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NASTRAN BENEFITS ANALYSIS

VOLUME II

FINAL TECHNICAL REPORT

Submitted to
NASA HEADQUARTERS
Washington, D. C.



15 FEBRUARY 1972

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COMPUTER SCIENCES CORPORATION

6565 Arlington Boulevard
Falls Church, Virginia 22046

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FOREWORD

This Final Report has been prepared by Computer Sciences Corporation, Systems Division, Systems Sciences Center, Falls Church, Virginia, for NASA Goddard Space Flight Center under Contract Number NAS5-11724, Work Order Number 79.

The Final Report consists of two volumes as follows:

Volume I - Executive Summary

Volume II - Final Technical Report

This is Volume II

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SECTION 1 - INTRODUCTION

Beginning in 1966 NASA undertook the development of a large computer program designated the NASA Structural Analysis Program (NASTRAN) to aid in the conduct of structural analysis for its aerospace vehicles and related hardware. Upon its completion in 1970, NASTRAN was deemed applicable to a wide variety of both aerospace and non-aerospace applications and was placed in the Computer Software Management and Information Center (COSMIC), Barrow Hall, University of Georgia, Athens, Georgia, for use by the general public. In the past two years the program has generated much interest and has been used by a number of industrial companies, government agencies, and academic institutions in order to aid in the solution of structural analysis problems.

NASA is now attempting to generate base line data for future comparisons of the costs and benefits of the program and to determine what impacts and benefits are accruing to current users of the NASTRAN program. To develop this information, questionnaires were mailed to users. In addition, a number of personal and telephone interviews were made to solicit further information. The questions in the questionnaire and in the interviews were related to benefits derived from the programs, areas of needed improvement, and applicable usage comments. The collected information has been compiled and analyzed. For emphasis and for ease of distribution, the major results have been separately bound in Volume I. This Volume II is complete within itself and contains the methodology, analyses, and results. The information in this study is applicable prior to the issue of NASTRAN Level 15 by NASA.

SECTION 2 - SUMMARY AND CONCLUSIONS

2.1 SUMMARY

A survey of NASTRAN users has been successfully completed to obtain NASTRAN benefits and usage. Some 205 persons, believed users, were selected for the survey. A mailed questionnaire went to each. In addition, telephone and personal interviews were conducted for additional information. A combined total of 152 responses were obtained from users and non-users; some were from potential users in the near future. A considerable amount of information on benefits and usage data was obtained which is detailed in the main body of the report and in the appendices. Paragraph 2.2 emphasizes the conclusions which pertain to NASTRAN benefits.

2.2 CONCLUSIONS

As a result of the NASTRAN Benefits Analysis Study, it is concluded that:

1. There is widespread acceptance and use of the program; 186 different applications have been reported in progress and 55 more are in the planning stage.
2. NASTRAN is considered to be a vital program to the structural analysis community since two-thirds of the current applications would not have been attempted without it.
3. Significant benefits are being obtained in specific areas such as the following:
 - o A large non-aerospace company is saving \$1,000,000 per month in quality assurance
 - o A NASA agency saved 500 man-hours in improved reliability analysis
 - o An aerospace company shortened development time by eight weeks.
4. NASTRAN users reported spending \$529,025 for some 50 applications. When extrapolated to 186 applications, this

figure multiplied by $(\frac{186}{50})$ conservatively approaches \$1,500,000.

5. Users have reported spending \$232,000 of their own funds for improvements and adaptations to the program. Presumably this is done with an increased productivity or profit motive.
6. About 80 percent of those users who answered the question stated that they received a benefit because of the NASA maintenance program. This benefit was estimated for 27 applications and saved the users \$324,000. Extrapolated over the 186 current applications, and the 55 planned, the savings $(\frac{241}{27})(324,000)$ are conservatively estimated at \$2,500,000.
7. NASTRAN is contributing to new product development. The number of responses indicating the dollar values of new products were few; however, the following are examples:
 - o A non-aerospace company \$5,000,000
 - o An aerospace company \$ 650,000
 - o A service bureau \$ 20,000/month
8. The users are interested and involved in the program as evidenced by 116 improvements and 35 future applications which have been recommended by the users.
9. Seven out of eight cost comparisons between running the same application with NASTRAN, and another program, were favorable to NASTRAN.
10. At the time the study was started, 667 persons (a majority being engineers) were reported to be using NASTRAN.
11. NASTRAN applications are sufficiently widespread that 21 service bureaus or corporations providing NASTRAN services have been identified.

