity of the technology [being developed by R&D workers] ... the more effective the computer supported communication systems seemed to be" (p. 56). Electronic communication cannot replace all in-person and telephone conversations, in part because in-person contact is essential to maintain mutual confidence and trust.

Employees in various departments (legal, sales, planning, engineering, purchasing, computer support) of several large manufacturing firms were studied by Lee and Treacy (1988). Subjects reported that information and communication technology allowed them to diversify sources of available information, increase the chances of finding relevant information, consult people with different expertise, schedule work more easily, improve planning, and reduce uncertainty about procedures and goals.

In summarizing the results of all of these empirical studies of network use in science and technology settings, there seems to be general consistency in findings related to the purposes for which electronic networks are used by people involved in scientific and technical work. Most authors cite uses in the general areas of planning and coordinating work, the actual conduct of work (e.g., to get ideas and information and to solve problems), and in the realm of social support in the workplace (e.g., to boost morale, initiate contact, and make work enjoyable). On the other hand, a number of conflicting findings exist. Eveland and Bikson (1987) conclude that networks mainly enhance existing interactions, while Feldman (1987) asserts that networks create new communication links and Foulger (1990) and Bizot, Smith, and Hill (1991) emphasize that networks create new ways of thinking and doing things. Some authors find that networks are used mainly to communicate with spatial and organizational remotes while others find that most electronic communication occurs between people who occupy proximate positions. Some studies conclude that networks are used mainly to contact individuals while others conclude that they are used mainly to contact groups.

The fact remains that no empirical studies have dealt exclusively or extensively with engineers, the degree to which networks are used in engineering work and communication, and factors--especially social and behavioral factors--associated with the engineering environment that may be related to network use. The current study, like the CSCW studies described in this section, identified technology uses and impacts after first gaining an understanding of the environment, work, and communication behaviors of the particular group under investigation.

2.6.5. Engineers' Use of Computer Networks: Summary and Conclusions

This section has suggested the importance of, and described current knowledge about, the use of electronic networks by engineers. In the policy arena, the Federal government is investing in national high-speed networks and developing networking systems and policies directed toward the solution of "grand challenges" in engineering. Government studies assert the potential impact of networking, but little empirical work has been done on the use of networks by engineers. A number of descriptions of the use of electronic networks in engineering settings have appeared; these provide important context information for the current study. As yet there have been no cross-organizational, empirical studies of the use of electronic networks by engineers. A number of empirical investigations of electronic networking have been conducted in science and technology settings, although the majority of research devoted to studying network use has been conducted in other environments, has lacked a user perspective, and has yielded a number of conflicting findings. Thus, the current study hopes to extend previous empirical work by taking an inductive approach in investigating networking use, impacts, and factors related to use in one important engineering community.

2.7. Conclusions: Implications of Previous Research for the Current Study

The purposes of the current research are to describe the use of electronic networks by aerospace engineers and to explore relationships among network use, engineering work, and engineering communication. This chapter reviewed literature in these major areas, and has attempted to achieve a balance of attention to topics and issues in this broad arena. A number of conclusions drawn from this review of the literature have implications for the conduct of the current study, which are discussed below.

First, the aerospace industry possesses a number of characteristics that may affect the use and impacts of electronic networks in aerospace engineering. Further, the unique characteristics of the aerospace industry must be kept in mind when interpreting the current study's findings, especially in terms of assessing the degree to which they are generalizable to other industries.

Engineering work is complex and multifaceted. Thus, it can, and should be classified along a number of dimensions in the current study (e.g., primary job responsibility, primary organizational unit). At the task level, aerospace engineering appears similar to other kinds of engineering. Engineering work encompasses a range of social and technical activities and communication is a major component of engineering work. This suggests that a variety of computer network applications (i.e., those supporting informal communication, computation, and information creation and retrieval) may be useful to aerospace engineers.

The diversity of aerospace engineering work is closely associated with the diversity of knowledge created and produced by aerospace engineers. Much knowledge appears to be transmitted within the technological community. Some forms of aerospace engineering may be suitable to electronic transmission, given the current state of networking technology, while others may not. Further, the emphasis in the literature on the role of the community suggests the importance of examining social factors and impacts related to network use.

Engineering communication occurs within both informal networks and formal organizations. Thus, the current study pays attention to organizational factors related to electronic networking. The literature on informal social networks in science and technology raises a number of interesting questions in an electronic age, e.g., will the uses and impacts of social networking be mirrored in electronic networking? Empirical studies of engineering communication and information use have achieved consensus on some findings, such as the importance of interpersonal communication in the conduct of engineering work, the importance of access as a determining factor in the use of engineering resources and communication channels, and the kinds of engineering resources used by engineers. These suggest relationships to be explored in the current study of electronic communication and information use. On the other hand, the exact nature of the relationship between the use of various engineering resources and the accomplishment of particular work tasks is far from fully explained. Finally, very few studies of engineering communication and resource use have included investigations of the use of computer networks.

The Federal government and individual organizations are investing in electronic networks in anticipation of certain outcomes. It is clear that electronic networks are being used in engineering settings. Very few empirical investigations of the use of electronic networks in engineering settings have been conducted, however, so it is difficult to predict whether investments are warranted, what factors affect network use, or which network designs and strategies would be most effective. The lack of empirical, user-based data also means that the current study can extend existing knowledge about networking uses, determinants and impacts in engineering settings.

The juxtaposition of literature related to engineering work, communication, and network use suggests a number of interesting issues and questions. For example, if much of engineering knowledge is nontextual and nonverbal, how useful are networks likely to be as a medium for communication and information processing? Do "invisible labs" and "invisible shop floors" (analogous to invisible colleges in science) exist? If so, will electronic networks extend their benefits? Some of these questions are explored in the current study; others offer insights into future research directions.

One major failure of current research on electronic networking is that it has not paid much attention to the work and communication needs and patterns of the various groups of people it studies. The literature reviewed here suggests that, given their work tasks and communication activities, aerospace engineers may benefit greatly from the implementation of electronic networks in the workplace. It also suggests that they are likely to encounter a number of problems. Due to the limited extent of previous work in engineering work, communication, and electronic networking, the literature provided only limited guidance on choice of variables for this study. Chapter 3 describes the development of this study's methodology, much of which was built on the ideas and techniques encompassed in the previous work that has been reviewed here.

CHAPTER 3: RESEARCH DESIGN AND METHODOLOGY

3.1. Introduction

The aim of this study is to explore and describe the use of computer networks by U. S. aerospace engineers. It investigates computer networking from a user perspective and focuses on the way that networks are currently used by aerospace engineers to facilitate communication and otherwise assist in the performance of work tasks. The study is guided by the following research questions:

1) What types of computer networks and network applications are currently used by aerospace engineers?

2) What work tasks and communication activities do aerospace engineers use computer networks to support?

3) What work-related factors are associated with the use of computer networks by aerospace engineers?

4) What are the impacts of network use on aerospace engineering work and communication?

Data to answer these questions were collected from a wide variety of aerospace engineers. The chief mechanism for gathering data was a national mail survey, but the mail survey was preceded by preliminary activities: initial site visits/interviews, a telephone survey, and primary site visits/interviews. The three preliminary activities were used to refine the mail survey instrument, to supply anecdotal and interpretive data not easily gathered in a mail survey, and to provide data that, when compared to the survey data, can be used to validate the mail survey results.

No previous study has collected extensive, cross-organizational, empirical data on the use of electronic networks by engineers. Study results will contribute to existing knowledge about both network use and the nature of engineering work and communication. Findings can be used by the aerospace community--and possibly others as well--to inform the development of more effective networking systems, services, and policies.

This chapter presents the basic elements of the plan for collecting data to answer the research questions presented above. The study's design and methods for collecting data are described, the framework for analyzing the results is presented, and the benefits and drawbacks of the chosen methods are discussed. Results from preliminary study activities that contributed to the development of subsequent data collection instruments, and can be used to triangulate mail survey results, are also presented.

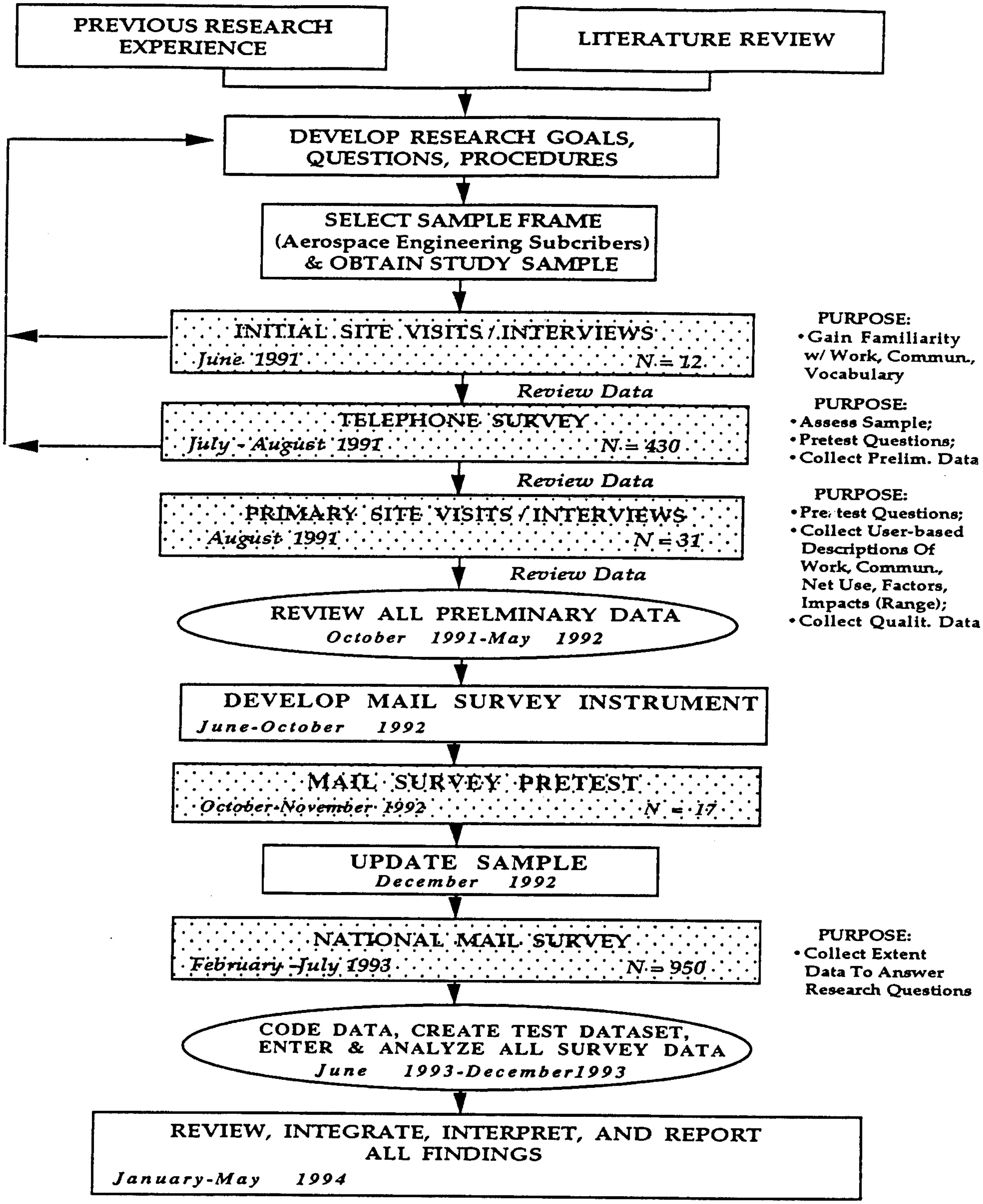
3.2. Plan of the Study

3.2.1. Overview

Aerospace engineers from a wide range of private, government, and academic institutions who perform a variety of engineering duties were included in this investigation. The study drew upon methodological approaches and techniques that have evolved in the fields of library and information science, communications, management, and sociology. Because it is a user-based, the study aimed to collect data directly from individual aerospace engineers on networking topics and issues that were related to their own personal experiences and concerns.

Figure 3-1 depicts the major activities comprising the study. Previous experience investigating scientific and technical information transfer and the use of networks by researchers was used to formulate preliminary research goals, questions, and methods for this study. Reviewing the literature on engineering work, communication, and network use also contributed to the early formulation of study goals. An appropriate sample frame was then identified and a sample obtained. Multiple data collection techniques were used to gather data on characteristics, perceptions, and activities of aerospace engineers that are related to network use, work tasks, and communication activities.

Figure 3-1. MAJOR STUDY ACTIVITIES



Initial site visits/interviews were conducted in June 1991 in order to become more familiar with aerospace engineering work and communication. A national telephone survey in July and August 1991 was used to contact a subset of the chosen sample and gather preliminary data from the 430 respondents on their use of electronic networks. Data from the initial site visits/interviews and telephone survey were reviewed and used to focus the study's goals and questions and assess the basic characteristics of the sample frame. The next major step was to develop, pretest, and conduct the study's primary site visits/interviews. These in-depth interviews of 31 aerospace engineers were conducted in August 1991 and were used to explore the range of aerospace engineers' perceptions and activities related to work tasks, communication activities, and network use; they also served as a pretest for a number of questions tentatively planned for the national mail survey.

During Fall 1991 and Spring 1992, these preliminary data were carefully reviewed, summarized, and used to inform the design of the national mail survey questionnaire. The questionnaire was developed during June through September 1992 and a pretest was conducted in October 1992. Pretest results were analyzed, leading to revisions to the questionnaire. The final version of the questionnaire was sent to approximately 2000 aerospace engineers at the end of February 1993. A second mailing of the questionnaire to nonrespondents was undertaken in early April. Coding and data entry procedures for the survey were reviewed and revised in May and June 1993. A test database containing the results of 144 randomly selected returned questionnaires was created to finalize coding, input, and analysis procedures. Returned surveys were accepted through July 15, 1993, after which all survey data from the 950 returned questionnaires were entered into the database. From July to December 1993, a number of simple statistical analyses were performed and results were reviewed. The final step in the study was the integration, interpretation, and reporting of the study's findings.

A major strength of the study is its use of multiple methods for gathering data. The data collection activities pursued in this research are cumulative. Each activity contributes to the study in a different way. Insights gained in preliminary activities were used to refine instruments and help interpret findings in subsequent data gathering stages. The preliminary data collection activities produced four important benefits. They helped in: (1) refining the study's goals and research questions; (2) designing items for the mail survey, so that the results yielded by the mail survey would be more valid and reliable; (3) allowing the collection of different kinds of data from study subjects, i.e., anecdotal data in the interviews and more structured responses in the surveys; and (4) supporting data triangulation, whereby data collected by different mechanisms, but related to the same variable, can be compared.

3.2.2. Framing the Research Questions: Definition of Key Study Concepts

Each of the study's research questions contains terms that represent important conceptual elements. This section will explain the constructs used in the research questions and suggest how, generally, the constructs used as variables were operationalized. The basic goal of this section is to explain which data the study sought to collect and why. A more detailed description of how data related to the study's key concepts were collected and analyzed is presented below in Section 3.4: Analysis Framework. Because this study was comprised of a number of different data collection activities, each with a somewhat unique focus and purpose, concept definitions evolved throughout the course of the research and precise, identical definitions were not used in every portion of the study. The definitions of key study concepts presented in Table 3.1 represent the general manner in which these concepts were used during the course of the study and, more specifically, how they were defined in the study's mail survey.

This study looks at the role of computer networking in one particular industry. Unlike most other studies of computer technology, it seeks to assess this role across specific job types, organization types, and technology implementations. The first aim of this research is to collect baseline data describing the current use of electronic networks by people involved in aerospace

Table 3-1. Definitions of Key Study Concepts

Key Concept	Definition in this Study
Aerospace engineer	Individuals engaged in research, development, design, testing, and manufacturing of a wide variety of commercial and military aeronautical and aerospace technologies, from commercial aircraft to guided missiles to space station equipment. Throughout the study, respondents were asked to characterize their organizations and jobs in terms of: • Job type (e.g., engineer, scientist, manager, technician) • Organizational unit (e.g., research, development, engineering, manufacturing, marketing) • Primary work activity (e.g., management, design, testing) • Principal aerospace subfield (e.g., electronic systems, propulsion, structures, aerodynamics). These characterizations serve to define the individual's role in aerospace engineering and were used as a primary means of grouping and reporting data on network use and other concepts important in the study.
Computer network	Telecommunication link that connects computers to each other or to other devices. "Electronic network" is used as a synonymous term. Examples of computer networks are linked workstations, a desktop computer linked to a mainframe or a printer, a dial-up link to a remote database, and a direct Internet link from a desktop computer. Throughout this study, respondents were instructed to interpret the term "computer network" according to this broad definition.
Types of electronic networks	Four types of networks were defined for the purposes of this study: • Local area networks: Connect to people, tools, or information within one building at the workplace. • Organizational networks: Connect beyond one workplace building to people, tools, or information within an individual's organization. • External/research networks: Connect to people, tools, or information outside an individual's organization; intended for research and educational use. • External/commercial networks: Connect to people, tools, or information outside an individual's organization; open for use by the general public.

Table 3-1(Cont'd). Definitions of Key Study Concepts

Key Concepts	Definition in this Study
Computer network application	A software program used to perform some function over an electronic network. Examples of the kinds of network applications investigated in this study are electronic mail, remote login, information retrieval, and file transfer.
Network use	Any instance in which a telecommunications link is employed by an individual. Extent of use is defined in this study in terms of self-reported frequency of use (e.g., daily, weekly) and intensity of use (i.e., percent of work week spent using networks).
Work tasks	Any activity engaged in by an individual that he or she perceives as being a part of, or related to, his or her job. The kinds of work tasks that aerospace engineers reported performing include such things as writing technical reports, producing detailed designs, procuring parts, preparing budgets, monitoring schedules, defining product requirements, conducting experiments, and ensuring compliance with product and process specifications.
Communication activities	Any instance in which an individual contacts either another person (such as a co-worker, customer, or supplier) or accesses some resource (such as a computational tool, experimental equipment, trade journal, design history, specification, or technical report) in the course of performing a work task.
Factors associated with network use	May be social, behavioral, situational, or technical, as perceived by individuals or suggested in their characterizations of themselves, their behavior and attitudes, their organizations, their work, or their communication.
Impact of network use	Any perceived or reported immediate or longer-term effect of network use on an individual or organization, or on the aerospace industry, in general. Dimensions of impact investigated in this study include: • The degree to which aerospace engineers use networks, i.e., how many engineers use particular types of networks and network applications for specific work tasks and communication activities; • The degree to which network use is associated with different reported patterns of work and communication; • Specific effects and impacts of electronic networks, as perceived by individuals; • Value of electronic networks, as perceived by individuals.

engineering. The first research question asks *"What types of computer networks and network applications are currently used by aerospace engineers?"* The second research question explores relationships among network use, aerospace engineering work, and aerospace engineering communication. It asks *"What work tasks and communication activities do aerospace engineers use computer networks to support?"* Throughout the study, participants were asked to describe the work tasks they perform, whom they communicate with, and which information resources and other tools they needed in their work. They were also asked to report the degree to which networks were used to access the people and other engineering resources needed to perform work tasks. Communication, whether with people or other engineering resources, is a fundamental engineering activity that pervades virtually every engineering task. In order to perform work tasks, engineers communicate with a wide range of people and access a variety of other engineering resources, such as computational tools, experimental equipment, and documents.

This research also attempts to identify aspects of aerospace engineering work that encourage or hinder network use. The third research question asks: *"What work-related factors are associated with the use of computer networks by aerospace engineers?"* Such work-related factors may be social, behavioral, situational, or technical; all of these are of interest in this study. The study assumes that factors associated with network use may or may not be perceived by aerospace engineers themselves, and may be suggested by their characterizations of themselves, their behavior and attitudes, their organizations, their work, or their communication. Aspects of the work environment which may be related to network use include the job dimensions described above (i.e., job type, organizational unit, primary work activity, and principal aerospace engineering subfield). Other factors suggested by this study's preliminary data collection activities include organization size, the proximity of co-workers, perceived organizational attitudes towards network use, the interdependence of one's work with the work of others, the degree to which work products and resources already exist in electronic form, the perceived difficulty of accessing or using networks, and the need for immediate, interpersonal interaction in a particular situation.

Finally, the study offers an assessment of the impact of electronic networking on aerospace engineers, their organizations, and the aerospace industry. The fourth research questions asks: *"What is the impact of network use on aerospace engineering work and communication?"* Impact is evaluated in this study by collecting and analyzing several kinds of data, including data on extent of network use, the degree to which networks change patterns of work and communication, and the value and effect of networks, as perceived by individual users.

Both the third and fourth research questions help build an understanding of the effects of network use on aerospace engineering work. An interesting perspective for the analysis of these two questions arises from what has been learned in the study of traditional (i.e., non-computerized) social networks, such as the "invisible colleges" and social networks of scientists (see, e.g., Crane, 1972; Cronin, 1982; Granovetter, 1973), organizational grapevines (see, e.g., Hellweg, 1987; Mueller, 1986), and community support groups (see, e.g., Dosa, 1985). These characteristics and effects can be summarized as greater access to expertise, ideas, resources, and social or moral support through increased contact with people--perhaps previously unknown--who share the individual's experiences, interests, and values. What kind of social networking exists in the engineering community? Are the characteristics and effects of traditional networking mirrored in the world of electronic networks? The current study will explore these kinds of issues and lay the groundwork for future research in this area.

3.2.3. Linking Important Concepts in the Study

This study's four research questions are intended to guide the collection of empirical data that will suggest relationships among aerospace engineering work, communication, and network use. In Chapter 1, a conceptual model depicting a framework for investigating network

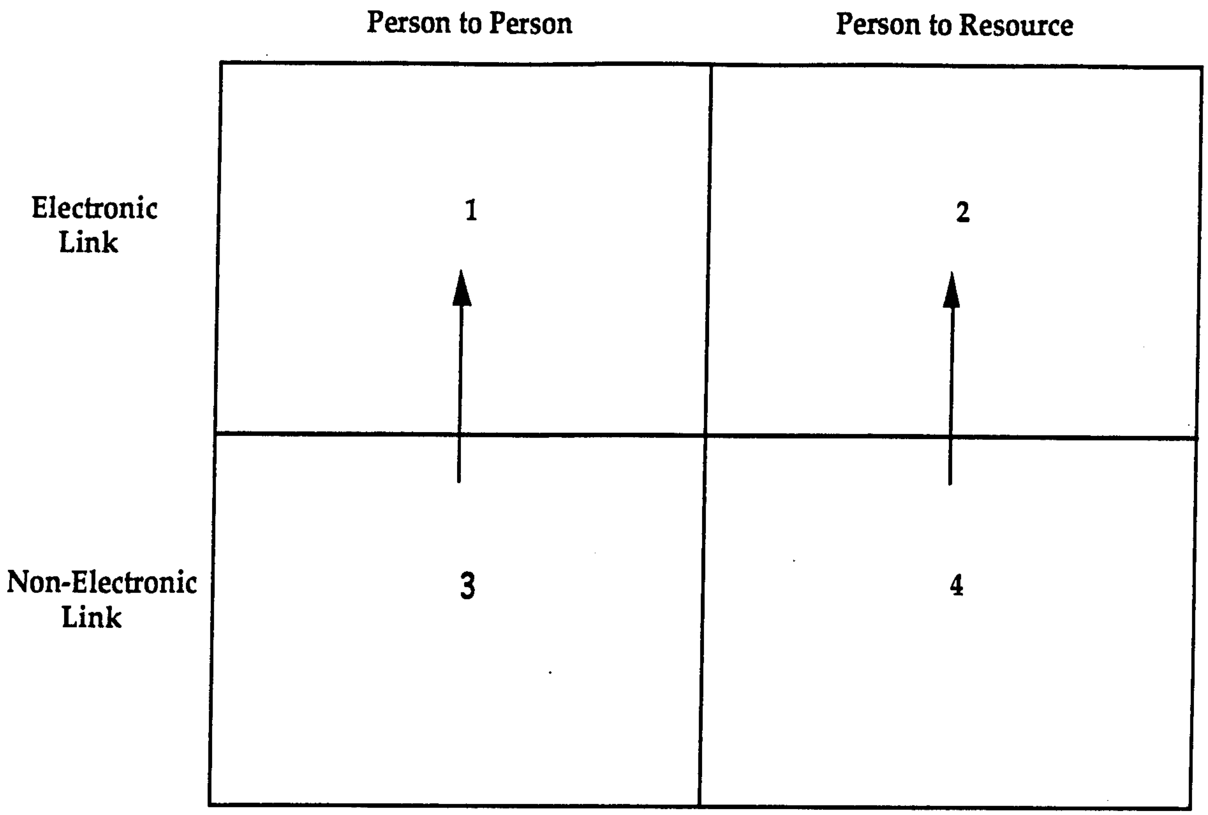


Figure 3-2.
Conceptual Links Among Major Elements in the Study

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use in the context of aerospace engineering work was described (see Figure 1-1). The major concepts associated with each research question were identified and described above in Section 3.2.2.

Figure 3-2 contains the same conceptual elements as Figure 1-1, but they are linked in a different way. The previously presented figure is a snapshot of one particular situation in which an aerospace engineer may use electronic networks to access specific engineering resources--human and other--to perform some work task. Figure 1-1 emphasizes the study's user perspective by depicting the individual engineer and the communication activities that may be associated with a particular work task, with the entire situation embedded in a complex matrix of social, behavioral, technical, and situational constraints. Figure 3-2, on the other hand, departs from the microcosm of the individual engineer's world in order to take a macrocosmic look at engineering communication activities. The columns represent the major types of resources (either a person or some non-human resource) that an engineer might communicate with in the course of performing his or her work. The rows represent the possible modes (either through an electronic or some non-electronic link) of accessing that resource.

One goal of the study is to describe the activities that take place within the cells in Figure 3-2. Cells 1 and 2 represent situations in which engineers are linked through electronic networks to other people (Cell 1) and engineering resources (Cell 2). Examples of Cell 1 activities include sending an electronic text file to a colleague or using an electronic bulletin board. Cell 2 activities would include the use of an electronic network to access CAD/CAM software or online business data. Cells 3 and 4 represent situations in which engineers access other people (Cell 3) and resources (Cell 4) *without* the use of electronic networks. Cell 3 activities include such things as telephoning a vendor or distributing a hardcopy memo to all project team members. Activities in Cell 4 would include such things as going to the library to browse trade journals or using word processing software on one's desktop computer.

The arrows in the diagram indicate that the second major goal of this research is to explore movement from Cells 3 and 4 to, respectively, Cells 1 and 2. The study seeks, in other words, to identify factors associated with the aerospace engineering work environment that may facilitate or hinder the move to electronic communication and to explore the impacts on engineering work and communication that may accompany the transition to network use. Diagonal links--e.g., the move from non-networked communication with a person to networked communication with some non-human resource--describe processes that, while in some cases are conceptually possible, are not a specific focus of this study. Similarly, although it is not a major focus of this research, study results can suggest lateral movement between Cells 1 and 2 that may be of theoretical or practical interest. For example, how does an engineer decide whether to acquire needed information from a networked colleague as opposed to a networked database or document?

In summary, this research involves a number of key variable groups. Network use is operationalized in terms of reported frequency or intensity of use, and includes various network types and applications. Engineering work tasks and communication activities are identified through aerospace engineers' reports of their work, which engineering resources they used, and what work-related purposes the resources are used for. Factors considered as being potentially associated with network use include individual, situational, job, and organizational characteristics. Network impacts are operationalized in terms of degree of network use, perceived value of networks, perceived effects, and self-reported behaviors related to impact.

Understanding relationships among network use, work, and communication will be useful to those people and organizations trying to estimate the potential impact of electronic networks on aerospace engineers, on their organizations, and on national productivity and competitiveness in the aerospace industry. Further, the results should be suggestive of the potential impact of networks on other kinds of work, based on the degree to which they resemble aerospace engineering work. It is the aim of this research to identify work characteristics and needs that *underlie* the use of networks. This type of user-based research on information and communication technology is important because it not only evaluates the status quo, it points to networking system features, implementation strategies, and use policies that could improve the effectiveness of the next generation of networked systems. For example, some researchers (e.g., Hesse & Grantham, 1991, draft; Murotake, 1990) suggest that, as networks and computers become virtually ubiquitous, the emergence of the networked organization will make it possible for workers to "telecommute," i.e., to do all their work from home with the aid of a computer and a modem. But is all work amenable to computerization and telecommuting? If networked virtual realities (i.e., shared access to visualization and simulation applications) can be used to computerize engineering work tools and share engineering products that up to now have existed only in physical formats, could engineers work effectively from their homes? Or would other underlying work and communication needs and factors militate against the success of such endeavors? What system capabilities and policies would facilitate such an endeavor? This example illustrates the potential that user-based research has for informing the design and development of new information and communication systems and the policies that must govern their use.

3.2.4. Research Design and Sample Selection

The previous section discussed the type of data collected in the study. The purpose of this section is to describe from whom these data were collected, and why. The choice of research design and sample for this investigation has its roots in the study's purpose and research questions. The research is exploratory and descriptive. It seeks to investigate relationships between network use and aerospace engineering work and communication as broadly as possible, and on a national level. Aerospace engineering work is a highly diverse activity in terms of the range of employers, products, jobs, and work activities it encompasses (Aerospace Industries Association, 1991; Kemper, 1990). Key dimensions of aerospace engineering work include job type (e.g., engineer, scientist, manager, technician), organizational unit (e.g., research, development, engineering, manufacturing, marketing), primary work activity (e.g., management, design, testing), and principal aerospace subfield (e.g., electronic systems, propulsion, structures, aerodynamics). This study collected data which explore and describe variations in network use and impacts that may be associated with these key dimensions of aerospace engineering work, as well as with situational and individual factors.

The chief aim of the study's research design, therefore, is to identify and gather data from individuals who are as diverse as possible in terms of the nature of the aerospace engineering work they perform. It is assumed that individuals who represent this work diversity will also vary along other dimensions of interest in the study, such as degree of computer experience and level of network use. The research design of the study involves securing the participation of people in aerospace engineering who work at different kinds of jobs in different kinds of organizations in the private sector, academia, and Federal laboratories. This design allows post hoc comparisons of differences in network uses and perceived impacts that may occur among various data groupings, such as by subdiscipline, job type, geographic location, type of institution, level of institutional support, degree of experience with information technologies, and engineering task.

The reason for securing the participation of subjects from different sectors, with different job types, working in different subdisciplines, and with different levels of networking experience is that these groups are expected to evince different communication and information-seeking patterns, perform different kinds of work tasks, and operate within different cultural environments and reward structures. The point of the study is to investigate how electronic networking is being incorporated into these different environments, and to look for commonalities and differences that may help explain variations in network use. National networking initiatives are intended for use by engineers in all of these groups; therefore, understanding the network behavior of and impacts upon these groups will contribute to the successful development and management of national networks. Achieving substantial variation within the chosen sample will improve the applicability of the results in that, for example, perceptions of impact described by managers in this study may be applicable to managers in other fields as well.

One key methodological concern is to find a sample frame that is representative of the population of interest. The sample frame is all of the people who have a chance to be included in the study sample, i.e., it is the group from which the sample is selected. Another concern is to collect data from a sample that is large enough to guarantee that the size of sampling error is acceptable for the purposes of the study, even for the smallest data group that is eventually analyzed. If these two issues are resolved, it is much more likely that observed effects will be "real" and that they will be generalizable to the population of interest (Fowler, 1984).

The first task in this study was to find a sample frame that is representative of the population of aerospace engineers. Unfortunately, there is no description of the population of aerospace engineers that characterizes the population along all the dimensions of interest in this study (Pinelli, 1991b), so representativeness can not be guaranteed. The National Science Foundation, however, collects and reports employment data from aerospace engineers related to a number of characteristics of interest in this study, such as employment sector, primary job responsibility, and educational level (see, e.g., NSF, 1987). These data on the national population of aerospace scientists and engineers provide one yardstick against which any chosen sample frame can be compared.

Typical sample frame options for studies of engineers include sets of relevant professional society members, employees of relevant organizations, and subscribers to relevant publications (Shuchman, 1981). Identifying and contacting a set of aerospace engineers through selected employers seemed the least efficient option. It also seemed that it would be very difficult to get variety along a range of work dimensions and identify a sample that was diverse enough to be representative of the general population, if respondents were associated with only certain employing organizations.

There are two professional societies for aerospace engineers. The American Institute of Aeronautics and Astronautics (AIAA) is research-oriented; its membership includes more people holding doctoral degrees, more people employed in academia, and more people engaged in R&D than does the population represented by the NSF employment statistics. Thus, the AIAA sample frame was judged not typical of the general population of aerospace engineers.

The Society of Automotive Engineers, or SAE (its name has not changed to reflect the fact that it has for many years been devoted to both aerospace and automotive industries), is geared more toward the practicing engineer; its membership more closely follows the statistical breakdown of the NSF aerospace employment data. A potential problem with using professional societies as sample frames, however, is the fact that their members are self-selected in a manner that may confound study results. The primary motivation for joining a professional society is likely to be a concern for professional advancement and a strong desire to interact with colleagues.

Each of the two professional aerospace societies publishes a weekly trade magazine. Subscribers to such publications are also self-selected, but the primary motivation for subscribing to a trade magazine is the desire to keep informed, generally, about a particular industry. Thus, it was decided that the subscriber databases provided a more general and diverse sample frame than society memberships; the SAE publication, *Aerospace Engineering* was chosen over the AIAA publication because it seemed that SAE magazine subscribers would be more representative of the population of aerospace engineers than AIAA magazine subscribers, for the reasons noted above. Subscribers to *Aerospace Engineering* are not required to be SAE members. Interestingly, the AIAA became aware of this study and requested permission to distribute the mail survey questionnaire to its membership. Permission was granted and if, in fact, the AIAA implements the survey, those results could be analyzed, at some later point in time, to investigate network use among aerospace engineers who are primarily engaged in R&D and to compare use in the two, somewhat different, aerospace communities.

Using the SAE subscriber database as the study's sample frame introduces the threat of selection bias, defined by Freeman, Pisani, and Purves (1980, p. 303) as a "systematic tendency on the part of the sampling procedure to exclude one kind of person or another from the sample." People excluded from the study's sample due to the selection of the subscriber database as the sample frame are those people who choose not to subscribe to *Aerospace Engineering.*

Nonsubscribers might include individuals who cannot afford to join the SAE or purchase a journal subscription, are less interested in keeping up to date with developments in the field, are too busy to read trade journals, have a copy of the journal available in their workplace through an institutional subscription, or are prohibited by their employers from allowing any identifying information about themselves and their work to be collected by an external organization (in cases where the utmost secrecy about their work must be maintained). Potential bias due to the exclusion of such people from the sample frame should be kept in mind when interpreting study results. For example, individuals who lack resources to purchase a journal subscription may also lack the resources required to gain access to networks, so extent of network use could be overestimated in study results. On the other hand, results related to the degree of security concerns aerospace engineers express about network use might be underestimated, due to the exclusion from the sample frame of those individuals most likely to be involved in classified or highly proprietary work.

After choosing a sample frame, the next important issues are deciding how many people to include in a study's sample and how to select them. The sample must be large enough to guarantee that the size of sampling error is acceptable for the purposes of the study, and the selection must also be designed to provide valid and reliable results. This research is comprised of a number of data collection activities, requiring different size sample sizes and sampling techniques.

The study required three random samples to be drawn from the SAE subscriber database, due to the length of time that elapsed between its preliminary data collection activities and the final mail survey. The first sample, drawn in Spring 1991, was used for the study's telephone survey and primary site visits/interviews, which were conducted in Spring and Summer 1991. The second sample was drawn in June 1992 and was used to pretest the mail survey in October 1992. As a result of discovering a significant number of pretest subject addresses that were no longer current, a final sample was drawn in December 1992 for the mail survey that was administered in February 1993.

For the study's telephone survey and primary interviews, a random sample of 1,200 individuals was drawn from the database that contains records for all people subscribing to SAE's weekly trade journal *Aerospace Engineering*. The database containing the 65,000 subscribers' names, addresses, telephone numbers, employers' names, and job types is maintained by the SAE. The database categorizes individuals according to whether they represent an aerospace industry (aircraft, missile, spacecraft, propulsion system, etc.), manufacturing, government, air transportation, suppliers, or services (including consultants, R&D services, and education). It also classifies subscribers according to their self-identified job classification (corporate management, engineering management, engineers and designers, R&D, manufacturing and production, purchasing and marketing, and "other"). Because of this study's interest in informing national networking policy development, only engineers employed in the United States were included in the sample. The database includes practicing aerospace engineers working on a wide range of aerospace products, in a wide variety of organizations and subfields, and with a variety of professional duties. Results from the telephone survey conducted as part of the study indicate that the SAE sample possesses characteristics in the same proportions as those reported in the NSF data (see Section 3.3.3.3 below).

A random subset of 695 subjects was drawn from the original SAE sample as potential participants for the study's telephone survey. About twenty individuals who represented a variety of job types and worked in organizations in the northeastern United States were initially selected (a purposive sample) for potential participation in the primary site/interviews visits.

Since the study's research questions will be answered primarily by results obtained in the mail survey, it is the nature and size of the mail survey sample that is most critical. A second sample was drawn from the SAE subscriber database in June 1992 in order to obtain a more current set of respondent addresses for the mail survey. In this sample, individuals were disproportionately drawn from the SAE database categories. Disproportionate stratified samples are recommended when, as in this study, reports about certain subgroups are important and, further, the study does not primarily aim to make estimates about the total population represented by the sample frame. This study, in other words, aims to compare different types of aerospace engineers on variables associated with network use. Its primary aim is not to estimate network use for subscribers to *Aerospace Engineering*. As noted by Sudman (1976, p. 111): "For comparison of subgroups, the optimum sample is one where the sample sizes of the subgroups are equal, since this minimizes the standard error of the difference."

The stratified sample for the national mail survey was obtained by first eliminating certain SAE database categories whose members would not be appropriate for the research because they are not U.S. aerospace engineers. These categories were "Air Transportation" (which includes air traffic controllers, pilots, etc.); "Foreign Government" employees; "Other Titled Personnel" (which includes librarians, many retirees, etc.) except for those in consulting and R&D "Services" or "Education"; and "Others Allied to the Field." An approximately equal number of subjects was randomly drawn from each of the remaining categories in order to obtain a substantial number of subjects representing different types of aerospace engineering work.

This study was particularly interested in exploring private sector network use by mainline engineers. Less research has been conducted in this arena, which is of critical importance in current national policy discussions of industrial competitiveness. Nonetheless, the sample was weighted to increase the percentage of government and academic respondents. These groups made up only about 13.6% and 5.2%, respectively, of the SAE database; if their representation in the sample were not increased, it would have been difficult to make meaningful comparisons across the three primary sectors of industry, government, and academia. The final sample, drawn in December 1992, was stratified in the same manner as the

Table 3-2. SAE Sample Strata Used in the Mail Survey

Category in SAE Subscriber Database	Approximate Number of Records Drawn from that Category
Corporate management	600
Research and development	600
Engineering management	600
Engineers and designers	600
Manufacturing and production	600
Other title personnel	300
Purchasing and marketing	500

sample drawn in June. It included 3,750 individuals, divided as shown in Table 3-2, with about 10% from academia and not-for-profit firms, 30% from government, and 60% from industry.

It was difficult to maintain absolute control over the distribution of the final sample. The sample was drawn by SAE staff according to instructions provided by the researcher. The resulting set of records did not identify categories, but examination of the sample records suggested that instructions had been followed. SAE staff, however, noted after drawing the December sample that it was difficult to obtain the exact distribution represented in the June sample, because the distribution across categories had changed since the earlier sample was drawn. One specific failure noted was that all retirees were apparently not weeded from the sample; a small percentage of survey respondents (1.8%) classified themselves as "retired." These respondents were retained in the study's analysis: a perusal of their questionnaires showed that they either answered questions according to their last job, or left segments of the questionnaire blank.

The main requirement for this study was to identify a sample frame that included people performing a wide variety of tasks within the aerospace engineering community with significant representation across sectors. This requirement was adequately met by the SAE subscriber database. The actual categories used in the database were helpful in ensuring a range of job types, but the categories themselves are of only minor significance, since they do not form the exact basis of any of the study's planned analyses.

One final adjustment was made to the mail survey sample in that 2000 records were randomly selected from the original 3750 supplied by SAE as being the maximum sample size that study resources could support. If the response rate were 50%, the final number of mail survey respondents would be about 1000. According to Fowler's calculations of sampling error (1984, p. 42), this means that, for the sample as a whole, chances are 95 in 100 that the real population figure lies in a range no greater than plus or minus three units for any characteristic identified in the study. For example, if survey results indicate that 50% of the respondents use electronic networks to transfer text files, chances are 95 in 100 that the actual percent of the sample frame that performs text file transfers is between 47% to 53%. Given the exploratory and descriptive nature of the study, that margin of error is acceptable.

Another important consideration in accepting 2000 as a final sample size was whether or not the number of responses in all sub-groups that would eventually be analyzed would be adequate for the analysis. This implies a certain amount of guesswork on the part of the researcher. The plan for analyzing survey results in this study calls for grouping data in a variety of ways and it was impossible to predict the exact size of most of the data groupings that would result. Recent surveys of members of SAE and AIAA found that a significant proportion of those surveyed were currently using electronic networks (Pinelli, 1991b; Society of Automotive Engineers, 1990). And results obtained in the SAE telephone survey that served as a preliminary data collection activity for this study suggested that about 20% of respondents would not use networks at all. Nonusers form one of the most important sub-groups in this study, one that would in all likelihood be used to form further sub-groups. It was estimated that beginning with 200 nonusers (assuming, again, that the final number of usable returns would be about 1000) would make it possible to achieve adequately-sized groups for comparing network users to nonusers along various dimensions of interest, such as primary job function.

3.2.5. Choice of Study Methods

After deciding which data to collect and from whom, the next task facing a researcher is to select appropriate methods for gathering data. A variety of methods have been employed in past research on network use (see, e.g., Williams, Rice, & Rogers, 1988) and some general concerns and issues have also been expressed (see, e.g., Rice, 1989). A number of researchers have noted the need for qualitative approaches in studying new information and communication technologies. Following Kirk and Miller (1986), qualitative research is used here to mean research that aims to investigate the nature--as opposed to simply the amount--of phenomena of interest, usually by interacting with people "in their own language, on their own terms" (p. 1).

Qualitative approaches are an important aspect of networking research because networking is new, because network communication is a complex human phenomenon, and because networking takes place within a social environment. Williams et al. (1988) argue that:

> Because research on the new media is at an early stage in its development, scholars studying it probably need to consider use of multiple methods, including more qualitative and triangulation methods of data-gathering and analysis, and the interpretive approaches to research. To date, however, most research on the new media has used only quantitative research methods and has been cast in a positivistic approach (p. 50).

Triangulation, or the use of multiple methods to explore phenomena, have also been recommended in studying networks by Lievrouw et al. (1987) and McClure et al. (1991).

This study focuses on describing and exploring network use from the point of view of individuals engaged in aerospace engineering work. It aims at generalizability in that it seeks to arrive at conclusions about the behavior and perceptions of people who are engaged in a particular kind of work. To the extent that all engineers or all managers, for example, possess similar information needs and perform similar work, results of this study may be applicable to engineers or managers in fields other than aerospace. Further, the study is intended to yield results that can be used by aerospace engineering organizations or by policymakers attempting to predict national impacts of networking. Given the study's goals and its user perspective, interview and survey methods were deemed more appropriate than other more quantitative methods that have been employed in networking research.

Interviews and surveys are recommended as a means of providing meaningful insights (especially when the goal of the research is "discovery" as opposed to "verification") into the use and impact of emerging communication technologies (Attewell & Rule, 1990; Galegher & Kraut, 1990; Johnston, 1989). Qualitative interviews are important for exploring the range of individuals' perceptions and experiences, while surveys can then test the extent to which these perceptions and experiences exist in the larger population.

Other options for studying electronic network use include network analysis, lab experiments, network transaction log analysis, and case studies. Network analysis studies seek to describe the structure of social networks through mathematical modelling (see Wigand, 1988, for an overview of this line of research). Social network analysis techniques typically ignore both the content or meaning of messages transmitted and the impact of communication on individual network "nodes." Case studies and ethnography may provide greater detail than data obtained in surveys and interviews, but results are often not generalizable. Lab experiments have also been used to study networking use and impacts. Experiments are most useful when testing specific hypotheses, well-founded in existing theory, and are not appropriate when the aim is to explore the entire work environment in a naturalistic manner. The constructs and relationships of interest in this study are not well-established enough in theory to be tested in this way. After extensive reviews of research related to information and communication technologies, Culnan and Markus (1987) and Steinfield (1986b) both remark on the serious lack of cross-organizational studies involving any qualitative component.

According to Eveland and Bikson (1987, p. 103), "The degree to which these [electronic communication] capacities are used ... depends on understanding how such tools are and are not like other more familiar tools." In order to gain an understanding of how aerospace engineers perceive and use electronic communication, subjects in this study were asked to characterize both electronic and traditional modes of communication. Such characterizations may be useful in suggesting impact, factors that affect use, and reasons why engineers use electronic networks in some situations and non-electronic means of communication in others.

A key feature of preliminary data collection in this study is the analysis of communication incidents and messages in order to better understand the situational context of the relationship between work tasks, communication activities, and network use. Various approaches for analyzing messages have been used in the field of linguistics known as pragmatics (See, e.g., Kedzierski, 1982; Malone et al., 1987; Stohl & Redding, 1987; and Winograd, 1988). The present study relies on the reports of message senders and receivers to arrive at a full interpretation of message function, purpose, and utility. Other studies have relied exclusively on the online logging and analysis of all computer messages. In these studies, the analysis of messages is performed by the investigator (see Rice, 1992). Thus, the analysis accounts only for the explicit content of messages (i.e., what was written, not what was meant) and provides no context for interpreting results. Further, the automatic logging of messages is not appropriate when, as in this study, non-computer messages are also of interest.

As noted earlier in this chapter, it is important to remember that the data collection activities pursued in this study were cumulative. In other words, insights gained in each activity were used to select specific methods and to refine instruments used in subsequent data gathering stages. The chief aim of the site visits/interviews was discovery. The interviews are used primarily to explore the *range* of attitudes and experiences associated with particular phenomena under investigation, e.g., What is the range of functions of computer-based messages--from the sublime to the ridiculous--as perceived by aerospace engineers? What is the range of network applications used by engineers? The mail survey, on the other hand, verifies the *extent* of the activities, behaviors, experiences, and perceptions identified and explored in the interviews. In other words, the survey increases the breadth of the study by providing answers to such questions as: What percentage of aerospace engineers report using each network application? What percentage of aerospace engineers cite various network impacts? The primary site visits/interviews and the telephone survey also offer a useful means of triangulating study findings; although the study's research questions are primarily answered by the final mail survey results, these results can be compared to the preliminary findings. Mail survey results can also be more effectively interpreted by reference to the more open-ended and in-depth data gathered in the interviews.

3.2.6. Reliability and Validity

Study data are reliable if the same question responses would have been obtained, no matter how many times the questions were asked. Study data are valid if they really measure what the researcher thinks they measure. This section identifies techniques useful in improving the reliability and validity of data and describes how such techniques were implemented in this research.

Because the study's research questions will be answered primarily through the tabulation and interpretation of results of the national mail survey, reliability and validity issues associated with the survey deserve special attention. According to Babbie (1990, p. 133), the way to obtain reliable survey results is to "ask people only questions they are likely to know the answers to, ask about things relevant to them, and be clear in what you're asking." These recommendations mirror the tenets of user-based research and are the primary rationale for the cumulative data collection activities described above. This study asks aerospace engineers about their own everyday work and communication activities and about their own perceptions. Mail survey questions were worded and formatted to emphasize that answers should reflect the respondents' own personal views and experiences. A number of questions were asked for responses related to some particular, recent event, thus reducing the potential for memory error. The preliminary data collection activities (site visits/interviews and telephone survey) were conducted in order to help ensure that the mail survey would be relevant and clear to those receiving it. Participants in these early activities were asked how they interpreted questions and what could be done to improve the clarity and interest of the questions.

In addition, the mail survey was pretested by three different categories of respondents: (1) researchers with expertise in CMC and survey design, (2) subjects from this study's preliminary data collection activities, and (3) respondents drawn randomly from the study's sample. Survey pretesting with the first two groups included a "debriefing" component, in which subjects were asked to discuss their interpretation of and reactions to individual questions. This also allowed questions perceived as ambiguous, threatening, boring, difficult, or biasing to be re-phrased.

A specific technique recommended by Whitney and Brandenburg (1974) for checking the reliability of survey results is to ask the same question in two different places in the questionnaire. Several such reliability checks were built into the mail survey (see Appendix C for a copy of the mail questionnaire). The same basic question was asked in slightly different ways in different survey questions; if the results are reliable, the responses to those matched questions should correspond to each other. For example, the percent of respondents answering that they had no access to local networks in the workplace (q.5) should jibe with the percent who indicated no network access to people in their workgroup in q.6. In addition, responses to open-ended questions were coded by two different people (the researcher and a coder who had no previous involvement with this study) in order to assess the reliability of analysis of these results. The outcomes of these reliability checks will be presented in Chapter 4.

The problem of validity is more difficult. This study employed three techniques recommended by Babbie (1990) to improve validity. The proposed wording of survey questions was compared to the wording of questions prepared by recognized experts. In this case, those experts are researchers (some of whom are engineers themselves) who have produced in-depth studies of the work and communication of engineers (e.g., Allen, 1977; Kaufman, 1983; Murotake, 1990; Rosenbloom & Wolek, 1970; Shuchman, 1981) or scientific and engineering organizations who have surveyed members of these professions.

Second, survey questions were developed as the result of intensive interaction with engineers during the earlier data collection activities. This interaction allowed the development of constructs which aerospace engineers themselves assessed as "valid." For example, questionnaire items representing aerospace work tasks and networking impacts directly reflect the earlier study subjects' characterizations of these constructs. And third, the mail survey pretest allowed for the subjective evaluation of the face validity of responses.

