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THE ROLE OF COMPUTER NETWORKS IN AEROSPACE ENGINEERING*

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Abstract

This paper presents selected results from an empirical investigation into the use of computer networks in aersopace engineering. Such networks allow aerospace engineers to communicate with people and access remote resources through electronic mail, file transfer, and remote log-in. The study drew its subjects from private sector, government and academic organizations in the U.S. aerospace industry. Data presented here were gathered in a mail survey, conducted in Spring 1993, that was distributed to aerospace engineers performing a wide variety of jobs. Results from the mail survey provide a snapshot of the current use of computer networks in the aerospace industry, suggest factors associated with the use of networks, and identify perceived impacts of networks on aerospace engineering work and communication.

I. The Need for User-Based Studies of Electronic Networking

Both individual engineering organizations and the federal government in the U.S. are making large investments in computer networks (i.e., telecommunications links that connect computers to each other or to other devices) in order to, among other things, increase R&D productivity, facilitate technology transfer, and improve industrial competitiveness. Federal policy makers, network system designers and service providers, and workplace managers are struggling to implement effective systems and to develop appropriate policies to govern network implementation and use. The success of institutional and national networking endeavors will depend on the development of network features, policies, and support programs that are based on solid knowledge of users' needs and habits and 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. And little is known about the extent of computer network use across different types of engineering organizations. 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 author 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 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

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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 subjects 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.

II. Background: Computer Networking in Engineering Settings

Engineers are employed to research, develop, design, test, and manufacture technology, which may exist in the form of either materials, products, systems, or processes. Engineering is a complex, information- and communication-intensive activity that involves invention, problem-solving, and coordination of many independent efforts. "Concurrent engineering," a notion that is currently popular in engineering management circles, focuses on the perceived need for better and faster communication, coordination, and integration of the work and information contributed by all of the 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[1] and improve the performance of engineers and the technical quality of their work.[2-8] Industrial 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, many engineering organizations have implemented their own private, high-speed networks that are used only by their own employees and affiliates. The need for the completely reliable electronic transfer of very large amounts of data also makes the use of most commercial networks inadequate for some industries and applications.

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. Computer networks are also playing an increasingly important role in engineering work. For example, engineers use networks to receive data collected by remote instruments. Networks facilitate the transfer 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. Networks are also used for information retrieval in connection with both in-house and commercial databases.[9-10]

Finally, engineers also use computer networks for a variety of communication purposes.[11-15] For instance, they can exploit computer-based message systems to call on the expertise, ideas, and advice of other members of their community and to locate resources. Electronic mail and various computer conferencing applications are also used to schedule and coordinate work or even conduct meetings, since they can be used to contact project team members, managers, people in other departments or divisions, and consultants in outside organizations. Electronic mail and bulletin boards are sometimes used to facilitate communication with customers and funders, as well.

There is a growing body of empirical research that examines the characteristics, use, and effects of computer-mediated communication.[16-21] Few studies attempt to describe these variables in terms of particular kinds of work, except by comparing broad job categories, for example, managers, professionals, and clerical workers.[22] With the recent proliferation of electronic networks, a number of empirical efforts dedicated to exploring the use of electronic networks for communication by scientists and engineers have been undertaken.[23-32] There seems to be agreement that electronic communication is used for administrative, technical, and social purposes. Much of this work seems compatible with findings about the nature of engineering communication and its relationship to engineering work and productivity, although virtually no studies have dealt exclusively or extensively with engineers. The capabilities and characteristics of electronic communication, in other words, seem to "match," to some extent, the nature and requirements of engineering work, knowledge, and communication. But new questions and issues have been raised and a number of conflicting findings have been presented. All in all, very little is known about the characteristics, use, and impact of electronic communication from the engineer's point of view.

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 highly computerized. It involves significant R&D, which is an especially 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[33] 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.[34] describe efforts at Grumman 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[35] 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). Moholm[36] 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 system may be a significant impetus to networking for aerospace firms.