By recapitulating the above data and using just some of the examples given, the direct economic benefits can be calculated as follows:

Annual Cost Savings

\$12,000,000 - Quality Assurance, Paragraph (3)
2,500,000 - Program Maintenance, Paragraph (6)

\$14,500,000

Funds Spent to Date for Applications and Improvements

\$ 232,000 - Improvements, Paragraph (5)
1,500,000 - Applications, Paragraph (4)

New Product Development

\$5,650,000 - Industry, Paragraph (7)
240,000 - (Annual) Service Bureau, Paragraph (7)

Other important findings from the study indicate that users are almost unanimous in their opinion that NASTRAN has caused a substantial reduction in real operating costs and therefore a great increase in productivity. Five primary factors listed by the users as increasing productivity are:

1. Analyses have been accomplished which could not have been done without NASTRAN.
2. More complete and accurate results have been attained
3. Development time has been shortened
4. Communications between engineers and programmers have improved because of the standardization of terminology and mathematical approaches developed in NASTRAN
5. Cost reductions in analysis have been achieved.

SECTION 3 - METHODOLOGY AND ANALYSIS

3.1 OBJECTIVES

This study has focused on determining and evaluating the direct economic benefits that accrue to users of the NASTRAN program. Supplementary data were also collected on program usage and on areas requiring improvement.

Users have been defined as government agencies (NASA and others), academic institutions, and industrial firms including service bureaus who have acquired NASTRAN and are active users.

For government agencies and academic institutions, the direct economic benefits were measured in terms of actual cost savings and/or increases in productivity achieved through the use of NASTRAN. In the use of NASTRAN the operating costs may increase, however, the increase in productivity may exceed the cost increase. The net gain in productivity is considered as the direct economic benefit. Since industrial organizations are profit oriented the direct economic benefits realized by them are reflected in an increase in their net profit. This increase is the result of any or all of the three factors: 1. an increase in productivity, 2. a decrease in operating costs, and 3. new business generated by NASTRAN applications which includes service bureau activities. Since NASTRAN would probably be a relatively small part of a firm's operations, an increase in net profits may not become immediately apparent, hence, attention is focused on identifying, evaluating, and measuring the above three factors which will ultimately be reflected in an increase in profits.

3.2 DATA COLLECTION

3.2.1 Identification of Users and Selection of a Survey List

The basic data to determine the economic benefits to users of the NASTRAN program were derived from a survey of users. Resource documents employed to determine the most probable actual users were:

1. A list of organizations that had purchased the NASTRAN

Tapes and Documentation from COSMIC as of 1 December 1971, 69 names

2. A list of personnel who had attended the NASTRAN Colloquium in September of 1971, 264 names
3. The distribution list of the NASTRAN News Letter, 784 names
4. A NASTRAN User information solicitation connected with the News Letter, 129 names.

In addition, several resource personnel who had been working with the program over a number of years were consulted for additional user names. These personnel were:

Mr. Joseph M. Carlson, NASA Headquarters

Mr. Thomas Butler, NASA Goddard Space Flight Center

Dr. John P. Raney, NASA Langley Research Center (NASTRAN Program Manager)

Dr. Deene Weidmann, NASA Langley Research Center

Mr. Roger Butler, NASA Langley Research Center

Mr. Frank Douglas, Computer Sciences Corporation

Mr. Howard Dielmann, Computer Sciences Corporation

Mr. Thomas Clark, Computer Sciences Corporation

Mr. Donald McLean, Computer Sciences Corporation

As a result of this effort, an approved list of 192 names were compiled of those believed to be users. Subsequently, 13 additional names were added by NASA Langley Research Center. The survey list composed of 205 names is attached as Appendix A.