Other validity checks are recommended by Whitney and Brandenburg (1974). First, they suggest that follow-up interviews be held with several subjects to ask for corroboration and explanation of their answers. This was accomplished in the mail survey pretest by probing in subsequent interviews to ascertain that responses reflected actual activities and experiences. For example, several respondents were asked to elaborate on their precoded response choice to a question asking them to identify the most important work task they performed during the last work week. This was done in order to verify that their choice reflected a "real" work task and that the "correct" category for that task had been selected.

Whitney and Brandenburg (1974) also suggest that data be cross-checked with other sources. This will be accomplished with this study's mail questionnaire in several ways. As with the reliability checks described above, specific validity checks were built into the mail survey by asking respondents to report experiences and opinions on one particular topic in several different ways. For example, the construct "extent of network use" in the aerospace industry is measured in the survey by asking respondents whether they agree with the statement "All the people, tools, resources I need are on the network," by asking them to characterize the extent of computer networking at their workplace, and by asking for a report of the frequency with which the individual respondent uses networks. The inclusion of open-ended questions in the survey also offers a means of improving the overall validity of results, in that respondents' own descriptions of, for example, networking impacts, can be compared to precoded responses on the same topic. In assessing the validity of mail survey results, selected data will also be compared to external data sources, e.g., the results obtained in this study's preliminary activities and in other studies of network use in engineering settings.

A final approach to improving validity--establishing rapport with respondents and employing other motivational techniques to decrease the likelihood that they will provide careless or intentionally false information--is mentioned frequently in the literature. The telephone and mail surveys used in this study were developed and implemented with special attention to the guidelines in this area offered by Dillman (1978), which are informed by social exchange theory. Dillman notes that researchers should offer a variety of "rewards" in exchange for participation, that they should:

- Act in an open, positive, and personal manner;
- Explain the social value of the study, e.g., how results may be used to resolve issues by describing how results will be brought to the attention of someone who has the power to act on the issues;
- Advertise study sponsorship so that respondents feel they are contributing to their profession, an important cause, etc.;

- Express verbal appreciation;
- Emphasize the importance of respondents' answers, allowing open-ended questions so that they express themselves more completely;
- Make the questionnaire interesting (e.g., place general questions first, demographic questions last);
- Offer to send respondents a copy of study results;
- Make the survey clear, concise, and simple in language and format;
- Produce visually attractive questionnaires;
- Eliminate questions that are too personal or embarrassing; and
- Eliminate any direct costs to respondents, such as postage.

Each of these guidelines was followed in preparing this study's mail survey and cover letter.

Specific and practical guidelines for the design and development of questionnaire items are described by Dillman (1978), Whitney and Brandenburg (1974), Fowler (1984), and the U. S. General Accounting Office (1986). Techniques are described for improving the reliability and validity of questionnaire items in a number of areas. A variety of question formats (e.g., open-ended, matrix, multiple choice, ranking, rating, and intensity scale) are described, and their appropriateness in different situations is explained. The need to avoid questions that are irrelevant to study goals or respondents' activities, too difficult to answer, ambiguous, or threatening is emphasized, and examples of "good" and "bad" questions are presented and explained. Techniques to improve the clarity of question wording are offered and recommendations are made to minimize bias, memory, and measurement errors. These sources were used extensively in the design of this study's national mail survey, which is described below in Section 3.3.5.

Many of the specific applications of the techniques described in these sources were used in this study. Definitions and examples of key terms were provided. Questions were revised throughout the course of the study to improve their clarity, reduce "leading" formulations, use terms familiar to people in the aerospace, and eliminate threatening questions. Critical incident techniques (described in more detail below) were used to minimize memory error. Cognitive difficulty was reduced by asking individuals to report only on their own personal experiences and opinions. Finally, open-ended questions allowed respondents the opportunity to elaborate on their responses or raise important topics not addressed in other survey questions.

Reliability and validity issues must also be addressed in the collection and analysis of interview data. Qualitative interviews used in the study served a number of purposes. They were used to gain a general familiarity with the population of interest; to explore the range of aerospace engineers' perceptions and activities related to work tasks, communication activities, network use, factors associated with network use, and network impacts; to generate user-generated descriptions of these phenomena that could be compared to reports in the literature; to pretest a number of questions tentatively planned for the national mail survey; and to provide qualitative data, i.e., open-ended responses and anecdotal reports, to complement the mail survey results.

The nature and purpose of research interviewing are discussed in Babbie (1989), Brenner (1985), Kahn and Cannell (1957), Kerlinger (1986), Kirk and Miller (1986), Patton (1990), and Payne (1951). Although Babbie (1989) and Kerlinger (1986) offer some useful advice, the methods they described were less qualitative and, thus, less appropriate than those discussed in, for example, Patton (1990) and Kirk and Miller (1986). These authors offer useful techniques for improving the reliability and validity of qualitative interviews. This study used the interview guide approach described by Patton (1990, p. 284), which called for the preparation of a list of questions and issues to be explored during the course of the interview (see Section 3.3.4.2 for a more complete description of the instruments and procedures followed in this study's primary interviews). The exact sequence and wording of questions is decided as the interview progresses, allowing for flexibility in suiting questions to the particular experiences and characteristics of specific individuals. As Patton notes, this approach helps ensure that interviews are conducted systematically, but also allows for conversational interviews that have a good situational base. Because exactly the same questions are not asked in exactly the same way of each respondent, however, interview results will not be strictly comparable across all subjects.

There is general agreement in these sources about the potential pitfalls to be avoided, as much as possible, when striving to obtain valid results in qualitative interviewing. Many of these are similar, of course, to the pitfalls confronted in questionnaire design. The basic principle of qualitative interviewing is to query subjects about their own experiences and perceptions, in a nonjudgmental manner, using their own terms and frames of reference. These sources recommend that the interviewer aim for neutrality in question format and content, while at the same time establishing a sense of rapport with the person being interviewed. In this study, interviews began with the questions that were least threatening and, perhaps, most interesting to subjects, i.e., those that asked for descriptions of work tasks and communication activities. The literature also describes techniques for probing, or asking follow-up questions to increase the richness of responses obtained and make sure that the response is fully understood. Patton discusses the problem with asking "Why?" questions, which assume rationality and cause and effect relationships and can lead respondents to provide "rational" as opposed to valid answers. Care was taken to avoid this question format in the study's interviewing. Other techniques were also used to increase the validity of the responses. Subjects were encouraged during the interviews to raise topics and issues of particular interest to them and to ask for (or offer their own) clarification of questions. Permission statements suggesting that all kinds of responses to interview questions were considered acceptable to the researcher were used to encourage respondents to be honest and complete in their answers.

The literature also discusses the importance of, and presented proper methods for, recording interview data in written form. In this study, responses were recorded as close to verbatim as time allowed, with verbatim responses enclosed in quotation marks. Interviewer reactions to each setting and interviewee were recorded as soon as possible after each interview, and were written either on separate sheets of paper, or in a different color pen, so that interviewee responses and interviewer reactions would not be confounded at a later point in time. Appropriate informal content analysis techniques, as described in these and other sources (e.g., Weber, 1990) were then applied to data collected in the study's interviews (see Section 3.3.4.2.3 below for a description of the specific procedures employed in analyzing this study's interview data).

3.2.7. Summary

This section provided an overview of the study's research design and methodology. The study's research questions were discussed, with variables of interest identified and defined. The type of data to be collected was described and the study's emphasis on qualitative data was explained. The four major data collection activities pursued in this study were outlined: initial site visits/interviews, telephone survey, primary site visits/interviews, and national mail survey. Important features of the study--its collection of cross-organizational data on the use of a wide range of networks, its inclusion of both network users and nonusers, and the cumulative nature of the data collection activities in order to enhance the validity and user-based perspective of results--were emphasized. The selection of subscribers to the SAE publication *Aerospace Engineering* as the study's sample frame was justified and procedures involved in drawing a sample were explained. Issues related to obtaining reliable and valid results were identified and the manner in which such issues were addressed in the study was described.

The next section presents, in greater detail, the methodology associated with each of the study's data collection activities.

3.3 Data Collection Activities

3.3.1. Introduction

This study is comprised of four data collection activities: (1) initial site visits/interviews, (2) a national telephone survey, (3) primary site visits/interviews, and (4) a national mail survey. The first three activities are considered preliminary, in that their results were used mainly for methodological reasons, i.e., to gain familiarity with the population of interest, to more precisely frame the study's research questions, to acquire a better understanding of the nature of the sample frame, and to improve the reliability and validity of the final mail questionnaire through an increased knowledge of how to design questionnaire items that would be comprehensible and of interest to potential respondents.

This section describes each of the study's data collection activities in turn, detailing their objectives, procedures, and contribution to the study.

3.3.2. Initial Site Visits/Interviews

3.3.2.1 Initial Site Visit/Interview Objectives

Preliminary site visits were conducted in June 1991 at several locations employing aerospace engineers. The objective of these visits was to become acquainted with the work environment, the work and communication activities, and the vocabulary of the aerospace engineering community. The initial site visits allowed the identification and preliminary development of *user-based* descriptions of work tasks, network uses, communication activities, and network impacts. These descriptions were compared to descriptions appearing in the literature and in earlier surveys and were used to refine study goals and questions and develop the subsequent telephone survey.

3.3.2.2. **Initial Site Visit/Interview Procedures**

The initial site visits were extremely exploratory. They began with one group interview with several aerospace engineering faculty on one university campus, who were then asked to identify other sites in the local area that employed aerospace engineers and to participate, themselves, in follow-up individual interviews. All potential participants were telephoned and after the study was described, they were asked whether they would be willing to participate in interviews that would focus on their use of computer networks and the nature of their work and communication activities. As a result, interviews were conducted with thirteen aerospace engineers who represented a variety of aerospace subfields and employment settings. Four were employed in a large industrial R&D center; five worked in academia, but also had experience working on Federal or private sector projects; two were employed by a small not-for-profit corporation; and two were the heads of their own small consulting firms. Most of the engineers were involved in the earlier stages of the engineering lifecycle process, i.e., research and development; five noted that management was one of their primary duties.

The content of the initial site visits/interviews was purposely left quite open. Interviewees were asked about the field of aerospace, in order to get a sense of how aerospace engineers themselves would categorize subdisciplines and job types, and how they would describe the major stages in a model of the product development process (which is one way of describing engineering work). During the first site visit, a small group of engineers tried to articulate and model this high-level process. This seemed to be a somewhat difficult exercise, probably because they were forced to agree on level of description and terminology. Further, they were being asked to describe the entire process, when most individuals had personal experience with only some of the stages represented in the model. In subsequent sessions, individuals were asked to name, model, and describe only those work stages in which they were personally involved.

To move to a more specific discussion of work, individuals were also asked to describe the particular tasks associated with the major product development stages which they personally performed. This led to a discussion of communication activities and partners associated with particular tasks. Also discussed was their use of computer networks, in terms of both types of networks used and reasons for use. Interviewees were also asked for their opinions about factors affecting their use of networks. Notes were taken during the interviews, during which an effort was made to capture the exact terms and phrases used by interviewees. At the conclusion of the interviews, the notes were reviewed and lists were compiled of the responses related to constructs of interest to the study: aerospace subfields, nature of primary duties, types of networks and network applications, network uses, modes or channels of communication, communication partners, and factors affecting network use.

3.3.2.3. Use of Initial Site Visit/Interview Results

The initial site visits/interviews were devoted primarily to a discussion of the relationship between work activities and communication patterns. These discussions were useful because they provided user-based descriptions of work and communication activities. The researcher received first-hand reports of "what engineers do" that corroborated and extended descriptions in the literature. Those engineers interviewed noted a wide variety of work tasks, from searching for funding opportunities, to proposal writing, to experimentation, analysis, and report-writing. They also spoke of the need to get ideas, solve problems, locate resources, and negotiate with others.

Participants were asked to describe their communication activities during various work tasks in terms of the identity of communication partners, and why and how they communicated with these partners. This discussion was not limited to the use of networks because its purpose was to help the researcher begin to understand the nature of engineering communication in its entirety. A wide range of communication partners (e.g., colleagues, people in other departments, vendors, customers, students, programmers, consultants, clients, friends, secretaries, foreign visitors), communication modes (e.g., technical literature, telephone, fax, grapevine, memos, meetings, hallway chats, "chalk talk," videoconferencing, letters, visits, and seminars), and computer network uses (e.g., to ship design data, solve technical problems, set up meetings, submit proposals, search online databases, provide client service and support, conduct casual discussions, and coordinate work) was articulated. These matched reports in the literature, although they encompassed a wider range of phenomena than what typically appeared in published reports.

Interviewees also provided interesting anecdotes and raised a number of issues related to factors that affected the use of electronic networks by themselves and their colleagues. Several people noted the proprietary nature of their work, the negative attitudes (or perceived negative attitudes) of managers, the difficulty of training, and the fact that only certain work tasks were computerized. Other factors mentioned included organizational inertia, lack of awareness of and familiarity with network tools and resources, the high bandwidth needed for transmitting the amount of data often created in aerospace work, the large capital investment initially required, and the need for high levels of network security.

The initial site visits/interviews provided data useful for the development of user-based classification schemes for many of the phenomena of interest in this study, such as work tasks and activities, network uses, communication partners and functions, and factors related to network use. Acquiring these data was the first step toward ensuring that items on the final mail survey questionnaire would be relevant to, and phrased in terminology appropriate to, aerospace engineers. The initial site visits/interviews also served other functions. They revealed that most aerospace engineers discuss their work and communication openly and with interest and seemed to understand and appreciate the objectives of this study. This augured well for the response rate and validity of subsequent data collection activities. Engineers also seemed able to articulate communication activities as a function of work tasks. In fact, it seemed natural for them to do so.

The initial site visits/interviews also suggested that choosing appropriate analytical frameworks for describing engineering work would be difficult. Standard means include job category (e.g., engineer, manager), engineering subfield (e.g., aerospace, mechanical, civil), and stage of the product development process (e.g., research, development, mainline engineering, manufacturing and production, service and maintenance, sales and marketing). The literature and site visits failed to provide consistent and unambiguous categorizations of engineering work and the product development process.

These initial discussions also made it clear that identifying and describing network impacts in a way that is meaningful to aerospace engineers, especially given the diversity of their work environments, would be problematic. The literature contains a number of schema related to network impacts, all valid given particular situations, settings, and stimuli. These, however, do not appear to be entirely applicable to the work and situations of aerospace engineers. Thus, an important objective of the subsequent telephone survey and primary site visits/interviews was to advance the development of descriptive schema related to the major phenomena of interest in the study, including work tasks, communication activities, and network impacts.

3.3.3. Telephone Survey

3.3.3.1. Telephone Survey Objectives

A national telephone survey of a randomly drawn subset of the original sample of 1,200 subscribers (created in April 1991) to the SAE weekly magazine called *Aerospace Engineering* was also conducted as a preliminary data collection activity. The telephone survey was conducted by the Center for Survey Research (CSR) at Indiana University in order to collect data for the NASA/DoD Aerospace Knowledge Diffusion Project, of which this study comprises only one part. The Project undertook the SAE telephone survey in order to gather data on the daily work activities of aerospace engineers and on various practices used by aerospace engineers to obtain scientific and technical information. It was agreed that a small set of questions asking aerospace engineers about their use of electronic networks--which this study's researcher designed--could be added to those questions already planned by other Project staff. Telephone survey questions on the daily work activities of engineers that were designed by Project staff, of course, were of interest to this study as well.

The telephone survey was an important part of this study because it provided a description of the characteristics of respondents, so that implications of using the SAE sample could be identified and described, and adjustments made to the sample frame, if necessary. A second purpose was to extend the user-based schema for work tasks, communication activities, and network uses that were developed as a result of reviewing the literature, examining the two cursory surveys of network use among members of the AIAA (Pinelli, 1991b) and SAE (Society of Automotive Engineers, 1991), and conducting the initial site visits/interviews. The telephone survey was also used to test whether proposed definitions of network applications would be understandable to aerospace engineers. Because of the limited space allowed by the Project for the additional set of questions on computer-mediated communication, not all phenomena of interest to this study could be explored in the telephone survey. It was decided to leave the investigation of networking impacts and factors affecting use, about which less was generally known, for the subsequent primary site visits/interviews. The more open and in-depth nature of those interviews would allow for a deeper and more exploratory discussion of those topics than was possible in the telephone survey.

3.3.3.2. Telephone Survey Procedures

The aim of the telephone survey was to test question formats and collect preliminary descriptive data related to respondent characteristics, nature of engineering work, and network use by aerospace engineers. Respondents were asked to characterize themselves as either "scientist," "engineer," "manager," or "other"; they characterized their work as "basic research," "applied research," process or product development," "manufacturing," "production," "service or maintenance," "sales or marketing," or "other." Other questions asked respondents to identify the type of organization in which they were employed and to report the number of years of their professional aerospace work experience and the highest educational level they had obtained. An open question asked respondents to describe their current work activities.

The questions on network use asked about:

- Network availability and frequency of use;
- Use of particular network functions;
- Types of communication partners; and
- Purpose of electronic communication.

Most of the questions on computer networking required only "yes/no" answers, selection from a list of pre-coded answers (such as, for the question on frequency of network use, "never," "once a month or less," several times a month," "several times a week," or "daily"), or the supply of a specific number (such as "approximate percent of past work week spent using networks"). Only the question on purpose of electronic communication invited a completely open-ended response.

Data collection for the SAE telephone survey began on August 14, 1991 and ended on August 26, 1991. Pretests of the survey were conducted on August 7, 8 and 12, 1991 with a small subset of individuals in the sample. After discussing with the CSR Director the conduct and outcomes of each round of pretesting, the researcher made minor revisions to the set of networking questions in order to improve question clarity and reduce the total amount of time needed to complete the telephone interview. Data were collected using the University of California Computer Assisted Survey Methods software (CASES). This software prompts interviewers with survey questions and instructions, automates skip procedures, and allows them to enter data directly online during each interview.

The data collection staff at CSR included seven supervisors and twenty-seven interviewers. All CSR interviewers receive at least 20 hours of training in interviewing techniques before production interviewing. Interviewers received two hours of specific training on the SAE telephone survey instrument and special procedures. Interviewers were instructed in the use of neutral probes and feedback phrases. Unobtrusive audio and visual monitoring of the interviewers was regularly conducted by the telephone survey supervisors using equipment in place at CSR.

All telephone numbers that rang but were not answered were called at least six times during the survey period. On the assumption that potential respondents would be unwilling or unable to complete the telephone interview while at work, only those people who provided a home telephone number were selected for the telephone survey sample; potential respondents were generally contacted on evenings and weekends. The average length of the interviews was about 15 minutes. Table 3-3 categorizes every case in the sample of 695 potential telephone interview participants according to its final disposition. The response rate for the telephone survey was 62%.

3.3.3.3. Use of Telephone Survey Results

Because of the limited intended use of the telephone survey results for this study, only simple descriptive summaries of the data and a few cross tabulations (selected by the researcher) were produced by CSR staff. A listing of all open-ended responses was also supplied. These responses had been recorded verbatim by interviewers, who read the responses back to the interviewees, to check their accuracy.

Table 3-3.
Disposition of Telephone Survey Responses

Number of Cases	Disposition
430	Completed interviews
48	Refused to be interviewed
28	Persistently unavailable for interviewing
45	Away during survey period
3	Inaccessible - not available for interviewing
4	Illness, disability, language problems
31	Contacted household, but respondent not living there
7	Group quarters/business phone
31	Non-working numbers
36	Phone rang/never answered after at least 6 attempts
32	Answering machines

The SAE phone survey results were useful in a number of ways. One important use was that they helped identify the characteristics of the sample frame, so that its representativeness in relation to the population described by NSF statistics (1987) could be assessed. Phone survey respondents identified themselves according to their basic work functions and activities (see Table 3-4). Although the categories are not strictly comparable, they suggest that the SAE sample is similar to the larger population of aerospace engineers as described by the NSF statistics, in terms of job types.

As shown in Table 3-5, the data on the educational background and employment sector of sample subjects are more strictly comparable to NSF data. These results indicate that subjects in this study's sample are very similar to the larger population of aerospace engineers. They also helped in estimating the size of data groupings associated with demographic

Table 3-4.
Work Characteristics of Telephone Survey Respondents, Compared to NSF Data

TELEPHONE SURVEY RESPONDENTS

Basic Job Function	% of Respondents Selecting that Category
Engineer	66
Manager	23 (but 95% of these closer to engineer than scientist)
Scientist	2
Other	8

Primary work activities	
Basic or applied research	14
Process or product development	63
Manufacturing or production	14
Service or maintenance	2
Sales or marketing	.3
Other	7

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Primary work activities	% of Respondents Selecting that Category
Basic and applied research	9
Development	37
Management (R&D and other)	28
Production/inspection	10
Service	.2
Sales	1

Table 3-5.
Education and Employment Sector of Telephone Survey Respondents, Compared to NSF Data

	% of Respondents in Telephone Survey	% of Respondents in NSF 1986 Data
Educational Background		
Bachelors or less	60	64
Masters	35	28
Ph.D. or more	4	7*
Employment Sector		
Industry	86	73
Government	12	16
Academic/Other	3	6

** 4% in 1988 figures; no Masters or Bachelors statistics are given in 1988 source, however.*

variables that are likely to be obtained the mail survey; given evidence from the telephone survey, the subsequent sample drawn from the SAE database was stratified in an attempt to reach a greater proportion of academic and government representatives. Further, these results also point out variations in the ways that different research and professional organizations have described aerospace engineering work and the difficulty of comparing and interpreting these different terms.

Respondents' open-ended descriptions of their work activities were not formally analyzed. A review of these responses corroborated the diversity of activities performed by aerospace engineers described in the literature and by engineers participating in this study's initial interviews. Responses ranged from the general to the very specific (e.g., "management" vs. "completed an employee evaluation form") and included a number of descriptions of communication-oriented activities (e.g., "scanned the literature," "negotiated with clients").

These results suggested that it would be difficult to come up with user-based descriptions of work and communication activities for the mail survey that would be all-encompassing, mutually exclusive, and at the same level of specificity. It was decided to ask for open-ended descriptions of work and communications activities in this study's primary site visits/interviews and then to compare interview with phone survey results (since the interviews would necessarily be restricted to a much smaller and less diverse group of participants) to make sure that no major types of work or communication activities would be excluded from the mail survey.

The network use data collected in the telephone survey revealed that the majority of aerospace engineers have access to and use electronic networks, for a variety of functions. Table 3-6 presents the telephone survey's networking questions (labelled CMC 1-8), along with a simple descriptive summary of results. In general, telephone survey results paint a picture of widespread use of electronic networks. The majority of respondents (83%) reported that networks were accessible to them in the workplace. Further, 71% of respondents who used computer networks indicated that they had network access to people at remote sites, i.e., across town or around the world. Of those respondents with access to networks, a full 44% indicated that they used them on a daily basis, and only 7% reported that they never used networks. The remainder of the responses were fairly evenly distributed between perceived use of "once a month or less," "several times a month," and "several times a week." In describing intensity of network use--as opposed to frequency--the most common response (32%) was that networks were used during 10-24% of the past work week; 13 percent of respondents, however, indicated that at least 50% of the past work week was spent using networks.

In describing their use of particular network functions, close to 80% of network users reported use of electronic mail, file transfer, and information or data retrieval related to commercial or in-house databases. About 50% used one-to-many electronic communication mechanisms, such as bulletin boards, newsletters or conferencing systems, and 55% used networks

Table 3-6.
Telephone Survey Questions and Results[a]

CMC 1: The next few questions deal with the use of electronic networks for such things as electronic mail, the control of remote equipment, and on-line information searching. We are interested in how the use of networks affects people's work.

At your workplace, do you have access to electronic networks?

Response	n	Percent
Yes	273	(83)
No	56	(17)
Don't know/Refused to answer	4	
TOTAL	329	(100)

CMC 2: About how often do you use networks? Would you say:

Response	n	Percent
Never	20	(7)
Once a month or less	43	(16)
Several times a month	49	(18)
Several times a week	40	(15)
Daily	120	(44)
Network not accessible	60	
Don't know/Refused to answer	1	
TOTAL	272	(100)

[a] N = 430. Base for each question varies. The 97 respondents who, in an earlier section of the survey, characterized their work as something other than "aerospace-related" were excluded from the all networking questions. Also excluded from the total base number of respondents for each question were those who gave "Don't know" as their response, or who refused to answer. All figures are rounded up to the nearest whole percent.

Table 3-6 (Cont'd).
Telephone Survey Questions and Results

CMC 2a: Do you use a network that allows you to connect to geographically distant sites, which could be across town or around the world?

Response	n	Percent
Yes	179	(71)
No	72	(29)
Network not accessible or never use networks	81	
Don't know/Refused to answer	1	
TOTAL	251	(100)

CMC 3: Now I'm going to list some functions that networks provide. Please tell me which you use, even if you don't use them often.

3a) Do you use electronic mail?

Response	n	Percent
Yes	196	(78)
No	55	(22)
Network not accessible or never use networks	81	
Don't know/Refused to answer	1	
TOTAL	251	(100)

3b) Do you use electronic bulletin boards or conferences?

Response	n	Percent
Yes	124	(50)
No	126	(50)
Network not accessible or never use networks	81	
Don't know/Refused to answer	2	
TOTAL	250	(100)

Table 3-6 (Cont'd).
Telephone Survey Questions and Results

3c) Do you use networks for file transfers?

Response	n	Percent
Yes	197	(78)
No	55	(22)
Network not accessible or never use networks	81	
Don't know/Refused to answer	0	
TOTAL	252	(100)

3d) Do you use networks to log into remote computers for such things as computational analysis or the use of design tools?

Response	n	Percent
Yes	139	(55)
No	112	(45)
Network not accessible or never use networks	81	
Don't know/Refused to answer	1	
TOTAL	251	(100)

3e) Do you use networks to control remote equipment such as laboratory instruments or machine tools?

Response	n	Percent
Yes	41	(16)
No	211	(84)
Network not accessible or never use networks	81	
Don't know/Refused to answer	0	
TOTAL	252	(100)

Table 3-6 (Cont'd). Telephone Survey Questions and Results

3f) Do you use networks for information searching or data retrieval?

Response	n	Percent
Yes	192	(76)
No	60	(24)
Network not accessible or never use networks	81	
Don't know/Refused to answer	0	
TOTAL	252	(100)

CMC 4: **4a)** Many people use electronic networks to communicate with other people. Do you exchange electronic messages or files with members of your work group?

Response	n	Percent
Yes	183	(76)
No	57	(24)
Network not accessible or never use networks	81	
Don't use electronic mail, bulletin boards, or file transfer	12	
Don't know/Refused to answer	0	
TOTAL	240	(100)

4b) Do you exchange electronic messages or files with other people in your organization who are not in your work group?

Response	n	Percent
Yes	182	(76)
No	58	(24)
Network not accessible or never use networks	81	
Don't use electronic mail, bulletin boards, or file transfer	12	
Don't know/Refused to answer	0	
TOTAL	240	(100)

Table 3-6 (Cont'd).
Telephone Survey Questions and Results

4c) Do you exchange electronic messages or files with people outside your organization?

Response	n	Percent
Yes	120	(50)
No	118	(50)
Network not accessible, never use networks, no remote access	82	
Don't use electronic mail, bulletin boards, or file transfer	12	
Don't know/Refused to answer	1	
TOTAL	238	(100)

CMC 5: People can use electronic messages for many purposes, for example, to keep in touch with friends, to schedule meetings, and to ask technical questions, among other things. If you think about the last several messages you sent or received, how would you describe their functions?

[240 respondents supplied an answer to this question]

CMC 6: About what percentage of the last work week was spent using networks for any purpose at all?

Response	n	Percent
None	14	(8)
1-4%	22	(13)
5-9%	46	(27)
10-24%	55	(32)
25-49%	12	(7)
50-74%	16	(9)
75% or more	7	(4)
Don't know	1	
Network not accessible or no reported use of networks	257	
TOTAL	172	(100)

for remote login to other computer systems. Only 16% reported use of electronic networks for the remote control of experimental or manufacturing devices.

Other survey questions explored the nature of network communication. About two thirds of those respondents who used electronic mail, bulletin boards, or file transfer reported that they communicated electronically with people in their work group or with others in their organization; fully half responded that they used networks to communicate with people outside their own organization. Finally, respondents were asked to recall and report the purpose of a recent electronic exchange (see Table 3-7). The majority of reported exchanges were related to what might be termed "technical" communication. Somewhat fewer examples of "administrative" exchanges were noted and substantially fewer respondents reported a recent exchange as being what might be called "social" in nature. These responses were used to help design user-based questions and response categories related to network use for the final mail survey.

The telephone survey data revealed relatively little variation in network access and use according to whether the respondents identified themselves as "scientists," "managers,"or "engineers." Managers reported slightly greater access to networks, engineers were the least frequent users, and scientists and engineers reported the most intense use. (Note: only five respondents classified themselves as "scientists."). These data suggest that if network use varies by the nature of the work one performs, more specific ways of describing that work (such as by specific work tasks) would have to be used in order to reveal the variations.

The telephone survey data also suggest that a small but significant portion of aerospace engineers do not use networks at all; this helps anticipate the size of various data groupings (e.g., users vs. nonusers) and subgroupings that will be obtained in the mail survey and that will be important in the analysis of the survey results. The mail survey sample size will have to be large enough to obtain enough nonuser respondents for the desired analyses. These data on network use can be used to triangulate study results by comparing them to results obtained in the

Table 3-7.
Telephone Survey Findings on Purpose of Electronic Communication[a]

Communication Function	Number of Respondents Citing that Function
Technical (e.g., send data, ask technical questions, obtain specifications, solve technical problems, forward designs)	155
Administrative (e.g., announce meetings, distribute status updates, announce policy decisions, schedule work)	103
General Information Exchange (e.g., relay information, share information, get company news)	38
Social (e.g., keep in touch with friends and colleagues, send personal messages)	20

[a] Of 430 survey respondents, 240 supplied an answer to the open question on purpose of electronic communication. In all, 417 purposes were elicited; some answers described more than one purpose.

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mail survey, thus suggesting the degree of reliability obtained in the mail survey.

The telephone survey data on network use can be used to triangulate study results by comparing them to results obtained in the mail survey, thus suggesting the degree of reliability obtained in the mail survey. Finally, the several rounds of pretesting and adjusting telephone survey questions also suggested improvements for wording questions about network use on the mail survey so that survey questions would less ambiguous to aerospace engineers, leading to greater overall validity of mail survey results .

3.3.4. Primary Site Visits/Interviews

3.3.4.1. Primary Site Visit/Interview Objectives

The major purpose of the primary site visits/interviews was to gather extensive user-based descriptions of the major phenomena of interest in this study: aerospace engineering work tasks and communication activities, network use, factors affecting network use, and network impacts. These descriptions were compared to similar findings in the literature and used to develop mail survey questions with a theoretical basis as well as validity within the context of aerospace engineering work. The interviews were also used to improve the clarity of mail survey questions and generate response categories for them. Interview results complement the mail survey results because the interviews allowed subjects to give more open-ended responses to questions and relate relevant anecdotes.

3.3.4.2. Primary Site Visit/Interview Procedures

3.3.4.2.1. Contacting Participants

A list of potential interview subjects was drawn from the initial SAE sample. Potential subjects were selected on the basis of geographic location and represented R&D and other aerospace engineering facilities located in upstate New York and Connecticut. An attempt was made to select from this list of potential interview subjects a subset which represented a wide range of job types, organization types and sizes, and engineering subfields. If the organizations selected were represented by only a few people on the list, the first subjects contacted were asked to identify colleagues who might be interested in participating in the interviews. A primary assumption of the study, and one that has been articulated by Taylor (1991), is that people engaged in particular kinds of work will exhibit similar information and communication behavior based on shared work norms, activities, and environment. Thus, it did not appear that interviewing some aerospace engineers who did not subscribe to SAE's *Aerospace Engineering* (i.e., did not appear in the SAE database) would distort interview results. The SAE database is used as the study's sample frame because it offers an efficient tool for the identification of a broad range of aerospace engineers, and it is used only under the assumption that journal subscribers are similar in work and communication activities to nonsubscribers.

Interviews were conducted with 31 aerospace engineers in ten different organizations (including two pretest and 29 actual interviews). Interview subjects were not limited to only those people who used electronic networks. Of the twenty-nine interview participants, fourteen came from the SAE database, while fifteen did not, having been selected after initial contact had been made at the organization. The ten organizations participating in the interviews offer substantial variety in terms of size, ranging from about 50 employees to over 100,000. The primary aerospace products they develop include sonar systems, radar systems, electronic warfare systems, aircraft simulators, rocket engine control valves, flight control actuation devices, propulsion components for satellites, land-based power transmission couplings, propeller systems, fuel controls, environmental control systems, space station materials, jet engines, helicopters, manufacturing systems, and design and testing systems.

Nine interview participants reported that they functioned primarily as a manager; 20 reported that their primary function was as an engineer. In terms of the work of the organizational unit in which they were employed, fifteen participants were employed in either applied research or development, ten worked in engineering, three in manufacturing and production, and one in information processing and systems.

3.3.4.2.2. Primary Site Visit/Interview Activities

Interviews were conducted at each organizational site, between August 29 and September 24, 1991. Potential interview subjects were contacted initially by telephone. During the initial conversation, the purpose of the research and the interviews was explained. Only one potential interview subject declined to be interviewed, although a number of people had to check with their superiors and/or with security staff before committing to the interviews. Subjects were subsequently sent a copy of the study abstract and a brief description of the nature of the scheduled interview. Interview activities were pretested with two subjects in order to determine the time required to complete them and to assess which activities were least fruitful in terms of eliciting relevant responses, in case it became necessary to drop some activities due to time constraints. The length of the interviews varied from one to one and a half hours. The interviews included four major activities (see Appendix A for a set of the interview instruments):

- Completion of the Job Tasks and Activities Worksheet, which elicited user-based descriptions of work tasks, communication activities, and network use; the worksheet was supplemented by open-ended questions on the nature of work and nature of the organization.
- Analysis of three communication incidents, using the Message Analysis Worksheet; subjects reported message purpose, channel used, partner characteristics, and why a particular channel was chosen in that particular situation.
- Open-ended questions on: networking impacts on work and communication at the individual and organizational levels; and factors that affect network use.
- Completion of the Interview Questionnaire on network use and background work characteristics.

Not all interview activities were completed with each subject, occasionally due to lack of time. In some cases, individuals with unique perspectives (e.g., primary responsibility for implementing networked systems or a recent job change from a highly networked to a minimally networked environment) were encouraged to spend most of the interview discussing their unique experiences.

An advantage of conducting the interviews onsite was that the researcher had the opportunity to view participants in their natural work environment. Interviewees could also demonstrate their network system or various work artifacts. The researcher was able to experience firsthand the nature of each work environment; thus, various attributes presented themselves as potentially significant factors in network use. For example, the high degree of security at one site was made dramatically clear when one interviewee pointed out how ankle bands were worn by some employees so that their movements could be traced at all times. In another setting, it was obvious that the physical layout--an open shop floor--eliminated much of the need for e-mail communication with immediate colleagues. 'See,' the interviewee exclaimed, 'everybody I need to talk to in my work is easily visible... when I need to talk to someone, I just look to see if they're around before walking over to their desk.' In a number of cases, the researcher was given a tour of the site so that the nature of the work done there could be apprehended in its entirety.

Each interview began by reviewing the nature and purpose of this study and describing the particular role of the interviews within that context. The four interview activities were then briefly described and key terms were defined, e.g., "computer networks" were defined as telecommunications links among computers or between computers and other devices, with examples including local area networks, linked workstations, company networks, and the Internet. All interviewees were encouraged to be completely candid in their comments because of the study's intention to focus on networking from the user's point of view, to uncover problems as well as benefits, and to obtain opinions from a broad range of people, including those who did not use networks at all. Throughout the interviews, respondents were encouraged to comment on interview instruments and procedures and to digress from them if topics and issues of concern to them were not adequately addressed by specific interview questions.

The Job Tasks and Activities Worksheet was introduced first because it dealt with topics that were potentially the least threatening and the most interesting to respondents, i.e., respondents were asked to describe their own work activities and environment. They described first the work tasks that they performed and each task description was written by the researcher in one of the boxes that made up the "Work Tasks" column in the center of the worksheet (see Appendix A). A number of people described tasks in some kind of logical sequence--e.g., going through the steps that they completed in order to develop some final product--while others simply noted a set of basic work activities, more along the lines of the kinds of things they did each day. Next, subjects were asked to look at each recorded task and identify the people they typically communicated with and the tools, devices, or information sources they typically used to complete each task. These were recorded in the boxes that made up, respectively, the worksheet's two outside columns on communication partners and work resources. Lines were added and labeled, as appropriate, to link specific tasks to their associated human and other resources.

With one interviewee (subject number S8), for example, the task "come up with conceptual approaches for simulating avionics" was linked to "software designers" with a line labeled "get their recommended best alternative"; to "customers" with a line labeled "find out what specific training features they want"; and to "upper management" with a line labeled "get costs." That same task box was linked to a resource box called "standard library of previous simulation approaches" with a line labeled "how done in past?" After all tasks, partners, and resources were elicited and recorded by the researcher, interviewees were asked which (if any) of the lines represented links made with computer networks, and to what extent. Any comments that came up during the entire process that were related to the nature of the interviewee's work or organization were recorded in the bottom corners of the worksheet; if no unprompted comments were made, these topics were explicitly raised by the researcher.

The next interview activity was the analysis of up to three "communication incidents," using the Message Analysis Worksheet (see Appendix A), which was completed by the researcher. Interviewees selected and discussed a recent message, identifying its general type (technical, administrative, social, or other), which channel was used (from among several subcategories of computer-mediated, telephone, face-to-face, or written communication channels), and whether the message was sent or received. They then described the specific substance or content of the message, the task context of the message, and the basic utility of the message. The next step was to identify their communication partner's job, organizational location, spatial location, and how well that person was known. Similar questions were used by Feldman (1987) to explore relationships between the use of electronic mail and communication partner characteristics. Finally, interviewees discussed the circumstances that led to the use of a particular channel in the particular situation being described.

Following on the previous example, S8 described a communication incident initiated by a colleague in his department in an informal face-to-face conversation that occurred in the interviewee's office and that was related to the task of conceptualizing a simulation approach. The colleague wanted advice on how to go about providing the display system for a newly-defined training requirement. The subject identified problems associated with the different display options, gave his colleague the names of other people to contact, and resolved to follow up later to see how a decision was reached. In describing why face-to-face communication was used, the subject said that it was the quickest way to convey the needed information, that it was easiest since his colleague's office was only 100 feet away, that his colleague brought a copy of the proposal so that they could examine relevant block diagrams, and that a formal meeting was not required since they were at an early stage of the process.

The next segment of the interviews involved the introduction of Open-ended Interview Questions on computer networking (see Appendix A). Respondents were asked to describe the positive and negative effects that computer networks were having on their work and on the way they communicated; their responses were recorded on the worksheet by the researcher. To elicit work-related factors associated with network use, interviewees were asked "What is there about you, your work, or your organization that might lead you to use networks?" and, similarly, "What is there about you, your work, or your organization that might limit your use of networks?" To give respondents one more chance to raise new issues and topics of their own choice, they were asked "Are there any other comments about networks or this study that you would like to make? Is there anything you feel is important to my understanding of the impact of computer networks on aerospace work and communication that hasn't come up yet?"

Interviewees--whether network users or nonusers, novices or experts--seemed to have little difficulty responding to these direct questions about network use factors and effects and, in fact, seemed to welcome the opportunity to carry on a general discussion of these topics. They raised both positive and negative points and spoke about current problems with, and future directions for, networking. Comments were not always directly related to the specific question posed (e.g., subjects sometimes discussed networking effects when asked about factors affecting use, or mentioned communication impacts when asked about work impacts), but the comments were nonetheless relevant to the study's research questions. While sometimes reiterating comments made in other portions of the interview, interviewees introduced new ideas here, as well.

Comments made by S8 in this portion of the interview provide an example of the nature of the responses typically elicited. He said that a definite future requirement will be to network simulators together to train pilots against each other in combat situations and that another application that would potentially be useful for him would be if he could use, from his office, specialized equipment that was 'plugged in onsite.' He did not use networks much at all, so the current impact on him personally was limited, although he knew they were a necessity for many design engineers. He noted that other people in the company got queries about their electronic capabilities, such as 'Can you ship that data electronically?' or 'Can we e-mail?' This interviewee felt that the biggest problem was that the technology kept changing, that when you finally master it, it changes, and that was what discouraged him from using networks. When probed about the sort of technology that provided this kind of difficulty, he gave learning how to use a Macintosh personal computer as an example, so he clearly was not talking about arcane hardware and software as the source of his problem. He noted further that it would take him about a week to learn how to use a Macintosh and that after that it might increase his productivity.

In response to the queries on factors affecting network use, he said that his company encouraged use by providing needed equipment and training. He was worried that storms would cause a loss of data; with networking, this could have a disastrous effect on the ability for recovery, he felt. This subject found the idea of the Internet interesting, but he admitted that he really hadn't given it any thought. He concluded this portion of the interview by stressing the importance, in his work, of real-time communication and high-speed data transfer capabilities; thus, he felt that distributed fiber networks would be required for the aerospace industry.

As the final interview activity, subjects were asked to complete a two-page Interview Questionnaire, which contained matrices on the availability, use, and perceived value of various types of networks and network applications (see Appendix A). It also required the completion of a set of background questions related to the subject's job and organization characteristics. The main purposes of this questionnaire were to initiate a more specific discussion about the use of particular types of networks and network applications and to provide an early assessment of the format and wording of basic questions in this area that were planned for inclusion in the national mail survey. Once participants had completed the questionnaire, they discussed their responses with the researcher, elaborating on their answers and commenting on their interpretations of the questions. Any comments that arose here--either about networks or about the questionnaire itself--that were deemed especially relevant were recorded by the interviewer in the margins of the questionnaire or on separate sheets of paper.

Upon completion of the interview, the researcher reviewed the four instruments to check for and correct any problems that might cause confusion in subsequent analysis of the data, such as missing subject identification numbers, illegible handwriting, or recorded comments not clearly attributed to either the researcher or the interviewee. Finally, the interviewer's own impressions of the interview were recorded.

3.3.4.2.3. Primary Site Visit/Interview Analysis Procedures

As stated above, the primary goal of the site visits/interviews was to elicit extensive user-based descriptions of the major phenomena of interest in this study: aerospace engineering work tasks and communication activities, network use, factors affecting network use, and network impacts. These descriptions were used to develop questions and response categories for the subsequent national mail survey. In addition, the interviews naturally allowed responses of a greater length and depth than would typically be given in a written survey. Thus, the interview results complement and augment mail survey results. The interviews provide depth of data (rich responses from a small number of people), while the survey provides breadth (short responses from a large number of people). Interview data are also useful when interpreting the mail survey results because they provide additional context.

In analyzing and summarizing the data obtained from the site visits/interviews, all of the instruments completed with each participant were reviewed, along with field notes. Individual responses from the instruments were used to compile user-based lists representing the major categories of phenomena of interest in this study. The intent of the analysis was to yield as broad a range of responses as possible; no further inferences or conclusions were drawn from the data. Data were summarized and organized, but not analyzed in the sense of looking for frequency or intensity of responses or of relating responses to other characteristics of subjects.

The categories and the manner in which the lists were constructed by the researcher are described in Table 3-8. All of the material summarized in these lists was recorded and coded by the researcher. Subject responses and researcher comments/perceptions were categorized according to the major categories listed above, with the researcher's comments/perceptions preceded by a bracket to distinguish them from the subjects' responses. Pertinent interviewee

Table 3-8.
Interview Data Sources and Analysis Categories

Analysis Category	Source of Data from Interview Instruments
Work tasks	Job Tasks and Activities Worksheet, center column of "work task" boxes. This list contained about 160 items.
Interpersonal communication activities	Job Tasks and Activities Worksheet, left-hand column of boxes for "Who do you communicate with?" This list contained about120 items.
Work resources	Job Tasks and Activities Worksheet, right-hand column of boxes for "What tools, devices and info sources do you use?" This list contained about 50 items.
Network applications/uses	All completed instruments and notes were reviewed and a comprehensive list of unique uses was compiled (i.e., uses mentioned by more than one subject were recorded only once). The majority of the recorded responses came from the Job Tasks and Activities Worksheet and the portions of the Interview Questionnaire that dealt with network types and applications. This list contained about 80 items. In addition, respondents' comments about the clarity of the Interview Questionnaire matrices were recorded separately and reviewed carefully.
Factors encouraging network use	All completed instruments and notes were reviewed and a comprehensive list of factors encouraging network use was compiled. The majority of the recorded responses came from the Open-Ended Interview Questions Worksheet and the portions of the Interview Questionnaire that dealt with network types and applications (i.e., from respondents' comments about why network applications were used). Also included here were responses on message substance and reasons for choosing a particular communication channel--for computer-mediated communication incidents--elicited by the Message Analysis Worksheet. The list contained about 130 items.

Table 3-8 (Cont'd).
Interview Data Sources and Analysis Categories

Analysis Category	Source of Data from Interview Instruments
Factors discouraging use	These items were compiled in a manner similar to that network described immediately above. This list contained about 250 items.
Work characteristics	All instruments were reviewed to compile a comprehensive list. Most responses came from the Job Tasks and Activities Worksheet, where "Nature of Work" and "Nature of Organization" comments were recorded in the lower corners, or from comments made while completing the Interview Questionnaire. All items in this category could also be considered as factors potentially related to network use. This list contained about 65 items.
Positive network impacts	All instruments were reviewed to compile a comprehensive list; virtually all items in the list came from responses elicited with the Open-Ended Interview Questions Worksheet, with the questions "How would you describe the effects that computer networks are having on your work, both positive and negative?" and "How would you describe the effects that computer networks are having on the way you communicate?" This list contained about 95 items.
Negative network impacts	These items were compiled in a manner similar to that described immediately above. This list contained about 15 items.

responses that were not directly generated in response to questions reflecting the major categories (i.e., unprompted responses) were preceded by an asterisk. For example, a interviewee might mention, in context of describing his or her work, that their work is complex, but does not explicitly offer that response in the context of discussing factors that affect network use.

Each item in the lists represented a particular individual's response, was recorded using the same terminology that appeared in the original interview instruments or in separately recorded researcher notes, and was coded with the respondent's identification number, followed by a number indicating which of the four interview instruments was the source of that item. For example, the first work activity elicited from S8 using the Job Tasks and Activities Worksheet (designated as Instrument 2) was recorded in the category "Work Tasks" as: "Come up with conceptual approaches for simulating avionics: 8.2."

3.3.4.3. Use of Primary Site Visit/Interview Results

This section describes the relevance and expected contribution of the primary interview data to each of the study's research questions. The first research question asks: *What types of computer networks and network applications are currently used by aerospace engineers?"* The Interview Questionnaire (see Appendix A) allowed the initial testing of the clarity of written questions and the adequacy of pre-coded response categories related to the network types and applications matrices. It was important to see whether the vocabulary was comprehensible, the matrix format could be completed correctly, and the range of response choices was appropriate to the respondents' experiences and extensive enough. In order to assess the clarity and appropriateness of these questions, respondents were asked, during the interviews, whether questions were unclear or difficult to answer. Some were asked to provide their own definitions and examples of particular terms that appeared in the interview instrument or to explain how they completed the matrix and why particular answers were given.

The use of network applications was described by respondents as they completed the network applications matrix, but some specific examples were also given by respondents throughout other portions of the interview while discussing network use, work and communication tasks, and impacts. Thus, all of the interview material was reviewed to come up with the most extensive list of network applications possible, recorded using respondents' own vocabulary. This list was used in developing items for the mail survey.

In general, those who used networks a lot had little trouble interpreting terms related to network types or applications; novice users, not surprisingly, were more inclined to misinterpret the terms. The terms used, in other words, were basically correct but were not clear to those not already familiar with them. Several specific problems with the instrument terminology were identified. For example, in the Interview Questionnaire section on "Type of Network," the definitions for "local network" ("connects computers within and among buildings at your workplace") and "organization-wide network" ("connects different locations belonging to one organization") seemed to overlap in respondents' minds. In thinking of their particular situations, some found it hard to decide whether, if their workplace was a large complex of buildings spread over, for example, several square miles, that should still be considered a "local" network. It was decided that defining "local network" as being confined to one building would make it easier to interpret responses.

Several problems were also revealed in analyzing data from the "Network Applications" matrix. The applications listed were in most cases too broad to give an indication of specific uses of the generic application. If these generic terms were used in the national mail survey, some responses would yield results more relevant to describing system use than to suggesting peoples' use of networks in performing particular work tasks and communication activities. "Information or data retrieval" for example, included online library catalog use, searching online internal phone listings, accessing software libraries or databases of aerodynamic equations, retrieving either empirical or administrative data for analysis, etc.

Another problem with these generic application terms was that respondents did not always associate their specific uses with the broader "jargony" phrases. For example, one manager used the corporate network to access the company's central payroll system in another part of the country, but did not check either "remote log-in" or "information or data retrieval" (or any other of the listed applications) to indicate this use.

In general, interview subjects seemed comfortable with the matrix format. They did not complain that it was too difficult to understand or too complex to complete and their explanations of their responses seemed to indicate that they had indeed filled out the charts correctly. Only a few problems were noticed. One respondent, for example, skipped the entire chart, except for the row associated with the one application used, even though the instructions indicated that the entire chart should be completed, even for applications not currently used. This suggested on the one hand that the instructions should be altered to emphasize that the entire chart should be completed and, on the other hand, that more effort should be made to make the entire chart relevant to both users and nonusers and to remove columns that were redundant.