Few empirical studies of computer networking in the aerospace industry have been conducted, although a number of the surveys conducted as part of the NASA/DoD Aerospace Knowledge Diffusion Project have included small components assessing the use of computing and communications technologies by aeropace students, faculty, researchers, and engineers. Beuschel and Kling conducted a case study of CIM in an aerospace firm[37] and found that effective technological integration was limited by complex social requirements for group coordination processes, such as negotiation and interpretation.

These reports reveal that a number of engineering organizations, including those in aerospace, are using electronic networks for a variety of 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 terms of better and faster product development and cost savings. 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 point to a number of factors that may hinder network use, such as security and proprietary concerns, the inability of networks to accommodate the negotiation and interpretation aspects of communication, and the substantial financial outlays required to implement networked systems.

III. A User-Based Study of Computer Networking in the Aerospace Industry: Method

This section describes briefly the method of the study whose results are reported here. As noted above, data to answer the study's research questions were gathered from a wide variety of aerospace engineers and the study sought specifically to collect data that reported network use (1) from the user's point of view, and (2) from within the context of aerospace engineering work and communication. The study drew upon methodological approaches and techniques that have evolved in the fields of library and information science, communications, management, computer science, and sociology.[23,25,28,29,38-42] Because it is user-based, the study aimed to collect data directly from individual aerospace engineers on networking topics and issues that were specifically related to their personal experiences and concerns. 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.

The primary mechanism for gathering data was a national mail survey, conducted in Spring 1993. The mail survey was preceded by site visits and in-depth interviews and a national telephone survey. These 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 triangulate study results. This paper will present results from the mail survey only.

The mail survey's respondents came from a stratified, random sample of 2000 U.S. subscribers to Aerospace Engineering, a weekly trade magazine published by the Society of Automotive Engineers (SAE), whose membership includes both automotive and aerospace engineers. The database containing records for the 54,600 journal subscribers is maintained by SAE, but subscribers are not required to be SAE members. The database categorizes individuals according to the aerospace industry they represent (manufacturing, government, air transportation, suppliers, and services -- including consultants, R&D services, and education) and their self-identified job classification (corporate management, engineering management, engineers and designers, R&D, manufacturing and production, purchasing and marketing, and other). The database includes practicing aerospace engineers working on a broad range of aerospace products, in a wide variety of organizations and subfields, and with a variety of professional duties. The SAE sample possesses characteristics in proportions that are similar to those reported in NSF employment data on the aerospace industry as a whole. The final, unadjusted response rate for the mail survey was about 48%, with 950 usable surveys returned.

The mail survey consisted of a ten-page booklet containing items on network availability and use, work and communication characteristics and activities, perceived network impacts, and demographic and employment characteristics of respondents. Most questions required respondents to circle the number of their selected answer or to fill in a matrix by placing check marks in cells corresponding to their answers. Several questions called for respondents to supply numerical answers or open-ended textual replies.

IV. Study Results

The mail survey's results are presented here with simple descriptive summaries. Most survey respondents were engaged primarily in design or product engineering (23%), advanced or applied development (14%) or research (13%) and were employed in industry (54%) or government (30%) settings. Other characteristics of survey respondents appear below (figures represent % of respondents):

Gender

Male	97
Female	3

Age

20-29 yrs.	3
30-39	24
40-49	24
50-59	32
60+	17

Size of Parent Organization (if private sector business)

1-4 employees	10
50-99	3
100-499	13
500-999	6
1000-4999	21
5000-9995	10
9996+	37

Job Type (self-identified)

Engineer	46
Manager	39
Scientist	5
Other	10

Branch of Aerospace (self-identified)

Aerodynamics	6
Structures	12
Propulsion	9
Flight Dynamics & Control	5
Avionics	12
Materials & Processes	14
Other	42

Primary Job Function (self-identified)

Administration	10
Research	13
Advanced or Applied Dev.	14
Design or Product Engr.	23
Industrial Engr.	6
Quality Control	6
Production	1
Sales or Service	7
Information Processing	3
Teaching	5
Other	12

In general, survey results paint a picture of widespread use of electronic networks. The majority of respondents (74%) reported that they personally used networks, 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 (from linked workstations within an organization, to a personal computer connected to a printer down the hall or a supercomputer across the country, to a dial-up link to the Internet) in their work. 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." 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.