Table 3-1 shows distribution by organizational affiliation of individuals who received the mailed questionnaire as compared to resource populations. The characteristics are very similar, and it was hoped that the characteristics of the response sample would parallel those of the

Table 3-1
NASTRAN Population Characteristics

Population	Total No. in Pop.	Industry			Government		Academic %	Service Bureaus %	Affiliation Unidenti- fied %
		Aero- space %	Non Aero- space %	NASA %	NASA %	Non NASA %			
COSMIC Pur- chasers of Tapes and Doc- umentations	69	40	28	16	6		5	5	0
Survey List	205	41	30	8	8		7	6	0
Colloquium (users and non- users)	264	35	19	16	14		5	11	0
News Letter (users and non- users)	784	36	32	7	8		10	4	3
Responded to 1st News Letter (and a user)	129	35	28	8	9		4	5	11

survey list (paragraph 3.2.4). Included in the survey list were all known NASTRAN installations, the 69 who purchased NASTRAN from COSMIC, and the several installations in government and service bureaus. In some cases more than one individual in an organization received a questionnaire. But this presented no significant problem since these individuals may have used different applications to accomplish varying objectives, and, hence, different types and levels of benefits may result. In any event, care was taken in the analysis of the results to avoid tabulation of duplicate benefits accruing to the same organization.

A basic assumption was made that the individuals receiving the questionnaire would have a good working knowledge of one or more of the NASTRAN applications. For such a new program, the perfect screening of the individual recipients was impossible, and a few returns were received as non users or those whose use had only recently begun (see paragraph 3.2.4).

3.2.2 Development of Questionnaires

Appendix C is the mailed questionnaire. The questions identify possible benefits and ask the recipient to select those which apply to him and, if possible, to quantify the benefits received in tangible terms.

The answers were difficult to estimate, they might not be available, and could in some cases be considered proprietary. Complete answers to all questions were not expected. Even in the event that questions remain unanswered, they may serve a valuable purpose in that they alert the individuals to various benefits and may create interest in them. The questions were developed by first determining what data was believed necessary in order to conduct an analysis of the impacts of NASTRAN and developing a question to obtain the required data. Technical CSC personnel, working under the guidance of an economist, prepared lists of candidate questions. These questions were discussed and amalgamated into a proposed candidate list. The list was discussed with Mr. Thomas Butler of NASA Goddard Space Flight Center and Drs. J. P. Raney and D. Weidman of NASA Langley Research Center. Some rearrangements and clarifications were made, and the list was submitted to Mr. Joseph M.

Carlson of NASA Headquarters and approved for mailing.

3.2.3 Personal and Telephone Interviews

Early returns from the mailed questionnaires indicated four persons were "address unknown" and 12 were non-users. From the remainder of the list, 30 candidates were selected for possible personal interview and 30 more for back up and telephone interview. These candidates were discussed with Mr. Joseph M. Carlson, Mr. Thomas Butler, Dr. J. P. Raney, and Dr. D. Weidman. A minor reshuffling of the candidates occurred and information was obtained on the candidates' backgrounds and their possible experience with NASTRAN. On January 10, 1972, contractor personnel began telephoning to secure personal interviews and to interview by telephone. By January 13th it became apparent that the recipients of the questionnaires (beyond the local area) did not desire personal interviews. Accordingly, eight personal interviews were confined to the Washington/Baltimore Area. A decision was made to increase the number of telephone interviews (eighty nine, were made). This stimulated a large number of personnel to return their mailed questionnaires. It also provided an opportunity to discuss NASTRAN with a large number of users and enabled CSC to fill out the supplementary questionnaires for 76 users and nine potential users.

3.2.4 Data Receipt

Receipt of the raw data consisting of the returned questionnaires and the telephone and personal interviews continued during the period January 3 to January 28, 1972. The latter date was selected as the final cutoff since the final report was due on February 15, 1972. Not all questionnaires were completely answered because of limited usage to date, proprietary information, and answers unknown. In general, the tabulated benefit information from the returns is provided in paragraph 3.3. Tabulation of usage results is shown in paragraph 3.4. Of the 205 names on the original survey list, 152 contacts were made by mailed return, by telephone, or by personal interview with the person named or with his designated colleague. Of course, not all of the 152 persons were users. The remaining 53 did not return questionnaires and were not contacted by telephone. Table 3-2

Table 3-2
Summary of Changes in "Modified" Address List
(See Appendix B)

1. Returned as undeliverable, address unknown or terminated, deleted from list	8
2. Definitely non-user, no interest at all, wrong man in company, deleted from list	7
3. Reported as non-user but interested, retained on list	11
4. Reported as non-user but definitely potential, retained on list	22
5. Replaced name by more applicable name, retained organization on list	20
6. Addition of new names to same organization.	21

summarizes general information about members of the survey list. A "modified" mailing list is attached as Appendix B. There are probably still some errors since not all of the original list were contacted. Since Appendix B is rather long, Table 3-3 provides a list of organizations reported as users of NASTRAN.