The second research question asks: *What work tasks and communication activities do aerospace engineers use networks to support?* Interview respondents were asked to identify the work tasks and communication activities they performed and the degree to which networks were used to perform each task (see Job Tasks and Activities Worksheet in Appendix A). The contribution of the interviews to this research question was to capture a more extensive list of user-based terms for work tasks and communication activities than was possible in the initial site visits/interviews. These user-based descriptions were used to help assure that the subsequent mail survey asked about work tasks that were appropriate to aerospace engineers, and that were phrased using their own terminology.

As noted above, about 160 separate work tasks and 120 separate interpersonal communication activities were elicited from interview respondents. When asked what they did all day, interview subjects said, for example, that they: conduct research, design signal processing algorithms, write project reports, analyze experimental data, track down citations and read research papers, review field support reports, write specs, make ground rules for bidding on new projects, smile and coerce, assign work, solve shop floor producability problems, attend meetings, tell mechanical engineers where to place components so that the design is good electronically as well as mechanically, communicate with customers, and play high-level "bad cop" with vendors and suppliers.

After comparison with the literature, the tasks and activities elicited in the interviews were collapsed into 21 pre-coded response categories for the mail survey pretest instrument. These categories represented work and communication activities that encompassed the most common technical and non-technical tasks performed by people in the aerospace industry. An attempt was also made to select the most important tasks, i.e., those more relevant to improved productivity and product quality. Reviewing the literature informed the selection in that some tasks, such as negotiation, are held to be less suitable for electronic communication channels; selecting that task for this study allows the finding from the literature to be tested. A final consideration in selecting representative tasks was their level of specificity. Tasks that were too specific were not included (e.g., "assure that post-shipping support was offered for installation"). Other specific tasks were represented by a more general phrase (e.g., "run wind tunnel experiment" was represented by the more general "conduct experiment or run test"). Tasks that were too general (e.g., "management") to elicit reliable answers were replaced by tasks whose meanings were more specific (e.g., "coordinate work").

The third research question asks: *What work-related factors are associated with the use of computer networks by aerospace engineers?* A number of the instruments completed by interview participants produced results relevant to this research question. First, the Interview Questionnaire elicited characterizations of work that might be associated with extent or nature of network use. The questionnaire asked interviewees to report their job title and identify the:

- Job category best representing their primary work activity (engineer, scientist, manager, technician);
- Type of organization where they worked (industrial/business, government, academic, not-for-profit);
- The work of their organizational unit (basic research, applied research, development, engineering, manufacturing/production, etc.);
- Principal aerospace subfield to which their work belonged (propulsion, structures, aerodynamics, etc.).

The Interview Questionnaires tested the clarity of these questions and the adequacy of the proposed pre-coded response categories. Even these relatively straightforward descriptions of work were not consistently interpreted and easily answered by all interview subjects, although job category, type of organization, and aerospace subfield caused few difficulties. For example, there was no direct mapping between official job titles and perceived job function; respondents seemed to feel that the precoded job category responses were more adequate as descriptions of their primary job function. For example, some people whose title was "Scientist" or "Manager" said they were really engineers, while some people whose title was "Engineer" said they functioned primarily as managers. Respondents' comments about these questions led to several changes in their format for the mail survey pretest instrument.

The interviews were also used to identify other aspects of work that might be related to network use. As noted earlier, subjects were asked to characterize the nature of their work and their organization. They also explicitly suggested factors related to network use in discussing their work and communication activities (in connection with the Job Tasks and Activities Worksheet) and in the open-ended questions on individual and organizational factors associated with networking (on the Open-Ended Interview Questions Instrument). Actual responses suggesting factors that encourage network use included: " I use networks because my work depends on information put together by other people," "I have the network connection right on my desktop machine," "everyone else uses it," and "I need immediate access to others and shared data." Interview responses that suggest, on the other hand, factors that discourage network use include: "some partners are infrequent users," "too much junk mail," "can't browse messages," and "too difficult to keep learning new applications."

Situational and other factors affecting network use were also identified in the Message Analysis Worksheet (see Appendix A) by asking respondents to describe individual communication incidents and then report the substance of the message communicated, which communication channel was used in each incident, and why that particular channel was chosen in that situation. Reasons for network use mentioned in the site visits/interviews included: "knew partner used e-mail," "message was trivial," "partner hard to get on the phone," "I didn't need an immediate answer," "message was brief," "that channel was most efficient," and " I wanted to leave a record of the fact that I'd contacted him." Factors related to the choice of a non-network channel were also mentioned: "if message were written and worded wrong, it could damage our purpose, which was to appear focused and responsive," "communication occurred totally spontaneously, it was just happenstance," "problem was complex," "knew there would be a subsequent question that required my answer," "I was asking him to do something for me, so wanted it to be a more personal request," and "wanted to encourage group feeling."

Thus, in both describing their use of networks to perform work tasks and discussing their general perceptions, subjects identified a wide variety of work-related factors that they felt either encouraged or discouraged network use. Some of these factors coincide with those consistently reported in the literature for all kinds of jobs, e.g., "personal preference for a particular channel," while others offer more unique insights into the fit between the capabilities and functions of electronic networks and the nature of engineering work, knowledge, and communication. As with the user-generated lists of work tasks, it was difficult to distill the resulting extensive list of factors potentially related to network use down to a manageable number of items for the mail survey. The criteria used to accomplish this were the same as those described above in connection with the list of work tasks that was elicited. Factors selected were those which, in the researcher's judgment, would result in a set of representative, varied, important, and theoretically meaningful items.

Because these interview results also contribute directly to answering the study's research question on factors associated with network use and to interpreting the mail survey responses to closed-ended questions, they will be discussed more fully, where appropriate, in the report of this study's results in Chapter 4.

The fourth research question asks: *What is the impact of network use on aerospace engineering work and communication?* The interviews contributed to this research question in several ways. Subjects' responses to open-ended questions about perceived outcomes of network use suggested impacts to be tested in the mail survey by posing structured questions with pre-coded response categories. Comments made by interviewees related to networking impacts included:

- Allows ideas, problems to be expressed at point of need;
- Time to market is cut, because the number of changes required is cut;
- Enhances ability of organization to function as a unit;
- Distributes available expertise to all employees;
- Makes me feel more empowered; gives me a greater sense of ownership, commitment, team spirit;
- Allows us to document, evaluate, improve our work processes;
- Downtime can be catastrophic;
- Provides access to lots of tools not available otherwise;
- Sharing information and expertise can result in fewer glitches at the end of a project; and can help us stop re-inventing the wheel;
- E-mail, bulletin boards have great utility because you can go both wide and deep in information searching;

- E-mail makes my communication more impersonal; I send a message (one-way communication) when I should go down and interact face-to-face; and
- Coordinating engineering and administrative systems yields NEW information.

Interestingly, respondents identified only a very few negative impacts from networking, even when probed on this point. Even problems commonly cited in the literature, such as information overload or security risks, did not seem to trouble many interviewees.

A number of the suggested impacts, such as "provides access to lots of tools not available otherwise," are generic in the sense that they may be felt as well by other types of users beyond those in an engineering community. Others suggest ways in which the capabilities of electronic networks are especially well- or ill-suited to the work tasks of engineers and to the way that knowledge is created, transferred, and used in engineering communities. Once again, it was difficult to select from the large number of impacts suggested in the interviews and integrate responses into a manageable and useful set of questionnaire items.

Interview reports of general perceived use of networks in connection with certain tasks and communication--such as accessing remote information or sending simple messages to busy colleagues--were also relevant to this research question. They suggested relationships to be further explored in the mail survey, i.e., how networks are being used most heavily. As with respondents' descriptions of factors related to network use, their extended comments about impact also provides data to answer this research question directly.

To summarize the application of the interview results, they served to improve both the theoretical and practical development of the written mail survey. The interviews greatly increased the researcher's familiarity with the context and conduct of engineering work, communication, and electronic network use in a variety of aerospace settings. This increased understanding improved the development of the planned mail survey, such as by suggesting relationships among network use, work activities, and work factors that are meaningful to aerospace engineers and could be explored in the survey. It also improved the clarity of questions posed in the survey and helped ensure that pre-coded response categories were adequately representative of the community and phenomena being studied.

3.3.5. National Mail Survey

3.3.5.1. National Mail Survey Objectives

This study culminated in a mail survey that provides descriptive data about the current extent of network use by aerospace engineers in the United States. The data can also be used to explore relationships between electronic network use and aerospace engineering work and communication. The data gathered in the mail survey were used to answer the study's four research questions. Nonetheless, the interpretation of the questionnaire data was assisted by comparing them to, or reviewing them in the context of, data obtained in the study's primary interviews and telephone survey.

3.3.5.2. National Mail Survey Questionnaire Development

The final version of survey instrument developed for this study consisted of 27 closed-ended questions, six open-ended questions, and five matrices. The matrices ranged in size from five rows by three columns (where each column required a selection from among several pre-coded response categories) to 30 rows by three columns. Most survey questions were very closely based on questions used in this study's earlier data collection activities. After several general questions on network use and overall perceived impact, the questionnaire was divided into sections under the headings: "Computer Network Availability, Value, and Use," "Work Resources in Aerospace," "Network Applications in Aerospace," "Aerospace Tasks and Activities," "Nature of Your Work Environment," "Impact of Computer Networks," "Important Background Information," and "Concluding the Survey." Questions used nominal, ordinal, or ratio scales for recording responses. To answer the closed-ended questions, respondents circled the number of a pre-coded response, filled in a blank line with a number or a response code, or placed a check mark in a matrix cell. The pretest version of the questionnaire is reproduced in Appendix B. The final ten-page survey booklet, and the cover letter that accompanied it, are reproduced in Appendix C.

The format and content of several survey questions were adapted from those developed by other researchers in earlier studies. For example, the question "Overall, how would you describe your current reaction to computer networks?" and its set of pre-coded responses were adapted from a question used by Hiltz (1984) in her study of communications system use by researchers and, subsequently, by Bizot, Smith, and Hill (1991) in their study of the use of electronic mail in an R&D organization. Bizot and her colleagues included a series of questions that listed effects of network use (e.g., "Professional/technical employees can use PROFS to do tasks traditionally assigned to clerical/secretarial personnel" (p. 91)) and then asked respondents to supply Likert scale responses indicating both the extent to which the stated effect occurred in their organization and the degree to which they felt that the occurrence represented a major problem or benefit. A similar set of questions was developed to assess network impacts for the current study, although the content of the questions was derived from data collected earlier in the study and a matrix format was used to collect these data from respondents.

Feldman's study of electronic mail and weak ties in organizations (1987) incorporated several questions about the spatial and organizational position of electronic communication partners. Ordinal scales were used to describe spatial and organizational spans. Similar questions were used in this study's mail questionnaire to explore differences among communication channels used by respondents and the geographic and organizational range that the different channels typically spanned. The use of an ordinal scale for indicating agreement or disagreement with a given statement is a common question format for written surveys. It was used, for example, by Rosenbloom and Wolek (1970) in their study of information transfer in industrial organizations, to collect data on respondents' attitudes about various aspects of technical communication. It was used by Allen (1984)--as it was in this questionnaire--to collect data not on attitudes, but on the nature of researchers' work .

The matrix format had been used previously by the researcher (McClure, et al. 1991), but it has also been employed in other surveys of technical communication and computer use. This question format was a primary feature of Murotake's (1990) study of the relationship between engineers' use of computer tools and project performance. Murotake's matrix contained a row for each type of engineering task. Columns were filled in with the number of hours spent on the task, the number of hours working on the task that were spent using computers, codes indicating the type of hardware and software used in the task, and codes representing the respondent's rating of the computer tools used in terms of their effect on job productivity and quality of work. Murotake asserted that this matrix, while complex, did not seem as difficult for engineers to complete as he had feared; he concluded that the matrix format was well-suited to the typical engineer's cognitive abilities.

Shuchman (1981) used a matrix to collect data from engineers about their assessment of different kinds of technological innovations for communication. Each new tool (e.g., video phone, teleconferencing) was listed as a row of the matrix; columns indicating that each tool was "available," "used," or "unavailable but would be useful" produced matrix cells that were filled in with check marks by respondents. In a study of factors related to the use of technical information in engineering problem solving, Kaufman (1983) asked respondents to complete a complex matrix in which, for each of twenty-two information sources listed, they supplied codes for how that resource was found, when it was found, why it was used, how it was used, how effective it was, and how efficient it was.

Although it was easy to incorporate the format of Interview Questionnaire items (used in this study's site visits/interviews) on the use of networks and network applications and on background information about individual and job characteristics, other major areas of the study's inquiry that were investigated in the site visits/interviews required a complete revision of question format to accommodate the constraints of a written, self-administered mail questionnaire. In the site visits/interviews, for example, respondents completed the Job Tasks and Activities Worksheet and the Message Analysis Worksheet to describe their work tasks and communication activities, resources used in their work, the extent to which networks were used in accomplishing these tasks and accessing these resources, and reasons for using particular communication channels in particular situations. These data were collected in the mail survey as well (*Note: question numbers provided throughout this section correspond to the numbering of the final survey instrument, reproduced in Appendix* C). First, a matrix (q6) collected data on the extent to which networks were used to access people and information resources used in one's work. Second, a set of questions (q.8-q.15) related to a "critical incident" selected by the respondent was incorporated in the questionnaire. The mail survey used the critical incident technique (as recommended by, e.g., Flanagan, 1954, and Lancaster, 1978) to improve the validity of survey answers by helping respondents focus and report on a specific, recent, and important work situation. The critical incident technique has been employed successfully in a number of studies of engineering communication (e.g., Kremer, 1980; Pinelli, 1991b; Rosenbloom & Wolek, 1970). In the mail survey questionnaire, respondents were asked first to select, from a list of 22 pre-coded responses, the "one most important work task" they performed during the last work week. After completing an open-ended question describing the task (q.9), respondents reported in closed-ended questions the number of other people involved in the task (q.10), the geographic (q.11) and organizational (q.12) spans of the task; whether they encountered any new resources while completing the task (q.13); which were the primary and secondary communication channels used to accomplish the task (q.14); and what their main reason was for choosing the primary channel used (q15).

In addition, some of the situationally-derived responses on reasons for the use of a particular communication channel (e.g., 'I needed to go to his office because we had to have all the drawings, parts, and contracts in front of us while we figured out what to do') that were reported in the interviews were phrased as general statements in a matrix on the mail survey (q.20), to which respondents either agreed or disagreed. This question asked respondents to report on other aspects of their work environment as well, such as:

- Work characteristics (e.g., routineness, proprietary nature);
- Organization characteristics (e.g., nature of organizational culture, degree of organizational support for networking);
- Individual characteristics (e.g., awareness of networked resources, lack of familiarity with computers); and
- Technology characteristics (e.g., unreliable transmission, incompatible systems).

One basic change, then, was the shift from a focus on specific messages (in the interviews) to a focus on specific work tasks and communication activities (in the mail survey). The shift makes this area of data collection in the mail survey more germane to the study's research questions. The message focus is biased towards individual, interpersonal communication exchanges, whereas the study aims to look more broadly at the use of various channels to link to people, tools, and information resources. Further, mail survey respondents may have found questions about specific messages too personal or too difficult to answer adequately in writing; these difficulties were mitigated in face-to-face interaction with interviewees, but would have been more difficult to overcome in a written questionnaire.

Data on network impacts were also obtained by the mail survey in a slightly different manner from that used in the site visits/interviews. As in the interviews, respondents were asked an open-ended question on perceived impacts from network use. But, in addition, they completed a matrix (q.21) which required that they provide pre-coded responses to questions about perceived impacts of networks on them as individuals and on their organizations. Respondents also provided Likert scale-type ratings of the perceived value of particular network types (q5) and applications (q.7), as well as of networked access to work resources (q6), in the matrices devoted to these topics.

Table 3-9 summarizes the data that the mail questionnaire was designed to collect. As intended, the format and content derived mainly from the study's earlier data collection activities. The mail survey incorporated lessons learned in the site visits/interviews and the national telephone survey, although the literature was also useful in devising questionnaire items. Response categories and question wording were developed primarily from responses obtained earlier and thus were more user-oriented and more meaningful within the context of aerospace engineering work than would have been possible without the preliminary data collection activities. Some format changes were necessitated in adapting interview instruments to the self-administered questionnaire developed for the national mail survey. The initial version of the mail survey questionnaire was pretested and a number of changes were incorporated in the final version of the questionnaire booklet. The procedures and results of the pretest are described below; this chapter ends with a description of the framework for analyzing this study's results, including a discussion of how the data obtained were used to answer the study's research questions.

3.3.5.3. National Mail Survey Questionnaire Pretest

3.3.5.3.1. Objectives and Procedures

The goal of the pretest for this study's mail survey was to test and refine the questionnaire instrument, as needed, based on three types of input: (1) comments from expert researchers; (2) comments from respondents who had participated in the study's earlier preliminary data collection activities; and (3) responses from new respondents. The pretest instrument was developed between June and October 1992. It was mailed to the three types of pretest participants, along with a cover letter, during the last two weeks of October.

Table 3-9.
Summary of Data Collected by the Mail Questionnaire

Demographic Information

- *Age*
- *Gender*
- *Highest degree obtained*
- *Years of professional aerospace work experience*
- *Industry sector* (e.g., industry/manufacturing, government, academic)
- *Size of parent organization, division, worksite, department*

Work/Communication Information

- *Current job title*
- *Primary job category*
  (e.g., engineer, manager)
- *Branch of aerospace*
  (e.g., aerodynamics, structures, propulsion)
- *Primary job function*
  (e.g., administration, research, service/maintenance)
- *Degree of work computerization*
  (percent of work week spent at computer; development of computer systems, components, software, or data as primary work feature; etc.)
- *Perceived characteristics of work*
  (e.g., task interdependence, proprietary nature of work)
- *Perceived organizational climate regarding network use*
  (e.g., extent of support, reward for networking)
- *Work resources used*
  (e.g., colleagues, journals)
- *Most important work task/communication activity performed*
  --Number of people involved in task
  --Geographic and organizational span of task
  --Discovery of new resources in performing task
  --Two most important communication channels in performing task
  --Reason for choosing channel in performing task

Table 3-9 (Cont'd).
Summary of Data Collected by the Mail Questionnaire

Descriptions of Network Use Behavior and Perceptions

- *Degree of computer network use*

  (e.g., whether used personally, through intermediary, or not at all; percent of work week spent using computer networks; perceived extent of networking at the workplace)

- *Types of networks available and used*

  (i.e., LAN, organizational, research, or commercial)

  --Location of their use

- *Network applications used*

  (precoded use category responses related to, e.g., electronic mail, electronic data interchange, file transfer)

- *Use of networks to access work resources*

  (precoded use category responses related to, e.g., technical reports, external vendors)

- *Perceived barriers to network use*

  (in open-ended question)

- *Perceived factors affecting network use*

  (in open-ended question and precoded responses related to work and networking environment)

- *Perceived impact of electronic networks*

  (on work, organization, quality of work life, career--in open-ended question and precoded responses related to positive and negative networking impacts; precoded assessment responses related to the value of networks, networked applications, networked access to work resources)

Five experts (Ronald E. Rice and Paul Kantor of Rutgers University, Elliot Siegel of the National Library of Medicine, Bradford Hesse of the American Institutes for Research, and Lee Sproull of Boston University) reviewed the pretest questionnaire. The review of research instruments by experts in the field has been found to be an important technique for improving research quality; experts offer suggestions for improvement that often differ from and prove more useful than those derived from the analysis of standard pretest results (Presser & Blair, 1994, in press). Each of the experts consulted in this study had experience in survey development and had conducted investigations involving people doing scientific and technical work. Four of the five have completed investigations of some aspect of computer networking. They were sought out for their unique combination of methodological and subject expertise; since this is a relatively new area of research, there are relatively few relevant models for questionnaires. These pretest respondents were expected to offer advice for improving the technical quality of the questionnaire and to provide feedback regarding the importance of the questions asked. One of the expert reviewers responded with only a general and brief e-mail message. The other four expert reviewers made comments on their copies of the questionnaire and returned them to the researcher. Three of the four also participated in subsequent discussions: one in person, one over the telephone, and one with e-mail.

The pretest questionnaire and cover letter were also sent to eight subjects who had participated in earlier phases of this investigation. The eight were selected because they represented a cross-section of ages, gender, job types, and settings. Previous participants were used because it was assumed that their previous participation indicated an existing commitment, i.e., they could be counted on to engage seriously in the pretest as well as to offer their assessment of how their peers would react to receiving such a survey. Their input on whether the questionnaire seemed a faithful and valuable follow-up to the earlier interviews in which they participated was also sought. These respondents were asked to complete (annotating it with any comments as they went along) and return the pretest questionnaire, and to participate in follow-up telephone interviews of about 20-30 minutes to discuss their responses. Six of those contacted completed this set of pretest activities.

Finally, the pretest questionnaire and cover letter were sent to ten new subjects, individuals selected randomly from the second sample pulled (in June 1992) from the SAE database of subscribers to *Aerospace Engineering*. The responses from this pretest group were used to predict the mail survey response rate, test SAE database accuracy, and assess the degree to which the pretest instrument generated complete and accurate responses. Four completed surveys were received, and a second survey was mailed to nonrespondents; two completed surveys were subsequently received and one was returned due to an insufficient address. Thus, six completed surveys were received from this pretest group. Follow-up telephone calls to the three nonrespondents revealed that one subject was no longer with the company to which the survey was sent, one said that he had filled out the survey on second mailing and returned it (although it was not subsequently received by the researcher), and the third said he had passed the survey on to someone else in the firm who was more familiar with networks (who apparently did not complete and return the questionnaire).

3.3.5.3.2. Use of Pretest Results

One reason for conducting the pretest was to get an idea of the expected response rate from the new SAE sample drawn in June 1992 and to try to gauge potential reasons for nonresponse, in order to adjust sampling procedures, if necessary. Forty percent of the ten new subjects who received the pretest survey and cover letter returned completed surveys after one mailing and another 20% after the second mailing, resulting in a final response rate of 60%. Half of the reasons for nonresponse were, in fact, due to problems with the currency or accuracy of the SAE database. In addition, one of the completions was from a retired person, whose survey was thus of less than optimal validity (i.e., the survey was answered by reporting on the latest employment situation).

Given the apparent problems with the currency of information in the sample database (drawn in June 1992), it was decided to draw a new stratified random sample from the SAE database (see Section 3.2.4 above). Hoping for about 800 to 1000 completions and assuming from the evidence of the pretest mailing to new subjects that the mail survey would achieve about a 50% response rate (since about 10% of those receiving the survey might be retired and, thus, might not complete the survey or might return surveys of questionable validity), it was decided to send the survey to 2000 people in the SAE database. As discussed above in Section 3.2.4 on research design and sample selection, 800 to 1000 returns were desired because that would represent about the maximum number that study resources could support. It would also provide a sufficient number of returns for exploratory study; even a data subgrouping of 5% would yield 40 responses to analyze.

Pretest participants made several useful comments about the survey's cover letter, most of which dealt with emphasizing to respondents the ultimate utility of their efforts (see Appendix B for a copy of the pretest cover letter and questionnaire). One previous subject remarked that emphasizing that the data would really be used would encourage her to complete the survey. One of the expert reviewers called the cover letter "informative and persuasive," but another was left wondering *who* would use study results. Another expert reviewer noted that the phrase "not used for commercial purposes" was vague (i.e., if results of the survey were published, commercial network services could use the results to improve their offerings, which would be good--so it would be more precise to say that individual responses would not be reported). One expert reviewer also suggested that the cover letter was too long. As a result of these comments, the cover letter was shortened, the utility of the results was retained as a key theme, and the phrases identified as ambiguous were clarified. The final version of the mail questionnaire was also accompanied by a cover letter from Thomas E. Pinelli, Assistant to the Chief, Research Information and Applications Division, NASA (see Appendix C). This letter highlighted the importance of the survey to NASA and suggested how the survey results would be used by NASA to formulate more effective policies and procedures.

Results from all three pretest groups were reviewed to assess respondents' overall reactions to questionnaire length, difficulty, content, and format. Considered in this assessment were both explicit comments from respondents as well as the general level of completeness and correctness of the completed questionnaires. General comments received from the expert reviewers were that the "questionnaire looks good, but awfully long," that the survey was "well-constructed" and the matrix style charts were "a nice way of getting a lot of information expeditiously."

Most previous respondents said it took them about 25 minutes to complete the survey. They acknowledged that the survey was on the long side, but the consensus seemed to be that the length was still within reason. A number of specific comments about question format were made, several of which were related to the matrix-style charts. One previous respondent said the questionnaire was "very clear ... didn't look too complex; engineers see lots of charts; it's not too technical." Another remarked that it was "easy to understand ... didn't have to rack brains to supply answers ... had information right at my fingertips..." and implied that, in general, the closed-ended and pre-coded response formats of most of the survey's questions were good because respondents "didn't want to write essays." On the other hand, a number of the respondents remarked that they wanted a few more "other" responses and open-ended questions to be included, especially in the realms of factors and impacts. Such questions were subsequently added to the final version of the questionnaire. One respondent said the matrix charts got "tedious," but that it was not hard to understand how to complete them.

The survey was basically filled in completely and correctly by all six previous respondents. Responses within and among matrices seemed consistent. In the matrices on network use, work resources, and network applications, however, three of the respondents skipped the subsequent columns on extent of use and value in at least one of these charts, when the initial column on basic availability was answered in the negative. In spite of the instructions to the contrary, in other words, respondents did not complete subsequent columns perceived by them as redundant or irrelevant.

The survey was generally answered completely and correctly by all six new subjects as well, leading to the conclusion that the questionnaire length should be trimmed slightly, if possible, but that no radical cuts were needed. No respondent used the concluding open-ended question (q.28) to complain about the survey length or complexity. One respondent, however, noted the number of unfamiliar terms without definitions and, in fact, supplied a definition of "computers" in q.2a. Only one respondent skipped a question (q8 asking "Approximately how many people were directly involved in performing this task with you?"), perhaps because the answer was not known. The most significant problem identified was in the matrices on network use, work resources, and network applications. As with the group of previous respondents, this group also did not complete subsequent matrix columns perceived as unnecessary, given their response in the first column. The solution devised for this problem was to collapse redundant columns and reword and reformat instructions regarding completion of the matrices, to make them clearer.

Several pretest participants commented on the overall importance and interest of the survey questions. One of the expert reviewers said that study lacked obvious theory and hypotheses to be tested, but another noted that the breadth and depth of the data collected was "a nice contribution of the research." Among the previous subjects, the general reaction was positive, with respondents remarking that the questionnaire did not get too boring. One person, for example, said the survey provoked interesting questions in the respondent's mind and that the survey would "root out" answers to the "right questions" about networking in aerospace. Another said that the survey was comprehensive and the questions were penetrating and practical; he especially liked the user orientation. Finally, he noted the timeliness of the study with the current emphasis in the federal government on NREN. One problem was noted by a university professor who did not use networks. He said--quite accurately--that the survey seemed more geared to current network users and to people in industry. He could still complete all the questions, but felt they were less relevant to his situation. Several previous respondents remarked that the questionnaire seemed to capture the breadth of discussion and the important issues and topics that have been raised in the preliminary interviews. One noted that he did not feel "led" by the questions or response categories.

Moderate interest in the nature of the study was shown by the new subjects in that half of the respondents said they would like to receive a summary of study results. The 60% response rate may also be interpreted as a positive indication of overall interest. One third of the new subjects said they would be willing to participate in follow-up research. One respondent indicated that the topic of networking in aerospace was important, reporting in q.26 that "In my view, a technologically current network with widely available data/information would greatly facilitate our work by improving quality, timeliness, and accuracy."

A number of revisions to format and wording of specific questions, precoded response items, and instructions were also made as a result of the pretest. Conversations with previous subjects made it possible to check on issues of reliability and validity by asking them to provide definitions or interpretations of particular questions, where it seemed the meaning of the questions might be ambiguous. Expert reviewers also made comments on the format and content of specific questions. Finally, one expert reviewer made several useful recommendations concerning the analysis of the survey questions on factors and impacts. He suggested that "data snooping" and "meaningless correlations" might be avoided in several ways:

- Use Chi-squares, contingency tables, or calculate correlation coefficients.
- Come up with a priori hypotheses, even if informal (asking what relationships the literature and this study's preliminary data collection activities would lead one to expect lets the researcher identify "weird" results and ponder them in a more informed way).

- If strict hypothesis testing is not appropriate to the study, set some predetermined limit on what would be accepted as a "significant" result, e.g., only considering it a probable impact if at least 50% of respondents say that impact occurs.

- Group like responses (e.g., "shortens product development time" and "decreases turnaround time...") in the analysis to increase the probability of obtaining real differences, that could then be subjected to informal hypothesis testing.

These suggested were followed, in a general fashion, in summarizing and presenting the results from the mail survey: chi-squares are calculated to test the significance of relationships described in contingency tables; informal hypotheses suggested by the literature (such as that internal communication is more important than external communication for engineers) are tested against survey data and unexpected results are identified and discussed; limits on assumed significance can be assigned by the reader and are, in some cases, used as a basis of reporting survey results; and similar factors (e.g., those related to training) and impacts (e.g., those related to work efficiency) are discussed in tandem.

3.3.5.4. National Mail Survey Administration, Response Rate, and Data Processing

This section describes the procedures used for administering the national mail survey and for coding and entering the resulting data into a computer file for subsequent analysis. To begin with, the subset of the database of subscribers to *Aerospace Engineering* that SAE provided for the survey's sample (see 3.2.4 above for a description of the sample selection) was imported into a Paradox database at the Center for Survey Research (CSR). Each respondent was assigned a unique identification number used throughout the survey process. An initial inspection and clean-up of the database was done; missing data on respondents, such as zip codes or incomplete addresses, were searched in an appropriate source.

On February 15, 1993 the survey was sent to the 2000 subscribers represented in the sample. The first mailing included: (1) the 10-page questionnaire booklet; (2) a cover letter describing the study and the use of its results that was signed by the researcher and printed on University of Illinois, Graduate School of Library and Information Science letterhead; (3) a cover letter printed on NASA letterhead describing the importance of the survey to NASA that was signed by Thomas E. Pinelli, the Assistant to the Chief, Research Information and Applications Division of NASA; and (4) a postage paid return envelope. Packets were resent if they were returned by the U.S. Postal Service with a corrected address. A copy of the questionnaire booklet and the two cover letters are included in Appendix C. At the end of February 1993, a postcard was sent reminding respondents to return their questionnaires and thanking those who had already done so. The survey was resent to the remaining 1214 nonrespondents on April 21, 1993. The follow-up packets contained the same basic elements as those in the first mailing.

The CSR received a total of 950 usable questionnaires by the cutoff date of July 15, 1993. The figures in Table 3-10 describe the final disposition of the survey. These figures amount to an unadjusted response rate of 47.5%. As cited in Pinelli (1991b, p. 173), Babbie (1973) comments that a response rate of 50% is adequate for reporting and analysis, while 60% is good and 70% is very good. According to Pinelli (1991b, p. 184-185), it is customary to delete individuals from the sample for reasons such as retirement, illness, death, wrong addresses, or those who indicated that the survey was totally inappropriate for their present duties. Doing so in this survey (i.e., removing those cases enumerated above), produces an adjusted N of 1852. Given the number of questionnaires returned, this results in an adjusted response rate of 51.3%. The response rate was presumably affected by the length and difficulty of the survey, along with the fact that intended respondents were not very specifically targeted, i.e., respondents were selected solely on the basis of belonging to the aerospace industry.

Some comparisons between survey respondents and nonrespondents can be made in order to judge whether respondents are indeed representative of the larger sample frame (see Table 3-11), although, unfortunately, little data on the characteristics of the individuals in the sample frame were readily available to the researcher. The records sent to the CSR for each individual included only their names and addresses. The SAE subscriber database does

Table 3-10.
Disposition of Mail Survey Responses

Number of Cases	Disposition
950	Usable returns
17	No address/incorrect address
7	Deceased
1	Too sick to complete
36	Retired -- survey not completed
18	Refusal
3	Out of the country
66	Questionnaire not applicable (e.g., recipient not in aerospace)

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categorize subscribers by job and industry type (and a stratified sample was pulled according to these categories), but survey questions on similar characteristics were not worded exactly the same way, so exact comparisons between respondents and the larger sample are not possible. In the figures presented in Table 3-11, the sample characteristics are labeled "approximate," because they are based on the researcher's request that the sample of 3750 drawn by SAE contain certain percentages in each category. From the sample that SAE subsequently sent to the CSR, 2000 subjects were randomly selected. In Table 3-11, the job categories used in the survey itself appear in parentheses, where they are significantly different from those terms used in the SAE database. Only data from comparable categories are presented.

According to the data in Table 3-11, it appears that survey respondents are quite similar to the sample as a whole, suggesting that, for certain dimensions important to the study, there is little difference between respondents and nonrespondents. Although it would

Table 3-11.
Comparison of Selected Mail Survey Respondent and Sample Characteristics

	Approximate % in Sample	% of Survey Respondents
Industry Sector		
Industry	60	54
Government	30	30
Academia/Non-profit	10	8
Job Category*		
Corporate/Engineering Management *(Administration)*	30	10
R&D	15	26
Engineering/Design	15	23
Manufacturing and Production *(Manufacturing Engineering; Quality Control; Production)*	15	13
Purchasing and Marketing *(Sales and Marketing)*	13	5

* The job categories used in the mail survey appear in parentheses, where they are significantly different from the terms used in the SAE database.

appear from the table that managers were more likely to be nonrespondents, another survey question asked respondents to characterize themselves as either engineers, managers, or scientists. For this question, 39% of respondents selected the term "manager."

It can probably be assumed that survey nonresponse is biased towards those people who do not use networks; such people would have less inclination to complete a long questionnaire on the topic of networking. Apparently, however, this nonresponse bias is minimal. In the earlier SAE telephone survey (where respondents were not self-selected based on their use or nonuse of networks), 76% of respondents stated that they used networks. In the mail survey (which was conducted about 18 months later), 85% of respondents claimed to be network users.

A complete record was kept at CSR of all questionnaires returned. CSR staff reviewed all questionnaires to assure their acceptability for processing; notations or corrections that might be required before processing were added. Once approved for processing, data were coded and entered by CSR staff according to previously specified procedures. The researcher received an initial codebook from CSR on May 19, 1993, based on the input of 102 randomly selected surveys. Data were entered using the Computer-Assisted Survey Execution System (CASES). The researcher then reviewed the codebook, getting clarification where needed, and eventually directed several revisions of the coding procedures. The researcher spent several days at the CSR at the beginning of June 1993 in order to work out the final procedures for data coding and entry. While there, the researcher carefully examined a number of the completed surveys to assess the quality of the responses and to see whether the proposed coding procedures would, in fact, allow the planned analyses to be performed. After directing the final revision of coding procedures, the researcher coded about 20 surveys according to the final coding scheme in order to gain personal experience with this aspect of the analysis.

The researcher also examined the coding that had been done already by CSR staff in order to check its overall accuracy. In fact, it was surprisingly easy to implement the final coding scheme and enter data, especially compared to how difficult it had been to develop the coding procedures themselves. While at CSR, the researcher also oversaw creation of a test dataset of 144 completed surveys. The test dataset was created in order to ascertain whether the analyses proposed for the questionnaire (see below) could actually be performed, given the agreed-upon coding and entry procedures. This cautionary step was deemed necessary because of the complexity of the survey data. The 102 surveys that had already been used to produce the preliminary codebook were recoded and re-entered, where necessary, and 42 additional surveys were coded and entered.

Working with CSR staff, the researcher attempted to use the CASES software to perform a number of the intended analyses for this study. While this exercise did not reveal any coding problems, it did lead to the realization that the intended analyses were beyond the capabilities of CASES. Thus, it was decided that survey data would have to be transferred to SPSS, a statistical analysis software package, for complete analysis. Once it was determined, through manipulation of the test dataset with SPSS, that all data processing procedures were adequate for the intended use of the data, all remaining questionnaires were coded and input at the CSR, and the final codebook was produced. Represented in the codebook are the survey's 319 variables.

3.4. Analysis Framework

This research represents an exploratory and descriptive study of network use in the aerospace industry. The types of data obtained in the study's various data collection activities include: demographic (individual and institutional), attitudinal and perceptual, and self-reports of behavior (e.g., work, communication, and networking activities). Quantitative data analysis techniques were used to produce descriptive summaries of: demographic data, data related to network use, precoded attitudinal and perceptual data related to network impacts and factors affecting network use, and precoded reports of work and communication characteristics and behavior. Content analysis techniques were applied to the study's qualitative data.

For quantitative data analysis, several simple statistical techniques were applied, using SPSS, to identify and analyze relevant trends and relationships in the mail survey data, for example, to compare network users and nonusers on particular characteristics and to explore the possible influence of particular work-related factors on network use. Only nonparametric tests, appropriate and useful in analyzing nominal and ordinal level data such as that generated by the mail questionnaire, were employed. The Chi-square test for independence between two variables was used in a number of instances. For example, it was used in contingency tables set up to look for a significant differences in network use, based on various respondent characteristics, such as gender. The null hypothesis in this case was that network use bears no relationship to gender. In those cases where larger contingency tables result from comparing two variables, the Chi-square test is less useful for locating specific differences. In such cases, as recommended by Roscoe (1975, p. 259), the cell frequencies themselves are examined to determine where the greatest differences between expected and actual frequencies lie.

The standard error of the difference was used to calculate the significance of differences in proportions in several analyses. For example, the percent of network users who agreed with the statement "The results of my work are integrated with the work of others" (q20) is compared to the percent of nonusers who agree, in order to determine whether highly integrated work is associated with network use, and whether that difference may be due to chance only.

Open-ended interview and survey data were summarized using content analysis, a set of procedures for organizing and analyzing useful textual information that is difficult to combine and analyze because it is diverse and unstructured (General Accounting Office, 1989, p. 6). Weber provides an alternative definition of content analysis as "a research method that uses a set of procedures to make valid inferences from text" (Weber, 1990, p. 9). These authors cite examples--such as analyzing newspaper editorials to look for trends in political opinion--where large bodies of unstructured text are analyzed to draw inferences about some population. The content analysis provides an unobtrusive measure, imposing an analysis purpose and structure on texts that were generated with some different purpose in mind. Since the goal of the analysis is to draw inferences, exact quantification and coding reliability are important, and statistical tests are often applied as the last step in the analysis.

In this study, content analysis was used to organize and summarize unstructured textual data, but it was not used to draw statistically valid inferences about the phenomena of interest. Content analysis was used to review the site visit/interview data, in order to develop user-based schemes for concepts such as network impacts, work characteristics and activities, and factors associated with network use. The specific content analysis procedures used in reviewing the interview data are described in section 3.3.4.2.3 above.

Content analysis techniques were also employed to explore and summarize the mail survey responses to q.18 ("What do you think are the biggest barriers to network use that you experience?") and q.19 ("What are the most important factors that encourage your network use or potential use?"); these two questions relate to factors associated with network use. Content analysis was also performed for the mail survey's open-ended question on network impacts: q.31 ("What do you most want to convey to network policymakers, service providers, or organizational managers about the impact of computer networks on work and communication in aerospace?"). The text being examined in this case is not completely unstructured; the pieces of text were originally generated in response to questions reflecting at least the broadest level of analysis categories, e.g., barriers to network use, and network impacts.

The intent of the analysis of these survey responses is exploratory as opposed to inferential; its purpose is to summarize and organize the open-ended responses in order to improve the validity of the study and increase its ability to discover unanticipated responses by not constraining respondents to precoded response categories for important study variables. Thus, results presented from this content analysis of responses to the survey's open questions are limited to the names of categories, the number of responses occurring in each, and an example of a response coded as belonging to that category.

The content analysis procedures used to analyze the survey data were as follows. The context unit (the material to be used in the content analysis) was survey questions 18 and 19, for factors affecting network use, and question 31, for networking impacts. The recording unit of analysis was any word or group of words (phrase, sentence) that embodied a specific perception or behavior of interest in the study. Coding categories were developed (by a coder not previously associated with the study) by reviewing all of the responses to each question in order to come up with a preliminary set of mutually exclusive categories that would exhaustively cover all responses. Each category was given a label and a description by the coder; several examples of responses falling into that category were recorded.

The researcher reviewed the content analysis scheme at that point, suggesting slight re-phrasing of category names, clearer category definitions, and some re-shuffling of the overall hierarchy of categories. Then, the coder examined and coded all responses as belonging to a particular category, with the researcher again reviewing the coding scheme that eventually resulted from this process. Responses not suited to an existing category were identified and examined to see if they suggested either a new category or a change in the definition of an existing category. The result of this iterative process was that the coder eventually classified and labelled all responses and produced a final listing of categories and their descriptions. The researcher reviewed the final output (i.e., coded items and scheme) carefully. Several categories were renamed or collapsed. Approximately ten percent of the items were recoded, based on the researcher's judgment that the coder had misapplied codes. About half of the items designated as "uncodable" by the coder were subsequently assigned codes by the researcher.

The primary ways in which the data gathered in this study were used to answer the study's research questions are outlined below. The use of specific statistical procedures is described in greater detail in the next chapter, in connection with discussion of the particular results they produced. Because the mail survey produced the study's primary data, it receives the greatest attention; Table 3-12 summarizes the relationship between each question in the mail survey and the study's four research questions.

The first research question asks: *What types of computer networks and network applications are currently used by aerospace engineers?* This research question was answered by tabulating the responses to several questions from the mail survey. First, findings reveal the percent of mail survey respondents who reported the use of computer networks generally, as well as the use of: local, organizational, research, and commercial networks; networks at work vs. at home or some other location; and various network applications (e.g., electronic mail, remote login, file transfer). The mail survey called for simple yes/no responses to questions about the use of these types of networks and for precoded reports of the frequency of the use of various network applications. Mail survey respondents were also asked to report whether the various network types and applications were, in fact, available to them. Answers to q.4 ("Do you ever use any kind of computer network in your work?") were used to divide mail survey respondents into network users and nonusers. This grouping was then used for other kinds of analyses conducted on the mail survey data, for example, to assess factors potentially related to network use by comparing various characteristics, attitudes, and behaviors of users and nonusers.

Network use questions were also asked in both the telephone survey and the primary site visits/interviews. The network use questions were included in the primary site visits/interviews to test the clarity of question wording and precoded response categories; thus, these responses were not formally analyzed. Network use questions were likewise included in the telephone survey to test the clarity of wording but served, in addition, to arrive at a

Table 3-12. Mapping Mail Survey Questions to the Study's Research Questions

SURVEY QUESTIONS	RESEARCH QUESTIONS I Network Use?	II Network Support of Work?	III Factors Related to Net Use?	IV Impacts of Network Use?	Other Background Data; Data for Future Use
Overall impact (q 1)				•	
Extent of net use at workplace (q2)	•				
Degree of computer use (q3)	•		•		
Degree of network use (q4)	•				
Matrix: availability, value, location of use of various types of networks (q5)	•			•	
Matrix: use and value of net access to human and information resources (q6)	•	•		•	
Matrix: use and value of net applications (q7)	•	•		•	
Critical incident: task performed (q8)		•			
Task description (q9)					•
No. of people involve in task (q11)			•		
Geographic span of task (q11)			•		
Organizational span of task (q12)			•		
Discovery of new resources in doing task (q13)			•		
Two channels used in performing task (q14)		•			
Main reason for channel choice (q15)				•	
Job category (q16)			•		
Aerospace branch (q17)			•		
Barriers to net use (q18)			•		
Factors encouraging net use (q19)			•		
Matrix: characteristics of work, network environment (q20)			•		
Matrix: impacts of computer networks (q21)				•	
Gender (q22)			•		
Age (q23)			•		
Highest degree obtained (q24)			•		
Years of professional aerospace work (q25)			•		
Organization type (q26)			•		
No. of employees in dept, div., org., etc. (q27)			•		
Primary job function (q28)			•		
Current job title (q29)					•
Degree of computer work (q30)			•		
Network impacts (q31)				•	
Other comments (q32)					•
Agree to partic. in further research (q33)					•

preliminary sense of the degree of network use in the aerospace community so that the size of various data groupings expected to result in the mail survey could be estimated. Frequency counts for the telephone survey responses to these questions were generated (see Table 3-6). They can be compared to the mail survey results, in order to triangulate the data.

The second research question asks: *What work tasks and communication activities do aerospace engineers use networks to support?* This research question was answered primarily by performing simple statistical analyses of descriptive data collected in the mail survey. The question was answered in gross terms by performing a cross-tabulation of network use data with precoded responses to questions on, for example, job type (e.g., engineer, scientist, manager, technician), primary job function (e.g., research, advanced or applied development,marketing), and principal aerospace subfield (e.g., propulsion, structures, aerodynamics). These gross categorizations, however, only suggest the work tasks and communication activities that might be performed within them. One might infer, in other words, from descriptions in the literature or by referring to the interview data, that engineers engaged primarily in management perform certain tasks. More specific answers to this research question were obtained by asking mail survey respondents to identify the extent to which networks were used to access various task- and communication-related work resources. In addition, the mail survey collected data from individuals on the relative use of networks (compared to other communication channels) to perform specific work tasks and communication activities, obtained by cross-tabulating each precoded task category with each precoded channel category. Reported in the findings are the percent of respondents who used each channel at all, the percent who used each channel for each task, and the percent who used network--as opposed to non-network channels--for performing a particular task.

Subjects who participated in the initial and primary site visits/interviews were asked to describe the major activities that make up their typical work week. Their responses were reviewed to generate user-based terms for work tasks and communication activities that were used as precoded response categories in the mail survey. The open-ended, anecdotal site visit/interview data on the use of electronic networks to perform work tasks and communication activities were also used to answer the second research question directly. Selected anecdotal responses are reported in the study results to complement the reported mail survey data, providing greater richness than could be achieved by the reporting of simple numeric summaries of precoded responses. Telephone survey data on the purpose of network communication (see Table 3-7) can also be used to triangulate study results related to network use and work tasks.

The third research question asks: *What work-related factors are associated with the use of computer networks by aerospace engineers?* The mail survey collected data on the use of various network types, applications and channels, as a means of answering the first research question. These data were cross-tabulated with precoded responses to mail survey items that describe individuals, their work, and their organizations (e.g., job type, branch of aerospace, organization size, geographic span of task), in order to explore possible relationships between aspects of work and network use. Correlating these responses with responses regarding network use reveals whether these characteristics are related to network use, although the survey data can not be used to establish causal relationships. Another mechanism for exploring the relationship between network use and various work-related factors involved cross-tabulating mail survey responses related to one's work and networking environment (in the q20 questionnaire matrix) with q4 responses, which distinguishes network users from nonusers. The content analysis of q18 and q19 on perceived barriers to, and factors that encourage, network use also revealed respondents' views of factors associated with network use. Finally, results related to the primary reasons that network communication channels were used, as opposed to other channels (q15), in performing a particular work task, are also reported.

The interview data were reviewed in order to both suggest which work factors to explore in the mail survey, and to determine how such questions and response categories should be worded in order to maximize clarity. Once again, selected interview data are also reported in the study's findings in order to compare and increase the richness of results related to this research question.

The fourth research question asks: *What is the impact of network use on aerospace engineering work and communication?* This question was answered by the mail survey in several ways:

- By the interpretation of the usage data collected in the survey, i.e., by reporting degree of network use, according to how many and what kinds of people use particular kinds of networks and network applications.
- From the analysis of specific work incidents by comparing different channels according to partner characteristics and communication purpose. Impact assessed would be the degree to which networks allow communication with different types or more distant people (i.e., changes in organizational communication patterns) and the degree to which networks are used to support particular work tasks. Channel substitution is suggested by comparing network users to nonusers (e.g., if nonusers mostly use print communication for administrative tasks, whereas people who do use networks use them for many administrative tasks, it may be that for administrative tasks, computer communication might be a good substitute for written communication).
- From the analysis of pre-coded responses in the matrix (q21) related to perceived effects of networks on various aspects of work.
- From the analysis of respondents' ratings of the perceived value of particular network types, applications, and network access to various work resources.
- From the content analysis of open-ended responses in (q31) on the perceived impact of networks on aerospace work and communication.

As in the previous two research questions, the primary site visit/interview data were analyzed in several ways in order to make them helpful in answering this research question. Interview subjects' responses to open-ended questions about perceived impact were integrated into a single list of suggested impacts. These responses were compared, in a general way, to responses provided in the mail survey, to triangulate study data.

In the interpretation of results obtained from this study, it is important to consider the time frame of the research. Data were collected over a period of time (1991-1993) during and after which computing and communications technologies have evolved considerably.

Obviously, reports of extent and nature of network use, as well as factors and impacts associated with network use, should be viewed within the appropriate historical context. The state of networking applications, costs, and policies during this period of time (as described by both study respondents and other sources) should be borne in mind when interpreting results related to the study's research questions.

The impact of the lapse of time between the study's telephone survey and primary interviews (conducted in summer 1991) and its final mail survey (conducted in spring 1993) on the analysis of study results should also be considered. Because the study's research questions are primarily answered by results obtained in the mail survey, there is little danger in the incorporation into the general reporting of findings of results obtained in the telephone survey and interviews, which were conducted 1 1/2 years earlier. The telephone survey results on extent of network use are used to assist in validating mail survey results, and the time lapse is taken into account (i.e., it is assumed that network use would have increased somewhat during that time). Site visit/interview results are also used to help validate survey results. In addition, they provide a source of anecdotal data and a sense of the actual physical environment of aerospace engineers that could not obtained be obtained in the mail survey. There is no reason to believe that critical changes in the nature of engineering work and work settings have occurred between the times when the interviews and mail survey were conducted.

The anecdotal data from the interviews are reported separately from survey results so, again, the reader can make judicious use of the interview data, keeping the time lapse in mind. In fact, because of the way the data are used in this study, the time lapse does not appear to be a significant problem. For example, responses to the "Message Analysis" portion of the interviews revealed that engineers used networks to send messages when they knew that the intended recipient was a frequent user of email and was unlikely to be easily reached with a phone call. Mail survey questions related to reasons for network use were framed differently, so the interview data provide results from a slightly different perspective which, nonetheless, corroborate open-ended survey comments that increased efficiency in communication encourages network use and that the lack of a critical mass of network users discourages use. The comparison of the two sets of results is valid because they are used to form, generally, a more complete picture of factors affecting network use and because there is no reason to think that workplace conditions have changed so dramatically that the earlier responses are no longer relevant.