Respondents also reported on availability and use of different types of networks (see Table 1). Computers connected to commercial networks that link users to people, tools, or information outside of

TYPE OF NETWORK	A computer or terminal connected to such a network is AVAILABLE for my use	Available network is USED
Local	85	91
Organizational	74	89
External/Research	50	88
External/Commercial	30	85

Table 1. Network Availability and Use
(% of Respondents Representing Each Response)

their own organization -- such as Compuserve -- were available to about 30% of respondents; 50% had 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. 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. As Table 2 indicates, the overwhelming majority of respondents used computer networks at work as opposed to at home or at some other location; of the various types of networks, external/commercial networks were, not surprisingly, most likely to be used at home.

TYPE OF NETWORK	Work	Home	Other
Local	84	10	4
Organizational	76	11	3
External/Research	52	8	2
External/Commercial	28	19	2

Table 2. Location of Network Use
(% of Respondents Selecting Each Location)

The mail questionnaire also asked respondents to describe the availability, use, and perceived value of various types of computer network applications (see Table 3). 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 login to run a computer program (80%), and electronic bulletin boards or conferencing systems (77%).

APPLICATIONS	% Who say that application is AVAILABLE	% USING application (if available)	% Who consider VALUE of application as "great" or "some"
E-mail	82	84	83
BBs, mail lists, conferencing	77	70	67
Real-time interactive messaging	70	51	54
Videoconferencing	66	44	58
Voice mail	77	78	76
Fax	94	96	94
Electronic journals	61	41	50
EDI	61	23	42
Run program on remote computer	80	71	73
Access data on remote computer	82	72	75
Search govt, commercial database	66	49	59
Card catalog search	62	57	62
Operate remote devices	62	27	43
CIM	63	24	41
Transfer data between computers	85	81	81
Access images	74	56	69
Other	69	50	52

Table 3. Network Applications

These applications were also the 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. As a point of general comparison, 94% of respondents indicated that fax was available in their workplace, and 77% reported the availability of telephone voice mail. The percent of respondents considering the value of each application to be "great" or "some" varied from 83% for electronic mail to a low of 41% for computer-integrated manufacturing (CIM). Throughout the survey, value judgments were made by all respondents, whether or not they currently had access to or used the network item in question. Overall value judgments, in this particular instance, may be colored by whether or not a specific application is used by a large number of respondents, even though respondents were also given the answer option of "Application is NOT APPLICABLE to My Work." For example, CIM may be assessed by a smaller percent of respondents as valuable to their work, because it is directly applicable to the work of a relatively smaller number of aerospace engineers.

Tables 4-5 report the availability, use, and value of network access to various work resources in aerospace engineering. In describing network access to human resources (Table 4), more respondents (about 85%) were able to communicate electronically with people within their own organization than with people in other organizations. Private sector colleagues or associates were least likely to be accessible over the network, with between 61% and 66% of respondents reporting such access. Network access to people in other departments of one's organization was judged valuable by the greatest number of respondents (81%), while access to external colleagues, customers, vendors, etc., was apparently considered slightly less important. This may reflect the feeling -- accepted as common knowledge by observers of the engineering enterprise -- that internal communication of any kind is generally more critical in engineering work than is external communication. On the other hand, the number of aerospace engineers who do use networks to communicate with various kinds of people outside their own organizations (between 52% and 72%) may surprise those who thought that such links, at least in the private sector, were still largely prohibited due to proprietary and security concerns.