Telephone survey and interview results were primarily used to develop questions and response categories that would accurately reflect the experiences, interests, and vocabulary of aerospace engineers. Thus, the time lag between the data collection activities could introduce a weakness in the mail survey if the phenomena of interest in the study--e.g., work tasks, communication activities, network uses--or the vocabulary of aerospace engineers changed dramatically during that time period. There is no reason to believe that the types of activities engaged in by engineers have undergone significant changes, or that the vocabulary used by engineers to describe those activities has changed, to the extent that the mail questionnaire would no longer be comprehensible to members of the aerospace community. Further, network uses were phrased in a generic fashion (e.g., "transferring data between computers") throughout the study, to account for specific technology or vocabulary variations. The survey was pretested in the fall of 1992, and no critical problems with question wording or the range of response categories were uncovered at that time. Finally, the mail survey allowed open-ended responses for questions relating to network use, work tasks and communication activities, factors associated with network use, and impacts of network use. This mitigates the threat to the validity of survey results in that respondents were free to reply in any manner they desired if survey questions or response categories inadequately reflected their vocabulary or experiences.

3.5. Summary

This chapter discussed this study's research questions and described the plan for collecting empirical data to answer them. It outlined the study's research design and methods and explained the rationale behind them. The study collected data that describe and explore the use of electronic networks by a broad range of aerospace engineers. An important strength of the study is its reliance on multiple data collection activities: site visits/interviews, a national telephone survey, and a national mail survey. One benefit of preceding the mail survey with more qualitative approaches to data collection is that the qualitative data can be used to improve the structure and content of the survey questions by making them clearer and more appropriate to the particular group being studied. The use of multiple data collection techniques is also beneficial because it allows a variety of data, both qualitative and quantitative, to be collected and compared. Interviews are best for providing qualitative data useful in understanding the meaning of complex and new phenomena. Surveys, on the other hand, provide the more efficient means of collecting data from a large number of widely dispersed people. Given the study's goals and conceptual framework, both of these goals are important. This chapter also suggested how concerns related to reliability and validity are addressed in the research. An overview of the plan for analyzing the study data was presented.

Computer networks have the potential to improve the efficiency and effectiveness of aerospace engineering work and communication, thus improving the quality of aerospace products and reducing the time needed to bring them to market. But such improvements will not be felt unless networking is better understood from the perspective of aerospace engineers themselves. Few empirical studies of the use of electronic networks in engineering contexts have been undertaken. No studies exist that take a cross-organizational, user-based approach in investigating links between network use, engineering work, and engineering communication. This study hopes to fill this gap. It aims to collect data that can lead to the development of more effective networking systems and services and that can be used by policymakers, at both the organizational and national levels, to estimate and understand the impacts that networking investments and policy decisions are likely to produce.

CHAPTER 4: STUDY RESULTS

4.1. Introduction

The success of institutional networking endeavors meant to enhance engineering work--and national efforts, such as those associated with the National Research and Education Network (NREN) or, more broadly, the National Information Infrastructure (NII)--will depend on the development of network features, policies, and support programs that are based on solid knowledge of users' needs and habits and on substantiated links between network use and engineering outcomes. But little empirical information has been gathered that can be used to help in understanding the impact of networking investments, designs, and policies on engineering work. The extent of computer network use across different types of engineering organizations is also largely unknown. Thus, many major investment, design, and policy decisions are being made solely on the basis of educated guesses about the current use of networks and the assumed contribution of networking to the scientific and technical enterprise.

In order to help remedy this situation, the researcher undertook an empirical investigation of computer networking in engineering that collected data from the network user's point of view. The study's aim was to describe and explore the use of electronic networks by one particular, though extremely heterogeneous, group: aerospace engineers. It focused on the way that networks are currently used by aerospace engineers to facilitate communication and otherwise assist in the performance of work tasks. The study was guided by the following research questions:

1) What types of computer networks and network applications are currently used by aerospace engineers?

2) What work tasks and communication activities do aerospace engineers use computer networks to support?

3) What work-related factors are associated with the use of computer networks by aerospace engineers?

4) What are the impacts of network use on aerospace engineering work and communication?

In order to include study participants representing a wide range of work and communication activities and to look at as many aspects of the aerospace industry as possible, "aerospace engineer" was interpreted very broadly. It included people engaged in all phases of the development and production of military and commercial aeronautical or aerospace equipment and processes.

This chapter presents selected results from this empirical investigation into the use of computer networks in aerospace engineering. Results presented here were gathered primarily in the study's final data collection activity: a national mail survey, conducted in Spring 1993, that was distributed to aerospace engineers employed in a wide variety of jobs. Mail survey results are supplemented by data gathered in the study's telephone survey and primary site visits/interviews. These results enrich and triangulate the mail survey data. Results from this research provide a snapshot of the current use of computer networks in the aerospace industry, suggest factors associated with the use of networks, and identify impacts of networks on aerospace engineering work and communication.

Given the study's exploratory and descriptive purposes, results are primarily presented with simple descriptive summaries, in quantitative and qualitative forms. In some instances--such as when examining differences between network users and nonusers--simple statistical analyses (e.g., Chi-squares and hypothesis tests of the difference between proportions) are used to establish the degree to which differences are statistically significant. Throughout this chapter, the numbers of the survey questions on which the results under discussion are based are noted. Most mail survey data are presented as the percentage of respondents who supplied particular answers, rounded up to the nearest whole percentage point. The total number of valid survey responses received was 950 (for an adjusted response rate of 51%; the base number of respondents answering each survey question varies somewhat and is reported throughout. Reported percentages are, for the most part, calculated on the base number of responses for each data element. Where significant cases of missing data occur, these are reported and explained along with the results for each question. For a copy of the questionnaire from which mail survey results are drawn, see Appendix E.

4.2. Respondent Characteristics

As is characteristic of the aerospace industry in the U.S., virtually all (97%) mail survey respondents are men, and most private sector respondents (68%) are employed in organizations with at least 1000 employees. Most mail survey respondents are engaged primarily in design or product engineering (23%), advanced or applied development (14%), or research (13%). Grouping together "industrial/manufacturing engineering," "quality control/assurance," "production," and "service/maintenance" reveals that about 15% of respondents are involved in the production end of the product development cycle. The majority of respondents are employed in industry (54%) or government (30%) settings. Other characteristics of survey respondents appear in Table 4-1.

In Table 4-1, the large number of "other" responses (42%) provided for "Branch of Aerospace" deserves explanation. Perusing the text of these responses revealed that many of them represented answers along other work dimensions, such as employment sector (e.g., "US government," "academic") or primary job function (e.g., "Manufacturing, "R&D," "Education"). Other responses reported more specific sub-branches of aerospace work (e.g., "Engine Test Cell Control Systems," "Flutter & vibration"), and a few people responded that their work encompassed a combination of a number of the branches of aerospace listed.

Table 4-1. Characteristics of Mail Survey Respondents[a]

Characteristics		Respondents n	(%)
Gender			
	Male	902	(97)
	Female	27	(3)
Age			
	20-29 yrs.	27	(3)
	30-39	214	(24)
	40-49	213	(24)
	50-59	279	(32)
	60+	161	(17)
Geographic Distribution			
	California	240	(25)
	Ohio	80	(8)
	Texas	71	(7)
	Virginia	54	(6)
	New York	42	(4)
	Washington	39	(4)
	Pennsylvania	33	(3)
	Illinois	27	(3)
	Kansas	26	(3)
	Arizona	25	(3)
	Maryland	23	(2)
	Connecticut	22	(2)
	Michigan	22	(2)
	New Jersey	22	(2)
	Florida	21	(2)
	Georgia	21	(2)
	Other	768	(20)

[a] Base varies, according to number of respondents who did not answer, or supplied an unusable answer to, each question: Gender = 929; Age = 894; Geographic distribution = 950.

Table 4-1. Characteristics of Mail Survey Respondents[a] (Cont'd)

Characteristics	Respondents n	(%)
Employment Sector		
Industry/manufacturing	505	(54)
Government	282	(30)
Academic	52	(6)
Not-for-profit	18	(2)
Retired or not employed	17	(2)
Other	54	(6)
Size of Parent Organization (if private sector business)		
1-99 employees	97	(13)
100-499	97	(13)
500-999	40	(6)
1000-4999	153	(21)
5000-9995	74	(10)
9996+	266	(37)
Job Type (self-identified)		
Engineer	428	(46)
Manager	362	(39)
Scientist	48	(5)
Other	95	(10)

[a] Base varies, according to number of respondents who did not answer, or supplied an unusable answer to, each question: Employment sector = 928; Size of parent organization = 732; Job type = 933.

Table 4-1. Characteristics of Mail Survey Respondents[a] (Cont'd)

Characteristics	Respondents n	(%)
Branch of Aerospace (self-identified)		
Aerodynamics	56	(6)
Structures	105	(12)
Propulsion	84	(9)
Flight Dynamics & Control	51	(5)
Avionics	107	(12)
Materials & Processes	131	(14)
Other	390	(42)
Primary Job Function (self-identified)		
Administration	88	(10)
Research	115	(13)
Advanced/Applied Development	124	(14)
Design/Product Engineering	212	(23)
Industrial/Manufacturing Engineering	58	(6)
Quality Control/Assurance	54	(6)
Production	5	(1)
Sales/Marketing or Service/Maintenance	74	(8)
Information Processing/Programming	36	(3)
Teaching/Training	48	(5)
Other	106	(12)

[a] Base varies, according to number of respondents who did not answer, or supplied an unusable answer to, each question: Branch of aerospace = 924; Primary job function = 920.

4.3. Extent of Network Use in the Aerospace Industry

4.3.1 Introduction

This study's first research question asks "What types of computer networks and network applications are currently used by aerospace engineers?" This section presents data on the degree to which networking is used in the aerospace industry, in general, and also on the extent of use of various types of computer networks and networking applications. Results presented here are derived primarily from the study's national mail survey, although comparisons with data from the preliminary telephone survey (conducted about 1 1/2 years before the mail survey) are also offered.

4.3.2. General Extent of Use

In general, mail survey results paint a picture of widespread use of electronic networks in aerospace engineering. The majority of the 893 respondents to the question "Do you ever use any kind of computer network in your work?" (q.4) reported that they personally used networks (74%), while 11% used networks through some kind of intermediary, such as a secretary or a librarian. Only 15% declared that they never used any kind of computer network in their work (whether linked workstations within an organization, a personal computer connected to a printer down the hall or a supercomputer across the country, or a dial-up link or direct connection to the Internet). In interpreting these figures, however, it should probably be assumed that results are slightly biased in favor of network use. (I.e., because of the length and topic of the survey, it is likely that potential respondents who did not use computer networks at all would be less inclined to complete and return the questionnaire... even though the cover letter emphasized the importance of the responses of nonusers.) One survey question attempted to put this potential bias in perspective by asking respondents to describe not their personal use, but the general use of computer networks in their workplace. These results suggest, in fact, a similar high level of use. In describing the extent of computer networking at their workplace, 40% of respondents reported that "Networks are used by most people; many tools are available on networks; most computer systems are linked together by a network; and network use is required or strongly encouraged" (q.2). A slightly higher proportion (48%) characterized the extent of networking at their workplace as use by "some" people, and only 7% reported use by "few" people with "little" organizational encouragement or even discouragement of network use.

Telephone survey results on extent of network use are fairly similar to the mail survey results. Only 7% of telephone survey respondents with access to networks claimed to never use them, but 17% of all respondents claimed that no networks were available to them, meaning that about 23% of telephone survey respondents can be considered nonusers, compared to the approximately 15% of mail survey respondents claiming to be nonusers of networks. The difference between the two figures might be explained by the passage of about eighteen months between the two surveys, or by the assumed underrepresentation of nonusers in the mail survey noted above.

Mail survey respondents who used computer networks also provided an estimate of the percent of their typical work week that they spent using computer networks. Although the intensity of network use varies across respondents, as Table 4-2 shows, almost a third of those using networks do so for less than five percent of their typical work week, while only about ten percent reported spending more than 50% of their work week in network use. Telephone survey results, again, are quite similar (see Table 3-6), with 21% of users claiming to have used networks for 0-4% of their last work week, and 13% claiming to have used networks for at least 50% of their last work week.

4.3.3. Availability and Use of Different Types of Networks

Respondents also reported on availability and use of different types of networks (see Table 4-3). It appears as if those networks providing access to the broadest range of other

Table 4-2. Intensity of Computer Network Use[a]

% of Typical Work Week Spent Using Networks	Respondents n	(%)
0-5	233	(31)
6-10	168	(22)
11-25	157	(21)
26-50	126	(17)
51-100	69	(9)

[a] Base = 754. From the total 950 survey respondents, 196 were removed from the analysis of this question: 135 who reported in the previous question that they never used networks; 2 who answered "don't know," and 59 who did not supply any answer to this question.

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people and resources are least likely to be available at the aerospace engineering workplace. Computers connected to commercial networks that link users to people, tools, or information outside of their own organization--such as CompuServe--are available to the smallest percentage of respondents (about 30%); 50% have access to an external research network such as the Internet; 74% reported that they were connected to an organizational network that linked them to resources beyond one workplace building; and 85% reported access to a local area network that connected them to people and resources within one workplace building. On the other hand, respondents were about equally likely to use any type of network available to them. Between 85% and 91% of respondents reportedly used each type of available network. Thus, it appears that lack of use of broader scope networks is due to lack of availability, not lack of perceived utility. The final column in Table 4-3 reveals the percentage of all survey respondents who reportedly used each type of computer network.

Table 4-3.
Availability and Use of Different Types of Networks

	Reported Availability [a]		Reported Use (If Available)[b]		Reported Use (All Respondents)[c]
	n	(%)	n	(%)	(%)
NETWORK TYPE					
Local	761	(85)	690	(91)	(77)
Organizational	667	(74)	595	(89)	(66)
External/Research	439	(50)	385	(88)	(44)
External/Commercial	259	(30)	220	(85)	(26)

[a] Base varies according to number of individuals who did not answer questions on network availability for each network type: Local = 893; Organizational = 900; External/Research = 884; External/Commercial = 855.

[b] Reported use was derived by calculating the number of individuals who reported using each type of network by checking off *any* of the locations of use listed in the q. 5 matrix: work, home, or "other." Percentage figures for "Reported Use" are based on the number of respondents who reported that each network type was available to them.

[c] Percentage is based on the base n for each network type

Mail survey respondents also reported the locations of their use of each type of network. Overall, about 60% of respondents used computer networks at work, while only about 12% reported use at home, and about 3% reported using any of the network types at some other location. Of the various types of networks, external/commercial networks were, not surprisingly, most likely to be used at home. It appears that few people access organizational or research networks from home; this may be due to the lack of network connectivity at home or to institutional prohibitions against logging into workplace accounts from home.

4.3.4. Availability and Use of Network Applications

The mail questionnaire also asked respondents to describe availability and use of various types of computer network applications (see Table 4-4). File transfer was the computer network application reportedly available to the greatest percent of respondents (85%), followed by electronic mail (82%), accessing remote data files (82%), remote log-in to run a computer program (80%), and electronic bulletin boards or conferencing systems (77%). These applications were also the network features most likely to be used. Less available were applications that supported access to published literature, such as electronic journals or newsletters (61%) or online library catalog searching (62%). It should be noted that these responses indicate a lack of *perceived* availability; some aerospace engineers may simply not be aware that certain applications are available to them. As a point of general comparison with the penetration of computer networking applications in the workplace, 94% of respondents indicated that fax was available in their workplace, and 77% reported the availability of telephone voice mail. Where the degree of use of an available application is comparatively low, barriers to use, lack of awareness, or lack of need for particular applications presumably exist. Again, as a point of comparison, 96% of those respondents who had access to fax actually used it. The final column in Table 4-4 portrays the percentage of all respondents who reported using each application. While more than two thirds of respondents use e-mail and file transfer, somewhat more than half use electronic bulletin boards or remote access to computers, about one third use online catalogs or bibliographic databases, and about one quarter use electronic journals or newsletters. E-mail, file transfer, and information/data access were also the three applications reportedly most used by this study's telephone survey respondents (see Table 3-6).

Mail survey respondents also reported the frequency with which they used the various network applications. Table 4-5 summarizes responses by portraying the percent of aerospace engineers who reportedly used each application "daily," "weekly," or "monthly or less."

Table 4-4. Availability and Use of Network Applications[a]

NETWORK APPLICATION	Reported Availability n	Reported Availability (%)	Reported Use, If Available n	Reported Use, If Available (%)	Reported Use, All Respondents (%)
Transferring data or text files between computers	730	(85)	589	(81)	(69)
Electronic mail	735	(82)	617	(84)	(69)
Logging into a computer NOT on your desktop to access data or text files	708	(82)	513	(72)	(59)
Logging into a computer NOT on your desktop to run a program (e.g., CAD/CAM, spreadsheet...)	697	(80)	495	(71)	(57)
Electronic bulletin boards, mailing lists, discussion groups, computer conferencing	666	(77)	463	(70)	(54)
Accessing or transferring images	619	(74)	346	(56)	(41)
Real-time, interactive messaging	763	(70)	305	(51)	(36)
Online bibliographic searching of commercial or govt. databases	553	(66)	273	(49)	(32)
Videoconferencing	550	(66)	243	(44)	(29)
Computer-integrated manuf'g (CIM)	521	(63)	126	(24)	(15)
Operation of computerized experimental, test, or production devices w/o being physically present	513	(62)	140	(27)	(17)
Online library card catalog searching	512	(62)	228	(57)	(35)
Electronic journals or newsletters	498	(61)	204	(41)	(25)
Electronic data interchange (EDI)	497	(61)	116	(23)	(14)

[a] Base varies according to number of missing cases ("don't know" or not answered) for each application, from 56 individuals who did not answer the frequency of use question for e-mail to 139 who did not supply any use answer for EDI. Percentage figures are based on the base n for each application (thus, the availability or usage n for a particular application may be higher than that of another, yet the % lower). It appears that some respondents skipped questions about use for un-used applications, rather than checking appropriate columns to explicitly indicate lack of availability and use.

Table 4-5.
Frequency of Use of Network Applications[a]

NETWORK APPLICATION	REPORTED FREQUENCY OF USE Daily n	(%)	Weekly n	(%)	Mo. or Less n	(%)
Transferring data or text files between computers	199	(23)	199	(23)	191	(22)
Electronic mail	399	(45)	120	(13)	98	(11)
Logging into a computer NOT on your desktop to access data or text files	198	(23)	148	(17)	167	(19)
Logging into a computer NOT on your desktop to run a program (e.g., CAD/CAM, spreadsheet...)	197	(23)	141	(16)	157	(18)
Electronic bulletin boards, mailing lists, discussion groups, computer conferencing	151	(18)	139	(16)	173	(20)
Accessing or transferring images	80	(10)	103	(12)	163	(20)
Real-time, interactive messaging	115	(14)	54	(6)	202	(24)
Online bibliographic searching of commercial or govt. databases	23	(3)	48	(6)	202	(24)
Videoconferencing	8	(1)	29	(4)	206	(25)
Computer-integrated manuf'g (CIM)	52	(6)	26	(3)	48	(6)
Operation of computerized experimental, test, or production devices w/o being physically present	35	(4)	36	(4)	69	(8)
Online library card catalog searching	22	(3)	47	(6)	159	(19)
Electronic journals or newsletters	36	(4)	55	(7)	113	(14)
Electronic data interchange (EDI)	25	(3)	40	(5)	51	(6)

[a] Base varies according to the number of missing cases ("don't know" or not answered) for each application, from 56 individuals who did not answer the frequency of use question for e-mail to139 who did not supply any use answer for EDI. Percentage figures are based on the base n for each application (thus, the availability or usage n for a particular application may be higher than that of another, yet the % lower). It appears that some respondents skipped questions about use for un-used applications, rather than checking appropriate columns to explicitly indicate lack of availability and use. Row percentages do not add to 100, because "Application not available," and "Never" responses are not reported in this table.

Daily use of e-mail was about double the daily use of other frequently used applications (file transfer, remote log-in, and electronic bulletin boards). Further, e-mail was the only application for which daily use was far more prevalent than weekly or monthly use. Amongst users of each application, use of file transfer, remote log-in, bulletin boards, CIM, remote operation of devices, and EDI was divided fairly equally among "daily," "weekly," and "monthly or less." At the other extreme, image transfer, interactive messaging, online searching of bibliographic databases and card catalogs, videoconferencing, and electronic journals were used "monthly or less" by most people who used those applications at all.

4.3.5. Summary: Extent of Network Use in the Aerospace Industry

Study results indicate that, in the aerospace industry, computer networks are used by the majority of engineers, although intensity of use varies substantially. Networks currently provide greater internal than external connectivity. File transfer, e-mail, remote log-in, and bulletin boards are the applications cited by survey respondents as both most available and most used. This suggests that interpersonal communication, sending and receiving information, and access to remote computers and data stores are the most widespread and important functional uses of computer networks by aerospace engineers. The next section of this chapter addresses the nature of network use more directly, forging a closer link between purpose of networking and aerospace work and communication.

4.4. Nature of Network Use in Aerospace Work and Communication

4.4.1. Introduction

This study's second research question asks "What work tasks and communication activities do aerospace engineers use electronic networks to support?" Data to answer this question were collected in the mail survey by eliciting reports of the extent to which computer networks were used to access various work resources (q.6). Another relevant section of the survey (q.8-15) used the critical incident technique to gather information from aerospace engineers about an important work task performed recently and the extent to which various communication channels--including computer networks--were used in performing that task.

4.4.2. Network Access to Work Resources

Mail survey respondents were asked to describe their use of various work resources (q.6). Table 4-6 reports the extent to which aerospace engineers communicate with various kinds of people in the course of their work, as well as the availability of network access to them (those human resources accessible to the greatest number of survey respondents via networks are listed first). Results indicate that people within one's own organization are much more likely to be contacted in the course of performing aerospace work than are people in other organizations.

Electronic access to other people appears quite common in the aerospace industry, but more respondents (about 85%) were able to communicate electronically with people within their own organization than with people in other organizations. This finding corresponds with the greater availability of local and organizational networks reported above. Private sector colleagues or associates were least likely to be accessible over the network, with between 61% and 66% of respondents reporting such access. This may reinforce the traditional view that internal communication is generally more common in engineering work than is extra-organizational communication. On the other hand, the number of aerospace engineers who do have electronic access to various kinds of people outside their own organizations (between 67% and 80%) may surprise those who thought that such links, at least in the private sector, were still largely prohibited due to proprietary and security concerns.

Table 4-6.
Network Access to Human Resources Used in Work

	Resource Used		Availability of Network Access to Used Resource	
	n	(%)[a]	n[b]	(%)[c]
HUMAN RESOURCES				
People in your workgroup or department	692	(73)	614	(89)
Other people in your organization	681	(72)	604	(89)
Colleagues in academia, government	395	(42)	318	(80)
Colleagues in private industry	387	(41)	283	(73)
External clients, customers, sponsors	358	(38)	251	(70)
External vendors, suppliers	364	(30)	245	(67)

[a] Respondents placed a check mark next to each resource used in their work. Percentage is based on the total number of survey respondents (N=950).

[b] Base varies according to number of missing cases in reporting network access and use for each resource, from 154 missing cases for "people in your workgroup or department" to 409 for "external clients, customers, sponsors." Respondents were instructed to skip items for un-used resources, hence the large number of missing cases. In this table, only the responses on network access of those people who checked that each resource was, in fact, used are reported.

[c] Percentage is based on the number of respondents who checked that each resource was, in fact, used.

As shown in Table 4-7, respondents reported a great deal of diversity in their use of various engineering information resources. The most commonly used resources--directories of people and drawings or designs--were used by only about half of the respondents. On the other hand, even the least used resource--lab notebooks--was used by 16% of respondents. Network

Table 4-7.
Network Access to Information Resources Used in Work

	Resource Used		Availability of Network Access to Used Resource	
INFORMATION RESOURCES	n	(%)[a]	n[b]	(%)[c]
Computer code or programs	405	(43)	341	(84)
Internal financial data	321	(34)	257	(80)
Production control data	246	(26)	197	(80)
Directories of people	464	(49)	357	(77)
Document citations, abstracts	399	(42)	298	(75)
Company newsletters, bulletins	420	(44)	312	(74)
Drawings or designs	458	(48)	334	(73)
Experimental or test data	395	(42)	287	(73)
Training materials, tools, programs	340	(36)	247	(73)
Internal technical reports	439	(46)	308	(70)
Design change forms	238	(25)	165	(69)
Technical specifications	424	(45)	276	(65)
Codes of standards and practices	324	(34)	206	(64)
Product or materials characteristics	318	(34)	204	(64)
Equipment or procedures manuals	372	(39)	233	(63)
Lab notebooks	153	(16)	89	(58)
Journal, trade magazine articles	386	(41)	220	(57)
Manufacturers' or suppliers' catalogs	300	(32)	168	(56)

[a] Respondents placed a check mark next to each resource used in their work. Percentage is based on the total number of survey respondents (N=950).

[b] Base varies according to number of missing cases in reporting network access and use for each resource, from 486 missing cases for "directories of people" to 797 for "lab notebooks." Respondents were instructed to skip items for un-used resources, hence the large number of missing cases. In this table, only the responses on network access of those people who checked that each resource was, in fact, used are reported.

[c] Percentage is based on the number of respondents who checked that each resource was, in fact, used.

access to information resources in the aerospace industry appears quite prevalent (those resources reported by the greatest number of responses as accessible via networks are listed first). The availability of network access to information resources used in work ranged from a low of 58% for lab notebooks to a high of 84% for computer code and programs. Information resources to which at least 70% of their users reportedly had networked access were internal financial data, production control data, directories of people, document citations and abstracts, company newsletters and bulletins, drawings or designs, experimental or test data, and training materials.

It is clear from study results that a wide variety of work resources are used by aerospace engineers and that networked access to these resources is quite widespread. But network access does not guarantee network use, when utilizing work resources. Reported next is the degree to which aerospace engineers take advantage of networked access to colleagues and to the information resources they use in their work. Use of computer networks in the performance of specific work and communication tasks is also examined.

4.4.3. Use of Networks in Performing Work Tasks

Although networked access to human and information resources appears to be quite prevalent in the aerospace industry, the actual use of networks to access work resources is far from guaranteed. Tables 4-8 and 4-9 report the frequency with which aerospace engineers reportedly use the network access available to them to connect to the people and information resources they need to accomplish their work.

Table 4-8 describes the extent to which computer networks are used by aerospace engineers to communicate with colleagues. The data reveal a clear trend: networks are less likely to be used for communication with people outside of one's organization, even when networked access to external people is available. For external colleagues, network communication with private sector colleagues is less likely than use of networks to communicate

Table 4-8.
Use of Computer Networks for Work Communication[a]

HUMAN RESOURCES	FREQUENCY OF USE OF AVAILABLE NETWORK FOR ACCESSING RESOURCE							
	Usually		Sometimes		Rarely		Never	
	n	(%)[b]	n	(%)[b]	n	(%)[b]	n	(%)[b]
People in your workgroup or dep't.	240	(39)	226	(37)	90	(15)	58	(9)
Other people in your org'n.	213	(35)	263	(44)	75	(12)	53	(9)
Colleagues in academia, gov't.	60	(19)	123	(39)	74	(23)	61	(19)
Colleagues in private industry	32	(11)	95	(34)	74	(26)	82	(29)
Ext'l. clients, customers, sponsors	30	(12)	73	(29)	67	(27)	81	(32)
Ext'l vendors, suppliers	25	(10)	73	(30)	49	(20)	98	(40)

[a] Base varies according to the number of missing cases ("don't know" or not answered) in reporting network use for each resource, from 154 missing cases for "people in your workgroup or department" to 409 for "external clients, customers, sponsors." Respondents were instructed to skip items on network use for unused work resources, hence the large number of missing cases. In this table, only the responses on network use of those people who checked that each work resource was, in fact, used are reported.

[b] Percentage is based on the total number of respondents reporting the availability of networked access to each resource they actually used in their work. In other words, the number of missing cases for the resources varies, and percentage figures **exclude** missing cases ("no network access" or not answered). Thus, the n for a particular resource may be higher than that of another, yet the % lower. Row percentages add to 100.

Table 4-9.
Use of Computer Networks to Access Information Resources[a]

INFORMATION RESOURCES	FREQUENCY OF USE OF AVAILABLE NETWORK FOR ACCESSING RESOURCE							
	Usually		Sometimes		Rarely		Never	
	n	(%)[b]	n	(%)[b]	n	(%)[b]	n	(%)[b]
Computer code or programs	158	(46)	105	(31)	45	(13)	33	(10)
Internal financial data	108	(42)	75	(29)	37	(14)	37	(14)
Production control data	93	(47)	52	(26)	27	(14)	25	(13)
Directories of people	115	(32)	131	(37)	62	(17)	49	(14)
Document citations, abstracts	65	(22)	131	(44)	59	(20)	43	(14)
Company newsletters, bulletins	118	(38)	101	(32)	42	(14)	51	(16)
Drawings or designs	135	(40)	97	(29)	38	(11)	64	(19)
Experimental or test data	99	(35)	104	(36)	35	(12)	49	(17)
Training materials, tools, programs	56	(23)	92	(37)	43	(17)	56	(23)
Internal technical reports	68	(22)	115	(37)	60	(20)	65	(21)
Design change forms	56	(34)	45	(27)	24	(15)	40	(24)
Technical specifications	86	(31)	84	(30)	41	(15)	65	(24)
Codes of standards and practices	42	(20)	57	(28)	41	(20)	66	(32)
Product or materials characteristics	47	(23)	66	(32)	32	(16)	59	(29)
Equip't. or procedures manuals	43	(19)	68	(29)	39	(17)	83	(36)
Lab notebooks	15	(17)	15	(17)	12	(14)	47	(53)
Journal, trade magazine articles	28	(13)	59	(27)	43	(20)	90	(41)
Manufacturers' or suppliers' catalogs	20	(12)	25	(15)	27	(16)	96	(57)

[a] Base varies according to number of missing cases ("don't know" or not answered) in reporting network use for each resource, from 486 for "directories of people" to 797 for "lab notebooks." Respondents were instructed to skip items on network use for un-used work resources, hence the large number of missing cases. In this table, only the responses on network use of those people who checked that each work resource was, in fact, used are reported.

[b] Percentage is based on the total number of respondents reporting the availability of networked access to each resource they actually used in their work. In other words, the number of missing cases for the resources varies, and percentage figures **exclude** missing cases ("no network access" or not answered). Thus, the n for a particular resource may be higher than that of another, yet the % lower. Row percentages add to 100, except in cases of rounding error.

with colleagues in academia and government. This trend appeared in the telephone survey results as well; just over 75% of network users communicated electronically with people in their own workgroup or organization, while only about 50% communicated electronically with people outside the organization.

Mail survey results further show that the use of computer networks to communicate with people is substantial, but not overwhelming. The greatest use of networks--to communicate with people in one's workgroup or department--still occurs "usually" for only 39% of the respondents. This suggests that computer-mediated communication is not amenable to all modes of communication and that barriers (either technical or social) to network use are greater in external than in internal communications.

Network access to information resources was also not universally used, even when it was available (see Table 4-9). The five resources that the greatest number of respondents said they "usually" accessed over the network were production control data, computer code or programs, internal financial data, drawings or designs, and company newsletters. The five resources that the greatest number of respondents said they "never" accessed over the network were all full-text resources: manufacturers' or suppliers' catalogs, lab notebooks, journal articles, equipment or procedures manuals, and standards. Lack of network use might be due to the lack of need for remote access to, or perceived difficulties in using, full-text resources in electronic form, especially over the network.

Interview results related to network use of information resources present a similar view of what is currently available and used online by aerospace engineers. The most commonly used network information resources noted by participants in this study's primary site visits /interviews (derived from the list of reported uses of computer networks mentioned by interviewees) were computer code or programs, drawings or designs, production control data, and internal financial data.

The reported use of computer networks to communicate with different types of colleagues and access various work resources suggests the ways in which computer networks are currently used to support work activities in aerospace. In another section of the mail survey, the link between network use and work tasks was investigated explicitly. Aerospace engineers were asked to identify the most important work task they performed during their last work week and to describe various aspects of the performance of that task by responding to a series of questions centered around the critical incident they had identified. Respondents could either choose one of the twenty-one work tasks listed in the questionnaire (q.8), or supply a task not listed. Table 4-10 lists the number of respondents selecting each of the work tasks listed in the questionnaire; items selected by the greatest number of respondents are listed first. Again, the diversity of the responses is striking, providing further evidence of the inherent variability of engineering work. Planning tasks or projects, writing proposals or reports, and coming up with new ideas or approaches were the work tasks performed by the greatest number of aerospace engineers, but no task was selected by more than 15% of respondents.

In order to determine the extent to which computer networks were used to support work and communication tasks, each respondent was asked to identify the two most significant communication channels they used (q.14) to perform the task about which he or she was reporting. Communication channels were selected from the list of pre-coded response categories, which included an "other" category along with eleven listed channels. Table 4-11 portrays the channels used in performing aerospace work tasks. The channels are listed in decreasing order of their reported use.

There are clear differences in the degree to which various communication channels are used in performing aerospace work tasks. Face-to-face interaction with others is clearly the most important channel, with print and telephone channels also used heavily. Computer networks to access people, information, or computers; direct examination of objects or phenomena; computers; and fax are used to a lesser degree. If the reported uses of the various forms of networking are combined (N=159; %=14), the importance of computer networks in

Table 4-10. Most Important Work Task Performed by Aerospace Engineers during Last Work Week[a]

Work Task	Respondents Identifying that Task as Most Important n	(%)
Plan tasks, projects, programs, etc.	141	(15)
Write proposal, report, paper, etc.	101	(11)
Come up with new ideas, approaches	91	(10)
Coordinate work	84	(9)
Solve technical problem	62	(7)
Produce drawings, designs	51	(6)
Assure conformance with requirements	43	(5)
Negotiate with co-workers, clients, vendors, students	37	(4)
Conduct experiment or run test	35	(4)
Identify requirements	27	(3)
Interpret results of experiments, tests	26	(3)
Troubleshooting, maintenance	24	(3)
Perform mathematical analysis	24	(3)
Keep up with new developments	22	(2)
Select or design methods or procedures	20	(2)
Produce prototypes or products	18	(2)
Produce specifications	13	(1)
Develop theories, concepts	12	(1)
Identify resources	11	(1)
Learn how to do something	9	(1)
Identify problem	8	(1)

[a] In response to this question, 24 people circled multiple responses, 39 provided an "other" response (the most common "other" response was "teaching"). Base = 922 (28 people provided no answer to this question).

[b] Percentage is based on the total number of responses received to this question (922).

performing aerospace work appears more significant, with their use occurring on a par with that of print material or the telephone. Voice mail and "snail mail" were least used as a primary means of communication.

Table 4-12 compares the use of network and non-network channels in performing specific aerospace work tasks. For those individuals reporting on one of the listed work tasks, 31% identified a computer network channel as used in performing that task. Networks were used more than non-network channels to perform mathematical analyses. Other tasks where computer networks were identified by 40% or more of aerospace engineers as being used to accomplish the task are learning how to do something, producing drawings or designs, developing theories or concepts, and selecting design methods or procedures. Networks were least likely to be used for identifying resources, producing specifications, and assuring conformance with requirements.

Data on the purpose of network use from the telephone survey offer a slightly different perspective on use of networks for conducting aerospace work, but the results from the two instruments seem to corroborate the finding that networks are used most often for technical communications. Fewer telephone survey respondents noted administrative, as opposed to technical, purposes for the last several electronic messages they sent (see Table 3-7). Similarly, as shown in Table 4-12, networks were used by a smaller proportion of those mail survey respondents performing administrative tasks (such as planning tasks and projects, or coordinating work) than many of the technical tasks listed (e.g., perform mathematical analysis, learn how to do something).

4.4.4. Summary: Nature of Network Use in Aerospace Work and Communication

Computer networks play a significant role in the accomplishment of aerospace work and communication activities. Because available networks are not used by all aerospace

Table 4-11. Communication Channels Used to Perform Aerospace Work Tasks[a]

Channels	Respondents Selecting that Channel as "Primary" Channel Used in Performing Work Task	
	n	(%)[b]
Face-to-face interaction with other person(s)	476	(41)
Examining printed material in own office or other location	148	(13)
Telephone	148	(13)
Own direct examination, testing of physical objects, devices, processes	85	(7)
Use of computer network to access information or data	67	(6)
Fax	55	(5)
Use of computer network to operate a computer or other device	51	(4)
Use of a non-networked computer	50	(4)
Use of a computer network to communicate with people	41	(4)
Voice mail	17	(1)
Internal (e.g., company or campus) or U.S. mail	15	(1)
Other	8	(1)
TOTAL	**1161**	**(100)**

[a] Respondents were instructed to select the two most important communication channels they used in performing the work task identified in an earlier question. They were to label one of the selected channels as "primary" and the other as "secondary." In fact, a significant number of respondents selected more than two channels and some simply supplied check marks as opposed to designating channels as primary or secondary. In this table, only actual "primary" responses are reported.

[b] Percentage is calculated on the base n of 1161, the total number of "primary" responses supplied by subjects.

Table 4-12.
Comparison of the Use of Network vs. Non-Network Channels in Performing Specific Aerospace Work Tasks[a]

	Respondents Using Network[b]		Respondents Using Non-Net Channel[c]	
Work Task	n	(%)	n	(%)
Perform mathematical analysis	16	(67)	8	(33)
Learn how to do something	4	(44)	5	(56)
Produce drawings, designs	22	(43)	29	(57)
Develop theories, concepts	5	(42)	7	(58)
Select or design methods or procedures	8	(40)	12	(60)
Identify problem	3	(38)	5	(63)
Conduct experiment or run test	12	(34)	23	(66)
Produce prototypes or products	6	(33)	12	(67)
Plan tasks, projects, programs, etc.	47	(33)	93	(66)
Solve technical problem	19	(31)	43	(69)
Identify requirements	8	(30)	19	(70)
Write proposal, report, paper, etc.	30	(30)	71	(70)
Troubleshooting, maintenance	7	(29)	17	(71)
Come up with new ideas, approaches	26	(29)	65	(71)
Coordinate work	23	(27)	61	(73)
Negotiate with co-workers, etc.	10	(27)	27	(73)
Interpret results of experiments, tests	7	(27)	19	(73)
Keep up with new developments	6	(27)	16	(73)
Identify resources	2	(18)	9	(82)
Produce specifications	2	(15)	11	(85)
Assure conformance with requirements	6	(14)	37	(86)
TOTAL (all tasks)	**269**	**(31)**	**589**	**(69)**

[a] Base varies. In identifying a task, 24 people circled multiple responses, 39 provided an "other" response (the most common "other" response was "teaching"), and 28 people provided no answer. A total of 26 individuals supplied no answer to the question on channel use. None of the data associated with these responses is included in this table.

[b] n= the number of individuals labelling at least one network channel as used (i.e., either primary, secondary, or checked)

[c] n = the number of individuals labelling no network channel as used.

engineers who have access to them, it appears that computer networks are better suited to certain activities than others, that social or technical barriers militate against ubiquitous use, or that computer networks are simply not needed in the performance of some activities.

Responses to the mail survey indicate that computer networks are used more for internal than external communication activities. Work resources accessed most over the network tended to be internal as well, and to exist as data, drawings, or computer code. Full-text resources needed to support work were less likely to be accessed over the net. Aerospace engineers used computer networks to a significant degree in accomplishing important work tasks: in almost one third of the critical work incidents reported, computer networks were cited as a channel used in accomplishing the task. Network use did not surpass reliance on face-to-face interactions, but it appears to be on a par with the use of telephone and print channels, and it surpasses the use of traditional mail and fax as a communication channel. The work and communication activities most commonly supported by computer network use covered a diverse range of engineering tasks. They included performing mathematical analyses, learning how to do something, producing drawings or designs, developing theories or concepts, and selecting design methods or procedures. Networks were least likely to be used for keeping up with new developments, identifying resources, producing specifications, assuring conformance with requirements, or identifying problems.

4.5. Factors Associated with Network Use by Aerospace Engineers

4.5.1. Introduction

Survey results discussed so far address extent of network use in the aerospace industry and the use of networks to support aerospace engineering work and communication tasks. Another aim of this study was to explore factors that might be associated with network use, i.e., to gain a better understanding of the degree to which, and the reasons why, networks are used by some aerospace engineers and not by others. Among the factors potentially associated with network use that were explored in this research were demographic characteristics of respondents, job type, task characteristics, and the nature of the work and networking environments of aerospace engineers.

4.5.2. Respondent/Job Characteristics and Network Use

Cross-tabulating various mail survey respondent characteristics with network use (see Table 4-13) suggests that some variation in use is based on demographics. Men and women used networks about equally. Network use did not vary greatly by age, except for those over sixty, who were much less likely to be network users. Network use appears to increase with educational level, except that those respondents with only a high school degree were more likely to use networks than those with a technical degree. Engineers who had been in the aerospace industry for a year or less were least likely to use networks, while those people who had been in the field for five to 19 years were the most likely to use networks.

Some broad job characteristics also seem related to network use (see Table 4-14). Network use among survey respondents is more extensive in academia, as opposed to other sectors. A greater percentage of respondents characterizing themselves as "scientists" used networks, as compared to those calling themselves "engineers" or "managers." In terms of primary job function, network use was most extensive among those engaged in teaching, research, advanced or applied development, and industrial engineering; those engaged in sales or marketing, service or maintenance, administration, and production appear to be the lightest network users. Results from the earlier telephone survey also depict engineers and managers as lighter users of networks than are people engaged primarily in scientific work . Mail survey results further reveal that aerospace engineers working in aerodynamics or flight dynamics were slightly more likely to use networks than were those in other branches of aerospace. Finally, as depicted in Table 4-15, network use appears to be more widespread in locations, departments, and organizations with a large number of employees.

Table 4-13. Personal Characteristics and Network Use[a]

Characteristics	Use Networks[b] n	(%)	Never Use Networks n	(%)
Gender				
Male	721	(85)	128	(15)
Female	21	(81)	5	(19)
Age				
20-29 yrs.	23	(88)	3	(12)
30-39	190	(93)	15	(7)
40-49	184	(92)	16	(8)
50-59	223	(85)	38	(15)
60+	91	(61)	58	(39)
Educational Level				
High School	19	(79)	5	(21)
Technical Degree	37	(69)	17	(32)
Bachelor's Degree	308	(83)	61	(17)
Master's Degree	263	(87)	38	(13)
Ph.D.	85	(92)	7	(8)
Post Doctorate	21	(100)	0	(0)
Other	8	(62)	5	(39)
Years in Aerospace				
<1	11	(73)	4	(27)
1-4	34	(85)	6	(15)
5-9	93	(91)	9	(9)
10-14	112	(90)	13	(10)
15-19	93	(92)	8	(8)
20-24	73	(83)	15	(17)
25-29	94	(86)	15	(14)
30+	223	(79)	61	(21)

a Base varies, according to number of missing cases: Gender = 875; Age = 842; Educational level = 874; Years in aerospace = 865. Row percentages add to 100, except in cases of rounding error.

b Combines survey q.4 responses "Yes, I personally use computer networks" and "Yes, I use computer networks, but only through an intermediary..."

Table 4-14. Job Characteristics and Network Use[a]

Characteristics	Use Networks[b] n	(%)	Never Use Networks n	(%)
Employment Sector				
Industry/manufacturing	404	(84)	75	(16)
Government	246	(92)	22	(8)
Academic	48	(98)	1	(2)
Not-for-profit	14	(82)	3	(18)
Retired or not employed	2	(13)	14	(88)
Other	27	(60)	18	(40)
Job Type				
Engineer	339	(83)	67	(17)
Manager	297	(87)	44	(13)
Scientist	41	(91)	4	(9)
Other	72	(84)	14	(16)
Primary Job Function				
Administration	68	(80)	17	(20)
Research	104	(94)	7	(6)
Advanced/Applied Dev.	105	(91)	11	(10)
Design/Product Engineering	159	(80)	39	(20)
Industrial/Manufg Engineering	52	(91)	5	(9)
Quality Control/Assurance	41	(85)	7	(15)
Production	4	(80)	1	(20)
Sales/Marketing	32	(73)	12	(27)
Service/Maintenance	18	(75)	6	(25)
Information Processing/Program'g	30	(88)	4	(12)
Teaching/Training	42	(98)	1	(2)
Other	84	(82)	18	(18)
Branch of Aerospace				
Aerodynamics	50	(94)	3	(6)
Structures	86	(85)	15	(15)
Propulsion	69	(85)	12	(15)
Flight Dynamics & Control	44	(90)	5	(10)
Avionics	83	(86)	14	(14)
Materials & Processes	100	(83)	21	(17)
Other	310	(84)	57	(16)

[a] Base varies according to number of missing cases: Employment sector = 874; Job type = 878; Primary job function = 867; Branch of aerospace = 869. Row percentages add to 100, except in cases of rounding error.

[b] Combines survey q.4 responses "Yes, I personally use computer networks" and "Yes, I use computer networks, but only through an intermediary..."

Table 4-15. Organization Size and Network Use[a]

Characteristics	Use Networks[b] n	(%)	Never Use Networks n	(%)
No. of Employees in Parent Organization				
< 50	41	(58)	30	(42)
50-99	9	(53)	8	(47)
100-499	74	(81)	17	(19)
500-999	34	(87)	5	(13)
1000-4999	126	(88)	18	(13)
5000-9995	63	(95)	3	(5)
9996+	239	(93)	18	(7)
No . of Employees at Worksite Location				
< 50	153	(74)	53	(26)
50-99	57	(83)	12	(17)
100-499	153	(92)	13	(8)
500-999	58	(87)	9	(13)
1000-4999	135	(93)	10	(7)
5000-9995	32	(100)	0	(0)
9996+	33	(92)	3	(8)
No. of Employees in Department (or equivalent)				
< 50	418	(85)	72	(15)
50-99 employees	76	(92)	7	(8)
100-499	90	(91)	9	(9)
500-999	21	(91)	2	(9)
1000-4999	5	(83)	1	(17)
5000+	4	(80)	1	(20)

[a] Base varies according to number of missing cases: No. of employees in parent organization = 688; No. of employees at worksite location = 728; No. of employees in department = 711. Respondents were instructed to answer only if they were NOT employed by an educational institution, hence the large number of missing cases. Row percentages add to 100, except in cases of rounding error.

[b] Combines survey q.4 responses "Yes, I personally use computer networks" and "Yes, I use computer networks, but only through an intermediary..."

Table 4-16 summarizes the results of Chi-square tests that were performed on the contingency tables derived from the output of the cross-tabulations presented above. These analyses were conducted in order to discover which of the relationships between network use and various respondent characteristics were statistically significant. Chi-square is a non-parametric test of association appropriate for nominal level data. It shows whether a relationship exists between variables, but not the direction or exact location of the relationship (which are more apparent in the results as presented above, in Tables 4-13 through 4-15). Another important limitation of the results presented in Table 16 is that they explore binary relationships only, i.e., they do not account for interactions among independent variables. For example, "years in aerospace" may be significantly related to network use because it interacts with "age."

The various respondent and job characteristics identified were cross-tabulated with both network use and with intensity of network use. Those characteristics significantly related to network use were age, educational level, number of years in the aerospace industry, number of employees in one's parent organization and at one's worksite, employment sector, job type, and primary job function. It should be noted, however, that looking at the actual contingency table cell values for employment sector suggests that the significant Chi-square result is due chiefly to the responses offered by retired and unemployed aerospace engineers.

For those variables most indicative of the nature of aerospace work--job type, primary job function, and branch of aerospace--it appears that they are more strongly related to the intensity of network use, as opposed to whether or not networks are used at all. While network use seems fairly consistent across various job types, those engaged in certain types of work appear to use networks more heavily. For example, close to 16% of survey respondents who characterized themselves as scientists estimated that over 50% of their typical work week was spent in network use. That intensity of network use was claimed by about 10% of engineers and only five percent of managers. Looking at primary job function, the cross-tabulations performed reveal that a full 38% of those engaged in information processing/programming spend more than half their work week using networks, while no respondents in production, teaching, or sales and marketing reported such a high degree of network use. In between are those in administration (with 6% reporting that networks were used more than 50% of the work week), research (7%), advanced or applied development (8%), service and maintenance (9%) and design or product engineering (10%).

One particular job characteristic that was anticipated to be strongly related to network use was whether or not an aerospace engineer's work involved, as a primary feature, the development or analysis of computer systems, components, software, or data (q.30). It was assumed that people engaged in such computer-intensive work would be heavy network users as well, in part because they would be familiar with much of the technology and skills involved in computer networking, and in part because the people they communicated with and the resources and products of their work would more likely be online. The anticipated relationship between computer-related work and network use was borne out by survey responses. Only about 10% of those engaged in computer-related work never used networks, compared to about 18% of those who were not engaged in computer-related work. Chi-square results related to computer-related work were highly significant at for both network use (Chi-square = 19.12; DF = 2; p = .00007; number of missing observations = 83) and intensity of network use (Chi-square = 54.79; DF = 5; p = .00000; number of missing observations = 87).