WORK RESOURCES USED	% With Net ACCESS to Resource	% USING Net Access	% Who consider VALUE of access as "great" or "some"
People in your workgroup or dept.	85	88	78
Other people in your organization	86	89	81
Colleagues in academia, government	70	72	66
Colleagues in private industry	66	62	62
External clients, customers, sponsors	62	58	66
External vendors, suppliers	61	52	63
Other	48	22	42

Table 4. Work Resources and Network Use: People

WORK RESOURCES USED	% With Net ACCESS to Resource	% USING Net Access	% Who consider VALUE of access as "great"or "some"
Document citations, abstracts	69	76	74
Journal, trade magazine articles	55	50	63
Equipment / procedures manuals	59	57	62
Internal technical reports	66	71	72
Company newsletters, bulletins	70	75	61
Suppliers' catalogs	52	34	61
Codes of standards & practices	58	57	63
Directories of people	73	79	72
Training material, tools, programs	67	67	69
Internal financial data	71	73	70
Production control data	70	69	64
Experimental data	66	73	76
Product, material characteristics	60	61	71
Technical specifications	62	69	79
Design change forms	61	58	61
Lab notebooks	50	33	47
Drawings and designs	71	74	79
Computer code / programs	77	82	79
Other	61	56	78

Table 5. Work Resources and Network Use: Information

Network access to information resources (Table 5) ranged from a low of 50% for lab notebooks to a high of 77% for computer code and programs. Other information resources to which at least 70% of respondents reportedly had electronic access were company newsletters or bulletins, directories of people, internal financial data, production control data, and drawings or designs. Those resources actually accessed via networks by at least 70% of respondents were document citations and abstracts, internal technical reports, company newsletters and bulletins, directories of people, internal financial data, experimental data, drawings and designs, and computer code and programs. The range of resources here suggests that network access to information supports a broad array of specific engineering tasks. Network access to those resources most crucial to the actual design and production of technologies -- such as technical specifications and designs -- was considered of "great" or "some" value by the greatest number of respondents.

Respondents were also asked to report the two most significant communication channels they used to perform an important work task. They could either choose one of the twenty-one work tasks presented in a list, or supply a task not listed. The tasks selected by the greatest number of respondents were:

- Identify requirements
- Conduct experiment or run test
- Interpret results of experiments, tests
- Produce drawings, designs
- Assure conformance with requirements
- Plan tasks, projects, programs, etc.
- Coordinate work
- Negotiate with co-workers, clients, vendors, students, etc.
- Solve technical problem
- Write proposal, report, paper, etc.

Figure 1 portrays the extent to which different communication channels were used in task performance, regardless of which task was reported. Face to face communication was used by a clear majority of respondents (69%), followed by the examination of printed material (37%) and use of the telephone (36%). Use of a computer network link to people, information, or a computer was greater than that of either voice mail or U.S. or company mail service. In examining the use of network channels for specific tasks, "Learning how to do something" was the one task that accounted for substantial use of all three kinds of network channels. Network links to information were also used most heavily for producing drawings or designs and identifying problems. Network links to people were also used most extensively to support work coordination and writing proposals and reports. Finally, network links to computers were also used to develop theories and concepts or produce drawings or designs.

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 the study was to explore factors that might be associated with network use. One questionnaire