4.5.3. Task Characteristics and Network Use

The critical incident portion of the mail survey was used to investigate the relationship between certain characteristics of work tasks and whether or not networks were used in performing those tasks. Table 4-17 presents the relationship between the reported size of the group involved in performing a recent important work task (q.10) and the use of computer networks as a communication channel in performing that task (q.14). The use of computer

Table 4-16.
Respondent Characteristics and Network Use: Summary of Chi-Square Results

Relationship Tested	Chi-Square Results: X^2	DF	Signif.[c]	No. of Missing Observations
Gender and net use[a]	1.68	2	.4316	75
Gender and intensity of net use[b]	3.78	5	.5814	79
Age and net use[a]	110.01	8	.0000***	108
Age and intensity of net use[b]	122.34	20	.0000***	112
Educational level and net use[a]	34.05	12	.0006***	76
Educational level and intensity of net use[b]	44.12	30	.0467*	80
Years in aerospace and net use[a]	88.86	24	.0000***	85
Years in aerospace and intensity of net use[b]	95.80	60	.0022**	89
Employment sector and net use[a]	109.85	10	.0000***	76
Employment sector and intensity of net use[b]	115.67	25	.0000***	80
Job type and net use[a]	9.26	6	.1594	72
Job type and intensity of net use[b]	31.32	15	.0080**	77
Branch of aerospace and net use[a]	9.49	12	.6602	81
Branch of aerospace and intensity of net use[b]	31.83	30	.3755	86
Primary job function and net use[a]	40.19	22	.0103*	83
Primary job function and intensity of net use[b]	125.65	55	.0000***	87
Employees in parent org. and net use[a]	96.76	14	.0000***	262
Employees in parent org. and intensity of net use[b]	100.14	35	.0000***	267
Employees at worksite and net use[a]	60.93	14	.0000***	222
Employees at worksite and intensity of net use[b]	77.81	35	.0000***	230
Employees in dept. and net use[a]	17.19	12	.1425	239
Employees in dept. and intensity of net use[b]	26.03	30	.6738	247

[a] Net use categories = Use personally, Use through an intermediary, Never use.

[b] Intensity of network use = Percent of typical work week spent using networks (with responses grouped into 0, 1-10, 11-25, 26-50, 51-75, 76-100%).

[c] An asterisk (*) indicates significance at the .05 level, i.e., the observed differences would occur by chance 5% of the time or less. Two asterisks (**) indicates significance at the .01 level. Three asterisks (***) indicates significance at the .001 level. Significance indicates that a relationship exists between network use and a particular characteristic.

4-17. Size of Task Group and Network Use[a]

	Networks Used as a Channel In Task Performance[b]		Networks NOT Used as a Channel In Task Performance[c]	
	n	(%)	n	(%)
Size of Task Group				
One person	55	(37)	92	(63)
Two people	41	(29)	100	(71)
3-5 people	94	(29)	228	(71)
6-10 people	46	(30)	108	(70)
11-20 people	25	(28)	65	(72)
>20 people	18	(29)	44	(71)
TOTAL	**279**	**(31)**	**637**	**(70)**

[a] Base = 916. Row percentages add to 100, except in cases of rounding error.

[b] n= the number of individuals labelling at least one network channel as used (i.e., either primary, secondary, or checked)

[c] n = the number of individuals labelling no network channel as used.

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networks varied remarkably little according to task group size. The percentage of respondents using networks as a communication channel, as opposed to using some non-network channel, was about 30%, regardless of the number of people involved in performing the task. Networks were used slightly more, however, by survey respondents performing a task by themselves.

Table 4-18 presents survey results that relate the geographic span of the critical incident task (q.11) to the reported use of computer networks in performing that task (q.14). Here again, the degree to which networks were reported as a channel in performing a work task did not vary significantly according to the geographic span of task participants. Those respondents involved in performing a task with people located across the country used networks slightly less (24%) than those involved in tasks with either a small or greater geographic span.

4-18. Geographic Span of Task and Network Use[a]

Geographic Span of Task Group	Networks Used as a Channel in Task Performance[b] n	(%)	Networks NOT Used as a Channel in Task Performance[c] n	(%)
Same office/lab	60	(32)	126	(68)
Same building	67	(31)	148	(69)
Same worksite	65	(37)	113	(64)
Same town	15	(29)	36	(71)
Same country	52	(24)	164	(76)
Across countries	24	(33)	49	(67)
Don't know	2	(40)	3	(60)
TOTAL	**285**	**(31)**	**639**	**(69)**

[a] Base = 924. Row percentages add to 100, except in cases of rounding error.

[b] n = the number of individuals labelling at least one network channel as used (i.e., either primary, secondary, or checked)

[c] n = the number of individuals labelling no network channel as used.

The degree of the organizational span of people involved in performing work tasks also seems to have very little effect on whether computer networks are used as a communication channel in task performance (see Table 4-19). Among survey respondents, use of computer networks (q.14) decreased only slightly as more organizational boundaries (q.12) were crossed. This trend is consistent with other study results that show less use of networks for interorganizational communication, although the relationship here between network use and organizational span appears weaker.

The result of the analyses of task group size, geographic span, and organizational span presented in Tables 4-16 through 4-19 suggest that use of computer networks remains fairly

4-19. Organizational Span of Task and Network Use[a]

Organizational Span of Task Group	Networks Used as a Channel In Task Performance[a] n	(%)	Networks NOT Used as a Channel In Task Performance[b] n	(%)
Same workgroup	58	(34)	111	(66)
Same department	46	(34)	91	(66)
Same division	45	(34)	89	(66)
Same organization	51	(31)	113	(69)
Across organizations	83	(27)	230	(74)
Don't know	2	(29)	5	(71)
TOTAL	**285**	**(31)**	**639**	**(69)**

[a] Base = 924. Row percentages add to 100, except in cases of rounding error.

[b] n = the number of individuals labelling at least one network channel as used (i.e., either primary, secondary, or checked)

[c] n = the number of individuals labelling no network channel as used.

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consistent within each of these variables (Chi-square tests were performed on these data and revealed, as expected, no significant relationships). These aspects of task performance in engineering work, in other words, appear to bear little relation to network use.

Other situational aspects of the performance of a particular task were also explored in the mail survey as possible factors governing the use of computer networks in aerospace engineering work. Respondents were asked to report their main reason for choosing the primary communication channel they used in performing the critical incident task (q.15), by either selecting a reason from a pre-coded list of responses or supplying some other reason of their own. Looking at responses across all tasks, "it allowed for most complete expression, interpretation, or interaction in information flow" and "it was the quickest way to accomplish the task" were each cited by about one third of respondents. Between five and ten percent of respondents selected the reasons "it allowed for the greatest accuracy of information flow," "it's what everyone involved was set up for," and "it was the most reliable." Fewer than three percent of respondents selected the reasons "preferred mechanism not available," it allowed for the most presentable expression of information," "tradition demanded it," "it required the least effort on my part," and "it was cheapest."

Table 4-20 presents selected data on the reasons that different communication channels were used in performing work tasks. The reported reasons for using computer networks were very similar to the reasons cited for using more traditional communication channels. As with all other communication channels except face-to-face and mail, the reason cited most often for the use of computer networks to access people, information, or computers was that networks were the quickest way to accomplish the particular task at hand. Other prominent reasons for computer network use were that networks were perceived as allowing for the complete expression of ideas, and allowing access to accurate information. Network use also appears to be linked to how ubiquitous its availability among task group members is, as "it's what everyone was set up for" was cited as a significant reason for using networks to access people and computers.

A more complete picture of why different communication channels are used by aerospace engineers in different situations is gained by examining the results of the "Message Analysis" portion of this study's site visits/interviews (see section 3.3.4.2). In this activity, interviewees described a particular communication incident and provided reasons for their use of the chosen communication channel. Typical characteristics of messages relayed via e-mail were that they were: short and simple queries, descriptions, or announcements; relayed to a computer system staff person; intended for distribution to a wide audience. The most common reasons cited for the use of networks in particular communication incidents were that: the sender knew that the recipient was a regular user of electronic communication channels; the sender knew that the recipient was unlikely to be reached at that particular time and/or unlikely to be brought into

4-20. Top Reasons for Use of Various Communication Channels in Performing Specific Work Task

Primary Channel Used In Task	% of Respondents Using Each Channel Who Identified Each of the Top Three Reasons for Use[a]	
Face-to-Face	Most complete expression, interpretation, interaction	53
	Quickest	27
	Allowed greatest accuracy	7
Examining Printed Material	Quickest	29
	Most complete expression, interpretation, interaction	18
	Allowed greatest accuracy of information flow	16
	What everyone was set up for	16
Direct Examination, Testing	Quickest	29
	Most reliable	22
	Allowed greatest accuracy of information flow	22
Network Access to People	Quickest	46
	Most complete expression, interpretation, interaction	18
	What everyone was set up for	18
Network Access to Information, Data	Quickest	50
	Allowed greatest accuracy of information flow	24
	Most complete expression, interpretation, interaction	16
Network Access to Computer	Quickest	39
	Most complete expression, interpretation, interaction	18
	Most presentable expression of information	18
	What everyone was set up for	18
Telephone	Quickest	50
	Most complete expression, interpretation, interaction	23
	Preferred mechanism not available	9
US or Internal Mail	Most complete expression, interpretation, interaction	67
	What everyone was set up for	33
Fax	Quickest	48
	Preferred mechanism not available	14
	Greatest accuracy of information flow	10
	Most complete expression, interpretation, interaction	10
	What everyone was set up for	10

[a] Base varies for each channel. In the case of tie scores on reasons for use, all reasons are listed.

contact serendipitously; a record of the communication was desired; it was the most efficient way to relay the message (e.g., faster to transmit, allowed sender to address and dismiss problem immediately, easier to transmit identical message to multiple recipients, eliminates telephone tag if sender knows that recipients won't be able to respond to message without first checking other information); or the content of the message was simple or required precision.

As described by interviewees, telephone communication tended to incorporate discussion, clarification and/or explanation, especially of complex technical problems; requests or orders that were difficult or unpleasant; or an initial contact with someone never met before or about a new task or project. The most common reasons reported for the use of the telephone in a particular communication incident were: it was the quickest means to communicate; immediate contact/response was desired; geographic distance separated sender and recipient; the sender anticipated the need for a dialogue (i.e., that a series of questions and answers would ensue and that some flexibility in setting the direction of the conversation was desired); that the interaction would involve opinion, explanation of a complex topic, or a topic that was emotionally or politically "touchy"; or that only a simple, short response was required.

The face-to-face interactions described by interviewees seemed to differ somewhat from that of electronic or telephone communications. The distinguishing characteristics of face-to-face interactions were that they tended to involve: multiple participants; lengthy, multi-topic, and multimedia discussions; and highly emotional (especially conflict resolution) or purely social content. The most common reasons advanced for relying on face-to-face communication were: physical proximity; the need to incorporate a variety of graphics, objects, documents; serendipitous contact; the need for group integration or consensus- or identity-building; the informality/triviality of the exchange; the need for in-depth discussion; the preference for personal contact, especially in very emotional situations. The first two reasons were often put into the context of convenience and efficiency.

4.5.4. Work and Networking Environment and Network Use

General descriptions of one's work and networking environment were solicited from mail survey respondents as another means of exploring factors associated with network use. One questionnaire matrix asked respondents to report the extent to which they agreed or disagreed with a number of statements describing their work and networking environments (q.20). Comparing the responses of network users to those of nonusers reveals relationships between network use and various factors (see Tables 4-21 and 4-22). Considering factors related to work environment, a significantly greater percentage of network users, compared to nonusers, agreed that their work results are stored in computerized form, they require a diverse range of information from a wide variety of sources, time pressures in their work are tremendous, their work is integrated with the work of others, the products they design are highly complex, and their field is extremely competitive. A significantly greater percent of network nonusers, as opposed to users, agreed that they spend their day working independently, all the people they need to communicate with are in their building, and their work is routine and predictable.

Significant differences between the networking environment of network users and nonusers also appear to exist. The accessibility of a networked computer is strongly associated with network use, as is the availability of networked applications well-suited to one's work. Organizational reward, external demand, the existence of relevant networked resources, knowledge of relevant network services, and formal training and support programs are also significantly associated with network use among this survey's respondents. Interestingly, more network users than nonusers agreed that networking is unreliable and that many incompatible systems exist. These results suggest that those who have never used networks, perhaps, are simply more optimistic about network capabilities.

4.5.5. Aerospace Engineers' Perceptions of Factors Encouraging or Discouraging Network Use

Mail survey respondents were also asked two open-ended questions designed to elicit factors

Table 4-21.
Factors Related to Network Use: Work Environment[a]

Factors	% of USERS Agreeing with Statement[b]	% of NONUSERS Agreeing with Statement[b]	Standard Error of the Difference	Critical Ratio/ Signif.[c]
Results of my work are stored in computerized form	67	40	.0455	5.935***
I spend my day working independently	42	63	.0453	4.640***
I require a diverse range of information from a variety of sources	84	65	.0432	4.403***
Time pressures are tremendous in my work	76	59	.0451	3.771***
The results of my work are integrated with the work of others	89	76	.0045	2.917**
All the people I need to communicate with are in my building	14	26	.0398	3.015**
The products I design, develop, or produce are highly complex	69	59	.0456	2.196*
I work in a field that is extremely competitive	69	59	.0456	2.196*
My org. is hierarchically structured	48	41	.0461	1.520
My work is routine, predictable	7	13	.0304	1.974*
Results of my work are proprietary	49	55	.0465	1.290
I often examine physical devices, instruments, materials, processes...	59	62	.0554	.542
Work discussions require having documents, devices ... all in hand	67	66	.0442	.226
My work is classified	22	21	.0381	.262

[a] Base = 893 (Users =758; Nonusers = 135), which includes neutral and missing responses for the matrix on work and networking environment (q.20), but does not include the 57 respondents who did not answer the question on network use (q.4).

[b] Groups together "Agree somewhat" and "Agree strongly" responses from the survey.

[c] Test statistic is the critical ratio, i.e., the difference between the two independent proportions (users and nonusers) divided by the standard error of the difference between the proportions, with critical values of 1.96 (to establish significance at the .05 level), 2.58 (to establish significance at the .01 level), and 3.30 (to establish significance at the .001 level. An asterisk (*) indicates that $p < .05$, or the difference between users and nonusers is significant at the .05 level would occur by chance 5% of the time or less). Two asterisks (**) indicate significance at the .01 level. Three asterisks (***) show significance at the .001 level.

Table 4-22.
Factors Related to Network Use: Network Environment[a]

Factors	% of USERS Agreeing with Statement[b]	% of NONUSERS Agreeing with Statement[b]	Standard Error of the Difference	Critical Ratio/ Signif.[c]
A networked computer is easily accessible to me	77	15	.0343	18.064**
Networking is not seamless ...	61	21	.0393	10.184**
Existing network applications are well-suited to my work	44	16	.0363	7.705**
Network use is actively encouraged, rewarded by my organization	35	11	.0320	7.496**
All the people, tools, resources I need are on the network	16	4	.0215	5.585**
I know all about networked information services relevant to my work	19	7	.0262	4.584**
Customers, clients, sponsors are demanding that I use networks	20	9	.0286	3.847**
Network transmission is unreliable	15	5	.0228	4.385**
I like to learn new computer things just for fun	65	56	.0461	1.952
Networking help comes from formal training or support programs	25	16	.0353	2.553*
Lack of network'g experience makes it hard to predict costs, benefits	45	36	.0451	1.996*
Networking requires too much effort to learn and keep up with	23	16	.0351	1.997*
I started my professional career without networks	88	84	.0351	1.187
Network costs outweigh benefits	11	12	.0302	.331

[a] Base = 893 (Users =758; Nonusers = 135), which includes neutral and missing responses for the matrix on work and networking environment (q.20), but does not include the 57 respondents who did not answer the question on network use (q.4).

[b] Groups together "Agree somewhat" and "Agree strongly" responses from the survey.

[c] Test statistic is the critical ratio, i.e., the difference between the two independent proportions (users and nonusers) divided by the standard error of the difference between the proportions, with critical values of 1.96 (to establish significance at the .05 level), 2.58 (to establish significance at the .01 level), and 3.30 (to establish significance at the .001 level. An asterisk (*) indicates that $p < .05$, or the difference between users and nonusers is significant at the .05 level would occur by chance 5% of the time or less). Two asterisks (**) indicate significance at the .01 level. Three asterisks (***) show significance at the .001 level.

they perceived as encouraging or discouraging network use. Their responses to these open questions augment the matrix results described in the previous section by providing opinions directly from the aerospace engineer's point of view. The content analysis process for summarizing the responses was inductive: the categories were developed from the responses themselves, rather than applying some pre-existing scheme. The presentation of factors related to network use in Tables 4-23 and 4-24, thus, represents only one possible way of summarizing the data. It is possible that another analyst would organize the responses into somewhat different schemes. The tables are arranged with the most commonly mentioned items listed first.

A full 86% (N=816) of survey respondents supplied answers to the question "What are the most important factors that encourage your network use or potential use?" (q.19). These responses were classified into the categories presented in Table 4-23. Most of the responses approach the question in terms of experienced or expected benefits of networks. One major thread running through the comments is efficiency gains, with somewhat less attention given to improved work effectiveness. Information access and handling improvements seem to be a major motivating influence for use, with improved interpersonal communication also seen as an important motivating factor. These data reinforce the responses provided in the survey matrix on factors related to use which were presented above; i.e., the need to integrate one's work with others and acquire a diverse range of information while under great time pressure is naturally related to the emphasis here on efficiency, information access, and communication with others.

The survey question "What do you think are the biggest barriers to network use that you experience?" elicited responses from 87% (N=829) of those completing the survey. Aerospace engineers listed a wide variety of barriers, including technical, cognitive, and social problems (see Table 4-24). The barriers that seemed most prominent in the minds of survey respondents are problems with access, financial costs, the lack of adequate education and training for a workforce that is still largely unfamiliar with computer networks, the lack of uniformity and

Table 4-23.
Factors Encouraging Network Use: Summary of Open Responses[a]

Numbers in parentheses indicate the number of items coded in each category. Examples of items appear in italics.

A. General factors (349)

1. Speed (82)
   Fast
2. Ease of use (72)
   Ease of use. CLEAR steps on screen to aid me through the maze
3. Availability (50)
   Availability of hardware and software
4. Efficiency (44)
   Efficiency
5. Accuracy (25)
   Increase accuracy
6. Convenience (22)
   Convenience
7. Reliability (17)
   Network reliability - no down time
8. General need (16)
   Essential tool
9. Flexibility (11)
   The flexibility it offers
10. Spans geographic distance (5)
    Too lazy to walk to another building
11. General capabilities (4)
    Their capability
12. Usefulness (1)
    It has potential for being extremely useful

B. Improved Information Access (273)

1. General: improved access and retrieval (124)
   Ease of information lookup
2. Speed of information access (58)
   Instant access to data
3. Access to large amount of information (36)
   Vast amounts of info
4. Currency and timeliness of information access (22)
   Accessibility to current information
5. Access to wide variety of information (17)
   Variety of information available
6. Improved accuracy of information accessed and transferred (8)
   Accuracy of data contained therein
7. Access to useful information (5)
   Information very useful in day-to-day operations
8. Access to reliable information (3)
   Instant access to reliable databases

[a] Base no. of responses = 816. Some responses were divided into multiple items (total coded items=1276) that were classified into multiple categories. 56 responses were uncodable (i.e., ambiguous or miscellaneous). Seven responses suggested that no encouraging factors existed.

Table 4-23.
Factors Encouraging Network Use:
Summary of Open Responses (Cont'd)

C. Work Improvements (184)

1. Time savings (79)
   ...quicker than sending a secretary to the library
2. Gains in work efficiency (45)
   Personal belief that a properly executed network would greatly increase my efficiency
3. Improved job performance and productivity (27)
   Long term payoff in productivity
4. Reduction of paper flow (13)
   Minimizing the flow of paper
5. Decrease in workload (9)
   Simplifies and lessens workload
6. Independent task performance (7)
   Minimizes secretarial/clerical need
7. Increase in competitiveness (3)
   Goal of world class competitor demands utilization of networks

D. Improvements in Information Management (158)

1. Information and resource sharing (46)
   Work-group sharing of documents
2. Information transfer (43)
   Ease of data transfer
3. Speed of information transfer (31)
   Ease of quickly transmitting detailed info
4. Information storage (14)
   Storage of large amounts of information
5. Documentation of transactions (14)
   A record of the transaction
6. Updating information (5)
   Easy to update once in system
7. Improved data analysis (5)
   Quality and increased capability of analysis

E. Improved Communication (118)

1. General (38)
   Improves communication
2. Provides more efficient or effective communication alternative (24)
   Organize thoughts and leave message without relying on telephone
3. Faster communication (17)
   The quick response to messages
4. Increases contact with co-workers in and across organizations (16)
   Improved culture, more frequent contact with work force
5. Improves information dissemination (11)
   Greater ease of distribution of updated information
6. Facilitates worldwide communication (6)
   Communication worldwide
7. Real-time exchange (3)
   Real-time exchanges of data, information and ideas
8. More accurate communication (3)
   Messages are transferred without errors the first time

Table 4-23.
Factors Encouraging Network Use:
Summary of Open Responses (Cont'd)

F. Particular uses (50)

1. Used for performing particular task (34)
   Administer airport planning program
2. Use of particular network feature or function (16)
   E-mail

G. Encouraged/required to use networks (47)

1. Organizational (18)
   Management decisions that by God we're going to have it whether it works or not
2. Required for performing particular task (12)
   It's required for printing purposes
3. Co-workers (8)
   Greater use by colleagues
4. Critical mass of use by others (8)
   Required to support our customers
5. Personal curiosity (1)
   Curiosity

H. Financial (35)

1. General: saves money or reduces costs (26)
   Most cost effective
2. Cost of network (6)
   Low cost
3. Less expensive than other communication media (3)
   Avoids postage

I. Improved access to tools, resources and services (34)

1. Access to other tools, resources, services (19)
   Use of physical resources outside my office
2. Access to software (15)
   Access to needed application software

J. Awareness, training and support (28)

1. Awareness/knowledge of network use, resources, or benefits (17)
   Know that it exists and can help
2. Training and support (11)
   Training of users

Table 4-24.
Factors Discouraging Network Use:
Summary of Open Responses[a]

Numbers in parentheses indicate the number of items coded in each category. Examples of items appear in italics.

A. Technical Problems (256)

1. Lack of standardization, uniformity (60)
   Lack of standardization
2. General or miscellaneous technical problems (50)
   Hardware glitches
3. Lack of compatibility (37)
   Lack of upward compatibility with new software and systems
4. Poor network performance, reliability (33)
   Network reliability is still occasionally questionable
5. Systems not user-friendly (32)
   Poorly designed (user unfriendly) systems
6. Problems with human-computer interaction (25)
   Clumsiness of interaction
7. Lack of connectivity (13)
   Inability to interface with networks externally
8. Memory requirements (6)
   TC/IP software without memory conflicts is rare

B. Lack of Access (208)

1. General inadequacy of access or availability (59)
   Limited access
2. Lack of awareness about what's available and how to access it (48)
   Poor communication of what's available
3. Lack of adequate technology (47)
   Equipment not available at our facility
4. Lack of critical mass of users (22)
   Wide scale use of networks by all parties involved
5. Networks not available to all potential users (21)
   Everyone having access to the network
6. Limited access to some networked information (8)
   Not all info open for my access
7. Network overload (3)
   Lack of access to the network proper because of overload

[a] Base no. of responses = 829. Some responses were divided into multiple items (total coded items=1150) that were classified into multiple categories. 25 responses were uncodable (i.e., ambiguous or miscellaneous). Nine responses suggested that no barriers existed.

Table 4-24.
Factors Discouraging Network Use:
Summary of Open Responses (Cont'd)

C. Social/Psychological Barriers (154)

1. Lack of encouragement, interest from managers and peers (56)
   Management's perception of computers as a toy or novelty...
2. Traditional views (36)
   Not the way we have done it in the past
3. Lack of fit with current work processes (16)
   Need to provide data in negotiated format
4. Networks not needed or inconvenient (11)
   Why use it? No perceived advantage prior to this study
5. Fear of computers, the unknown, etc. (9)
   Computer phobia
6. Lack of understanding of benefits (9)
   Ignorance of potential gain from networking
7. Need for face-to-face communication (5)
   Little or no personal interaction
   Conflicts with system administrators (4)
   The tyranny of the network system managers
8. Reliance on paper (3)
   Many specifications and requirements not softcopy
9. Lack of adequate planning (3)
   Lack of complete and coherent site plan
10. Bad experience with networks in the past (2)
    Past experience with difficult systems

D. Financial Costs (139)

1. General (128)
   Cost to smaller companies
2. Cost justification (9)
   Justifying installation expenses, then justifying operating expenses
3. Training costs (2)
   Cost of training

E. Lack of Understanding or Experience (111)

1. Networking (64)
   Lack of experience with using networks
2. Difficulty of gaining needed expertise (26)
   Too complex once I go beyond Quick Mail environment
3. Computers (14)
   Computer hardware knowledge

Table 4-24.
Factors Discouraging Network Use:
Summary of Open Responses (Cont'd)

F. Time-Related Barriers (106)

1. Slowness of network transactions (41)
   Poor response time
2. Time required to achieve competency in using networks (25)
   Too much time on learning curves for large no. of specialized info services
3. System downtime (21)
   Your [sic] at a stand still if the main frame is down. Time wasted
4. General time expenditures in setting up or using networks (19)
   Time taken to set them up

G. Inadequate Education and Training (88)

1. Inadequate education and training (68)
   User education
2. Inadequate documentation and directories (11)
   No "How to Use" manuals
3. Lack of technical support (9)
   Need for computer pros who understand the applications better

H. Security Issues (52)

1. General (32)
   Security considerations
2. Concern for classified information (8)
   Classified materials
3. Concern for proprietary information (6)
   Protection of proprietary work
4. Fear of viruses (4)
   Protection against virsis [sic]
5. Privacy and confidentiality (2)
   Lack of privacy

I. Problems with Network Content (36)

1. Networked information does not meet needs (14)
   Lack of databases which contain the necessary information
2. Unwanted information (9)
   Information overload
3. Lack of quality in networked information (9)
   Availability of excessive un-calibrated information
4. Difficulty in maintaining currency of networked information (4)
   Control of data so that everyone works with the latest data

compatibility among networked systems, and the lack of acceptance and support of networking on the part of managers and colleagues who are reluctant to change the status quo.

During one portion of the interview/site visits that were conducted for this study, participants were asked to identify factors that they thought either encouraged or discouraged their use of networks. Their responses were similar to those elicited by the mail survey (i.e., the same factors were cited, in about the same degree), although they tended to be more specific and centered on particular work occurrences. For example, rather than just saying, perhaps, that networks were not always needed, an interviewee commented that 'I more often use hallway chats and post-its because I'm usually returning a document that I've read at home, with my comments.' This greater specificity may be due to the ability of the interviewer to probe if an initial response was too general.

There were, however, two general topics that arose in interviews to a greater extent than they did in the mail survey. First, interviewees more often included mention of their particular preferences and skills when noting factors that influenced their choice of a particular communication channel, e.g., 'I prefer the phone, because I can talk faster than I can type,' 'I can write faster than I can type, so nets aren't very useful to me,' 'I don't use videoconferences--even though the organization pushes us to--because I 'd rather take a trip,' 'It's too hard to sketch on the computer, so I send faxes,' 'I prefer calling so I can pick up on people's intonations,' 'I used file transfer to make a point... everyone else uses FedEx and I got pissed: this is the 90s and everyone should be using the network for this!' Interviewees also mentioned organizational turf battles and "empire building" more often than survey respondents did as a factor that discouraged use. Interviewees noted several ways that this behavior affected network implementation and use: individual departments would deny access to their systems to particular user groups, departments would fight over financial resources allotted for systems, departments would refuse to work towards achieving greater compatibility of systems.

4.5.6. Summary: Factors Associated with Network Use by Aerospace Engineers

Demographic characteristics are, generally, not strong predictors of network use, although network use appears to be much less common among people under sixty or with less than a year's tenure in the aerospace industry, and to increase with educational level. Network use appears to be less widespread in the private sector than in government and academic spheres, with bench engineers and those engaged primarily in administrative or support work somewhat less likely to use networks than those engaged in research. Use of networks is clearly associated with organization size; smaller organizations appear to have adopted networks to a much lesser degree than have the giant aerospace conglomerates.

Certain task characteristics are only minimally associated with network use. Task group size appears to bear virtually no relation to network use, except that individuals performing tasks independently made somewhat greater use of electronic channels. The geographic dispersion of a task group also appears to bear little relation to network use: network use appears to be slightly greater in tasks spanning several buildings at a single worksite and slightly less likely for task groups spanning the U.S. (interestingly, though, network use for internationally dispersed task groups exceeded use for nationally dispersed groups). Network use appears to be inversely proportional to the organizational span of a workgroup; confirming other survey results, networks were used slightly less in performing tasks that involved interorganizational communication.

Survey respondents claim similar "generic" reasons for using networks as for using other communication channels in performing work tasks, implying that factors associated with use are to some extent situationally-based, e.g., engineers will use whatever channel is most efficient or effective, given a particular task situation. Interview responses elaborate on the nature of situational factors that encourage network use (e.g., short and simple messages, knowledge that intended recipients will read and respond to e-mail) or discourage it (e.g, need to communicate about a complex, ambiguous, or highly emotional topic; need to incorporate multiple formats--graphics, documents, physical devices--into the discussion). Perceived enhancements to the speed of accomplishing work is obviously a factor associated with network use; more survey respondents considered networks--as opposed to face-to-face, examining printed material, mail, or direct examination--to be the quickest means of accomplishing a task. The other most often cited reasons for using networks were the accuracy and completeness of the communication allowed by networks, and the fact that everyone was set up for their use.

A number of factors associated with the engineer's work environment seem to bear a significant relationship to network use, especially the existence of work results stored in digital form, the need to conduct and integrate one's work with others, diverse information needs, intense time pressures, and the need to communicate with people beyond one's own building. Network awareness and accessibility, the availability of suitable network applications and resources, organizational or external encouragement, and formal training programs seem to be the characteristics of the engineer's networking environment that are most strongly associated with use. A traditional, hierarchical organizational structure and the performance of classified or proprietary work seem to have little effect on determining whether an aerospace engineer uses networks. Further, network problems--such as training difficulties, incompatible and unreliable systems, and the difficulty of predicting costs and benefits--are more widely recognized among users than nonusers... while these discourage greater use, perhaps, they seem not to prevent use altogether. When asked for their personal opinions about factors encouraging network use, aerospace engineers most often mentioned efficiency gains, ease of use, improved information access, retrieval and sharing, and enhanced communication capabilities. Factors most often perceived as discouraging use were technical difficulties, lack of access, financial costs, lack of expertise, security concerns, and lack of understanding and encouragement on the part of managers and peers.

4.6. Impact of Networks in the Aerospace Industry

4.6.1. Introduction

This study's final research question asks *"What are the impacts of network use on aerospace work and communication?"* The concept of impact was approached in the mail survey by asking aerospace engineers to report on the extent to which they used networks, to give their summary assessment of network impact on the aerospace industry, to report their perceptions of both the value of networks and the impact of networks on their work, and to provide data on their use of various communications channels which could then be used to explore the manner in which computer networks were substituted for other channels. Each approach sheds a slightly different light on the nature of networking impact on aerospace work and communication. This section reports on the results of each approach separately, adds data from the study's interviews where relevant, and synthesizes the knowledge gained from each source of data.

4.6.2. Summary Assessment of the Impact of Computer Networks on the Aerospace Industry

The impact of networking on the aerospace industry may be considered, first of all, by reviewing the extent of network use by aerospace engineers. Survey results indicate that a majority of aerospace engineers (85%) use computer networks, so the technology has made substantial inroads into this particular work community. But while extensiveness of use indicates an effect, it does little to reveal the nature of that effect or, more specifically, the role that computer networks play in the worklife of the aerospace engineer.

The first question on the mail survey elicited an overall assessment of impact from respondents. The question was placed at the beginning of the survey so answers would mirror the most spontaneous reaction of respondents, before they had worked through an entire survey on network use. The percent of respondents selecting various replies to the question "Overall, how would you describe your current reaction to computer networks?" is presented in Table 4-25.

4-25. Summary Impact Assessment[a]

Response Choices	Respondents n	(%)
They have revolutionized aerospace work	186	(21)
They are very useful in many respects	494	(55)
They have certain worthwhile uses	168	(19)
I am neutral or indifferent to them	34	(4)
I have reservations about their value	11	(1)
They have limited value and can cause serious problems	4	(.4)
They are worthless and should not be implemented	0	(0)

[a] Base = 897 (missing cases = 53). In cases where percentage is between 0 and 1, the decimal percentage is given, rounded to the nearest tenth of a percent.

It is clear that the overwhelming majority of aerospace engineers surveyed perceived the impact of computer networks on aerospace to be positive. While about one fifth of the respondents declared the impact to be revolutionary, about an equal percentage were lukewarm, declaring that the impact of networks varied according to the use to which they were put.

Impact assessments were cross-tabulated with selected respondent characteristics (major job type, branch of aerospace, job function, and size of parent organization) and chi-square statistics generated from the results. Some variation in assessed impact was discovered, with significant variation in assessed impact appearing according to size of parent organization ($X^2 = 58$; DF = 35; $p = .0089$) and, to a lesser extent, according to job function ($X^2 = 78$; DF = 55; $p = .0215$). Table 4-26 presents selected results from the cross-tabulation. It reveals the proportion of respondents in each category who judged the impact of networks on the aerospace industry to be

Table 4-26. Summary of Highest Impact Assessment, by Various Respondent Characteristics[a]

Respondent Characteristics	Respondents Declaring that Networks Have "Revolutionized Aerospace Work" n	(%)
Job Type (n = 882)		
Engineer	81	(20)
Manager	71	(21)
Scientist	13	(28)
Other	20	(23)
Primary Job Function (n = 871)		
Administration	10	(12)
Research	30	(26)
Advanced/Applied Dev.	24	(21)
Design/Product Engineering	30	(15)
Industrial/Manuf'g Engineering	11	(19)
Quality Control/Assurance	12	(26)
Production	0	(0)
Sales/Marketing	4	(9)
Service/Maintenance	7	(30)
Information Processing/Program'g	15	(44)
Teaching/Training	8	(19)
Other	25	(25)
Branch of Aerospace (n = 873)		
Aerodynamics	19	(37)
Structures	19	(19)
Propulsion	17	(21)
Flight Dynamics & Control	8	(16)
Avionics	21	(21)
Materials & Processes	17	(14)
Other	84	(23)
No. of Employees in Parent Org. (n = 688)		
< 50	5	(8)
50-99	1	(6)
100-499	18	(20)
500-999	6	(15)
1000-4999	33	(23)
5000-9995	10	(15)
9996+	65	(25)

[a] Base varies according to number of missing cases and is given in parentheses following each respondent category.

revolutionary. The table suggests that computer networks have had the greatest impact on the work of scientists, people whose primary job function is information processing, people working in the field of aerodynamics, and people employed in very large organizations.

4.6.3. Perceived Value of Networks

The mail survey also explored the impact of computer networks on aerospace work and communication in terms of the value ascribed to them by aerospace engineers. Table 4-27 reports the perceived value of different types of networks by both users and nonusers of each type (q.5). A clear pattern emerges in respondents' views, with the perceived value decreasing as the scope of the network type expands beyond the engineer's immediate community. Local networks, defined as connecting the user to people and resources within one workplace building, were perceived as having "great" value to one's work by over half of the respondents. The perceived value dropped off substantially for organizational, external/research, and external/commercial networks in turn, each of which represents an ever broader link to those beyond the engineer's immediate group of co-workers. It also appears that a substantial number of people who do not use networks have difficulty imagining the potential value of external networks to their work. Not surprising, nonusers' assessments of the value of different network types were much lower than those of users, either because they had tried using networks and stopped after finding them of little value, or because they had never tried networks and did not anticipate that their use would be of great benefit.

Mail survey respondents also reported their assessments of the value provided by electronic access to work resources (q.6). The value judgments of the actual users of each type of work resource are presented in Tables 4-28 and 4-29. Table 4-28 summarizes the extent to which aerospace engineers perceived that network access to different kinds of people with whom they communicated was valuable in their work. Once again, network access to resources within one's

4-27. Value of Each Network Type
(as Perceived by Both Users and Nonusers of Each Network Type)[a]

TYPE OF NETWORK/ Type of Respondent	Respondents' Assessments of Network Value				
	Great n (%)	Some n (%)	Slight n (%)	None n (%)	Don't Know n (%)
LOCAL (n = 851)					
Nonusers	46 (26)	55 (31)	31 (18)	29 (17)	15 (9)
Users	416 (62)	210 (31)	44 (7)	5 (1)	0 (0)
All Respondents	462 (54)	265 (31)	75 (9)	34 (4)	15 (2)
ORGANIZATIONAL (n = 844)					
Nonusers	54 (22)	79 (33)	39 (16)	41 (17)	29 (12)
Users	326 (54)	208 (35)	57 (10)	7 (1)	4 (1)
All Respondents	380 (45)	287 (34)	96 (11)	48 (6)	33 (4)
EXTERNAL/RESEARCH (n = 787)					
Nonusers	58 (16)	113 (32)	61 (17)	66 (19)	56 (16)
Users	162 (37)	176 (41)	76 (18)	11 (3)	8 (2)
All Respondents	220 (28)	289 (37)	137 (17)	77 (10)	64 (8)
EXTERNAL/COMMERCIAL (n = 716)					
Nonusers	31 (7)	97 (22)	99 (23)	116 (27)	90 (21)
Users	75 (27)	103 (36)	77 (27)	18 (6)	10 (4)
All Respondents	106 (15)	200 (28)	176 (25)	134 (19)	100 (14)

[a] Base varies according to number of missing cases and is given in parentheses following each respondent category. Row percentages add to 100, except in cases of rounding error.

organization appears to be most important to engineers, with about 40% of all respondents indicating that network access to people within their own workgroup or institution was of "great" value. Network access to various kinds of people outside one's organization was considered of "great" value by only about 25% of respondents overall, with electronic access to colleagues in academia or government outdistancing electronic access to clients, customers, and sponsors in perceived value. This last group, in fact, received substantially more "none" and "don't know" responses than any other category of human resource. Engineers without network access were more consistent in their assessments of the potential value of network access to various kinds of people, but appear most anxious to acquire electronic links to people within their own organizations and, to a somewhat lesser degree, to external vendors and suppliers and other colleagues in the private sector.

In general, aerospace engineers judged network access to information resources to be of greater value than network access to people (see Table 4-29). The proportion of respondents rating the value of networked access to information resources they used in their work as "great" ranged from 25% for laboratory notebooks to 60% for computer programs. Other network resources that were considered of "great" value by more than half of the respondents were internal financial data, experimental or test data, and drawings or designs. Most full-text network resources--such as journal articles, equipment or procedures manuals, company newsletters, and manufacturers' catalogues--received the highest value rating from only about 30% of respondents. In general, the value ratings of those with and without access to networked information resources seem more closely aligned than the two group's value ratings for network access to people. And, in contrast to perceptions about network types and the ability to communicate with others electronically, it is those *without* electronic access to a few of the information resources who actually assign the greatest value--or, in their case, potential value--to the ability to access such resources electronically. The lower value ratings by actual users of networked information resources may be due to the difficulty of electronic access and use, which

4-28. Value of Network Access to Human Resources
(as Perceived by Those With & Without Network Access to Each Resource)[a]

RESOURCE/ Type of Respondent	Respondents' Assessments of Value of Net Access				
	Great n (%)	Some n (%)	Slight n (%)	None n (%)	Don't Know n (%)
PEOPLE IN WORK-GROUP OR DEPT. (n = 642)					
No Net Access	14 (26)	18 (33)	13 (24)	6 (11)	3 (6)
Net Access	240 (41)	230 (39)	77 (13)	30 (5)	11 (2)
All Respondents	254 (40)	248 (39)	90 (14)	36 (6)	14 (2)
OTHER PEOPLE IN ORG. (n = 626)					
No Net Access	15 (29)	21 (40)	10 (19)	2 (4)	4 (8)
Net Access	246 (43)	223 (39)	75 (13)	17 (3)	13 (2)
All Respondents	261 (42)	244 (39)	85 (14)	19 (3)	17 (3)
COLLEAGUES IN ACADEMIA, GOV'T. (n = 363)					
No Net Access	11 (18)	25 (42)	17 (28)	2 (3)	5 (8)
Net Access	106 (35)	110 (36)	58 (19)	16 (5)	13 (4)
All Respondents	117 (32)	135 (37)	75 (21)	18 (5)	18 (5)
COLLEAGUES IN PRIVATE INDUSTRY (n = 345)					
No Net Access	17 (22)	32 (41)	20 (26)	5 (6)	4 (5)
Net Access	69 (26)	106 (40)	59 (22)	19 (7)	14 (5)
All Respondents	86 (25)	138 (40)	79 (23)	24 (7)	18 (5)
EXTERNAL CLIENTS, CUSTOMERS, SPONSORS (n = 319)					
No Net Access	31 (7)	97 (22)	99 (23)	116 (27)	90 (21)
Net Access	75 (27)	103 (36)	77 (27)	18 (6)	10 (4)
All Respondents	106 (15)	200 (28)	176 (25)	134 (19)	100 (14)
EXTERNAL VENDORS, SUPPLIERS (n = 319)					
No Net Access	20 (24)	32 (39)	18 (22)	5 (6)	8 (10)
Net Access	62 (26)	90 (38)	52 (22)	17 (7)	15 (6)
All Respondents	82 (26)	122 (38)	70 (22)	22 (7)	23 (7)

[a] Base varies according to number of missing cases and is given in parentheses following each respondent category. Row percentages add to 100, except in cases of rounding error.

4-29. Value of Network Access to Information Resources
(as Perceived by Those With & Without Network Access to Each Resource)[a]

RESOURCE/ Type of Respondent	Respondents' Assessments of Value of Net Access: Great n (%)	Some n (%)	Slight n (%)	None n (%)	Don't Know n (%)
DOCUMENT CITATIONS, ABSTRACTS (n = 336)					
No Net Access	25 (37)	2 (32)	17 (25)	2 (3)	2 (3)
Net Access	106 (40)	112 (42)	37 (14)	9 (3)	4 (2)
All Respondents	131 (39)	134 (40)	54 (16)	11 (3)	6 (2)
JOURNAL, TRADE MAGAZINE ARTICLES (n = 300)					
No Net Access	35 (33)	35 (33)	24 (22)	8 (8)	5 (5)
Net Access	50 (26)	75 (39)	36 (19)	20 (10)	12 (6)
All Respondents	85 (28)	110 (37)	60 (20)	28 (9)	17 (6)
MANUALS (n = 301)					
No Net Access	27 (29)	26 (28)	29 (31)	7 (7)	5 (5)
Net Access	57 (28)	80 (39)	43 (21)	16 (8)	11 (5)
All Respondents	84 (28)	106 (35)	72 (24)	23 (8)	16 (5)
INTERNAL TECHNICAL REPORTS (n = 364)					
No Net Access	33 (37)	29 (33)	21 (24)	2 (2)	4 (5)
Net Access	106 (39)	103 (38)	44 (16)	12 (4)	10 (4)
All Respondents	139 (38)	132 (36)	65 (18)	14 (4)	14 (4)
COMPANY NEWS-LETTERS, BULLETINS (n = 351)					
No Net Access	16 (25)	19 (29)	18 (28)	8 (12)	4 (6)
Net Access	86 (30)	110 (39)	62 (22)	22 (8)	6 (2)
All Respondents	102 (29)	129 (37)	80 (23)	30 (9)	10 (3)
MANUFACTURERS', SUPPLIERS' CATALOGS (n = 234)					
No Net Access	29 (32)	32 (36)	18 (20)	5 (6)	6 (7)
Net Access	38 (26)	46 (32)	25 (17)	23 (16)	12 (8)
All Respondents	67 (29)	78 (33)	43 (18)	28 (12)	18 (8)

[a] Base varies according to number of missing cases and is given in parentheses following each respondent category. Row percentages add to 100, except in cases of rounding error.

4-29. Value of Network Access to Information Resources (Cont'd)

(as Perceived by Those With & Without Network Access to Each Resource)

RESOURCE/ Type of Respondent	Respondents' Assessments of Value of Net Access									
	Great		Some		Slight		None		Don't Know	
	n	(%)	n	(%)	n	(%)	n	(%)	n	(%)
CODES OF STANDARDS, PRACTICES (= 258)										
No Net Access	28	(38)	19	(26)	20	(27)	3	(4)	4	(5)
Net Access	53	(29)	66	(36)	42	(23)	15	(8)	8	(4)
All Respondents	81	(31)	85	(33)	62	(24)	18	(7)	12	(5)
DIRECTORIES OF PEOPLE (n = 384)										
No Net Access	23	(37)	22	(35)	14	(22)	2	(3)	2	(3)
Net Access	131	(41)	110	(34)	60	(19)	11	(3)	9	(3)
All Respondents	154	(40)	132	(34)	74	(19)	13	(3)	11	(3)
TRAINING MATERIALS (n = 290)										
No Net Access	11	(20)	19	(35)	13	(24)	6	(11)	5	(9)
Net Access	79	(35)	91	(40)	34	(15)	10	(4)	12	(5)
All Respondents	90	(32)	110	(39)	47	(17)	16	(6)	17	(6)
INTERNAL FINANCIAL DATA (n = 271)										
No Net Access	14	(41)	9	(27)	4	(12)	3	(9)	4	(12)
Net Access	124	(52)	73	(31)	27	(11)	7	(3)	6	(3)
All Respondents	138	(51)	82	(30)	31	(11)	10	(4)	10	(4)
PRODUCTION CONTROL DATA (n = 205)										
No Net Access	8	(33)	8	(33)	4	(17)	2	(8)	2	(8)
Net Access	92	(51)	54	(30)	23	(13)	8	(4)	4	(2)
All Respondents	100	(49)	62	(30)	27	(13)	10	(5)	6	(3)
EXPERIMENTAL OR TEST DATA (n = 331)										
No Net Access	30	(44)	19	(28)	9	(13)	5	(7)	5	(7)
Net Access	136	(52)	82	(31)	26	(10)	13	(5)	6	(2)
All Respondents	166	(50)	101	(31)	35	(11)	18	(5)	11	(3)

4-29. Value of Network Access to Information Resources (Cont'd)

(as Perceived by Those With & Without Network Access to Each Resource)

RESOURCE/ Type of Respondent	Respondents' Assessments of Value of Net Access				
	Great n (%)	Some n (%)	Slight n (%)	None n (%)	Don't Know n (%)
PRODUCT/MATERIALS CHARACTERISTICS (n = 260)					
No Net Access	37 (48)	23 (30)	12 (16)	2 (3)	3 (4)
Net Access	80 (44)	60 (33)	28 (15)	9 (5)	6 (3)
All Respondents	117 (45)	83 (32)	40 (15)	11 (4)	9 (4)
TECHNICAL SPECIFICATIONS (n = 342)					
No Net Access	50 (54)	23 (25)	12 (13)	4 (4)	4 (4)
Net Access	115 (46)	90 (36)	25 (10)	11 (4)	8 (3)
All Respondents	165 (48)	113 (33)	37 (11)	15 (4)	12 (4)
DESIGN CHANGE FORMS (n = 193)					
No Net Access	17 (39)	7 (16)	13 (30)	3 (7)	4 (9)
Net Access	66 (44)	43 (29)	26 (17)	9 (6)	5 (3)
All Respondents	83 (43)	50 (26)	39 (20)	12 (6)	9 (5)
LAB NOTEBOOKS (n = 124)					
No Net Access	9 (21)	10 (23)	15 (35)	7 (16)	2 (5)
Net Access	22 (27)	19 (24)	17 (21)	17 (21)	6 (7)
All Respondents	31 (25)	29 (23)	32 (26)	24 (19)	8 (7)
DRAWINGS, DESIGNS (N = 384)					
No Net Access	40 (56)	15 (21)	12 (17)	2 (3)	3 (4)
Net Access	183 (59)	73 (23)	29 (9)	19 (6)	8 (3)
All Respondents	223 (58)	88 (23)	41 (11)	21 (6)	11 (3)
COMPUTER CODE, PROGRAMS (n = 346)					
No Net Access	16 (50)	8 (25)	5 (16)	2 (6)	1 (3)
Net Access	193 (62)	77 (25)	25 (8)	14 (5)	5 (2)
All Respondents	209 (60)	85 (25)	30 (9)	16 (5)	6 (2)

could limit the value of network accessibility.

Table 4-30 reports mail survey responses related to aerospace engineers' perceptions of the value of different network applications (q.7) and presents the responses of both users and nonusers of each application. Nonusers include those for whom a particular network application is not available, as well as those who never use a particular application, even if it is available. In order that value assessments not be colored by a respondent's lack of need for an application that might have no utility, given his or her work responsibilities (e.g., design engineers would declare computer-integrated manufacturing to be of no value in their work if they had no connection at all with the manufacturing process), respondents were given the option of indicating that a particular network application was not applicable to their work. Voice mail and fax were included in the list of applications, for the sake of comparison between CMC applications and other recent advances in telecommunications that would also be part of the suite of communication channels open to engineers.

Ranking applications in order of the proportion of all respondents who perceived them as having "great" value to their work reveals that the five most valuable CMC applications are: transferring data or text files (55%), e-mail (51%), remote login (44%), remote access to data or text files (43%), and accessing or transferring images (38%). Fax was deemed of "great" value by the highest number of respondents overall (77%), and voice mail also ranked high (48%) as a valuable application.

It appears as if assessed value varies with the "generality" of an application; applications such as e-mail and fax that can support virtually any work task are among those applications rated as most valuable, while more single-purpose applications such as EDI and online library catalog searching ranking lower. One the other hand, several more "generic" applications such as electronic bulletin boards and videoconferencing also ranked lower; it may

4-30. Value of Network Applications
(as Perceived by Both Users and Nonusers)[a]

APPLICATION/ Type of Respondent	Respondents' Assessments of Application's Value: Great n	(%)	Some n	(%)	Slight n	(%)	None n	(%)	Don't Know Not Applic. n	(%)
ELECTRONIC MAIL (n = 847)										
Nonusers	56	(23)	78	(32)	34	(25)	23	(14)	53	(22)
Users	378	(63)	168	(28)	50	(8)	2	(.3)	5	(.8)
All Respondents	434	(51)	246	(29)	84	(10)	25	(3)	58	(7)
ELECTRONIC BB's, MAILING LISTS, etc. (n = 796)										
Nonusers	40	(12)	103	(30)	73	(21)	42	(12)	86	(25)
Users	159	(35)	198	(44)	91	(20)	1	(.2)	3	(.7)
All Respondents	199	(25)	301	(38)	164	(21)	43	(5)	89	(11)
REAL-TIME MESSAGING (n = 767)										
Nonusers	49	(10)	101	(22)	118	(25)	68	(15)	132	(28)
Users	133	(45)	88	(29)	71	(24)	7	(2)	0	(0)
All Respondents	182	(24)	189	(25)	189	(25)	75	(10)	132	(17)
VIDEOCONFERENCING (n = 743)										
Nonusers	77	(15)	116	(23)	86	(17)	73	(14)	152	(30)
Users	84	(35)	100	(42)	50	(21)	2	(1)	2	(.8)
All Respondents	161	(22)	217	(29)	136	(18)	75	(10)	154	(21)
VOICE MAIL (n = 788)										
Nonusers	48	(17)	71	(24)	51	(18)	44	(15)	76	(26)
Users	330	(66)	119	(24)	36	(7)	7	(1)	6	(1)
All Respondents	378	(48)	190	(24)	87	(11)	51	(7)	82	(10)
FAX (n = 832)										
Nonusers	22	(29)	21	(28)	6	(8)	9	(12)	17	(23)
Users	619	(82)	115	(15)	18	(2)	0	(0)	3	(.4)
All Respondents	641	(77)	136	(16)	24	(3)	9	(1)	22	(3)

[a] Base varies according to number of missing cases and is given in parentheses following each respondent category. In cases where percentage is between 0 and 1, the decimal percentage is given, rounded to the nearest tenth of a percent. Row percentages add to 100, except in cases of rounding error.

4-30. Value of Network Applications (Cont'd)
(as Perceived by Both Users and Nonusers)

APPLICATION/ Type of Respondent	Respondents' Assessments of Application's Value: Great n	Great (%)	Some n	Some (%)	Slight n	Slight (%)	None n	None (%)	Don't Know Not Applic. n	Don't Know Not Applic. (%)
ELECTRONIC JOURNALS, NEWSLETTERS (n = 724)										
Nonusers	55	(10)	144	(27)	129	(25)	65	(12)	133	(25)
Users	47	(24)	71	(36)	71	(36)	5	(3)	4	(2)
All Respondents	102	(14)	215	(30)	200	(28)	70	(10)	137	(19)
ELECTRONIC DATA INTERCHANGE (n = 710)										
Nonusers	48	(8)	99	(17)	79	(13)	124	(21)	247	(41)
Users	40	(35)	46	(41)	22	(20)	5	(4)	0	(0)
All Respondents	88	(12)	145	(20)	101	(14)	129	(18)	247	(35)
REMOTE LOG-IN (n = 808)										
Nonusers	53	(16)	74	(23)	44	(14)	59	(18)	96	(29)
Users	304	(63)	113	(23)	54	(11)	2	(.4)	9	(2)
All Respondents	357	(44)	187	(23)	98	(12)	61	(8)	105	(13)
REMOTE ACCESS TO DATA, TEXT FILES (n = 743)										
Nonusers	49	(16)	81	(26)	51	(16)	50	(16)	93	(30)
Users	298	(60)	144	(29)	50	(10)	0	(0)	6	(1)
All Respondents	347	(43)	225	(28)	101	(13)	50	(6)	99	(12)
ONLINE BIBLIOG. SEARCHING (n = 754)										
Nonusers	82	(17)	106	(22)	93	(19)	67	(14)	138	(28)
Users	113	(42)	92	(34)	59	(22)	2	(1)	2	(1)
All Respondents	195	(26)	198	(26)	152	(20)	69	(9)	140	(19)

4-30. Value of Network Applications (Cont'd)
(as Perceived by Both Users and Nonusers)

APPLICATION/ Type of Respondent	Respondents' Assessments of Application's Value: Great n	(%)	Some n	(%)	Slight n	(%)	None n	(%)	Don't Know Not Applic. n	(%)
ONLINE LIBRARY CATALOG SEARCHING (n = 736)										
Nonusers	70	(14)	101	(20)	95	(19)	81	(16)	166	(32)
Users	109	(49)	78	(35)	29	(13)	4	(2)	3	(1)
All Respondents	179	(24)	179	(24)	124	(17)	85	(11)	169	(23)
OPERATION OF REMOTE DEVICES (n = 728)										
Nonusers	61	(10)	95	(16)	83	(14)	129	(22)	228	(38)
Users	74	(56)	29	(22)	25	(19)	1	(1)	3	(2)
All Respondents	135	(19)	124	(17)	108	(15)	130	(18)	231	(32)
COMPUTER-INTEGRATED MANUFACTURING (n = 734)										
Nonusers	91	(15)	61	(10)	59	(10)	153	(25)	248	(41)
Users	72	(60)	29	(24)	14	(12)	4	(3)	2	(2)
All Respondents	163	(22)	90	(12)	73	(10)	157	(21)	250	(34)
TRANSFERRING DATA OR TEXT FILES (n = 805)										
Nonusers	57	(25)	49	(21)	29	(13)	31	(13)	66	(28)
Users	387	(68)	132	(23)	48	(8)	2	(.3)	4	(1)
All Respondents	444	(55)	181	(23)	77	(10)	33	(4)	70	(9)
ACCESSING OR TRANSFERRING IMAGES (n = 752)										
Nonusers	72	(17)	92	(22)	43	(10)	64	(15)	148	(35)
Users	212	(64)	81	(24)	35	(11)	1	(.3)	4	(1)
All Respondents	284	(38)	173	(23)	78	(10)	65	(9)	152	(20)

be that the group communication and access to published literature functions are not perceived by aerospace engineers of being of critical importance, or that technology supporting any activity engaged in only intermittently (such as interactive group communication or accessing published literature) would be perceived as less value to work than technology supporting activities that occurred on virtually a daily basis (such as communicating with another individual or accessing some kind of text or data). Examining only the responses of users of each application paints a slightly different picture; although the same applications are ranked most highly by the largest number of respondents (with the exception of computer-integrated manufacturing, whose assessed value rises to such a degree that it becomes, with remote access to data and text files, the sixth most highly ranked network application), the proportion of "great" value assessments for each application is much higher.

4.6.4. Channel Substitution

The degree to which a new communication channel supplants traditional means of interacting with others or of creating and transferring knowledge is of interest for several reasons. First, the substitution of one channel for another is an important impact in its own right, often heralding social and economic changes within organizations, communities, or society at large. In addition, an exploration of reasons behind any channel substitution can throw the nature of the communication itself into relief, suggesting how it fits within the larger context of the community being studied and delineating its features more obviously.

In this study, mail survey responses were used to gauge the impact of computer networks in the aerospace industry in terms of their substitution for other communication channels. Survey responses (from q.14 and q.4) were analyzed to compare the degree to which network users and nonusers relied on channels other than computer networks in performing some important work task. The point of this analysis is to identify which traditional channels appear to be most often replaced by computer networks among those engineers who use networks in their work.

According to the results presented in Table 4-31, it would appear that computer networks have not caused aerospace engineers to alter greatly their use of other communication channels. The relative use of various communication channels by network users and nonusers is quite similar. Aerospace engineers who use computer networks seem less likely than nonusers to rely on the telephone in performing work tasks, but that appears to be the only channel substitution that has occurred to any great degree. As has been found in other studies as well, computer use apparently does not reduce the need for face-to-face interactions with other people; in fact, a higher percentage of network users (70%) than nonusers (63%) used face-to-face communication in performing a recent, important work task. While the proportion of network users who employed all other channels was indeed lower than the proportion of nonusers relying on them, the difference was minimal.

If telephones are used for informal communication between individuals, then that is where computer networks would appear to be having the greatest impact. Reductions in phone use could result in cost savings (if long distance charges are replaced by cheaper network costs), and in efficiency gains (as "phone tag" and the need to contact each message recipient individually are eliminated). Social implications could be both positive (e.g., a record of the exchange is left for greater control) and negative (e.g., as one experiences a lack of personal contact).

4.6.5. Perceived Impacts on Aerospace Engineering Work and Communication

The survey also solicited aerospace engineers' assessments of specific networking impacts. In one questionnaire matrix (q.21), respondents first indicated whether they thought networks decreased greatly, decreased somewhat, had no effect on, increased somewhat, or increased greatly each of the aspects of work and communication listed. They then indicated whether they had personally experienced the effect indicated, and whether they considered the perceived networking effect to be a major problem, a major benefit, or neither. Table 4-32 presents selected results from this section of the survey. All "increase greatly" and "increase

Table 4-31.
Substitution of Computer Networks for Other Communication Channels in Performing Work Tasks[a]

(Comparison of the Proportion of Network Users vs. Nonusers Who Utilized Each Channel)

Channel Utilized in Performing Work Task[b]	Network Users n	(%)	Network Nonusers n	(%)	Standard Error of the Difference	Signif.[c]
Telephone	263	(35)	61	(45)	.0462	2.382*
Face-to-face interaction	531	(70)	85	(63)	.0448	1.564
Fax	138	(18)	33	(24)	.0393	1.526
Examining printed material	275	(36)	58	(43)	.0460	1.521
Non-networked computer	89	(12)	22	(16)	.0337	1.484
Internal or US mail	46	(6)	12	(9)	.0261	1.150
Voice mail	57	(8)	12	(9)	.0265	.377
Direct examination, testing	126	(17)	23	(17)	.0350	.114

[a] Base = 893 (missing cases = 57).

[b] Includes all responses indicating that communication channel was utilized (i.e., respondents preceded channel by a "P" indicating primary channel, an "S," indicating secondary channel, or a check mark, indicating use *per se*).

[c] Test statistic is the difference between the two independent proportions (i.e., users and nonusers) divided by the standard error of the difference between the proportions, with the critical value of 1.96 (to establish significance at the .05 level). An asterisk (*) indicates that the difference between users and nonusers is significant at the .05 level (i.e., would occur by chance 5% of the time or less).

somewhat" responses were grouped together and the summary figure reported in the table; the same procedure was followed for all "decrease" responses. Results appear in descending order, with the effects perceived by the greatest percent of respondents listed first. The table also shows the percent of respondents who felt that each network effect represented a major problem or benefit in aerospace work.

A word of caution about interpreting all results stemming from the impacts matrix is necessary. Review of the survey data suggests that many respondents experienced difficulty in completing the "Impacts" matrix, finding the question format too complex and ambiguous to answer easily. As discussed below (and in section 4.8 on reliability and validity of study results), some of the responses appear illogical and, further, several respondents commented explicitly on the difficulty of the matrix. Thus, results should be interpreted with caution; results associated with the most ambiguous items should be viewed with skepticism, and a higher standard of effect size should be applied.

Some of the impacts listed relate directly to information transfer processes themselves, while others represent efficiency or effectiveness gains in work and communication. Other impacts, such as the increased "coherence with one's work community" describe second order effects, which are also important within the general work context. Many of the impacts listed, such as "increases the amount of information available" are generic in the sense that they may be felt by other types of users beyond those in the engineering community.

Over half of the respondents felt that networking produced a "major benefit" in relation to the following aspects of work and communication:

- The amount of information available
- The exchange of information and ideas across organizational boundaries
- The efficiency of contacting people
- The ability to complete projects on schedule
- Responsiveness to customers, clients, etc.

- The ability to stay on the cutting edge of new knowledge
- The documentation, evaluation of work processes
- The ability to communicate with otherwise inaccessible people
- The ability to express problems and ideas at point of need
- The performance of work at home, on the road, off-site
- The feasibility and size of collaborative efforts
- The turn-around time on solving problems.

The two effects cited by the greatest number of respondents deal with information access and exchange. Two of the next most commonly cited impacts signify important efficiency gains. Because most respondents considered the increase in the amount of information available to be a major benefit, it appears as if the problem of information overload does not figure prominently with aerospace engineers. Exchanging information across organizational boundaries--a key tenet of concurrent engineering--would indeed appear to be fostered by computer networks in the aerospace industry.

Of those impacts listed that would provide a direct personal benefit to the individual engineer, it is those related to knowledge transfer that appear to be the strongest (i.e., "ability to stay on the cutting edge of new knowledge" and "ability to express ideas and problems at the point of need"). Impacts related to work flexibility appear next, along with "coherence with one's work community." Finally, only about a third of those aerospace engineers surveyed felt that computer networks increased their status among their peers or contributed to career advancement; on the other hand, virtually no respondents felt that networks had a negative effect on professional status and gains.

Citing the increased turnaround time in solving problems as a major benefit seems counterintuitive, if one assumes that it is always advantageous to solve problems as quickly as possible. This may be an artifact of the general complexity of the matrix format used in this question, as noted above. Some respondents apparently had difficulty with the "decrease/

Table 4-32. Perceived Impacts of Computer Networks: Summary of Matrix Results[a]

	Respondents Reporting Effect Is To:				Respondents Reporting Effect Is a Major:			
	Decrease		Increase		Problem		Benefit	
Aspects of Work and Communication	n	(%)	n	(%)	n	(%)	n	(%)
Amount of information available	18	(2)	771	(87)	20	(3)	562	(76)
Exchange of information, ideas across organizational boundaries	22	(3)	645	(74)	9	(1)	471	(72)
Efficiency of contacting people	36	(4)	609	(70)	23	(3)	434	(64)
Ability to complete projects, develop products on schedule	53	(6)	563	(65)	17	(3)	411	(64)
Responsiveness to customers, clients	17	(2)	563	(65)	20	(3)	417	(65)
Ability to stay on cutting edge of new knowledge	20	(2)	555	(64)	7	(1)	390	(61)
Documentation, evaluation of work processes	31	(4)	557	(64)	14	(2)	388	(60)
Ability to communicate with otherwise inaccessible people	17	(2)	545	(63)	12	(2)	401	(62)
Use of expensive computers and computerized devices	91	(11)	535	(62)	154	(24)	183	(28)
Ability to express ideas, problems at point of need	46	(5)	523	(60)	22	(3)	372	(57)
Need for face-to-face interaction	486	(55)	85	(10)	75	(11)	226	(34)
Performance of work at home, on the road, off-site	18	(2)	463	(53)	18	(3)	315	(51)
Management control	65	(8)	458	(53)	36	(6)	305	(49)
Feasibility, size of collaborative efforts	24	(3)	460	(53)	12	(2)	301	(51)
Flexibility in work structures, patterns	30	(3)	456	(53)	16	(3)	289	(48)

[a] Base varies, according to number of missing cases, which ranged from 66 missing cases (for "Amount of information available") to 89 (for "Flexibility, size of collaborative efforts").

Table 4-32. Perceived Impacts of Computer Networks: Summary of Matrix Results (Cont'd)

	Respondents Reporting Effect Is To:				Respondents Reporting Effect Is a Major:			
	Decrease		Increase		Problem		Benefit	
Aspects of Work and Communication	n	(%)	n	(%)	n	(%)	n	(%)
Coherence with one's work community	70	(8)	454	(52)	26	(4)	283	(45)
Duplication of effort	451	(52)	120	(14)	67	(11)	309	(48)
Ability to complete projects within budget	48	(6)	410	(47)	32	(5)	284	(46)
Turnaround time on solving problems	223	(29)	408	(47)	22	(3)	472	(70)
Major system security problems	29	(3)	372	(43)	267	(45)	27	(5)
Amount of time spent fooling around	79	(9)	372	(43)	182	(29)	58	(9)
Leaks of proprietary or sensitive information	32	(4)	329	(38)	238	(40)	30	(5)
Number of changes required in final products	281	(32)	136	(16)	41	(7)	253	(42)
Degree of status among one's peers	7	(1)	259	(30)	11	(2)	122	(21)
Sense of ownership of, commitment to work product	62	(7)	251	(29)	28	(5)	159	(27)
Rate of career advancement	13	(2)	209	(24)	19	(3)	124	(22)
Communication with people NOT on the network	190	(22)	126	(14)	135	(22)	84	(14)
Number of staff employed	192	(22)	92	(11)	39	(7)	107	(19)

"increase" scale used in that question, applying it rather as the degree of "bad" to "good" influence of networks. But another possible explanation is that some respondents felt that networks allowed for more extensive input into the problem-solving process, which increased the time required to arrive at a solution, but also improved the quality of the solution.

Of the major problems cited, 45% of respondents perceived a risk of system security problems and 40% feared leaks of proprietary information. About 30% of aerospace engineers surveyed felt that the effect of networks on the time that people spent "fooling around" was a major problem while about 20% cited as a major problem the effect of networks on communication with nonusers of networks.

A separate analysis was undertaken to compare network users' and nonusers' responses about the degree of effect of networks on aerospace work. The results indicate little difference in perceived impacts between the two groups, although network users systematically perceived a slightly larger effect than did nonusers for each aspect of work and communication.

An obvious question to raise is: how many aerospace engineers have actually experienced the impacts that were proposed in the mail survey? Table 4-33 provides an answer, reporting the percent of all respondents who claimed to have personally experienced each degree of network impact on the various aspects of work and communication listed. These data suggest that a substantial number of aerospace engineers are experiencing some impact on their work and communication due to computer networks, although the degree of impact experienced, by and large, is not considered great. Over half of the respondents claimed to have personally experienced an increase in the amount of information available. At least a third reported that they had experienced a decrease in the need for face-to-face interaction and an increase in the exchange of ideas and information across organizational boundaries, the efficiency of contacting people, the use of expensive computers and computerized devices, and the ability to express ideas and problems at the point of need. More than a quarter reported having personally experienced an increase in the ability to complete projects and develop products on schedule,

Table 4-33. Impacts of Computer Networks Experienced by Aerospace Engineers[a]

Aspects of Work and Communication	Decrease Greatly n	(%)	Decrease Somewhat n	(%)	No Effect n	(%)	Increase Somewhat n	(%)	Increase Greatly n	(%)
Amount of information available	6	(1)	6	(1)	5	(1)	172	(19)	311	(35)
Exchange of information, ideas across organizational boundaries	2	(.2)	4	(.5)	19	(2)	220	(25)	127	(15)
Efficiency of contacting people	5	(1)	10	(3)	34	(4)	196	(23)	153	(18)
Ability to complete projects, develop products on schedule	6	(1)	20	(2)	25	(3)	191	(22)	82	(9)
Responsiveness to customers, clients	1	(.1)	4	(.5)	28	(3)	175	(20)	86	(10)
Ability to stay on cutting edge of new knowledge	4	(.5)	6	(1)	34	(4)	150	(17)	76	(9)
Documentation, evaluation of work processes	1	(.1)	5	(1)	29	(3)	170	(20)	89	(10)
Ability to communicate with otherwise inaccessible people	3	(.4)	3	(.4)	35	(4)	178	(21)	90	(10)
Use of expensive computers and computerized devices	8	(1)	26	(3)	16	(2)	169	(19)	117	(14)
Ability to express ideas, problems at point of need	6	(1)	18	(2)	28	(3)	192	(22)	120	(14)
Need for face-to-face interaction	48	(5)	247	(28)	69	(8)	26	(3)	15	(2)
Performance of work at home, on the road, off-site	2	(.2)	7	(1)	39	(5)	121	(14)	81	(9)

Respondents Experiencing Each Degree of Effect

[a] Base varies according to number of missing cases, which range from 66 missing cases (for "Amount of information available") to 89 for ("Feasibility, size of collaborative efforts"). Percentages are calculated on the base for each aspect of work listed, i.e., on the number of individuals offering a response for that aspect of work. The "don't know" responses are not reported. In cases where percentages are between 0 and 1, the decimal percentage is given, rounded to the nearest tenth of a percent. Row percentages do not add to 100, because they are calculated on the base of all respondents, not the base of those respondents who had personally experienced impacts.

Table 4-33. Impacts of Computer Networks Experienced by Aerospace Engineers (Cont'd)

	Respondents Experiencing Each Degree of Effect				
	Decrease Greatly	Decrease Somewhat	No Effect	Increase Somewhat	Increase Greatly
Aspects of Work and Communication	n (%)	n (%)	n (%)	n (%)	n (%)
Management control	9 (1)	17 (2)	36 (4)	148 (17)	65 (8)
Feasibility, size of collaborative efforts	0 (0)	4 (.5)	31 (4)	115 (13)	61 (7)
Flexibility in work structures, patterns	1 (.1)	6 (1)	27 (3)	128 (15)	58 (7)
Coherence with one's work community	5 (1)	22 (3)	38 (4)	165 (19)	59 (7)
Duplication of effort	64 (7)	139 (16)	33 (4)	42 (5)	17 (2)
Ability to complete projects within budget	4 (.5)	15 (2)	44 (5)	133 (15)	43 (5)
Turnaround time on solving problems	33 (4)	97 (11)	18 (2)	126 (14)	103 (12)
Major system security problems	2 (.2)	6 (1)	49 (6)	57 (7)	27 (3)
Amount of time spent fooling around	15 (2)	16 (2)	53 (6)	126 (15)	27 (3)
Leaks of proprietary or sensitive information	2 (.2)	7 (1)	44 (5)	58 (7)	19 (2)
Number of changes required in final products	39 (5)	86 (10)	42 (5)	44 (5)	20 (2)
Degree of status among one's peers	2 (.2)	0 (0)	83 (10)	93 (11)	22 (3)
Sense of ownership of, commitment to work product	6 (1)	9 (1)	66 (8)	86 (10)	22 (3)
Rate of career advancement	3 (.4)	2 (.2)	88 (10)	53 (6)	18 (2)
Communication with people NOT on the network	19 (2)	75 (9)	113 (13)	42 (5)	18 (2)
Number of staff employed	9 (1)	63 (7)	68 (8)	32 (4)	4 (.5)

responsiveness to customers and clients, the ability to stay on the cutting edge of new knowledge, the documentation and evaluation of work processes, the ability to communicate with otherwise inaccessible people, coherence with one's work community, and the turnaround time on solving problems. Increases in security problems and leaks of proprietary information, and reduced communication with nonusers of networks, were actually experienced by only about 10% of respondents; close to 20% of respondents, however, said they personally experienced an increase in the amount of time people spent fooling around, due to networks. Once again, these results indicate that computer networks are having a substantial positive effect on the conduct of work in the aerospace industry. The negative effects should also be taken seriously: few organizations would consider a 10% chance of major security problems acceptable.

Although the list of possible network impacts was drawn from the literature and the preliminary site visits/interviews for this and study and, thus, should provide an adequate picture of range of impacts perceived by aerospace engineers, the mail survey also contained an open question on impacts in order to elicit descriptions of effects framed from respondents' own experiences and expressed in their own words. In a section labelled "Concluding the Survey" aerospace engineers were asked (q.31): "What do you most want to convey to network policymakers, service providers, or organizational managers about the impact of computer networks on work and communication in aerospace?" Answers to this question were provided by 601 survey respondents (63%), suggesting that people were interested in expressing their opinions on this matter. Many of their comments dealt only tangentially with impact, in that they offered comments and recommendations about computer networks and how they should be implemented in order to achieve desired results; these results are discussed below in section 4.7. Responses tallied in Table 4-34 include those indicating both actual and potential impacts.

The open responses correspond quite closely with the results derived from the closed responses from the survey matrix, although each question format elicited some unique responses and the examples of impacts presented by engineers in their open responses provide additional

Table 4-34. Computer Network Impacts and Recommendations: Summary of Open Responses[a]

Numbers in parentheses indicate the number of items coded in each category. Examples of items appear in italics.

A. Positive Impacts (226)

1. Enhances productivity, quality of work processes and products (60)
   There is a tremendous improvement in the quality of design work and accuracy of translating designs into manufactured products
2. Improves information access and processing (38)
   a. Improves information access (21)
      *Vastly enhanced capability to access the*greatest* volume of *current* data and doing so in the *least* amount of time*
   b. Improves information storage, updating, transfer, and control (17)
      They are certainly necessary for prompt information flow
3. General (35)
   A very significant positive impact!
4. Improves efficiency (25)
   Increases efficiency
5. Improves communication (24)
   "PROFS", no longer available at my work location, provided a major improvement in communication...
6. Facilitates teamwork, integration of efforts, information and resource sharing (20)
   Networks provide an invaluable link between individuals, work groups, divisions, and subsidiaries within a company
7. Enhances competitiveness (12)
   Greatly needed to stay competitive in the global market
8. Saves money (9)
   Will be highly cost effective
9. Improves quality of worklife, job satisfaction (3)
   People ... can have more flexibility in their work environment

B. Negative Impacts (59)

1. Decreases work efficiency, effectiveness, productivity (22)
   ... we can make further reaching and more complex mistakes than ever
2. Leads to problems in communication (14)
   a. Inadequate substitute for FTF (7)
      Work is becoming too impersonal. Face-to-face discussion and negotiation is disappearing
   b. Other communication problems (8)
      The resources are usually limited and only part of the organization is given access to the network. This creates communications problems between the "haves" + the "have nots"...
3. Engenders security problems (13)
   a. Entails security risks (7)
      The risk of data sabotage is increased by networking
   b. Leads to leaks of proprietary information (6)
      Networking and abundance of proprietary information is allowing economic espionage.
4. Networks are too expensive, not cost-effective (10)
   I don't want to spend more money on Technical/Systems Support than the actual user savings I am anticipating.

[a] Base no. of responses = 601. Some responses were broken into multiple items (total coded items= 897) that were classified into multiple categories. 64 responses were uncodable (i.e., ambiguous, miscellaneous, not relevant, or 'no comment').

Table 4-34. Computer Network Impacts and Recommendations: Summary of Open Responses (Cont'd)

C. Recommendations: User Needs (314)

1. Improve ease of use (154)
   Make them simple and easy to use!
2. Improve awareness, training, and support (79)
   a. Improve education and training (48)
      A greater allocation of training time is required to gain the greatest benefits
   b. Increase awareness of what's available (12)
      Make the services readily available and thoroughly announced. Do not hide the services from potential users
   c. Improve documentation (10)
      ... and provide easily understood instructions on its use
   d. Increase understanding of how best to incorporate network use into work (5)
      ... but people need to be educated on how to restructure their attitudes and approaches to doing work in order to become cost effective in an electronic working environment
   e. Improve network administration and support services (4)
      ... try to have a dedicated system/network administrator
3. Broaden and facilitate access to networks and networked resources (60)
   We need a network not just at work but on the road and at home
4. Gain better understanding of user needs (21)
   a. Incorporate user feedback in design, implementation, evaluation (15)
      ... listen to the users and adapt
   b. Understand functional requirements (6)
      Don't let technology drive functional requirements

D. Recommendations: Management of Networks (142)

1. Resolve security issues (44)
   a. Tighten security (29)
      Security and access control should be highest priority
   b. Don't restrict information and system access unduly (17)
      Stressing security of information and restricting its dissemination will threaten the quantity and quality of available information
2. Resolve resource issues (40)
   a. Make networking affordable (23)
      Development of less costly equipment
   b. Ensure adequate funding and investments (17)
      Don't skimp on hardware and software
3. Better understanding, planning, management of networks is needed (27)
   ... cannot be managed as an afterthought
4. Network implementation and improvement should continue (8)
   Do it!
5. Encourage or require use (6)
   Demand its use once up & running. If nothing more-send all messages out on e-mail
6. Beware of too much policy and politics (6)
   No need for policy
7. Increase understanding of costs and benefits (6)
   Clear cost/benefit relationships are hard to quantify and many investments are made just to "be in style"
8. Improve maintainability and maintenance (5)
   Make it easier to maintain!

Table 4-34. Computer Network Impacts and Recommendations: Summary of Open Responses (Cont'd)

E. Recommendations: Technology Improvements (134)

1. Increase standardization (47)
   Find and use standards
2. Additional technical advances are needed (41)
   a. Increase speed, bandwidth (21)
      Must be fast
   b. Miscellaneous (13)
      Reengineer your functional processor
   c. Graphics/multimedia capabilities (7)
      Need more bandwidth within internet to support digital multi-media communications
3. Achieve greater compatibility, integration across systems (24)
   Too many different systems--none of which talk to one another
4. Increase reliability (15)
   Make them reliable
5. Systems must be flexible (7)
   Must be flexible for specific needs in different organizations

F. Recommendations: Networked Information (24)

1. Improve organization and retrieval mechanisms (12)
   Present systems are time consuming to search
2. Improve range and quality of networked information (12)
   Improve content: meaningful databases, focused BBS's, etc.

specificity. Descriptions of positive impacts outweigh negative ones. (It appears as if aerospace engineers perceive more problems in the appropriate implementation and use of networks than problems resulting from networks *per se*.) Improved organizational integration, efficiency, communication, and information access and handling figure prominently in both open and closed descriptions of positive impacts. Effectiveness and productivity gains are more clearly elucidated in the open responses; and the ability of networks to enhance competitiveness is one key impact that was not addressed at all in the closed responses.

As in the closed responses, security problems appear as the most prominent negative impact, and concerns about the reduction of face-to-face communication are also expressed. The open responses provide a more complete picture of aerospace engineers' concerns that computer network use can hamper work effectiveness and efficiency in various ways, especially if implementation and training do proceed in an optimal manner. Comments in this area included the time wasted as one tried to figure out how to use complex or incompatible systems, the need (or misguided attempt) to fit all work to network applications and constraints, the infelicities and redundancies required because all people and information were not yet online, and the inability of networks to achieve expected or positive results in certain areas, such as enhancing creativity.

The results related to networking impacts that were generated by the mail survey corroborate the comments made by aerospace engineers who participated in the study's site visits/interviews. Dominant positive impacts noted by interviewees were efficiency gains and the ability to share common data and, thus, integrate work. Many fewer negative than positive impacts were mentioned in the interviews. The harmful effect noted most often was the catastrophic effect of downtime, once dependency on computers and networks was established. The loss of human interaction in interpersonal communication was noted by several interviewees. Other negative impacts noted were the creation of new work, and the need to alter existing work procedures. One subject commented, for example, that 'technology completely rewrites requirements and causes new formal procedures,' and another remarked that 'The fact that computers can do a lot of things creates work; it means that the government (our customer) can demand such a fine level of detail that may in the end not be needed or useful.'

One slight difference in results obtained in interviews (compared to the mail survey responses) appears to be an increase in the number of personal, affective comments made. Interviewees seemed a little more inclined than survey respondents to frame their remarks in the first person and to volunteer information from a more emotional perspective. For example, one aerospace engineer commented that 'You feel more empowered, more ownership when you have access; it reduces empire-building and verifies your value and management's trust of you... you feel more part of a team.'

4.6.6. Summary: Impact of Networks in the Aerospace Industry

According to study results, networks are having a significant positive effect on the aerospace industry, although a number of specific negative impacts have been felt, as well. The majority of aerospace engineers appear to consider networks very useful, while some declare the impact to be either revolutionary or of circumscribed utility. Based on their perceptions of overall impact, networks seem to be having the greatest effect on the work of scientists and those engaged primarily in information processing, people working in the field of aerodynamics, and those employed in very large organizations. These are also the areas where network use is most widespread. In fact (and not surprisingly), network value and degree of impact are generally perceived as greater by those people currently using networks. It may be that personal experience convinces one of the merits of networking or, on the other hand, that greater use follows upon successful networking experiences.

The perceived value of various types of networks decreases as the scope of the network expands, with the value of local networks declared to be great by slightly over half of all survey respondents. Indeed, it is network access to internal work resources and co-workers that appears to be of greatest value to aerospace engineers. Access to networked information resources seems to be more highly valued than networked access to people; of the various kinds of information resources, network access to data and drawings was declared more valuable than network access to full-text resources. In contrast to the general association of use with value, those engineers *without* the ability to access some information resources electronically were most likely to tout the value of network access to those resources. The most valuable network applications in aerospace appear to be--in decreasing order--file transfer, e-mail, remote login, remote access to data, and image transfer. Even the most highly rated network application scored substantially below fax, however. Electronic bulletin boards, videoconferencing, electronic journals, and various kinds of online bibliographic searching appear to be of limited value for most aerospace engineers, although results do not explain whether technological failings, lack of need, or some other reason is behind the lack of perceived value for these applications.

Study results suggest the nature and extent of particular networking impacts, both positive and negative, on aerospace engineering work. Impacts seem to be felt to a substantial degree, but effects appear to be neither extreme nor universal. Computer network use seems to be replacing telephone conversations to some extent, but appears to have little effect on the use of other forms of communication. Over half of the aerospace engineers responding to the mail survey claim to have personally experienced an increase in the amount of information available to them, while at least a third report a decrease in the need for face-to-face interaction and an increase in the exchange of ideas across organizational boundaries, the efficiency of contacting people, the use of expensive computers and devices, and the ability to express problems and ideas at the point of need.

A number of impacts perhaps most directly related to improving work performance and productivity were personally experienced by more than a quarter of survey respondents, such as increases in the ability to complete projects on schedule, responsiveness to clients, the ability to stay on the cutting edge of new knowledge, and coherence with one's work community. Security problems and reduced communication with nonusers have been experienced by only about 10% of those surveyed, while about twice as many claim to have felt an increase in the amount of time spent on unnecessary or trivial activities. Responses to an open question on network impact parallel those elicited by the survey's set of closed questions, with improved organizational integration, work efficiency, communication and information access and handling appearing most prominently as benefits. Security problems and reduced productivity due to specific problems with network implementation and use were the negative impacts cited most often.

4.7. Recommendations on Networking Elicited from Aerospace Engineers

About two thirds of the mail survey respondents (n=601) took advantage of an open question inviting them to communicate their thoughts on network impact to policymakers and managers (q.31). Their recommendations reiterate, from a slightly different perspective, the opinions expressed in response to the open questions on factors encouraging and discouraging network use (q.18-19) and create a context for the impacts described, in the sense that the recommendations specify actions to be taken in order to achieve desired impacts and avoid harmful ones.

The content analysis of respondents' recommendations paints a clear picture of what was uppermost in the minds of aerospace engineers as they considered the manner in which computer networks are currently incorporated into the worksite (see Table 4-34). The clustering of the majority of the responses around several suggestions and the vehemence and eloquence of many of individual comments are both noteworthy. The greatest cry among respondents was to improve the usability of networks by, first and foremost by making systems simple and easy to use and, second, by improving the means by which aerospace engineers are trained in network use. A smaller, but still substantial, number of respondents focused quite specifically on the need to incorporate direct knowledge of users' needs into the design and implementation of networked systems. Improved access appears to be a major user need; recommendations in this area included increasing the number of networked stations in the workplace, allowing greater access to workplace systems from remote locations, increasing the number of resources (especially external resources) available on the network, and striving to ensure that network use was incorporated into the jobs of all aerospace workers and not just those in certain fields or occupations.

Achieving standardization and compatibility among systems clearly arises as the major technical improvement demanded by respondents; the multi-faceted and collaborative nature of engineering work seem to demand the ability to transform and transmit information easily to a diverse range of people. Greater bandwidth and reliability were the other technical improvements sought by a significant number of respondents. Security and resource issues appear to be major areas of concern, but, in contrast to the other recommendation categories, suggestions in both of these areas conflict with each other somewhat. While the majority of responses strongly advocated increased security controls, about a third warned against a myopic disregard for the importance of open information access and communication. Recommendations for the best means of dealing with the expense of networking were fairly evenly split between pleas for reduced costs and virtual taunts that organizational managers should stop nitpicking over costs and start focusing on the obvious benefits. A significant proportion of responses were criticisms directed toward workplace managers generally, faulting them for their lack of understanding (both technical and functional) of networks and the basic lack of proper planning and implementation in the realm of networking.

A final topic addressed by a fair number of respondents was the need to improve the content and retrieval of networked information. The less than overwhelming number of suggestions in this area may be due to the general feeling--apparent from other survey data--that existing increases in access to information overshadow the remaining problems. Or perhaps respondents subsumed specific calls for improving network navigation and retrieval under more general comments about making systems more user friendly.

One important impact-oriented theme emerging from the recommendations made by aerospace engineers is the integration of workplace efforts made possible by networks. Without more ubiquitous access, greater expertise in the workforce, and the ability to easily link and transfer information across disparate systems, organizational productivity that depends on coordination and collaboration of individuals and departments cannot be maximized.

4.8. Reliability and Validity of Study Results

Section 3.2.6 described the procedures implemented during the design of study instruments and collection of preliminary data to enhance the reliability and validity of study results. This section reports on reliability and validity checks applied to results obtained in the national mail survey and provides the researcher's assessment of particular threats to the quality of the survey data.

The reliability of the survey data depends on the degree to which survey questions elicit comparable results from all respondents. Questions, and desired response formats, should be clear enough that all respondents supply "correct" answers, i.e, that identical responses in fact represent--at least on the surface--identical opinions or behaviors. Another way of expressing the concept of reliability is that the same responses should be elicited, no matter how many times the question is asked. One mechanism to test the reliability of a questionnaire is to determine whether the same responses were generated by identical questions that appear several times in the survey. This test can be applied, in this study's mail survey, to three survey questions that ask respondents, in slightly different ways, to report on the extent to which computer networks are accessible to them.

The matrix presented in q.5 asks "Is a computer or terminal connected to a local network (one that connects you to people, tools, or information within one building at your workplace) available for your use?" A total of 117 respondents answered "No" to this question. A question where one would expect to see virtually identical responses appears in the matrix on the use of network applications (q.6), where respondents are asked "How often do you access [people in your workgroup or department] via a network?" A total of 116 respondents chose "Not applicable--No network access" for their answer to this question, suggesting a high degree of reliability. A third question also deals with network accessibility, although it is not phrased in a way that results are strictly comparable: one item in the matrix on one's networking environment (q.20) asks respondents to report the extent to which they agree that "A networked computer is easily accessible to me." A total of 126 respondents replied either "Not applicable/Don't know" (n=48) or "Disagree strongly" (n=78) to this question, again suggesting that respondents supplied the same answer when asked the same question in a slightly different guise.

A close examination of patterns in responses to certain survey questions revealed, on the other hand, particular threats to the reliability of results obtained. These threats are due to ambiguities and complexities in the questions themselves. If respondents do not understand a question, they are likely to provide not only inconsistent, but invalid answers. Three questions on the mail survey seemed to pose particular problems for respondents, but in all cases the reliability threats were addressed by the subsequent coding and analysis of the data.

In the survey's critical incident component on aerospace tasks, respondents were asked to identify the two most important communications channels they used in performing an important work task by labelling the primary channel with a "P," and the secondary channel with an "S" (q.14). A close examination of the total number of "P" and "S" responses, as well as individual surveys, revealed that a significant number of people labelled more than the requisite two channels and that some people simply labelled channels with a check mark. Individual coding of each type of label allowed subsequent analyses to be performed and interpreted in a meaningful way; further, an additional code was added to identify which responses were expressed correctly, i.e., included one and only one "P." Only those correct responses were used in the analysis of results to the subsequent question "What was your main reason for choosing the primary channel used?" (q.15).

A number of respondents apparently had difficulty with the more cognitively complex matrices used in the study. This was unexpected, because site visit/interview and pretest subjects expressed the opinion that the matrices were simple to complete (the format of the "Impacts" matrix was revised after pretesting, however, and the revisions apparently raised the level of difficulty). In q.6, for example, respondents were instructed to complete only those portions of the matrix devoted to resources that they actually used in their work. Nonetheless, a fair number of respondents completed matrix items on the use and value of network access to resources which they did *not* check as being used in their work. In order to guarantee that answers could be interpreted in a consistent manner, subsequent analyses of the use and value of networked access to work resources incorporated only the correctly completed responses.

The matrix devoted to the "Impact of Computer Networks" (q.21) seemed to present the most difficulty for respondents. The difficulties became apparent in the recognition of seemingly illogical results, e.g., seven people gave responses indicating that the decrease in major system security problems was a major problem, while 11 people said that the perceived increase in security problems was a major benefit. In some such instances, it is conceivable that respondents were expressing opinions that merely ran counter to the researcher's expectations, e.g., the majority of respondents felt that networks increased turnaround time on solving problems and, further, that this was a major benefit. Review of open-ended responses on impact subsequently offered some explanation of these results, as several respondents suggested that networks allowed more people to be brought into the decision process, which lengthened its duration but increased the quality of the resulting decision. Nonetheless, the complexity of the matrix is undeniable. A small number of respondents even remarked on the question's difficulty explicitly, in their answer to the survey's final open question, which solicited their final comments on research topic and on the survey itself. One respondent wrote, for example, "I got bogged down on 21," and another pinpointed one specific source of confusion with the question "Does increase an aspect mean it is better or worse?" The approach to addressing this threat to the reliability of survey results is to interpret the data with extreme conservatism, putting faith only in results tied to the least ambiguously-worded items and in results indicating very large effects.

Reliability of the coding of the survey's open responses on factors affecting network use and network impacts was assessed by comparing the coding that had been independently performed by the researcher and a student for one of the survey's open-ended questions. For the question on factors encouraging network use (q.19), the researcher revised the codes applied to only 66 (or 5%) of the 1213 items coded by the student as factors, and supplied codes for 28 (or 80%) of the 35 items coded by the student as "no factors perceived by respondent as encouraging use" and for 77 (or 61%) of the items coded by the student as "uncodable." Thus, the two independent coders were very consistent in assigning open-ended responses into the scheme developed for summarizing and analyzing theses results.

The application of the various specific tests of the mail survey's reliability described above leads the researcher to conclude that an adequate level of reliability can be ascribed to the questionnaire results. In those cases where special threats to reliability were identified, mechanisms were put in place to counteract them.

The issue of validity was addressed throughout this study by various efforts, recommended in the literature and described in section 3.2.6, that were designed to ensure, that, among other things: different data sources could be used to triangulate results; study questions were of interest to potential respondents; respondents would be asked to report on their own opinions or recent experiences; and important constructs evolved from interaction with participants in the study's preliminary data collection activities and, hence, genuinely reflected the concerns and terminology of aerospace engineers. These efforts worked towards building confidence that would be both willing and able to supply valid answers to study questions, i.e., that study results would measure what the researcher intended them to measure.

As with reliability, the validity of results obtained in the study can be assessed by applying specific tests to the data obtained. One such test is to look for evidence that respondents found the survey interesting and worthwhile, in which case it can be reasonably assumed that their answers would be both thoughtful and accurate, that the "match" between the questions and the interests and experiences of respondents is good and thus yields valid responses. Given the length and complexity of the survey, the adjusted response rate of 51% itself indicates that the survey struck a responsive chord amongst the sample of aerospace engineers to whom it was sent. The high response rate to the survey's open questions on factors affecting use (about 86%) and impacts (63%) also suggests that the questionnaire addressed issues of interest to respondents, in terms that made sense to them. Surprisingly, even after completing a relatively long and complex survey and having been given the opportunity to express their opinions in open questions, about a third of the respondents said they would be interested in participating in follow-up research related to the study.

Explicit evidence of respondent interest and approval appeared in the survey's final open question (q.32), which solicited any additional comments about the study that people might care to make. Of the 316 responses to this question, 44 expressed negative reactions to the study, 25 of which were complaints about the length of the questionnaire. Thirty-three respondents made favorable comments about the design or usefulness of the study, including "Very thorough!," "I thought this was a very worthwhile and well thought-out study," and "This study seems like a great idea. I am interested in the results."

Another way to both assess and increase the validity of study results is to investigate comparable results obtained from different data sources both within and among study instruments. In the mail questionnaire, the results of several similar questions can be compared;

if responses jibe, then the validity of responses to each question can be assumed and the overall validity of results is raised.

Several comparisons can be made among survey questions focusing on the value of network applications and networked access to resources. For example, 34% of survey respondents considered the value of networked access to document citations and abstracts (q.6) to be "great." A similar question yielded similar results: 29% of respondents judged the value of online bibliographic searching of commercial and government databases to be "great" (q.7). Along the same lines, 54% of respondents indicated that the value of networked access to drawings and designs (q.6) was "great," while 43% were of the opinion that the value of accessing and transferring images (q.7) was "great." The questions being compared are not identical, so one would not expect them to elicit identical responses; given this, the fact that the responses are in the same ballpark suggests that the results yielded are valid. Two questions that address extent of network use also yield complementary results: 85% of respondents declared that they used networks; 88% characterized the extent of networking within their organizations as use by "most" or "some" people.

Comparisons can also be made between the responses given to open and closed questions that address similar topics and issues. Such comparisons have already been made, above, in the presentation of the mail survey's results related to factors affecting network use and to network impacts. In both of these cases, open and closed responses paint similar pictures of respondents' views and experiences. For example, system security problems and leaks of proprietary data were the network impacts noted as major problems by the greatest number of respondents completing the impact matrix. These problems also figured prominently in open responses about negative impacts of networking. Similarly, a major theme in respondents' recommendations for improving networks was to increase standardization and compatibility of systems; in an earlier closed question, 61% of network users agreed that networking was not seamless and that many incompatible systems exist.

There are many other instances in which survey responses to related questions serve to corroborate each other; those noted here provide some indication of the overall level of validity of questionnaire results. The use and comparison of multiple data sources (i.e., data derived from different samples and through the use of different types of instruments) also contributes to overall study validity. Survey results have been compared throughout this chapter to related results obtained in the study's preliminary data collection activities, and the results generated by the different instruments have been found to be comparable. Telephone survey data on extent of network use and variations in use among different segments of the aerospace industry, for example, corroborate data obtained in the mail survey. Interview responses expressing reasons for using and not using networks were very similar to responses generated by the mail questionnaire, lending credence to the belief that the major factors and impacts revealed by the study are indeed valid.

Finally, to test the validity of this study's results, selected data can be compared to other studies of network use in the aerospace industry. In a survey of aerospace scientists and engineers conducted in 1989, Pinelli (1991, p. 320) found that about 54% of respondents used e-mail, about 30% used electronic bulletin boards, 21% used videoconferencing, and 89% used fax or telex. Pinelli's results are comparable to those obtained in this study's mail survey (conducted three and a half years later), which found that 69% of respondents used e-mail, about 54% used electronic bulletin boards or other one-to-many network applications, 29% used videoconferencing, and 90% used fax. Recent survey results on network use in another engineering domain echo those obtained in this study. The 1994 Member Opinion Survey conducted by the Institute of Electrical and Electronics Engineers (IEEE) found that 68% of engineers surveyed used e-mail (Electric Word, 1994, p. 38).

In summary, the reliability and validity of study results are judged by the researcher to be acceptable. They were enhanced by the use of multiple data sources and by the use of early interactions with aerospace engineers to achieve a better understanding of their work, concerns, and vocabulary. Results obtained within the mail survey and across the various instruments used in the study are comparable, and comparison of this study's findings on extent of computer network use are similar to those generated by an earlier study of the aerospace industry. The greatest threats to the reliability and validity of the mail survey are due to its length and to the complexity of some of its matrices; results were analyzed and interpreted in a way, however, designed to minimize the particular problems identified.

CHAPTER 5: CONCLUSIONS

5.1. Introduction

The previous chapter presented this study's findings on the use of computer networks in aerospace engineering work and communication. Results from the various research activities undertaken were described and integrated, and their reliability and validity were assessed. This final chapter summarizes study results and places them within the context of recent developments in network applications and policy. The chapter considers the contribution of the study to existing knowledge about engineering work and communication and to the development of a conceptual framework for studying the use of computer networks by engineers. It also offers recommendations, based on study findings, related to network implementation and use in engineering environments. Finally, directions for further research are suggested.

5.2. Summary of Study Results

Few studies have appeared that examine computer networking in engineering--as opposed to scientific or scholarly work--or that relate electronic communication determinants and effects to the situations and environments of particular communities of users. The current study extends existing knowledge by employing a user-based approach to explore the role of electronic networks in engineering work and communication. It collected data that describe the types of computer networks and applications used in the aerospace industry, the engineering work tasks supported by networks, factors associated with use of networks by aerospace engineers, and impacts of networks within the aerospace industry. Reported in Chapter 4 were key results from the study's telephone survey, site visits/interviews, and national mail survey.

The primary data used to answer this study's research questions came from the national mail survey, a ten-page booklet distributed in the Spring of 1993 to 2000 subscribers to the SAE trade journal *Aerospace Engineering*. Surveys were received from 950 respondents, for an adjusted response rate of 51%. The overwhelming majority of survey respondents were male (97%). The highest academic degree obtained by most respondents was either a Bachelor's (43%) or Master's (34%) degree, as is typical of the engineering profession. The mean age of respondents was 48 years old (with about equal numbers of respondents in their thirties, forties, and fifties), and the mean number of years of professional aerospace work experience was 22. Most of the respondents were employed in private industry (54%) or government (30%) settings, and in an organization with over 1,000 employees (68%). Most characterized themselves as either an engineer (46%) or a manager (39%), and worked in the areas of materials and processes (14%), avionics (12%), or structures (12%). The most common primary job functions reported were those of design/product engineering (23%), advanced/applied development (14%), research (13%), and administration (10%).

Networks appear to be used widely for both communication and computation purposes by engineers in the aerospace industry. The vast majority of survey respondents used computer networks, either personally (74%) or through an intermediary, such as a secretary or librarian (11%). Among network users, intensity of use was fairly evenly distributed among those spending less than 5% of the typical work week using networks (31%), those spending between 6% and 10% of the typical week using networks (22%), and those spending between 11 and 25% of the typical week using networks (21%). Network availability and use diminished as the organizational and geographic scope of the network increased: local area networks were used by 77% of respondents, organizational networks by 66% of respondents, external research networks (like Internet or NSFNet) by 44% of respondents, and external commercial networks (like CompuServe) by 26% of respondents. Similarly, respondents were most likely to use computer networks to communicate with people who were close to them organizationally (in their own workgroup or department) and geographically; use generally declined as distance increased. Further, respondents perceived internal electronic links as being more valuable than external links.