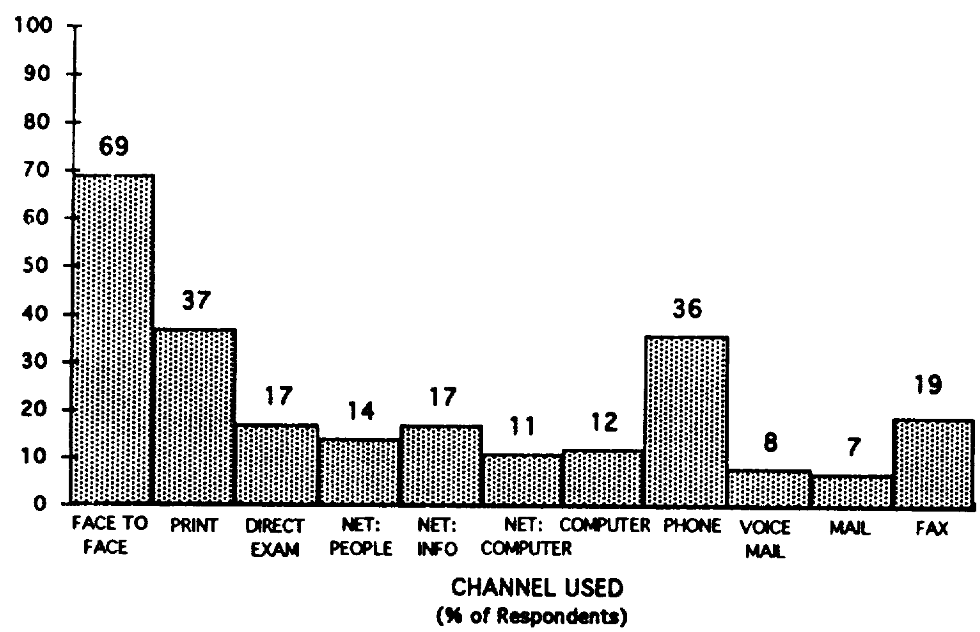

Figure 1. Use of Networks, Compared to Other Channels, For Performing Work Tasks

matrix asked respondents to report the extent to which they agreed or disagreed with a number of statements describing their work and networking environments. Comparing the responses of network users to nonusers reveals possible relationships between network use and various factors (see Table 6).

For example, a greater percent of network users, compared to non-users, agreed that their work is integrated with the work of others, that the people they need to communicate with are all in their building, that they require a diverse range of information from a wide variety of sources, and that time pressures in their work are tremendous. A greater percent of network nonusers agreed that they spent their day working independently. The accessibility of a networked computer is strongly associated with network use, as is work output that is stored in computerized form; these are frequently cited in the literature as factors that encourage network use, but they may also reflect results of extensive network use. Organizational reward and external demand seem to be significant

FACTORS	% of USERS agreeing with statement	% of NON-USERS agreeing with statement
The results of my work are integrated with the work of others	89	77
I spend my day working independently	42	63
All the people I need to communicate with are in my building	75	26
I require a range of information from a variety of sources	84	65
Time pressures are tremendous in my work	76	59
My work is routine, predictable	7	13
Work discussions require having documents, devices & drawings	67	66
I examine physical devices, instruments, materials, processes	59	62
The products I design, develop, produce are highly complex	69	59
I work in a field that is extremely competitive	69	59
My organization is hierarchically structured (not project-based)	48	41
My organizational culture is rigid and authoritative	34	24
My work is classified	22	21
Results of my work are proprietary	49	55
Results of my work are stored in computerized form	67	40
I started my professional career without networks	88	84
I like to learn new computer things just for the fun of it	65	56
Networking requires too much effort to learn and keep up with	23	16
I know about networked information services relevant to my work	19	7
Networking help comes from training or support programs	25	16
Network transmission is unreliable	15	5
Existing network applications are well-suited to my work	44	16
All the people, tools, resources I need are on the network	16	4
Networks are not perfect-many incompatible systems	61	21
Networking costs outweigh its benefits	11	12
Network use is encouraged, rewarded by my organization	35	11
Lack of experience makes it hard to predict costs/benefits	45	36
A networked computer is easily accessible to me	77	15
Customers, clients, sponsors are demanding that I use networks	20	9

Table 6. Factors Affecting Network Use

factors in encouraging network use. Interestingly, more network users agreed that networking is not seamless and that many incompatible systems exist; nonusers, perhaps, are simply more optimistic about network capabilities.