The applications used by the greatest proportion of respondents were file transfer (69%), electronic mail (69%), remote login to access files (59%) or computer programs (57%), and electronic bulletin boards or other types of conferencing systems (54%). Less used applications include those related to accessing published literature, such as electronic journals (25%), online bibliographic searching (32%), or online library catalogs (35%); or special purpose applications, such as electronic data interchange (14%) or computer-integrated manufacturing (15%). The resources most often accessed over computer networks were production control data, computer programs, internal financial data, drawings or designs, and company newsletters.

In performing work tasks, face-to-face interactions were cited by the greatest number of respondents as the primary communication channel used. But use of computer networks as a communication channel was on a par with reading printed material or conducting telephone conversations, and far exceeded fax and regular mail. Computer networks were used most often as the primary channel for performing mathematical analyses, learning how to do something, producing drawings or designs, developing theories or concepts, selecting or designing methods and procedures, and identifying problems. Network use did not vary greatly according to the geographic or organizational span of the task (although network use was reported as slightly more prevalent in accomplishing tasks whose participants were located at a single worksite and slightly less prevalent when tasks spanned divisions or organizations), or according to how many people were involved in performing it (although network use was reportedly most common in tasks performed independently by an individual, while network use remained constant across task performance by groups of any size). The reason most often given for the choice of networks as the primary communication channel was that they were the quickest mechanism available for performing the task. Other common reasons were: that they allowed the greatest accuracy of information flow; that they allowed the most complete expression, interpretation, or interaction; or that they were what everyone was set up for. These were also common reasons for the choice of other communication channels.

Interview results shed additional light on why networks were used in aerospace engineering work and communication. The most common reasons cited for the use of networks in particular communication incidents, for example, included that: the sender knew that the recipient was a regular user of electronic communication channels; the sender knew that the recipient was unlikely to be reached at that particular time and/or unlikely to encounter serendipitously; a record of the communication was desired; and the content of the message was simple or required precision in its expression.

Organizational sector and size, as well as primary job function and educational level, appear to influence network use. According to mail survey results, the greatest use occurs in academia and government and less use occurs in industry and not-for-profit organizations. Network use generally increases with the number of employees in one's organization; it is most prominent among people engaged in teaching, research, advanced or applied development, and industrial engineering and least prominent among people engaged in sales, service, production, administration, and design or product engineering (differences among various job types in intensity of network use also were reported). Use generally increased with educational level. Other demographic characteristics of mail survey respondents do not, generally, seem to differentiate network users from nonusers as well as specific job and organizational environment characteristics. Network use did not vary by gender and did not vary greatly by age (except that those over 60 were much less likely to use networks); use was least likely with survey respondents having spent either less than one or more than thirty years in aerospace.

Considering the work and networking environment of engineers, network use was significantly more likely among mail survey respondents who reported that their work is stored in computerized form, who require a diverse range of information, who experience tremendous time pressures in their work, whose work is integrated with the work of others, who develop complex products, and who work in competitive fields. Network use was also significantly more likely among people who said that a network computer was easily accessible, that network applications were well-suited to their work, that network use was actively encouraged by their organizations, and that customers and sponsors demand network use. Network use was significantly less likely among people who said that they work independently, need to communicate only with people in their building, and perform routine and predictable work. Involvement with classified or proprietary work and a traditional hierarchical organizational structure did *not* distinguish network users from nonusers. Among aerospace engineers, lack of standardization and compatibility across systems, cost, inadequate access, lack of expertise and inadequate training, and traditional views and lack of understanding among managers and peers were the factors most often cited as discouraging use.

The impact of computer networks on the aerospace industry has apparently been overwhelmingly positive, with study participants generally reporting gains in areas of work efficiency and, to a somewhat lesser extent, work effectiveness. Improvements in job satisfaction and career advancement were not highly touted by study participants, and a number of significant problems were also perceived. Impacts seem to be felt to a substantial degree, but effects appear to be neither extreme nor universal. Computer network use seems to be replacing telephone conversations to some extent, but appears to have little effect on the use of other forms of communication. Over half of the mail survey respondents reported having personally experiencing--due to networks--an increase in the amount of information available, which was seen as a major benefit. Over a third reported that they had experienced a decrease in the need for face-to-face communication and an increase in the exchange of ideas across organizational boundaries, the efficiency of contacting people, the use of expensive computers, and the ability to express problems and ideas at the point of need. At least 20% reported that they had experienced a decrease in duplication of effort and an increase in the ability to complete projects on schedule, perform work offsite, be responsive to customers and clients, stay on the cutting edge of new knowledge, maintain coherence with one's work community, exert management control, and complete projects within budget. Nearly 20% had experienced an increase in the amount of time people spent fooling around, and about 10% said they had experienced system security problems or leaks of proprietary information. Responses on network impact elicited by open survey and interview questions emphasized enhanced work productivity and quality, as well as improved organizational integration, communication efficiency, and information access and handling.

As noted in Chapter 4, perhaps the most important impact-oriented theme emerging from the recommendations made by aerospace engineers relates to the integration of workplace efforts made possible by networks. The potential ability of networks to facilitate boundary spanning in organizations was lauded by study participants, but they believed that without more ubiquitous access to networks, greater networking expertise in the workforce, and the ability to easily link and transfer information across disparate systems, organizational productivity that depends on coordination and collaboration of individuals and departments would not be maximized.

5.3. Discussion: Networks and the Engineering Enterprise

The results generated by this study provide some simple guideposts for engineering organizations and policymakers. Baseline data on computer network use, collected throughout the aerospace industry, can help them discern where we are now and where we are (or should be) headed. While characteristics of the aerospace industry (e.g., its high technology and strong R&D base, its emphasis on time to market, the huge financial risks associated with product development, its ties to the defense industry, and the extensive teamwork required) make it unique in some ways, some study results can be applied to other branches of scientific and technical work as well, at least in a general way, by analyzing their similarities and differences with the aerospace enterprise. Further, many study results are aligned with particular characteristics and features of work, allowing their potential generalizability beyond the aerospace realm. For example, the findings that network use is greatest in large organizations and among people whose work must be integrated with the work of others, are likely to pertain to other industries as well. Individual organizations can use study findings to compare themselves to others; they can also benefit from others' experience. This research can help both NII policymakers and workplace managers identify pitfalls and anticipate impacts related to the implementation of computer networks. On a more theoretical note, this study has added to our knowledge of the nature of engineering work and communication, by exploring the relationship between work tasks and the communication practices interwoven with them.

What conclusions can be drawn from study results about the use of computer networks in the aerospace industry? It is clear that the majority of aerospace engineers currently use computer networks, and that use supports knowledge creation, storage, access, and transfer. The combined technologies of computers and telecommunications facilitate the use of computer networks across all of these stages of knowledge transfer--from using remote computer programs to generate designs or produce test results, to accessing production control data, to transmitting memos to workgroup members. While study results indicate that networks are currently more widely used for certain work and communication activities than for others, any discussion of work practices in the aerospace industry must begin from the assumption that networks will play an increasingly important role in the creation and exchange of information, as well as in the design and manufacturing of aerospace products.

It is also clear that policymakers and workplace managers need to take a variety of steps to assure that network use in work performance is not unbalanced, inefficient, or even detrimental to aerospace engineering productivity. Signs of these dangers are evident in study findings and suggest that the implementation of computer networks will remain problematic until clear policy directions are articulated and advanced within the aerospace community. Network use is proceeding apace, but in a piecemeal and largely unexamined fashion. Competing social, economic, political, and technical forces seem to struggle for dominance at the organizational level, where policy lacks coherence and vision. The costs and benefits of network information technologies and services are described by study participants, yet it is also clear that, in most organizations, costs and benefits have yet to be considered in a holistic or programmatic manner that proceeds from a reasoned consideration of fundamental aerospace engineering goals.

How appropriate, in the near term, is the use of computer networks for work and communication in the aerospace industry? Considering first the ability of aerospace engineers to utilize computer networks, survey results indicate that while widespread, network use is far from ubiquitous. Aerospace engineers in small organizations are much less likely to use computer networks than are their counterparts in the nation's largest firms. Network use is also less prevalent among engineers who are older, have just entered the profession, are working in the private sector, or are engaged in work other than research and development. Thus, knowledge created or disseminated via computer networks is likely to bypass these segments of the engineering community; creators of network tools and information resources produced for these groups will have to undertake special efforts to reach their intended users. Conversely, as many respondents pointed out, this lack of complete employment of networks across the aerospace industry has limited the willingness of knowledge producers to add to the industry's digital information base. The primary reasons that networks are not used more extensively include lack of training and awareness, clumsy and incompatible systems, lack of resources, and the inability of workplace managers to resolve fundamental policy issues. These problems suggest that network availability will not equal use. It is not enough for a knowledge producer--whether NASA, professional aerospace societies, an individual engineer disseminating work results, or a firm's librarian--to make information resources available electronically to engineers in the aerospace industry. Nor is it enough for network tools and applications to be put in place in engineering organizations. Attention must be paid by all of the players involved in the knowledge utilization process to removing the myriad barriers confronting the intended user of network tools and resources.

This study found a number of links between network use and the nature of engineering work and communication. One of this study's most striking findings is that informal and internal knowledge is currently much more likely to be exchanged via computer networks than is formal or externally stored knowledge. The nature of an engineering resource itself, in other words, may either encourage or discourage network access to it: fulltext, externally-produced resources (such as journals, manuals, and standards) and external communication partners, for example, are deemed less valuable and are less likely to be accessed over a computer network, even if the means to do so are in place. Internally produced drawings and data, or interpersonal messages that are exchanged within a particular workgroup, are currently used more and perceived to be of greater value by aerospace engineers.

External, published knowledge in digital form may be less used by engineers because of the lack of access to and integration of different network services and the difficulty of learning how to use disparate systems. Publishers have yet to resolve completely issues of copyright management and the conduct of commercial transactions on the Internet and published information is organized and retrieved differently in existing information services. These results suggest that knowledge transfer in the network environment will remain bifurcated for the immediate future, with publishers poorly positioned to disseminate their material electronically to aerospace engineers in a manner that allows easy access and effective use.

The greater use of networks to access internal resources in the form of colleagues, data or text files, computer programs, and images also makes sense when one considers previous research on the nature of engineering work and communication. Key findings from the literature reviewed in Chapter 2 are that engineers create new knowledge through the analysis of data they have generated, that interpersonal communication is extremely important for engineers, that most of this communication is internal, and that visual information is a key component in engineering work. Earlier work emphasizes the importance of informal communication, shared through social networks (e.g., Beveridge, 1957; Cronin, 1982; Garvey, 1979; Ravetz, 1971; and Ziman, 1968), which often supersedes the importance of published literature. The extensive use of electronic mail and the substitution of electronic messaging for telephone conversations found in the current study confirm the importance of social networks in engineering and the basic suitability of current applications for fulfilling the function of informal communication. The continued importance of face-to-face interactions, however, makes it clear that social and technical barriers prevent the simple adoption of networks for all forms of interpersonal engineering communication.

Other studies have found that engineering communities focused on the production of a particular technology are likely to form within institutions and to share goals, norms, and expertise. Allen (1984) and others describing the nature of engineering communities (e.g., Constant, 1984; Vincenti, 1990) assert the importance of shared culture and knowledge in reducing semantic noise and misinterpretation in communication. Their work provides one possible explanation for the reported tendency of aerospace engineers who participated in the current study to use computer networks more extensively for communication with colleagues who were close to them both organizationally and geographically. Spanning institutional and spatial boundaries is certainly an important capability of computer networks, but "cultural" differences cannot be bridged by mere technology.

Recent developments in networking tools and policies may soon have an effect in encouraging greater use of external computer networks, however, especially for accessing fulltext documents. NCSA Mosaic makes browsing complete documents online somewhat more palatable and, due to its availability on different platforms and use of generic retrieval protocols, helps solve the problem of integrating disparate systems. Greater commercial use of the Internet may stimulate technical advances (such as improved security and interoperability) and social changes (such as increased familiarity with "netiquette") that will increase the comfort with which people in different industrial organizations conduct their relationships electronically. And the greater ubiquity of use attendant on such advances is, of course, its own reward, engendering an upward spiral of network value and proliferation.

Other study findings also shed light on the type of engineering work tasks and communication activities for which networks seem most suitable. Survey results indicated that network use varied considerably according to the nature of the task being performed. Network use was greatest in performing mathematical analyses, learning how to do something, producing drawings, developing theories and concepts, and selecting or designing procedures. Networks were used less often by engineers to coordinate work, negotiate with colleagues, and identify resources. As noted in the summary of results presented above, network use also varies according to the type of engineering job one holds, and the nature of one's work environment, including one's information and communication needs. The nature of the situation surrounding a particular communication incident also appears to govern network use. Study results support previous findings that computer networks do not provide a rich enough channel to support such tasks as negotiation, generating ideas, and problem-solving, but that electronic communication is useful for conveying simple information quickly to people who are hard to reach through other communication channels. On the other hand, the assertion that networks are more common in project-based organizations with few security concerns is not confirmed by this study's finding that involvement with classified or proprietary work and a traditional hierarchical organizational structure did *not* distinguish network users from nonusers.

Another important finding about the nature of engineering work and its relationship to network use is that, apparently (and in spite of the importance of networks for facilitating collaboration and communication), the most characteristic use of computer networks in aerospace engineering is still for a lone engineer to connect to a computer to perform some kind of computational task. Survey results suggest, in other words, that networks are used most frequently for tasks performed independently, that computer programs are the networked resource used most frequently, that mathematical analysis is the task most often performed via the network, and that the existence of one's work products in digital form is associated with network use.

In spite of the greater suitability of computer networks for certain tasks and the existing barriers to easy and ubiquitous use, networking among engineers is growing and will no doubt continue to grow. The benefits are already obvious and, in some sense, telecommunications "progress" is relentless. Castells (1991) analyzes the role of information technology in the social and economic restructuring of industrial organizations, cities, and regions. He argues that a new industrial space is emerging, one based on information flows, rather than geographically-defined places:

> By this we understand the deployment of the functional logic of power-holding organizations in asymmetrical networks of exchanges which do not depend on the characteristics of any specific locale for the fulfillment of their fundamental goals. The new industrial space and the new service economy organize their operations around the dynamics of their information-generating units, while connecting their different functions to disparate spaces assigned to each task to be performed; the overall process is then reintegrated through communication systems (Castells, 1991, p. 348).

The majority of mail survey respondents in the current study felt that computer networks increased management control, the exchange of information across organizational boundaries, the feasibility and size of collaborative efforts, the performance of work off-site, and flexibility in work structures and patterns. These findings support Castells' thesis that information technology can produce a shift from large centralized corporations to decentralized networks of different kinds of organizational units, facilitating the establishment of a flexible system of management and production.

While Castells concedes that the social and economic restructuring he describes has obvious advantages, he also fears that isolation and fragmentation of local societies--which are fostered within a particular geographic space--will occur as a result. Could the same detrimental effects perceived by Castells on a societal level also obtain in local engineering work communities? The majority of mail survey respondents in the current study felt that networks increased coherence with one's work community, while reducing the need for face-to-face interaction. Perhaps place is not as socially important in defining one's intellectual or work community. Nonetheless, a number of study participants expressed a growing sense of social isolation as more and more communication occurred online. An interesting issue is the shift in the balance of local relationships due to networks. Local relationships could be cemented as networks allow greater communication with people in other local, functional units, i.e., with those at a particular site who otherwise are virtually inaccessible. Online organizational newsletters, mailing lists, or bulletin boards may also foster a sense of community with a variety of local cohorts. On the other hand, increased interaction with and loyalty to a workgroup or loose community of widely dispersed colleagues might decrease an engineer's sense of "kinship" with the local institution and the people occupying nearby offices.

Boeing offers, today, an example of the kind of decentralized design and production process--based on information technologies--that mirrors Castells' vision and may become commonplace for other aerospace firms in the near future. In 1993, Boeing manufactured its first commercial aircraft based on a completely digital mock-up that was produced by thousands of engineers whose work was coordinated and integrated over computer networks. Computer networks allowed the production of the Boeing 777 to be outsourced to suppliers around the world; experts believe the networked design and manufacturing process resulted in a 20% cost reduction for the company (Office of Technology Assessment, 1994, p. 8).

NASA's development and deployment of networked information resources and services also points the way for others in the aerospace industry. Their prototype NASA Access Mechanism (NAM) is an Internet gateway tool meant to facilitate both interpersonal communication and information retrieval in aerospace engineering (Duncan, Generous, & Hunter, 1993). As such, it provides another example of the decentralization of the function of a particular organizational unit, the library, as information technologies open up an information space that is not dependent on a physical locality. It also represents an attempt to span the traditional boundaries of formal and informal communication that traditionally pertain in the delivery of library services to engineers.

An attractive point and click graphical user interface integrates a variety of functions in NAM: users may search NASA indexing and abstracting databases, locate peers, communicate electronically via electronic mail or bulletin boards, and link to various Internet navigation services, such as Gopher and World Wide Web browsers. The requirements analysis that led to the design of NAM produced results similar to those obtained in this study. Duncan and her colleagues (pp. 39-40) found that colleagues are important in the information search process as well as for providing current, tacit expertise not typically found in formal literature, and that collaboration across disciplines, organizations, and nations is growing. They also concluded that Internet access presents a clear advantage to users but is not uniformly available; that the information sources required by aerospace engineers are extremely diverse; and that access to networked resources must be convenient and provided in a manner that does not interrupt the normal workflow, i.e., networked resources must be accessible from each desktop and intuitively easy to use.

Given Castells' vision of a new industrial space and the network-enabled transformation in communication and work processes represented by Boeing and NASA, how best can an organization promote network use? What factors hinder potential efficiency and effectiveness gains and what drawbacks associated with network use must engineers strive to avoid? By exploring network use from the perspective of individual engineers working in a wide range of settings, this study has suggested which factors are most important in both encouraging and blocking the transition to the effective use of networked channels in accessing the human and information resources needed in engineering work (as modeled in Figure 3-2).

Earlier studies on the choice of communication channels by those engaged in scientific and technical work generally conclude that channel accessibility, quality of the information made available through that channel, ease of use, and familiarity are important determinants of channel selection (see, e.g., Allen, 1984; Gerstberger & Allen, 1968; Kaufman, 1983; and Kremer, 1980). The current study adds to this knowledge by considering a much broader range of factors and eliciting factors from the point of view of engineers themselves. Results generally confirm earlier findings: access, ease of use, and adequate training (somewhat analogous to the concept of familiarity) are important factors in encouraging network use. One important conclusion to be reached from the current study is that network use is still from easy for most people, even those who routinely use computers, have strong technical backgrounds, and work in high tech environments.

Speed of communication--emphasized by this study's survey respondents--was identified as a prominent influence on channel choice by only a few previous researchers (e.g., Holmfeld, 1970). The emphasis on the ability of networked systems to improve accuracy in information exchange seems to parallel earlier consensus on the importance of technical quality in determining the use of particular communication channels and sources. This study identified a range of additional factors associated with network use. Aside from the demographic, situational, work-related, and technical characteristics noted above, organizational encouragement and customer demand also seem to affect network use.

What are biggest potential gains that engineering firms might expect to achieve through networking? And what drawbacks should they strive to avoid? This study found that aerospace engineers perceived the greatest benefits of networking in the realms of increased access to information, an enhanced ability to exchange information across organizational boundaries, and improved work and communication efficiency. Study results offer broad-based empirical evidence to confirm the anecdotal reports and projections offered in earlier literature. Such reports have generally been limited by their authors' experience with only a small number of settings or by the simple fact that projections were offered before the technology had been introduced on a significant scale. Based on personal experience and investigation of several firms, for example, Mueller (1986, p. 74) noted that computer networks "can multiply the effectiveness of a decentralized human network in speed, capacity, and accuracy" and he called for the use of networks to foster "cross-level" communication to improve organizational effectiveness (p. 13).

When applied to the engineering enterprise, the benefits noted by this study's respondents lead to higher quality products, improvements in productivity, and cost savings. Improved job performance appears to outdistance more personal gains, such as those related directly to job satisfaction and reward. Negative impacts were noted by survey respondents in the areas of effectiveness and efficiency (with responses to open-ended questions suggesting that these were due primarily to inappropriate implementation strategies and uses, the likelihood of far-reaching damage as mistakes reverberate throughout the organization, difficulties of use, and the loss of face-to-face communication), security breaches, and massive investments that do not produce adequate returns. Negative social impacts may occur along the lines of those suggested by Castells; in addition, the general sense of frustration when confronted with "unfriendly" systems, little organizational support or training, inadequate access, and colleagues and managers who do not understand networks suggests a very real danger to work satisfaction.

The impact of computer networks on organizational health has been raised in the literature and was explored peripherally in the current study. As discussed in Chapter 2, a number of researchers have noted the organizational maintenance benefits of informal social networks in organizations (see, e.g., Clampitt, 1991; Farace, Monge, & Russell, 1977; Hellweg, 1987). Organizational grapevines allow employees to develop social bonds with co-workers, make comments "off the record," and gather information not available through formal channels. While some fear that this type of casual exchange--especially if the information shared is erroneous--can lead to low morale and poor decisions, the organizational benefits inherent in allowing employees to relax, express opinions freely, and get to know their co-workers better are also widely recognized. Kraut, Galegher, and Egido (1989, draft) found that frequency of communication--via a range of channels--is associated with work satisfaction and efficiency, but that physical proximity is the best technology for supporting the spontaneous, casual conversations needed for group maintenance and socialization.

In this study, organizational maintenance benefits associated with networks did not figure prominently in participants' interview or open survey responses. One survey respondent noted that "[Computer networking] facilitates the amount of *informal* communication in and through an organization. This is *good,* not bad." But comments that specifically alluded to the benefit to an organization of facilitating communication that was not solely task-oriented, or to the suitability of networks for facilitating this kind of communication, were relatively rare. In the mail survey matrix on network impacts, however, the majority of respondents felt that computer networks increased one's ability to express ideas and problems at the point of need, as well as increased coherence with one's work community. These two impacts might be seen as related to the support of organizational health. In the same matrix, 43% of respondents felt that networks increased the amount of time people spent "fooling around." Since this questionnaire item was phrased in a general as well as pejorative fashion, it is difficult to infer whether more positive organizational maintenance functions may have been behind people's responses. When asked in the telephone survey to report the purpose of a recent electronic communication exchange, only 58 of the 417 descriptions of purpose were categorized as "general information exchange" or "social," while 103 were categorized as "administrative" and 155 as "technical" (see Table 3-7), which would suggest that networks are used less extensively for organizational maintenance, as compared to other functional uses. No substantial conclusions about the contribution of computer networks to organizational maintenance can be drawn from the current study. While responses suggest that networks are not prominently used as an informal grapevine--and may even be reducing casual conversations with important maintenance functions in reducing face-to-face communication--it may be that this phenomenon was simply not adequately elucidated by this study's methodology. Even though permission statements were used in the interviews and surveys to encourage study participants to describe the full range of their experiences candidly, it may be that respondents felt it would be inappropriate to describe network uses that might seem trivial.

Negative impacts resulting from the application of inflexible information systems to work that is highly complex and uncertain were suggested in open responses elicited from this study's participants. This threat to the quality of engineering work has been noted by other researchers as well. For example, Henderson's study (1993) of the use of CAD/CAM systems highlights problems that may result when collaborative engineering work practices related to design are automated. Her analysis provides a user-based perspective on the type of networked design initiative carried out by Boeing in the production of the 777 and suggests negative impacts from networking in both social and technical terms. She argues that:

> The representations [sketches, drawings, designs] are the product of and resources for situated practice. The destruction of such visually-oriented situated practices may occur because of a fundamental misunderstanding of their crucial role in the social organization of distributed cognition in team design work. When such fundamental misunderstandings are built into inflexible computer graphics programs designed with the misleading idea of a definable linear process from concept to design to production, then the social mechanisms with ordinarily repairs frequently occurring problems are left out of the process with potentially disastrous results (Henderson, 1993, p. 166).

More specifically, Henderson provides examples from her participant observation of engineering work in several design firms of the importance of sketches and hardcopy designs to the kind of idea generation and negotiation that occur--often across organizational boundaries--in the design process. Two of the major assertions of Henderson's report echo comments made by subjects in the current study's interviews/site visits. Subjects in both studies noted that the process of sketching on paper is often the best way for an engineer to think through an initial idea; viewing, discussing, and editing paper designs in face-to-face group meetings seems to offer the best mechanism for "getting the big picture" and working out problems. Henderson suggests that networked access to computerized designs may serve best as a record-keeping device and concludes that new technologies used in the production of visual images in engineering can affect the work of individuals interacting with the design, the structure of work at the group level as individuals and organizations interact with each other and with the design, and the official job status and responsibilities of those engaged in design work.

Henderson's findings lend further credence to Schö n's (1983) rejection of the model of technical rationality as being appropriate for describing engineering work. Networked systems, apparently, are not generally capable of handling work that is characterized by complexity, uncertainty, and value conflicts. The case studies conducted by Henderson and Schön provide possible insights into why many aerospace engineers, in the current study, emphasized the importance of flexibility in system use and why several survey respondents specifically cautioned against the thoughtless application of computers and networks to all work tasks.

Achieving positive impacts and reducing negative ones depends largely upon workplace managers. Results from the current study indicate, however, that many engineering organizations are less than well-prepared to deal with the consequences of networked knowledge creation and transfer. The complaints and recommendations of survey respondents point to a lack of coherent and visionary management policy regarding system implementation and use. Organizational managers must first be open to innovations in both information technology and communication and work processes. They must achieve a fundamental understanding of networking costs and benefits and of the relationship between business goals and network capabilities. They must involve potential users in the development of appropriate and usable network applications, resources, and policies; and they must provide adequate access and training. Workplace and network managers must promote through social, financial, and technical means--within and among organizations--the ubiquity of use and the integration of networked information resources that are necessary for maximum productivity gains.

Achieving desirable impacts, however, also depends on federal policy decisions and trends in the production of information technology. A recent federal study investigated the nature of the networked enterprise, its impact on economic growth, and the role of government in developing an advanced information infrastructure that could enhance organizational productivity and U.S. economic competitiveness (Office of Technology Assessment, 1994). It offers conclusions that echo those derived from this study, namely that "Information networking technologies will need to be varied, flexible, open, and easily interconnected if they are to serve business and the nation's needs" and that the technology must be widely deployed (p. 2). The report also suggests appropriate private sector and government roles:

> In the context of the National Information Infrastructure, the private sector clearly has the primary role for developing, deploying, and operating the NII. For the most part, industry will develop the technology, provide bandwidth, offer connectivity, and ensure the availability of services and products in the pursuit of profit. Government, however, cannot stand idly by. In its various roles as regulator, broker, promoter, educator, and institution builder, the government must establish the rules of the game and the incentive structure that will help determine private sector choices (p. 4).

Government policies and practices, of course, may also be directed at the consumers of network technologies, e.g., at engineering organizations themselves. Policies, financial support, and R&D that facilitate greater understanding and use of networks in engineering and related firms should all be considered if encouraging the further spread of networked enterprises is held forth as a policy goal.

Peters (1994) summarizes the implications of the current move toward the networked enterprise that this study has shown is already underway for many aerospace organizations. He offers advice for workplace managers that substantially echoes a number of important themes identified by participants in the current study. Peters asserts that the "extent, capacity, and resiliency of [the] enterprise information infrastructure must be a matter of common knowledge and subject of common concern" (p. 26) and that the development of telecommunications technologies, resources and services, and organizational integration efforts must proceed in tandem. Participants in the current study , similarly, argued for the inclusion of all potential users in the implementation process and noted the need for changes in organizational thinking and processes that would parallel the changes in information technology.

Peters also notes that while many people are simply using networks to "automate" their previous work, others have begun to exploit the transformational power of the Internet; he concludes that "this broad and uneven process of social learning is typical of socially transforming technologies" and, thus, that "exploration and discovery are particularly appropriate strategies" for encouraging effective use at both the individual and organizational levels (Peters, 1994, p. 27). Engineers and managers, as respondents in the current study noted, must be open to new ways of doing things and all people must be given ample time to gain familiarity with networks and explore the ways in which networks might support or transform work and communication. Further, this study offers one potentially useful means of vicarious exploration and discovery, in that it allows the reader to gain insight from the networking experiences of a wide range of engineers.

5.4. Towards a Conceptual Framework for Understanding Network Use

This study was based on a particular conceptual model of engineering work and the role of computer networks in that work, which was developed from a review of relevant literature. The model helped frame the study's research questions and the manner in which data were collected and analyzed to answer those questions. One assumption guiding the study was that engineering work and communication tasks involve a situation in which an engineer accesses particular resources within a particular work environment. Another assumption was that the engineering work environment consists of interrelated social, behavioral, and technical aspects (see Figure 1-1). This research was based on the belief that networking should be viewed within the context of engineering work in order to collect useful data for understanding factors and impacts associated with network use, i.e., that the extent and nature of network use would be related to the nature of the aerospace engineer's work and communication activities. Further, it was believed that collecting data from individual engineers about their own experiences and perceptions was critical if one hoped to design networked systems, services, and policies well-suited to their needs. The model and the assumptions underlying it served to describe the phenomena and relationships that would be examined in the study and guided the design of the study's data collection instruments.

How accurate was the model in its assumption that network use would be related to various aspects of engineering work? And how successful was the study's methodological approach in guiding the collection of data that would be useful to those responsible for implementing network systems and policies? An important theoretical conclusion is that the study did identify links between the use of networks in aerospace engineering and 1) individual tasks, 2) specific engineering resources, 3) the nature of engineering work and communication activities performed by engineers, 4) situational aspects of task performance, and 5) certain organizational characteristics. The conceptual model guiding the study, then, proved to be valid in that the move from a non-networked to a networked mode of access for human and other resources (see Figure 3-2) was shown to be influenced by a range of these work-related factors. Thus, study results contribute to theory development: for example, findings indicate not only that network use is related to nature of work, they also suggest specific relationships, such as that network use is more likely among people whose work must be integrated with the work of others.

Integrating study findings that address the broad context of engineering work and are derived from multiple data collection instruments is complex, but the collection of data in this manner on usage, factors affecting use, and impacts gives those hoping to implement networks effectively in their organizations a more realistic view of what to expect and how to proceed. One particular problem in the utility of the study's results, however, is that collecting data across organizations makes pinpointing problems and solutions for a new organization difficult. While results reveal a general agreement that networks are hard to use, they do not suggest particular solutions beyond basic admonitions that greater standardization, better documentation, more training and support, and user-friendly graphical interfaces are needed.

The study's conceptual model of network use within the context of engineering work--which focused on tasks, resources, and the task environment--helped to triangulate and interpret results. For instance the individual findings that mathematical analysis is the task most likely to be performed with a network, that remote login to computational tools is one of most common and valued uses of networks, that computer programs are the most accessible networked resource, that improvements in work productivity were the most commonly named benefit in the open survey question on impact, and that lack of convenient access is seen as major barrier to use converge to portray a coherent vision of factors and impacts associated with a particular use of networks by engineers. Similarly, the overwhelming complaint about the lack of standardization and integration across systems, taken with the finding that the exchange of information and ideas across organizational boundaries is one of the most widely perceived benefits, suggests that remedying this particular problem would result in significant gains for an organization trying to improve coordination across units.

Another methodological conclusion is that questioning about both specific tasks and the general environment yielded helpful results and a better understanding of network use. For example, the first perspective produced the finding that most tasks performed with networks were performed by one person. Yet the second revealed that those working independently are less likely to use networks, generally. Thus, it appears that the need to coordinate and collaborate motivates the use of networks, even though networks are better at enabling the performance of independent tasks.

The methodological decision to include open questions also proved helpful for improving the quality of study results. Open responses provided a way to capture the intensity and specificity of the individual engineer's experience. Interview and, especially, survey respondents, seemed to welcome the chance to express the views and relate their experiences in their own words. Open responses also proved a useful aid in interpreting quantitative results and brought up important information that the researcher had not built into response categories for closed questions (and which was not elicited by the "other" response category for closed questions). For example, as noted above, productivity gains were the most frequently mentioned positive impact in an open question. This critical networking benefit was not adequately represented in closed questions, and so the study's findings would have been misleading if the open question had not been included in the mail survey instrument. Several examples of the forceful and rich responses elicited by the survey question which asked respondents what they were most eager to convey to policymakers, service providers, and workplace managers about the impact of networks on aerospace work are provided below:

> "Networking can certainly improve information flow in the design process. Lack of information is always a big problem in producing a product cheap, fast, and accurate. Usually only two of the three are possible."
>
> Networks have been very helpful--but we need a seamless system--so data can flow quickly and easily. Networks cannot now replace human interaction (especially more than 2 people). My most productive activity is to 'brain storm' a specific problem with a small group of people (3-6) using verbal, written, black board, scratch paper, etc."
>
> "PROFS, no longer available at my work location, provided a major improvement in communication and documentation. It was eliminated because of perceived abuse and cost."
>
> "It is critical that the tail *STOP* wagging the dog; the data systems org. *EXISTS* solely to support the mission. In candor, I cannot be optimistic about this--For whatever reasons, data systems organizations have become entrenched as the *PRIMARY* organization in many, if not most places. Data system people are in fact, not technically trained people in most cases; they can and have caused major foul-ups due to thinking they understand the science involved in projects they 'support.' A perfect example: Fairing the data at the stall of an airfoil smoothly & continuously when the stall is in fact, abrupt, and there is a discontinuity in the fairing" [graph to demonstrate was also drawn].

While quantitative results can be more useful for summarizing the extent of networking in the aerospace industry and the degree to which certain impacts and factors associated with use are felt, the qualitative responses yield greater insight into the nature of particular problems and benefits.

This study's conceptual focus on the network use environment and situations of engineers has contributed to current knowledge about the extent of network use in the aerospace industry and about the multifaceted forces which facilitate and impede the successful implementation of networked systems intended for aerospace engineers. While the nature of the study's method and goals precluded the testing of hypotheses, results nonetheless contribute to our understanding of factors that encourage or discourage the use of networks by the individual aerospace engineer and of the problems and benefits that aerospace engineers are likely to--or could--experience as a result of the implementation of networked systems in their organizations. Through the lens of network use, the study also contributes to knowledge about the nature of engineering work, communication, and communities, in that the tasks, activities, and environments of aerospace engineers were explored at some depth. For example, this research appears to confirm the conclusion of many previous studies that internal communication is more important in engineering work than external communication. To the extent that the work tasks and characteristics of aerospace engineers are shared by people in other professions, study results may be generalizable to other types of network users.

The study's user-based approach has yielded results that have not been achieved in studies that focus more narrowly on economic and technical aspects of networking. Another strength related to the utility of study results is the fact that in-depth data were collected from nearly one thousand respondents in a wide range of aerospace engineering occupations and organizations, providing a useful snapshot of the current state of networking throughout the industry. Thus, study results should affect information technology decisions at both the organizational and national level. The current extent of network use has been described (along with some indication of where use is greatest and why the lack of more ubiquitous use threatens the ability of networks to achieve anticipated benefits); impediments to effective and efficient network use, as well as actions to encourage use, have been articulated by intended users themselves; and the positive and negative impacts actually experienced by a range of aerospace engineers have been articulated.

5.5. Study Implications for the Current NII Policy Framework

Federal information policy developments during the Clinton administration have clearly encouraged the implementation and use of computer networks both within the Federal government and on a national level. The "information superhighway" is a fixture in popular culture, and considerable executive and legislative activity centers on the development of the National Information Infrastructure (NII). As of Fall 1994, the Federal government was pursuing major networking policy initiatives in a number of key areas. Most relevant to network implementation in engineering are efforts to promote:

- Greater access to networks for all citizens;
- The development of standards related to networking;
- Increased network access to government employees and information;
- Reforms in telecommunications regulations;
- Reforms in intellectual property laws; and
- The development of computing and networking applications meant to support science, business, and industry.

Results from the current study offer evidence that such initiatives are needed and are bound to have a great influence on network implementation and use in aerospace.

The latest round of advances in Federal networking policy began with the High Performance Computing Act of 1991 (P.L. 102-194), which established government support for the development of the National Research and Education Network (NREN). Policymakers contended that the high-speed, high-capacity network was designed to provide researchers, educators, and students with links to computer and information resources; its chief aims were to foster U.S. leadership in high performance computing and communications and to promote advances in science and industrial competitiveness (Bishop, 1991). Benefits of the NREN were also expected to be felt in a broader sphere, but in an indirect manner and at a somewhat later point in time. Research and education benefits would eventually make their way to a wider range of disciplines and lower educational levels. General economic prosperity and national well-being would eventually be felt as the U.S. strengthened its superior position in international high technology markets and made rapid advances in cutting-edge science and engineering. Some attention was given to the need to connect schools and libraries, provide NREN information and training services to potential users, and take advantage of the potential of the NREN to improve the dissemination of government information. Cooperation with the private sector in building the NREN was endorsed and important policy issues needing attention were identified, such as protecting intellectual property rights, maintaining network security and privacy, and guiding the transition to commercial use.

In the last two years, however, Federal policy has begun to envision--and to call for--a dramatically more inclusive use of networking capabilities (Bishop and Bishop, in press). Rapid and widespread commercialization of infrastructure and services, broader social goals, greater focus on network application development and on use and users, and community and organizational level participation in networking through Internet connections are now important policy goals. This new vision of a seamless mesh of high performance computing and communications resources that would reach every U.S. community and enhance the life and work of each and every citizen cried out for a new acronym, and the NII was born, with ubiquity and multipurpose use set as new goals for national networking endeavors.

For example, the Clinton administration's *Technology for America's Economic Growth: A New Direction to Build Economic Strength* (Executive Office of the President, 1993, February 22), stresses the need to harness technology, including information technology, to make a difference in the lives of Americans by creating more and better jobs, a cleaner environment, a more competitive private sector, and more vital educational and research communities. Vice President Gore's *Creating a Government that Works Better & Costs Less: Report of the National Performance Review* (1993, September 7) puts substantial emphasis on the use of new information technologies to improve the delivery of government services to the American citizen. The report concludes that the potential for new technologies to make government services more effective and efficient is great, but that affordable, easily accessible, easy to use applications are essential. Equally important is the development of policy and management approaches that are based on a true understanding of the utility and impact of new technologies and that provide incentives for innovation, encourage participation by end users in the design and implementation process, and incorporate a rigorous program of testing and evaluation.

In a report that elaborates on the obstacles and options related to improving government service delivery, the Office of Technology Assessment (1993, September) identifies a range of policy, technology, and management improvements. Chief findings are that the move to electronic service delivery is inevitable, that the Federal government lacks a coherent and innovative vision and strategy, that cost-effectiveness and proper attention to "the human factor" are not assured, that the wide range of existing technologies are underutilized, and that policy and management structures are outdated. OTA's findings and recommendations are relevant to this study for several reasons. First, the findings echo the reports obtained from network users and nonusers in this study and hence provide further evidence that user and management problems are endemic across a wide range of organizations and situations. Second, to the degree that OTA's findings and recommendations apply directly to the delivery of electronic services by NASA and other government bodies that directly serve the aerospace industry (and the findings of this study suggest that they do), OTA's conclusions should be given even greater attention.

Considering the findings of OTA and this study in tandem, it appears that the most important recommendation for the aerospace community lies in the revitalization of the principles and practices of information resources management (IRM). It is clear that innovative, integrative approaches to the management of information, information technologies, and information services are lacking in both government and private sector organizations. Networked systems and services are fragmented, users are forgotten, and organizational transformations are rarely engineered or even understood. Thus, organizational goals are not well-served and networked systems are not realizing their full potential. This study's findings show that OTA's call for leadership and innovation (not to mention increased knowledge and skills related to network technologies) among those charged with managing information resources within an organization, enduser involvement, directories of electronic resources and services, and the preliminary evaluation of new networked systems, should be applied with equal force to governmental and other organizations in aerospace.

The proposed National Information Infrastructure Act of 1993 (H.R. 1757), which passed the House on July 26, 1993, exemplifies the current policy trend toward ubiquity and multipurpose use of computer networks in both its name and nature. The bill amends the NREN portion of the High Performance Computing Act of 1991 to more clearly define and establish the government's national networking program; while the earlier NREN legislation emphasized infrastructure R&D and deployment, the new bill complements and extends this policy by focusing on the development of applications and training to make sure that the network infrastructure is put to good use in both the public and private sectors. Funds authorized to support the bill's provisions increase from $102 million in FY94 to $400 million in FY98. Similar NII legislation was passed in the Senate in March, 1994, in the form of the National Competitiveness Act of 1994 (S. 4), which includes a section (Title VI) on information infrastructure and technology. The Senate and House bills were combined as H.R. 820, but that bill died in conference committee at the end of the 103rd Congress.

The proposed Communications Act of 1994 (S. 1822) was the primary instrument prepared by the legislative branch in support of telecommunications regulatory reform; it, too, failed to become law in the 103rd Congress. The bill required all common carriers to contribute to a universal service fund, opened up new avenues of competition between local and long distance telephone companies as well as between telephone and cable TV companies, and reserved a small portion of telecommunications capacity for public uses. While the ultimate impact of such reforms on the use of computer networks in the aerospace industry is virtually impossible to predict, the intended results of broader, cheaper access to telecommunications infrastructure and services would be of obvious benefit. Respondents in this study noted both the lack of ubiquitous access to networks among aerospace engineers and the prohibitive costs of installing and maintaining network infrastructure. Those most often by-passed were employees in smaller aerospace firms.

Although the most crucial pieces of legislation related to NII application development and telecommunications reform were not passed into law in 1994, they will undoubtedly influence the development of subsequent legislation and the debate that will surround it. The policy trend toward encouraging the broader use of computer networks through application development, increased competition among telecommunications carriers, and universal access will undoubtedly continue.

Executive branch activities related to national networking have also increased in pace and visibility over the past several years. President Clinton has brought together representatives from key federal agencies to form a National Information Infrastructure Task Force (NIITF), under the direction of the Secretary of Commerce. The task force, in concert with various other advisory groups, is to play a major role in shaping federal NII policy. It has formed working groups devoted to several critical policy areas, such as universal service, intellectual property rights, privacy, and government information. The Clinton administration released a statement elaborating its NII agenda (Executive Office of the President, 1993, September 15), in which the NII is defined as an amalgam of technology, applications and software, standards and transmissions protocols, the people who will develop the infrastructure and provide services (primarily in the private sector), and information. The administration's stated objectives for the NII are to (Tab A, p. 1-2):

- Promote private sector investment;
- Extend the concept of universal service to ensure that information resources are available to all people at affordable prices;
- Act as a catalyst to promote technological innovation and new applications;
- Promote seamless, interactive, user-driven operation of the network infrastructure;
- Ensure information security and network reliability;
- Improve management of the radio frequency spectrum;
- Protect intellectual property rights;
- Coordinate with other levels of government and with other nations; and
- Provide access to government information and improve government procurement.

These objectives are to be achieved not only through government investments but through the reform of relevant regulations and policies. The Clinton administration's vision for the widespread use of networks in U.S. industry is clear :

> Electronic commerce (e.g., on-line parts catalogues, multimedia mail, electronic payment, brokering services, collaborative engineering) can dramatically reduce the time required to design, manufacture, and market new products. "Time to market" is a critical success factor in today's global marketplace. [Electronic] commerce will also strengthen the relationships between manufacturer, suppliers, and joint developers. In today's marketplace, it is not unusual to have 12 or more companies collaborating to develop and manufacture new products (Tab C, p. 3).

Results from the current study suggest that this depiction of network use and benefits is especially applicable to the aerospace industry. Study respondents, however, also provided ample evidence that issues of standardization, user awareness and support, security, cost, and the development of applications well-suited to engineering work must be more adequately addressed before widespread use and benefits are felt among aerospace engineers.

The research uses envisioned for the NII also apply to aerospace engineering work, which clearly encompasses basic scientific endeavors. Mentioned in Clinton's agenda are the design and simulation of next-generation aircraft; remote access to scientific instruments; and support of research collaboration through network access to databases, computational resources, shared documents, digital libraries, and geographically-dispersed colleagues. The role of advanced information technologies in promoting large-scale, interdisciplinary research is elaborated more fully in a report on "national collaboratories" produced by the National Research Council (1993).

Findings from the current study contribute baseline data on the extent to which networks are currently deployed in the aerospace industry, an industry prominently mentioned in NII policies because of its strategic scientific, technical, and economic importance. This study has provided ample evidence that computer networking can improve productivity in the aerospace industry. Federal networking and STI policy, as well as the policies and practices of NASA and other agencies crucial to the conduct of work in the aerospace industry, must develop mechanisms to facilitate use, if the desired gains are to be achieved. Study results indicate that, for some aerospace engineers, the NII vision is rapidly becoming a reality. For many others, however, major barriers still inhibit their ability to take full advantage of networking. Network functionality is expanding to encompass a variety of applications, but ubiquity of connections and use--indeed recognized as critical goals--lie farther out on the horizon.

Another critical conclusion from the study that should guide policy development is that computer networks are simply too difficult for many aerospace engineers to use. Enhancing usability must become a primary policy consideration. Programs that facilitate awareness and supply training and support should be encouraged, as should efforts to improve the usability of the technology itself, as discussed below. The central finding that aerospace engineers have difficulty using computer networks has obvious implications for NII development, generally. If this highly educated and computer literate community complained so vehemently about the usability of computer networks, what hope is there that the "average citizen" will be able to use networks easily?

The study also revealed the bifurcation among aerospace engineers in the use of organizational and research networks, compared to the use of external, commercial networks. A number of survey respondents noted their inability to, in a sense, merge the resources of these network types, and access both work and other resources from any location. A number of comments were made in the survey about the need to reduce this bifurcation of network types and access:

> "We need an infrastructure that gets that power to every desktop, whether the desktop is at the office or the home."
>
> "Great impact with potential in future for substantial impact in peoples's lives both at work and home."
>
> "Business/government should allow more employees the latitude to work at home by installing systems and networks there. High congested areas like Los Angeles, New York, etc., should be a high priority for this endeavor."
>
> "I believe my employer's computer department could improve the value of the computer system with minor changes in policy. 1) Allow access by users to the outside world. I have accessed bulletin boards, using my PC at home, to obtain info. for work purposes. 2) Allow access from outside. In my previous employment I have submitted overnight computer runs and later check from home, corrected errors, and had good results the next day."
>
> "We need a network not just a work but on the road and at home."

These comments also reflect favorably on the NII vision generally, in that they note the benefits of making access to high quality infrastructure available for general citizen use in the home.

5.6. Recommendations

The results of this study point naturally to recommendations for organizational managers and network policymakers concerned with the effective introduction and use of computer networks in the aerospace industry, specifically, and in the engineering enterprise, generally.

On the national level, efforts should be made to:

- Help smaller organizations in the private sector to connect to the NII;
- Encourage universal network service;
- Pursue policies and R&D that will facilitate standardization and interconnection of networked systems;
- Continue efforts to protect system security and intellectual property rights;
- Consider implementing the kind of "co-determination" policies in force in several Scandinavian countries that mandate employee involvement in the design and implementation of all workplace technologies (Bishop and Bishop, in press);
- Undertake a major reform of the Federal Information Resources Management (IRM) program to increase the technical expertise of IRM staff, foster innovation, and encourage understanding of how to manage information resources and technologies to support organizational goals and individual's work tasks. As part of this reform, establish a center for the provision of technical assistance to agencies wishing to establish new networked systems;
- Encourage the development of directories and clearinghouses of aerospace information in electronic form;
- Encourage the greater availability and usability of electronic government information and services, generally;
- Encourage NASA in the transfer of its innovations in networked systems to other organizations in the aerospace industry;
- Support network training and education programs in libraries and schools as well as in individual aerospace firms;
- Fund R&D aimed at improving the usability of networked systems; and
- Support pilot projects and other research efforts aimed at studying network use and usability, especially those that will provide insight into understanding and managing organizational changes related to network implementation.

These recommendations do not, for the most part, suggest radical changes in current Federal initiatives and trends.

Managers in aerospace organizations could also do more to encourage the effective and efficient use of networked systems. Study results suggest that efforts should be made to:

- Increase use in sales and marketing, administration, design/product engineering, and service and maintenance units. These are currently weak links in the networked enterprise.

- Get more organizational resources online and allow external connections to facilitate resource access, communication, and collaboration across organizational boundaries.

- Rethink the nature of organizational boundaries that separate people and information stores:

  -- Balance access with control;
  -- Deal with security issues, both technically and philosophically;
  -- Integrate resource access and use across units, both technically and conceptually.

- Since access to and manipulation of online archives of data and software is currently more widespread than access to full text, especially published literature, devote particular attention to bringing this type of resource into the networked environment. To facilitate this process, increase the involvement of on-site librarians in system development.

- Increase the individual engineer's network access, in terms of both the availability of needed hardware and software and the awareness of network capabilities and resources.

- Improve standardization and compatibility among organizational systems.

- Make organizational support of, and reward for, networked activities more explicit.

- Anticipate and avoid conflicts by discovering where attitudes and expectations vary among different groups. Foster communication among managers, system administrators, and users. Incorporate the experiences and views of the intended users of the networked system in the design and planning phases. Some examples of the differing views revealed in this study are:

  -- Many nonusers have unrealistic expectations about reliability and compatibility, and the degree of effort required to keep up with networking applications;
  -- Many nonusers cannot imagine how use will benefit them;
  -- Some people have exaggerated fears about the potential use of computer networks to leak classified or proprietary information.

- Facilitate understanding of networking impacts and benefits by increasing the awareness of, and discussion about, both direct and second order effects within an organization. Incorporate plans for network implementation with the organization's overall strategic plan.

- Training and support programs appear to increase use; both need dramatic improvement. Mechanisms to improve user education and support include:

  -- Pay special attention to training needs of new and older employees;

-- Allow adequate time for the steep learning curve associated with many information technology applications;
-- Deal more aggressively with particular fears, e.g., loss of personal contact with colleagues;
-- Target those engaged in tasks most appropriate to the use of network channels (e.g., performing mathematical analyses, learning how to do something, producing drawings or designs, developing theories or concepts, selecting design methods or procedures);
-- Include computer experts in network awareness and training efforts; they, too, need help understanding the wide variety of potential network uses and resources and learning how to navigate network information systems and communicate electronically.

These recommendations are necessarily fairly general, as they were derived from the reports of network users and potential users in a wide variety of engineering work settings. Respondents based their perceptions on, and relayed experiences related to, the mix of technical and social constraints making up their particular work and networking environments. Although some problems (and their recommended solutions) seem to apply to virtually all organizations, others vary according to the circumstances of the individual organization.

More specific suggestions geared to particular situations might also be derived from study data; but, by and large, the selected analysis of results performed to date was intended to ascertain major trends and outcomes and, so, does not lend itself to this type of interpretation. Similar research, however, conducted from a user perspective but performed within a single organization, would generate specific data that could be utilized by that organization's managers, system designers, and service providers to: develop products and services well-suited to customer/client needs; choose appropriate network designs and features to meet users' real needs; devise strategies to promote network use; develop appropriate management and use policies; and implement effective mechanisms for user training and support.

5.7. Directions for Further Study

This study combined site visits/interviews, a telephone survey, and a national mail survey to collect descriptive data on the use of computer networks in the aerospace industry. Results describe the nature and extent of computer network use across the industry as a whole, and suggest factors and impacts associated with use. Further research could complement and advance the knowledge gained in this study. It could also address issues that arose in the context of the current study. Specific directions for further study are outlined below:

- Conduct case studies of specific aerospace organizations representing different degrees of network implementation. Such research would allow a more specific identification of networking success and failure factors (in training, access, organizational network implementation procedures and policies, system design).

- Carry out more specific probing--in forms ranging from additional manipulation of data gathered in this study, to new studies incorporating, for example, ethnography or formal hypothesis-testing--on reasons for the use and nonuse of networks. Comparison of network use by various job categories is one area in which data from the current study could be analyzed more fully. One particular question raised by the current study is why network use is lower for managers and design engineers than for those engaged in other types of work. Is this because networks are not needed in the performance of these types of work? Or do special barriers exist for these types of users? Another question raised in this study is which network features, functions, and applications are easiest to learn and most effective for engineering work.

- Conduct additional studies to analyze the current and potential role of librarians in network system design and training, and the role of libraries in the delivery of networked information. Specific questions to explore include: Could librarians effectively increase and improve network training and support offered in organizations? Will networked personal collections replace some library functions? And, if so, will they be more useful for providing access to relevant published literature?

- Repeat the current study after several years have elapsed to document the extent and direction of growth in network use in the aerospace industry: How quickly will Internet access and use spread among small organizations? Will home-based access to organizational networks become more widespread? To what extent will use by certain types of aerospace engineers increase? In what ways will networks impacts increase and evolve?

- A host of specific questions arose in this study that can only be adequately addressed by further research. These include:

  -- Those engineers who use networks were about equally likely to use any and all available types of networks, from local to global. Is this because all network types are equally useful? Or because getting over the initial learning curve is the hardest part of network use?

-- Gaps exist between the availability and use of particular applications (e.g., network retrieval of document citations and abstracts). Is this due to a lack of need, training, or sufficient technical capabilities?

-- Why are full-text resources used in one's work not accessed over the network, even when network access is available?

-- Why do those with network access to certain resources used in their work consider the value of network access to those resources to be great, while users of the same resources who lack network access to them do not? Conversely, why do those without network access to certain resources consider the value of network access to be great, while those with network access to the same resources consider the value of network access to be slight?

-- What makes internal network communication more common: ubiquity of internal connections, standardization of in-house systems, the relative lack of "cross-cultural" problems in internal communication, or, simply, the greater need for internal communication among engineers?

-- Why are computer bulletin boards not more widely used and valued? This application seems intrinsically useful for engineering work, given its utility for tapping the expertise of unknown colleagues, preventing duplication of effort, and speeding up the process of finding answers to specific technical questions.

-- Why did network use in tasks performed by individuals located in different countries outstripped use by task groups dispersed within the United States?

This study has collected extensive cross-organizational, empirical data on the use of computer networks in the aerospace industry. In doing so, it has filled a gap in existing knowledge. Virtually all other studies of network use have been limited to a small number of organizations, users of a particular job type, or users of a particular system or network application. And few in-depth studies of engineering work and information transfer have described the role of current computing and communications technology within that context. The data collected in this research aids in expanding our current knowledge of the nature engineering work and communication, network use by engineers, and how these are related. As we move toward the creation of a global information infrastructure, information about the current extent of network use, factors inhibiting and promoting network use, and the impacts of network use provide basic guideposts that can be used by workplace managers, system designers, and policy makers to inform the development of more effective networking systems, services, and policies. By placing this study in the context of other research in this area--and following it up with additional investigation--we can formulate a more complete picture of the current role of computer networks in engineering work and communication. This informed picture can help us consider strategies for both facilitating effective use and minimizing some of the negative implications of networking for individuals and organizations.

APPENDIX A:

INSTRUMENTS USED IN PRIMARY SITE VISITS/INTERVIEWS

Use of Computer Networks in Aerospace Engineering
Interview Questionnaire (1.0)

Subject ID # _____

1. Please complete the chart below (by checking the appropriate boxes) to indicate the type of computer networks you have access to and use.

TYPE OF NETWORK	Are you CONNECTED?			Do you USE?			LOCATION(S) of use?		
	Yes	No	Not Sure	Yes	No	Not Sure	Work	Home	Other
Local network: connects computers within and among buildings at your workplace									
Organization-wide network: connects different locations belonging to one organization									
Cooperative network: connects people in a range of different organizations (e.g., BITNET, Internet)									
Public commercial network: connects all customers (e.g., CompuServe, Tymnet)									

2. Please complete the chart below (by checking the appropriate boxes) to indicate the frequency with which you use various network applications, and their value to your work.

NETWORK APPLICATIONS	AVAILABLE?			How frequently do you USE?				IF used, VALUE to work?			
	Yes	No	Not Sure	Daily	Weekly	Mo. or less	Never	Great	Some	Slight	None
•Email ("one-to-one" messages)											
•Electronic conferences, bulletin boards, etc. ("one-to-many")											
•Electronic journals or newsletters											
•File transfer - documents											
•File transfer - designs, drawings, other images											
•File transfer - data											
•Remote log-in to computers for computation, design, etc.											
•Remote control of equipment											
•Information or data retrieval											

Are there any other network applications that you use? (Please specify): ____________________

Please supply the following background information about yourself and your work:

3) Current position or job title: ______________________________

4) Employed by (name of organization): ______________________________

5) Which job category best represents your primary work activity? (Circle number for response)

1 Engineer 2 Manager 3 Scientist 4 Technician
5 Other (please specify): ______________________________

6) Which of the following best describes the type of organization where you work?

1 Industrial/business 2 Government 3 Academic 4 Not-for-profit
5 Other (please specify): ______________________________

7) If you work in business or industry, what would you estimate as the number of employees in your company? _______ (Your job site) _______ (Total in company)

8) To which area of aerospace engineering does your work belong?

1 Aerodynamics 2 Structures 3 Propulsion 4 Flight dynamics and control
5 Avionics 6 Materials/Processes 7 Other: ______________________________

9) What is the primary aerospace product or process to which your work is devoted?

10) Does this product or process include, as a primary feature, the development or analysis of computer systems software, or data? 1 Yes 2 No

11) Approximately what percentage of your workday is spent at a computer or terminal? ____ %

12) How would you describe yourself as a NETWORK USER? 1 Expert 2 Intermediate 3 Novice 4 Don't use

13) Which best describes the work of the organizational unit in which you're employed?

1 Basic Research (Work of a general nature intended to apply to a broad range of applications or to the development of new knowledge about an area)

2 Applied Research (Research directed toward determining the means by which a specific need may be met; the creation of new concepts or technologies, but not development for operational use)

3 Development (The application of known facts and theory to the study, design, and testing of distinctly new products or processes)

4 Engineering (Cost/performance inprovement to existing products or processes; recombination, modification and testing of systems using existing knowledge)

5 Manufacturing/Production

6 Service/Maintenance

7 Sales/Marketing

8 Information Processing or Programming

9 Other (please specify): ______________________________

THANK YOU !

Job Tasks and Activities Worksheet

Subject ID # _____

Who do you communicate with?	WORK TASKS	What tools, devices and info sources do you use?

Message Analysis Worksheet

Subject ID # ____
Message ID # ____

0 Communication Type: 1 Technical 2 Administrative 3 Social 4 Other: ____

What communication channel was used?

Message Type: 1 CMC 1a - email 1b - bb 1c - journal 1d - file
2 Phone 2a - phone 2b - voice mail
3 FTF 3a - Informal/one 3b - Informal/many 3c - Formal/one 3d - Formal/many
4 Written 4a - memo 4b - letter 4c - document 4d - fax

5a Subject initiated message (after 6, go to 7a)
5b Subject received message (after 6, go to 7b)

What did you communicate about?

6 Message substance or content (data, theory, schedule):

→ 7a Task or problem that message arose from:

→ 7b Task or problem that message contributed to:

8 Message utility (How did it help/affect you? What did you do next?):

Who did you communicate with?

9 Relationship of partner(s) to subject (manager, customer, colleague):

10 Organizational location (s): ____

10a Same lab/dept. 10b Same division 10c Same org 10d Outside org

11 Spatial location (s): ____

11a Within 100 yds 11b In building 11c Same site 11d In town 11e Out of town

12 How well known?

12a Not at all 12b Slightly 12c Somewhat 12d Fairly well 12e Extremely well

13 **Why was that communication channel chosen in that situation? What was there about the info conveyed or the partner that led to the choice of that channel?**

Subject ID # ____

Open-ended Interview Questions

1a) How would you describe the effects that computer networks are having on your work, both postive and negative?

1b) How would you describe the effects that computer networks are having on the way you communicate?

2) What factors do you think affect your use of networks?

2a) What is there about you, your work, or your organization that leads you to use networks?

2b) What is there about you, your work, or organization that limits your use of networks:

3) Are there any other comments about networks or this study that you would like to make? Is there anything you feel is important to my understanding of the impact of computer networks on aerospace engineering work and communication that hasn't come up yet?

APPENDIX B:

PRETEST QUESTIONNAIRE FOR THE MAIL SURVEY

SURVEY ON THE ROLE OF COMPUTER NETWORKS IN AEROSPACE WORK AND COMMUNICATION

We are conducting this survey to learn more about the impact of computer networks on people in the aerospace industry. Your opinions and experiences are important, even if you do not use computer networks. Results of this survey will provide network developers and policy makers with information about networking needs, uses, and impacts from the point of view of a wide range of individuals. So please answer each question as completely as possible.

Computer networks are telecommunications links that allow you to utilize a computer to communicate with other computer users, use remote computers or computerized devices, or access remote information. In the context ot this survey, COMPUTER NETWORKING DOES NOT INCLUDE FAX .

1. Overall, how would you describe your current reaction to computer networks? (Circle best response)

   1 They have revolutionized aerospace work.
   2 They are very useful in many respects.
   3 They have certain worthwhile uses.
   4 I am neutral or indifferent.
   5 I have reservations about their value.
   6 They have limited value and can cause serious problems.
   7 They are worthless and should not be implemented.

2a. Do you use computers in your work? (Circle best response)

1 Yes
2 No

→ 2b. If yes, approximately what percent of your typical work week is spent using computers? ___ %

3a. Do you use computer networks in your work? (Circle best response)

1 Yes, I personally use computer networks
2 Yes, I use computer networks through an intermediary, e.g., secretary, librarian
3 No

→ 3b. If yes, approximately what percent of your typical work week is spent using computer networks? ___ %

COMPUTER NETWORK AVAILABILITY AND USE

We'd like to get a clearer picture of the current availability and use of specific types of computer networks in aerospace.

4. Please complete the chart by placing check marks in the appropriate cells to describe YOUR access to and use of specific types of computer networks.

<u>If you don't use networks</u>, please complete the first two columns.

<u>If you do use networks</u>, please complete all three columns.

Very often, people cannot say for sure what kinds of computer networks they are connected to or may be using. That's fine; please place a check mark in the "Not Sure" columns, if this is the most appropriate response for you.

AVAILABILITY AND USE / TYPE OF NETWORK	Is a computer connected to such a network AVAILABLE for your use? (Check only one)			Do you USE this type of network? (Check only one)			If used, LOCATIONS of your use of that network? (Check ALL that apply)		
	Yes	No	Not Sure	Yes	No	Not Sure	Work	Home	Other
LOCAL: Connects you to people, tools, or information within ONE BUILDING AT YOUR WORKPLACE									
ORGANIZATIONAL: Connects you BEYOND ONE WORKPLACE BUILDING to people, tools, or information WITHIN YOUR OWN ORGANIZATION									
EXTERNAL/RESEARCH: Provides a variety of services. Connects you to people, tools, or information OUTSIDE YOUR OWN ORGANIZATION and is INTENDED FOR RESEARCH AND EDUCATIONAL USE (e.g., Internet, BITNET, NSFNet)									
EXTERNAL/COMMERCIAL: Provides a variety of services. Connects you to people, tools, or information OUTSIDE YOUR OWN ORGANIZATION and is OPEN FOR USE BY THE GENERAL PUBLIC (e.g., Prodigy, BIX, CompuServe, GEnie)									
EXTERNAL/DIRECT A DIAL-UP OR LEASED LINE connection to specific remote sites or services OUTSIDE YOUR OWN ORGANIZATION through regular telephone lines									

WORK RESOURCES IN AEROSPACE

We'd like to know more about the wide variety of resources you use in your work and the extent to which these resources are accessible over computer networks.

5. **Please complete the entire chart below, even if you don't use networks. Place a check marks in the appropriate cells to describe YOUR access to, use of, and assessment of specific types of work resources via computer networks.**

   For any resource currently accessible to you via computer network, describe your assessment of the VALUE OF NETWORK ACCESS to each resource, based on your experience.

   For any resource not currently accessible to you via computer network, describe your assessment of the POTENTIAL VALUE OF NETWORK ACCESS to each resource, based on your opinion.

STOP! Information resources (e.g., journal articles, internal technical data) should NOT be considered network accessible unless the full text or content of the information—as opposed to just the bibliographic citation or database listing—can be viewed over the network.

ACCESSIBILITY AND USE / WORK RESOURCES	Are any resources of this type ACCESSIBLE to you via a network at your workplace? *(Check only one)*			When using this resource at your workplace, how OFTEN do you access it via a network? *(Check only one)*				VALUE of network access? (ACTUAL value if accessible; otherwise POTENTIAL value) *(Check only one)*			
	Yes	No	Not Sure	Usually	Some-times	Rarely	Never	Great	Some	Slight	None
People in your workgroup or dept.											
Other people in your organization											
Colleagues in academia, government											
Colleagues in the private sector											
External clients, customers											
External vendors, suppliers											
Internal administrative data											
Internal technical data											
Internal operational data											
Journal, trade magazine articles											
Manuals, documentation											
Internal technical reports											
External technical reports											
Codes of standards and practices											
Product, materials characteristics											
Technical specifications											
Design change forms											
Laws, regulations											
Patents											
Company newsletters, bulletins											
Manufacturers' or suppliers catalogs											
Memoranda											
Lab notebooks											
Drawings, Designs											
Models											
Computer code, programs											
Scientific instruments											
Test equipment											

NETWORK APPLICATIONS IN AEROSPACE

We're trying to gain a fuller picture of the extent to which different network applications are used by people in aerospace and which are considered most valuable.

6. Please complete the entire chart below, even if you don't use networks. Place check marks in the appropriate cells to describe your access to, use of, and assessment of specific types of computer network applications.

   For any network application CURRENTLY AVAILABLE to you, describe your assessment of its VALUE, based on your experience.

   For any network application NOT CURRENTLY AVAILABLE to you, describe your assessment of its POTENTIAL VALUE, based on your opinion.

AVAILABILITY AND USE / NETWORK APPLICATIONS	Is the application AVAILABLE for your use at your workplace? (Check only one)			How FREQUENTLY do you use it? (Check only one)				VALUE to work? (ACTUAL value if used; otherwise POTENTIAL value) (Check only one)			
	Yes	No	Not Sure	Daily	Weekly	Monthly or Less	Never	Great	Some	Slight	None
Electronic mail											
Electronic bulletin boards, newsgroups, mailing lists, or conferencing systems											
Videoconferencing											
Electronic journals or newsletters											
Electronic data interchange (EDI)											
Running a program on a remote computer (e.g., CAD/CAM, spreadsheet, wordprocessing, modeling)											
Remote collection of experimental or test data											
Computer-integrated manufacturing (CIM)											
Online bibliographic searching											
Accessing remote databases or files											
Searching library catalogs											
Transferring data between computers											
Accessing or transferring images											
Other:											

AEROSPACE TASKS AND ACTIVITIES

People working in aerospace have told us that they perform a wide variety of important tasks and activities. We'd like to understand more about how you performed some particular task that was important to your work.

7. From the list presented below, please circle the number of the most important work task YOU performed during your last workday:

1 Come up with new ideas, approaches
2 Keep up with new developments
3 Develop theories, concepts
4 Formulate requirements
5 Find out how to carry out a particular task
6 Design experimental methods, procedures
7 Conduct experiment
8 Run test of materials, products, processes
9 Perform mathematical analysis
10 Interpret results of tests, analyses
11 Produce drawings, designs, specs
12 Design manufacturing, test procedures
13 Identify parts and materials
14 Produce prototypes or products
15 Assure conformance w/ requirements
16 Troubleshooting, maintenance
17 Coordinate work
18 Solve technical problem
19 Resolve non-technical issue
20 Negotiate with others
21 Write proposal, report, etc.
22 Other: ____________________

8. Approximately how many people were directly involved in performing this task with you? (Please supply number from 0 up) ___

9. What was the geographic span involved in performing the task, in relation to your primary work location? (Circle number of best response below)

1 Same office/lab
2 Same building
3 Same worksite
4 Same town
5 Same country
6 Other country

10. What was the organizational span involved in performing the task, in relation to your primary work location? (Circle number of best response below)

1 Same workgroup
2 Same department
3 Same division
4 Same organization
6 Other organization

11. In performing this task, did you come into contact with any useful people, information, or tools not previously known to you? (Circle number of response)

1 Yes
2 No

12. What were the two most important mechanisms you used in performing this task?

On the lines provided, please write one "P," to indicate the primary mechanism you used, and one "S," to indicate the secondary mechanism you used.

___	Face-to-face interaction with other person(s)	[FTF]
___	Using printed material in own office or other location	[P]
___	Own direct examination, testing of physical objects, devices, processes	[D]
___	Use of computer network to contact people	[NP]
___	Use of computer network to access information or data	[NI]
___	Use of computer network to operate a computer or other device	[NC]
___	Use of a non-networked computer	[C]
___	Telephone	[T]
___	Mail	[M]
___	Fax	[F]
___	Other (please describe): ______________________	[O]

13. What was your main reason for choosing the PRIMARY mechanism used? (Circle best response)

1 Preferred mechanism not available (Supply code, from previous question, for preferred mechanism, e.g., printed material = P: ____)
2 Tradition demanded it
3 It was quickest
4 It required the least effort
5 It was cheapest
6 It was the most reliable
7 It allowed the greatest accuracy of information flow
8 It allowed for the most complete information flow
9 Other (please describe): ______________________

NATURE OF YOUR WORK AND WORK ENVIRONMENT

We'd like to learn more about your work environment in order to explore work-related factors that may be associated with network use.

14. How would you describe yourself? (Circle best response):

1 Engineer
2 Manager
3 Scientist
4 Technician
5 Businessperson
6 Teacher/trainer
7 Other: ______________________

15. In which branch of aerospace do you work? (Circle best response)

1 Aerodynamics
2 Structures
3 Propulsion
4 Flight dynamics and control
5 Avionics
6 Materials and processes
7 Other: ______________

The chart below explores other factors associated with your work and netwbrking environment.

16. Please complete the chart by placing a check mark in the appropriate column to indicate the extent to which YOU agree or disagree with each of the statements listed.

STATEMENTS CONCERNING WORK AND NETWORKING ENVIRONMENT	EXTENT TO WHICH YOU AGREE? *(Check only one)*					
	Not applicable/ Don't know	Disagree strongly	Disagree somewhat	Neither agree nor disagree	Agree somewhat	Agree strongly
The results of my work are integrated with the work of others						
I spend my day working independently						
The people I need to communicate with are all in my building						
I require a diverse range of information from a wide variety of sources						
Time pressures are tremendous in my work						
The constraints affecting my work change constantly						
My work discussions require having documents, devices, drawings all at hand at the same time						
My work is classified						
Results of my work are proprietary						
Results of my work are stored in electronic form						
My work involves examining physical equipment, instruments, materials, processes						
I started my professional education/career without networks						
I like to learn new computer things just for the fun of it						
Networking requires too much effort to learn and keep up with						
Networking help comes mostly from formal training or support programs						
Network transmission is unreliable						
Network applications currently available are relevant to my work						
All the people, tools, resources I need are on the network						
Network implementation not seamless; still lots of islands						
Network implementation and use is not cost-effective						
Network use is actively encouraged, rewarded by organization						
Lack of experience with networking makes it hard to predict costs, effects						
We can't introduce networking without re-writing our procedures						
A networked computer is easily accessible to me						
Customers, clients are demanding that we use networks						

IMPACT OF NETWORK USE

In interviews that we conducted earlier, people involved in the aerospace industry suggested a wide variety of impacts that result from network use.

17. For each of the suggested impacts listed below, please indicate the extent to which YOU believe that each stated impact occurs. Then place a check mark in ONE of the final columns for any impact that you believe clearly represents either a critical benefit or a critical problem in aerospace work.

If you use networks, base your assessment on your own personal experiences with computer networking.

If you don't use networks, base your assessment on your own personal opinions and expectations regarding computer networks.

	EXTENT TO WHICH IMPACT OCCURS? (Check only one)					IS IMPACT CRITICAL? (Check if yes)	
USE OF COMPUTER NETWORKS:	Don't know	Not at all	Slightly	Moderately	A great deal	Critical benefit?	Critical problem?
Allows ideas, problems to be expressed at point of need							
Increases the amount of information available							
Reduces need for face-to-face interaction							
Creates new information by linking different systems							
Reduces communication with people not on the network							
Provides integrated view of entire organization							
Increases ability to react quickly to change							
Enhances ability to function as a unit, coordinate work							
Reduces the number of changes required in final products							
Extends use of expensive computers and computerized devices							
Increases ability to complete projects within budget							
Decreases turnaround time on solving problems							
Shortens product development time							
Reduces loss of past knowledge; prevents duplication of effort							
Increases efficiency of contacting people							
Gives individuals greater control over how, when things done							
Increases sense of ownership, commitment, team spirit							
Increases performance of work at home, on the road							
Contributes to career advancement							
Helps one gain status among one's peers							
Provides satisfaction of being on the leading edge of technology							
Facilitates documentation, evaluation of work processes							
Increases management control							
Improves responsiveness to customers, clients, etc.							
Increases feasibility, size of collaborative efforts							
Leads to flexibility in work structures, patterns							
Reduces staff							
Causes leaks of proprietary or sensitive information							
Causes major system security problems							
Wastes time because people just fool around on networks							

BACKGROUND INFORMATION

The information that you provide in this section will be used to help determine whether people with different backgrounds and jobs differ in regard to their network use.

18. Gender (Circle one):

    1 Male
    2 Female

19. Age: ____

20. Highest degree obtained (Circle one):

    1 High School Diploma
    2 Technical/Vocational Degree
    3 Bachelor's Degree
    4 Master's Degree
    5 Doctorate
    6 Post Doctorate
    7 Other:

21. Years of professional aerospace work experience: ____ years

22. Type of organization where you work (Circle best response):

    1 Industry/Manufacturing
    2 Government
    3 Academic
    4 Other: ________________________________

23. If you work in a private-sector organization, what is the approximate number of employees in your organization? ________ employees

24. Which category best describes your primary job function? (Circle the best response)

    1 Administration
    2 R&D
    3 Design/Product Engineering
    4 Industrial/Manufacturing Engineering
    5 Quality control/Assurance
    6 Production/Processing
    7 Sales/Marketing
    8 Service/Maintenance
    9 Information Processing/Computer Programming/Systems Management
    10 Teaching/Training
    11 Other: ________________________________

25. Does your own work involve, as a primary feature, the development or analysis of computer systems, components, software, or data? (Circle one)

    1 Yes
    2 No

CONCLUDING THE SURVEY

26. Is there anything else you would care to say regarding the use of computer networks in the aerospace industry or regarding this study?

27. Would you like to receive a summary of the results of this research? (Circle one)

1 Yes
2 No

If yes, please make sure that your address is correct. If you would like to change the address to which results will be sent, write the new address here:

28. Would you be interested in participating in follow-up research related to this study, such as a brief telephone interview or a short questionnaire on some specific aspect of network use? (Circle one)

1 Yes
2 No

If yes, please provide a telephone number where you can be reached:

THANK YOU!

APPENDIX C:

COVER LETTER AND QUESTIONNAIRE FOR THE MAIL SURVEY

National Aeronautics and
Space Administration

Langley Research Center
Hampton, Virginia
23665-5225

NASA

Reply to Attn of 180A

February 15, 1993

Dear Dr. Kennedy:

The U.S. aerospace industry remains a national and global leader and a critical element in the U.S. economy despite significant challenges from international competitors. Continuing U.S. world leadership in aerospace depends, to a considerable extent, on the ability of U.S. aerospace engineers and scientists to identify, acquire, and utilize technical information. However, we know little about how knowledge diffuses throughout the aerospace industry.

The NASA/DoD Aerospace Knowledge Diffusion Research Project is providing a practical basis for understanding the aerospace knowledge diffusion process and its implications at the individual, organizational, national, and international levels. The need for more frequent and effective use of technical information characterizes the strategic vision of today's competitive aerospace marketplace. There is considerable agreement that computer networks will enhance the productivity of U.S. aerospace engineers and scientists by improving access to technical information, colleagues, computers, and other network resources. However, very little is known about how networks are used in aerospace work and communication and whether they contribute to improved productivity and competitiveness.

The enclosed survey is part of the Aerospace Knowledge Diffusion Research Project. I encourage you to complete and return this survey as soon as possible. Doing so will provide useful information that is needed to develop a set of innovation-adoption technology policy goals for aerospace and a coherent, integrated program directed at attaining these goals. Should you have questions or need additional information, please contact me by telephone at (804) 864-2491 or by email at tompin@teb.larc.nasa.gov.

Sincerely,

Thomas E. Pinelli, Ph.D.
Assistant to the Chief
Research Information and
Applications Division

University of Illinois
at Urbana-Champaign

Graduate School of Library
and Information Science

410 David Kinley Hall
1407 West Gregory Drive
Urbana, IL 61801-3680

217 333-3280
217 244-3302 *fax*

February 15, 1993

John M Kennedy
Indiana University
1022 E 3rd St
Bloomington, IN 47405

Dear Dr. Kennedy:

We need your help. Many aerospace organizations are investing heavily in computer networks, but very little is known about who's using networks and whether they really improve productivity and competitiveness. So we are conducting a study to learn how people in aerospace use computer networks and what they see as the problems and benefits. Your name is part of a small sample that was provided to us by SAE.

As you know, when interviewing only a small sample, it is important to achieve a high response rate. Please complete the enclosed survey and return it in the enclosed postage paid envelope at your earliest convenience. *Even if you do not use computer networks, we care about your views.* The findings from this study will be used to identify current problems and will be made available to the aerospace and computer networking communities to help them in their efforts to develop computer network systems, services, and policies that are better suited to people's needs and more likely to achieve projected benefits. We appreciate your participation and will send you a summary of survey results at the end of this study.

This survey was developed following in-depth interviews with a wide variety of people in aerospace. It will require about 20 minutes to complete. The data from the survey will be kept confidential in that no data will be tied to individual respondent's or organization's identities. If you have any questions about the study, please contact me.

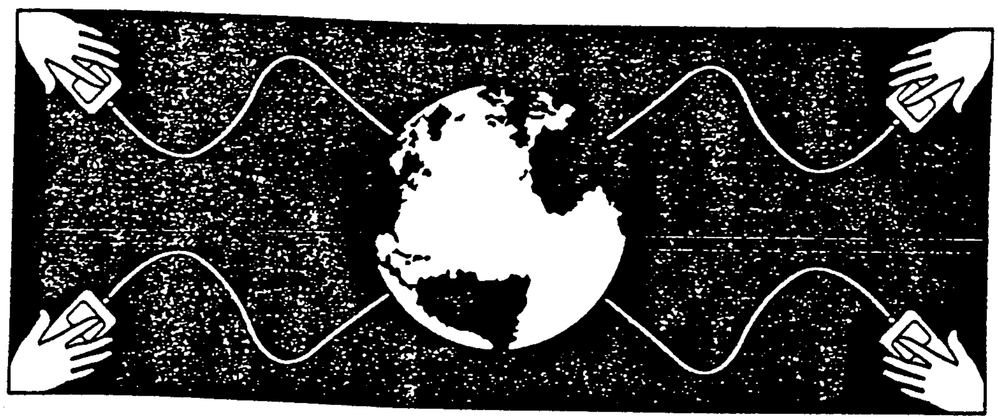
Thanks for your time and cooperation.

Sincerely,

Ann P. Bishop
Assistant Professor
abishop@uiuc.edu

PHASE 1 OF THE
NASA/DOD AEROSPACE KNOWLEDGE
DIFFUSION RESEARCH PROJECT

The Role of Computer Networks in Aerospace Work and Communication: SAE Study



SPONSORED BY THE NATIONAL AERONAUTICS AND SPACE ADMINISTRATION AND THE DEPARTMENT OF DEFENSE WITH THE COOPERATION OF INDIANA UNIVERSITY, THE UNIVERSITY OF ILLINOIS, AND THE SOCIETY OF AUTOMOTIVE ENGINEERS (SAE)

SURVEY ON THE ROLE OF COMPUTER NETWORKS IN AEROSPACE WORK AND COMMUNICATION

The purpose of this survey is to learn more about the current and potential impact of computer networks on work and communication in the aerospace industry from the point of view of a wide range of individuals. Your opinions and experiences are important, even (perhaps especially) if you do not use computer networks. So please answer each question as completely as possible.

PLEASE READ THIS DEFINITION BEFORE BEGINNING THE SURVEY:

COMPUTER NETWORKS are defined as telecommunications links between computers. They take many forms, for example: linked workstations within an organization; a desktop computer or terminal connected to a nearby printer or linked to a central mainframe; a dial-up link between your computer and a supercomputer or database located in some other part of the country; or a link through your computer to services on the Internet or CompuServe. With a computer network, you can communicate with other computer users, utilize remote computers or computerized devices, and access information located on systems beyond your own desktop. IN THE CONTEXT OF THIS SURVEY, COMPUTER NETWORKING DOES NOT INCLUDE VOICE MAIL or TELEPHONE TELEFACSIMILE TRANSMISSION (FAX).

1. Overall, how would you describe your current reaction to computer networks? (Circle number of best response)

   1 They have revolutionized aerospace work.
   2 They are very useful in many respects.
   3 They have certain worthwhile uses.
   4 I am neutral or indifferent to them.
   5 I have reservations about their value.
   6 They have limited value and can cause serious problems.
   7 They are worthless and should not be implemented.

2. Which description below BEST characterizes the extent of computer networking at your workplace? (Circle number of best response)

   1 Networks are used by *most* people; *many* tools and resources are available on networks; *most* computer systems are linked together by a network; network use is *required or strongly encouraged.*

   2 Networks are used by *some* people; *certain* tools and resources are available on networks; *some* computer systems are linked together by a network; network use is *encouraged in some cases.*

   3 Networks are used by *few, if any* people; *few, if any* tools and resources are available on networks; *few, if any* computer systems are linked together by a network; *organization does little to encourage, or even discourages network use.*

   4 Don't know/Not applicable

3. Do you ever use any kind of computer in your work, such as a PC, terminal, mainframe, laptop, handheld computer, etc.? (Circle number of your response)

   1 No, I never use computers
   2a Yes
   → 2b If yes, approximately what percent of your typical work week is spent using computers? ___ %

4. Do you ever use any kind of computer network in your work? (Circle number of best response)

   1 No, I never use computer networks
   2a Yes, I personally use computer networks
   2b Yes, I use computer networks, but only through an intermediary; e.g., secretary, librarian, computer support staff
   → 2c If yes, approximately what percent of your typical work week is spent using computer networks? ___ %

COMPUTER NETWORK AVAILABILITY, VALUE, AND USE

This section of the survey aims at obtaining a clearer picture of the current availability, perceived value, and use of specific types of computer networks in aerospace.

5. Please complete the chart below by placing check marks in the appropriate cells to describe YOUR access to, assessment, and use of specific types of computer networks.

If you NEVER use networks, please complete COLUMNS I-II. Record in column II your personal assessment of the POTENTIAL VALUE of each type of network listed.

If you DO use some type of network, please complete COLUMNS I-III. Record in column II your personal assessment of the ACTUAL VALUE of each type of network that you use and the POTENTIAL VALUE of each type that you do not use. Record the LOCATION OF YOUR NETWORK USE in column III.

Very often, people cannot say for sure what kinds of computer networks are available to them. That's fine; please place a check mark in the "Not Sure" cell, if this is the most appropriate response.

AVAILABILITY, VALUE, AND LOCATION OF USE / TYPE OF NETWORK	I Is a computer or terminal connected to such a NETWORK AVAILABLE for your use? *(Check only one)*			II VALUE of this type of network TO YOUR WORK? (ACTUAL value if used; POTENTIAL value if not currently used) *(Check only one)*					III IF YOU USE this type of network, WHERE do you use it? *(Check ALL that apply)*		
	Yes	No	Not Sure	Great	Some	Slight	None	Don't Know	Work	Home	Other
LOCAL: Connects you to people, tools, or information within ONE BUILDING AT YOUR WORKPLACE (i.e., Local Area Network or LAN)											
ORGANIZATIONAL: Connects you BEYOND ONE WORKPLACE BUILDING to people, tools, or information WITHIN YOUR OWN ORGANIZATION (e.g., corporate Wide Area Network or WAN; campus network)											
EXTERNAL/RESEARCH: Provides a variety of services. Connects you to people, tools, or information OUTSIDE YOUR OWN ORGANIZATION and is INTENDED FOR RESEARCH AND EDUCATIONAL USE (e.g., Internet, BITNET, NSFNet, Usenet)											
EXTERNAL/COMMERCIAL: Provides a variety of services. Connects you to people, tools, or information OUTSIDE YOUR OWN ORGANIZATION and is OPEN FOR USE BY THE GENERAL PUBLIC (e.g., Prodigy, BIX, CompuServe, GEnie, MCIMail)											
OTHER (please describe):											

WORK RESOURCES IN AEROSPACE

This section of the survey asks about the wide variety of resources you use in your work and the extent to which these resources are accessible over any kind of computer network. Please complete the entire chart below FOR ANY WORK RESOURCE YOU USE, <u>even if you don't use networks</u>.

6. First, CHECK OFF ANY RESOURCE THAT YOU USE in your work. Then, place check marks in each of THOSE ROWS ONLY to describe YOUR use and assessment of computer network access to that work resource. If any resources you use do not appear in the chart, add them in the "Other" rows.

<u>For any resource CURRENTLY ACCESSIBLE TO YOU VIA COMPUTER NETWORK</u>, describe your assessment of the ACTUAL VALUE OF NETWORK ACCESS to that resource, based on your experience.

<u>For any resource NOT CURRENTLY ACCESSIBLE TO YOU VIA COMPUTER NETWORK</u>, describe your assessment of the POTENTIAL VALUE OF NETWORK ACCESS to that resource, based on your opinion.

WAIT! Information resources (e.g., journal articles, internal financial data) should NOT be considered network accessible unless the <u>full text or content</u> of the information—as opposed to just the bibliographic citation or database listing--can be viewed over the network.

	USE AND VALUE OF NETWORK ACCESS / WORK RESOURCES	IS RESOURCE USED in your work? *(Check if yes)*	When using this resource, HOW OFTEN DO YOU ACCESS IT <u>VIA A NETWORK?</u> vs. by telephone, in print, etc. *(Check only one)*					VALUE of <u>NETWORK ACCESS</u> to YOUR work? vs. telephone, etc., access (ACTUAL value if network access exists now; otherwise POTENTIAL value) *(Check only one)*				
			Not Applicable—No Network Access	Usually	Some-times	Rarely	Never	Great	Some	Slight	None	Don't Know
HUMAN RESOURCES	People in your workgroup or dept.											
	Other people in your organization											
	Colleagues in academia, government											
	Colleagues in private industry											
	External clients, customers, sponsors											
	External vendors, suppliers											
	Other:											
INFORMATION RESOURCES	Document citations, abstracts											
	Journal, trade magazine articles											
	Equipment or procedures manuals											
	Internal technical reports											
	Company newsletters, bulletins											
	Manufacturers' or suppliers' catalogs											
	Codes of standards and practices											
	Directories of people											
	Training materials, tools, programs											
	Internal financial data											
	Production control data											
	Experimental or test data											
	Product or materials characteristics											
	Technical specifications											
	Design change forms											
	Lab notebooks											
	Drawings or designs											
	Computer code or programs											
	Other:											

NETWORK APPLICATIONS IN AEROSPACE

It's important to gain a fuller picture of the extent to which different network applications (computer AND non-computer) are used in aerospace and which ones are considered the most valuable. **Please complete the entire chart below, <u>even if you don't use networks</u>.**

7. Place check marks in EACH ROW to describe YOUR use and assessment of each of the specific types of network applications listed.

<u>For any network application that YOU CURRENTLY USE</u>, describe your assessment of its ACTUAL VALUE, based on your experience.

<u>For any network application that YOU DO NOT CURRENTLY USE</u>, describe your assessment of its POTENTIAL VALUE, based on your opinion.

AVAILABILITY, USE, AND VALUE / NETWORK APPLICATIONS	How FREQUENTLY do YOU use this application AT YOUR WORKPLACE? *(Check only one)*					VALUE of application TO YOUR WORK? (ACTUAL value of application IF USED; otherwise POTENTIAL value) *(Check only one)*					
	Application NOT AVAILABLE at Workplace	Daily	Weekly	Monthly or Less	Never	Application NOT APPLICABLE to My Work	Great	Some	Slight	None	Don't Know
Electronic mail (sending messages to individuals)											
Electronic bulletin boards, mailing lists, discussion groups or computer conferencing systems (for group messages)											
Real-time, interactive messaging											
Videoconferencing											
Voice mail											
Telefacsimile (Fax)											
Electronic journals or newsletters											
Electronic data interchange (EDI) for exchanging orders, bills, etc.											
Logging into a computer NOT on your desktop to run a program (e.g., CAD/CAM, spreadsheet, modeling)											
Logging into a computer NOT on your desktop to access data or text files (e.g., personnel or project data, reports)											
Online bibliographic searching of commercial or government databases											
Online library card catalog searching											
Operation of computerized experimental, test, or production devices without being physically present											
Computer-integrated manufacturing											
Transferring data or text files between computers											
Accessing or transferring images											
Other:											

AEROSPACE TASKS AND ACTIVITIES

In interviews conducted earlier, people working in aerospace discussed the wide variety of important tasks and activities they perform. This section of the survey asks how YOU performed some particular task that was important to your work.

8. The one most important work task I performed during my last work week was to (Circle number of SINGLE BEST response):

1 Come up with new ideas, approaches
2 Keep up with new developments
3 Develop theories, concepts
4 Identify requirements
5 Learn how to do something
6 Select or design methods and procedures
7 Conduct experiment or run test
8 Perform mathematical analysis
9 Interpret results of experiments, tests
10 Produce specifications
11 Produce drawings, designs
12 Identify resources
13 Produce prototypes or products
14 Assure conformance with requirements
15 Troubleshooting, maintenance
16 Plan tasks, projects, programs, etc.
17 Coordinate work
18 Identify problem
19 Negotiate with co-workers, clients, vendors, students, etc.
20 Solve technical problem
21 Write proposal, report, paper, etc.
22 Other: ______________________________

9. Please describe the task briefly: ____
____

10. Approximately how many OTHER people were directly involved in performing this task with you?
____ other people (Please supply number from 0 up)

11. What was the geographic span involved in performing the task, in relation to your primary work location at the time? (Circle number of best response)

1 Same office/lab
2 Same building
3 Same worksite
4 Same town
5 Same country
6 Across countries
7 Don't know

12. What was the organizational span involved in performing the task, in relation to your primary work location at the time? (Circle number of best response)

1 Same workgroup
2 Same department
3 Same division
4 Same organization
5 Across organizations
6 Don't know

13. In performing this task, did you come into contact with any useful people, information sources, or tools not previously known to you? (Circle number of response)

1 Yes
2 No

14. What were the two most important communication channels you used in performing this task? On the lines provided below, please WRITE a "P" in front of the PRIMARY communication channel used. WRITE an "S" in front of the SECONDARY channel used.

		Mechanism Code
___	Face-to-face interaction with other person(s)	FTF
___	Examining printed material in own office or other location	P
___	Own direct examination, testing of physical objects, devices, processes	D
___	Use of computer network to communicate with people	NP
___	Use of computer network to access information or data	NI
___	Use of computer network to operate a computer or other device	NC
___	Use of a non-networked computer	C
___	Telephone	T
___	Voice Mail	VM
___	Internal (e.g., company or campus) or U.S. Mail	M
___	Fax	F
___	Other (please describe): ____________________	O

15. What was your MAIN REASON for choosing the PRIMARY channel used? (circle SINGLE BEST response)

1 Preferred mechanism not available: _____ (Supply *Mechanism Code* from previous question to specify preferred mechanism)
2 Tradition demanded it
3 It was quickest way to accomplish the task
4 It required the least effort on my part
5 It was cheapest
6 It was the most reliable
7 It allowed the greatest accuracy of information flow
8 It allowed for the most complete expression, interpretation, or interaction in information flow
9 It allowed for the most presentable expression of information
10 It's what everyone involved was set up for
11 Other (please describe): ____________________

NATURE OF YOUR WORK ENVIRONMENT

This section seeks information about your work environment in order to explore work-related factors that may be associated with network use.

16. In your present job, do you consider yourself primarily a(n)? (Circle number of SINGLE BEST response):

1 Engineer
2 Manager
3 Scientist
4 Other (please describe): ____________________

17. In which branch of aerospace do you work? (Circle number of SINGLE BEST response)

1 Aerodynamics
2 Structures
3 Propulsion
4 Flight dynamics and control
5 Avionics
6 Materials and processes
7 Other (please describe): ____________________

18. What do you think are the biggest barriers to network use that you experience? ____________________

19. What are the most important factors that encourage your network use or potential use? ____________________

20. Please complete this chart on YOUR WORK AND NETWORKING ENVIRONMENT by placing a check mark in each row to indicate the extent to which YOU agree or disagree with each of the statements listed. Please complete the <u>entire chart</u>, even if you don't use networks.

	STATEMENTS CONCERNING WORK AND NETWORKING ENVIRONMENT	EXTENT TO WHICH YOU AGREE? (Check only one): Not applicable/ Don't know	Disagree strongly	Disagree somewhat	Neither agree nor disagree	Agree somewhat	Agree strongly
WORK ENVIRONMENT	The results of my work are integrated with the work of others						
	I spend my day working independently						
	All the people I need to communicate with are in my building						
	I require a diverse range of information from a wide variety of sources						
	Time pressures are tremendous in my work						
	My work is routine, predictable						
	Work discussions require having documents, devices, drawings all in hand						
	I often examine physical devices, instruments, materials, processes, etc.						
	The products I design, develop, or produce are highly complex						
	I work in a field that is extremely competitive						
	My organization is hierarchically structured (as opposed to project-based)						
	My organizational culture is rigid and authoritative						
	My work is classified						
	Results of my work are proprietary						
	Results of my work are stored in computerized form						
NETWORKING ENVIRONMENT	I started my professional career without networks						
	I like to learn new computer things just for the fun of it						
	Networking requires too much effort to learn and keep up with						
	I know about all the networked information, services relevant to my work						
	Networking help comes mostly from formal training or support programs						
	Network transmission is unreliable						
	Existing network applications are well-suited to my work						
	All the people, tools, resources I need are on the network						
	Networking is not seamless; still many unconnected, incompatible systems						
	Networking costs outweigh its benefits						
	Network use is actively encouraged, rewarded by my organization						
	Lack of experience with networking makes it hard to predict costs, benefits						
	A networked computer is easily accessible to me						
	Customers, clients, sponsors are demanding that I use networks						

IMPACT OF COMPUTER NETWORKS

In interviews conducted earlier, people involved in the aerospace industry suggested a wide variety of impacts, representing both problems and benefits, that may result from network use. Please complete the entire chart below to share YOUR OWN OPINIONS AND EXPERIENCES, regardless of whether or not you currently use networks.

21. Indicate in COLUMN I the extent to which YOU believe that NETWORKS INCREASE OR DECREASE each work aspect listed. Place a check in COLUMN II IF YOU HAVE PERSONALLY EXPERIENCED that effect. Indicate in COLUMN III whether you believe the effect represents a MAJOR PROBLEM OR BENEFIT in aerospace work.

EFFECT OF NETWORKS / ASPECTS OF WORK	I Is the effect of networks to INCREASE? or DECREASE? each aspect of work (Check only one)						II	III If effect occurs, is it a MAJOR PROBLEM or BENEFIT? (Check only one)			
	Don't know/ Not applic.	DECREASE Greatly	DECREASE Somewhat	NO EFFECT	INCREASE Somewhat	INCREASE Greatly	Have you PERSONALLY experienced this effect? (Check if yes)	Don't know/ Not applic.	MAJOR PROBLEM	MAJOR BENEFIT	Neither/Both
Ability to express ideas, problems at point of need											
Amount of information available											
Need for face-to-face interaction											
Coherence with one's work community											
Communication with people NOT on the network											
Exchange of information, ideas across organizational boundaries											
Efficiency of contacting people											
Number of changes required in final products											
Use of expensive computers and computerized devices											
Ability to complete projects within budget											
Turnaround time on solving problems											
Ability to complete projects, develop products on schedule											
Duplication of effort											
Ability to stay on the cutting edge of new knowledge											
Sense of ownership, commitment to work product											
Performance of work at home, on the road, off-site											
Rate of career advancement											
Degree of status among one's peers											
Ability to communicate with otherwise inaccessible people											
Documentation, evaluation of work processes											
Management control											
Feasibility, size of collaborative efforts											
Flexibility in work structures, patterns											
Number of staff employed											
Leaks of proprietary or sensitive information											
Major system security problems											
Amount of time spent fooling around											
Responsiveness to customers, clients, etc.											
Other (please specify):											
Other (please specify):											

IMPORTANT BACKGROUND INFORMATION

The information that you provide in this section will be used to help determine whether people with different backgrounds and jobs differ in regard to their network use.

22. Gender (Circle number of your response):

    1 Male
    2 Female

23. Age: ____

24. Highest degree obtained (Circle number of the SINGLE BEST response):

    1 High School Diploma
    2 Technical/Vocational Degree
    3 Bachelor's Degree
    4 Master's Degree
    5 Doctorate
    6 Post Doctorate
    7 Other (please describe): ____________

25. Years of professional aerospace work experience: ____ years

26. Type of organization where you work (Circle number of SINGLE BEST response):

    1 Industry/Manufacturing
    2 Government
    3 Academic
    4 Not-for-Profit
    5 Retired or Not Employed
    6 Other (please describe): ____________

27. If you work in an organization other than an educational institution, what is the approximate number of employees in your organization? (Please supply number of people for each category below that is applicable):

    27a ____ people in parent organization

    27b ____ people in my division

    27c ____ people in my location

    27d ____ people in department (or the equivalent)

28. Which category BEST describes your primary job function? (circle number of SINGLE BEST response)

    1 Administration
    2 Research
    3 Advanced or Applied Development
    4 Design/Product Engineering
    5 Industrial/Manufacturing Engineering
    6 Quality Control/Assurance (testing, inspection, etc.)
    7 Production
    8 Sales/Marketing
    9 Service/Maintenance
    10 Information Processing/Computer Programming/Systems Management
    11 Teaching/Training (may include research)
    12 Other: ____________

29. What is your current job title? ____________

30. Does your own work involve, as a primary feature, the development or analysis of computer systems, components, software, or data? (Circle number of your response)

    1 Yes
    2 No

CONCLUDING THE SURVEY

31. What do you most want to convey to network policymakers, service providers, or organizational managers about the impact of computer networks on work and communication in aerospace?

32. Is there anything else you would care to say about the use of computer networks in the aerospace industry? About this study?

33. Would you be interested in participating in follow-up research related to this study, such as a brief telephone interview or a short questionnaire on some specific aspect of network use? (Circle number of your response)

1 Yes
2 No

THANK YOU!

Mail to:

NASA/DoD Aerospace Knowledge Diffusion Research Project
NASA Langley Research Center
Mail Stop 180A
Hampton, VA 23681-0001

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13. ABSTRACT *(Maximum 200 words)*
This research used survey research to explore and describe the use of computer networks by aerospace engineers. The study population included 2000 randomly selected U.S. aerospace engineers and scientists who subscribed to *Aerospace Engineering*. A total of 950 usable questionnaires were received by the cutoff date of July 1994. Study results contribute to existing knowledge about both computer network use and the nature of engineering work and communication. We found that 74% of mail survey respondents personally used computer networks. Electronic mail, file transfer, and remote login were the most widely used applications. Networks were used less often than face-to-face interactions in performing work tasks, but about equally with reading and telephone conversations, and more often than mail or fax. Network use was associated with a range of technical, organizational, and personal factors: lack of compatibility across systems, cost, inadequate access and training, and unwillingness to embrace new technologies and modes of work appear to discourage network use. The greatest positive impacts from networking appear to be increases in the amount of accurate and timely information available, better exchange of ideas across organizational boundaries, and enhanced work flexibility, efficiency, and quality. Involvement with classified or proprietary data and type of organizational structure did not distinguish network users from nonusers. The findings can be used by people involved in the design and implementation of networks in engineering communities to inform the development of more effective networking systems, services, and policies.

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