Cross tabulating various respondent characteristics with network use (see Table 7) revealed, for the most part, only small differences use due to respondent characteristics. 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. Network use is more extensive in in academia, as opposed to other sectors and is more widespread in very large organizations. Table 8 reports variations in network use according to different work characteristics. Scientists appear to use networks more than engineers do. In terms of primary job function, network use is most extensive among those engaged in teaching, research, advanced or applied development, and industrial engineering. Aerospace engineers working in aerodynamics or flight dynamics are slightly more likely to use networks than are those in other branches of aerospace.

RESPONDENT CHARACTERISTICS	Network Use (in %) USE Networks	NEVER USE Networks
Gender:		
Male	85	15
Female	81	19
Age:		
20-29	89	11
30-39	93	7
40-49	92	8
50-59	86	14
60+	61	39
Education Level:		
High School	80	20
Technical Degree	69	31
Bachelor's Degree	83	17
Master's Degree	88	12
Ph.D	93	7
Post Doctorate	100	0
Type of Organization:		
Industry/Manufacturing	85	15
Government	92	8
Academic	98	2
Non-Profit	83	17
Retired	12	88
Other	60	40
Organization Size:		
<50	58	42
50-99	53	47
100-499	81	19
500-999	87	13
1000-4999	87	13
5000-9995	95	5
9996+	94	6

Table 7. Respondent Characteristics and Network Use

RESPONDENT CHARACTERISTICS	Network Use (in %) USE Networks	NEVER USE Networks
Job Title:		
Engineer	84	16
Manager	87	13
Scientist	91	9
Other	84	16
Job Function:		
Administration	80	20
Research	94	6
Advanced/Applied Development	91	9
Design/Product Engineer	81	19
Industrial Engineer	91	9
Quality Control	85	15
Production	80	20
Sales or Marketing	73	27
Service or Maintenance	75	25
Information Processing	88	12
Teaching	98	2
Aerospace Branch:		
Aerodynamics	94	6
Structures	85	15
Propulsion	85	15
Flight Dynamics	90	10
Avionics	85	15
Materials	83	17

Table 8. Work Characteristics and Network Use

The final aspect of networking considered in this study was its impact on aerospace engineering work and communication. The percent of respondents selecting various replies to the question "Overall, how would you describe your current reaction to computer networks/" is presented below:

- They have revolutionized aerospace work (21%)
- They are very useful in many respects (55%)
- They have certain worthwhile uses (19%)
- I am neutral or indifferent to them (4%)
- I have reservations about their value (1%)
- They have limited value and can cause serious problems (.4%)
- They are worthless and should not be implemented (0%)

Thus, the overwhelming majority of aerospace engineers surveyed perceived a very positive impact from networks.

The survey also solicited aerospace engineers' assessments of specific networking impacts. In one questionnaire matrix, 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 considered the perceived networking effect to be a major problem, a major benefit, or neither. Table 9 presents selected results from this section of the survey. Responses related to degree of increase or decrease were grouped, and only the larger of the two resulting values is reported in the table. 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. Over half of the respondents felt that major benefits of networks were that they increased:

	% Reporting Network Effect is to:		% Reporting Effect is:	
ASPECTS OF WORK AND COMMUNICATION	DECREASE	INCREASE	MAJOR PROBLEM	MAJOR BENEFIT
Amount of information available		87		76
Exchange of information, ideas across organizational boundaries		74		72
Efficiency of contacting people		70		64
Ability to complete projects, on schedule		65		64
Responsiveness to customers, clients, etc.		65		65
Ability to stay on the cutting edge of new knowledge		64		61
Documentation, evaluation of work processes		64		60
Ability to communicate with otherwise inaccessible people		63		62
Use of expensive computers & devices		62		28
Ability to express ideas at point of need		60		57
Need for face-to-face interaction	55			34
Performance of work at home, on the road, off-site		53		51
Management control		53		49
Feasibility, size of collaborative efforts		53		51
Flexibility in work structures, patterns		53		48
Coherence with one's work community		52		45
Duplication of effort	52			48
Ability to complete projects within budget		47		46
Turnaround time on solving problems		47		70
Major system security problems		43	45	
Amount of time spent fooling around		43	29	
Leaks of proprietary or sensitive information		38	41	
Number or changes required in final products	32			42
Degree of status among one's peers		30		21
Sense of ownership, committment to work product		29		27
Rate of career advancement		24		22
Communication with people NOT on the network	22		22	
Number of staff employed	22			19

Table 9. Network Impacts

- 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 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

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. It may be that that some respondents had difficulty with the "decrease/increase" scale used in that question, applying it rather as the degree of "bad" to "good" influence of networks. Another possible explanation is that some respondents felt that networks allowed for more 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, the risks of system security and leaks of proprietary information were perceived by over 40% of respondents. Almost a third of aerospace engineers surveyed felt it was a major problem that networks increased the time that people spent "fooling around," while about a fifth cited the problem that communication with nonusers of networks was reduced.

A number of these impacts, such as "increases the amount of information available" are generic in the sense that they may be felt as well by other types of users beyond those in the engineering community. Some of the reported impacts relate directly to efficiency or effectiveness gains. Others, such as the increased "coherence with one's work community" describe second order effects, which are also important within the general work context.

IV. Conclusions

Few studies have appeared that examine 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 hopes to extend existing knowledge by employing a user-based approach to explore the role of electronic networks in engineering work and communication.

This paper has reported selected data on the use of electronic networks in engineering environments. Networks appear to be used widely for both communication and computation purposes by engineers in the aerospace industry, with interorganizational links available to half of those surveyed. Nonetheless, respondents perceived internal electronic links as being more valuable than external communication capabilities. A significant number of respondents reported their network access to a variety of tools and resources and judged network access highly valuable for a variety of resource types, from analytical tools like computer programs to experimental data to literature citations and abstracts. While computer networks are apparently not as important as face-to-face, telephone, and print channels in the conduct of aerospace engineering work, they were used more often than voice mail or regular mail services, and almost as often as fax. Electronic mail and file transfer are the applications that are most available, most used, and judged most valuable.

While organizational sector and size and primary job function appear to influence network use, other demographraphic characteristics of respondents do not, generally, seem to differentiate network users from nonusers as well as specific job and organizational environment characteristics, such as the accessibility of networked computers, whether network use is rewarded by one's organization, or whether one requires a wide range of information to perform one's job. Lack of network training and awareness were noted by both network users and nonusers; this may be one area that organizations could target if they wish to increase network use by their employees.

The impact of computer networks on the aerospace industry has apparently been overwhelmingly positive, with respondents generally reporting gains in certain areas of work efficiency, effectiveness, and satisfaction. A number of significant problems were also perceived, including lack of ubiquitous connections and inadequate security controls.

In addition to the questionnaire findings, comments made by study respondents in in-depth interviews suggest some of the limitations and advantages of electronic communication in engineering work. Although electronic communication is perceived to contribute to engineering efficiency and effectiveness, its use is limited (at least in terms of today's technology) by engineers' need for immediate, highly interactive discussion of complex problems of both a technical and non-technical nature. Networks do not provide adequate means to convey the multi-faceted, multimedia information that is typically exchanged in those situations where, for example, engineers discuss issues and negotiate while simultaneously consulting drawings, contracts, financial data, test results, and physical devices. Use may also be limited by organizations' lack of experience with electronic communication: while dangers are easy to imagine and costs easy to tally, benefits are harder to predict and quantify.

Research conducted from a user perspective can be utilized by network policy makers, system designers, and service providers in a number of ways. It can help them:

- Anticipate and avoid conflicts by discovering where attitudes and expectations vary among different groups;
- Understand and estimate networking impacts and benefits by revealing both direct and second order effects;
- 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;
- Implement effective mechanisms for user training and support by finding out who is having what kind of problem;
- Prepare appropriate evaluations of network systems and services by identifying a variety of goals and objectives and assessing the degree to which they have been met.

Thus, user-based research offers an important complement to networking investigations that concentrate on technical and financial analyses and can help assure that networking goals will be optimally met.

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