3.2.5 Response Sample Characteristics

Table 3-4 lists the characteristics of the response sample as compared to the survey list and the other NASTRAN populations. It had been assumed that the aerospace users might overwhelm the response and thus skew the sample, but such was not the case. The response sample characteristics are very close to that of the other NASTRAN populations. The sample contains 1. current users, 2. potential users (those who are studying the program, may have purchased it, and expect to use it in the very near future) and 3. non-users who are interested in the program but whose use may be a year or two away. It does not contain those who stated they were definitely non-users. As expected, the aerospace returns were more complete since they have been working with the program for a much longer time than other users.

Table 3-3. Organizations Reported as Users of
NASTRAN

Aerojet Solid Propulsion Company	Sacramento, California
A. O. Smith Corporation	Milwaukee, Wisconsin
Argonne National Laboratory	Argonne, Illinois
Atlantic Research Corporation	Costa Mesa, California
AVCO, Lycoming Division	Stratford, Connecticut
Bell Aerospace Company	Buffalo, New York
Bell Helicopter	Fort Worth, Texas
Bell Telephone Laboratory	Whippany, New Jersey
Boeing Aerospace Company	Seattle, Washington
Boeing Computer Service	Kent, Washington
CHI Corporation	Cleveland, Ohio
Computer Sciences Corporation	Richland, Washington
Computer Sciences Corporation	Los Angeles, California
COMSAT Laboratory	Clarksburg, Maryland
Control Data Corporation	Minneapolis, Minnesota
Control Data Corporation	Chicago, Illinois
COSMIC	Athens, Georgia
Esso Production and Research	Houston, Texas
Fairchild Industries	Germantown, Maryland
Ford Motor Company	Dearborn, Michigan
Franklin Institute	Philadelphia, Pennsylvania
General Dynamics/Convair	Fort Worth, Texas
General Dynamics/Convair	San Diego, California

Table 3-3. Organizations Reported as Users of
NASTRAN (continued)

General Dynamics/Corporation	Pomona, California
General Motors Research Laboratory	Warren, Michigan
Georgia Institute of Technology	Atlanta, Georgia
Goodyear Aerospace Corporation	Akron, Ohio
B.F. Goodrich	Akron, Ohio
Grumman Aerospace Company	Bethpage, New York
Hercules	Magna, Utah
Hercules	Cumberland, Maryland
Itek Corporation	Lexington, Massachusetts
Jet Propulsion Lab	Pasadena, California
Johns Hopkins University	Silver Spring, Maryland
Lockheed Georgia Company	Marietta, Georgia
Lockheed California Company	Burbank, California
Louisiana Tech. University	Ruston, Louisiana
Los Alamos Scientific Laboratory	Los Alamos, New Mexico
LTV Aerospace Corporation	Dallas, Texas
MacNeal - Schwendler	Hampton, Virginia
Martin - Marietta Corporation	Denver, Colorado
McDonnell-Douglas Aircraft Corp.	St. Louis, Missouri
McDonnell-Douglas Automation Co.	St. Louis, Missouri
McDonnell Douglas	Huntington Beach, California
McDonnell Douglas	St. Louis, Missouri
NASA Goddard Space Flight Center	Greenbelt, Maryland
NASA Ames Research Center	Moffett Field, California

Table 3-3. Organizations Reported as Users of
NASTRAN (continued)

NASA Manned Spacecraft Center	Houston, Texas
NASA Lewis Research Center	Cleveland, Ohio
NASA Marshall Space Flight Center	Huntsville, Alabama
NASA Kennedy Space Center	Cape Kennedy, Florida
NASA Langley Research Center	Hampton, Virginia
Naval Air Development Center	Warminster, Pennsylvania
Naval Ship Research and Development Center	Washington, D. C.
North American Rockwell Space Div.	Downey, California
Northrop Services Incorporated	Huntsville, Alabama
Old Dominion University	Norfolk, Virginia
Perkin Elmer Corporation	Danbury, Connecticut
Pioneer Services Incorporated	Chicago, Illinois
Pratt & Whitney Aircraft	West Palm Beach, Florida
Raytheon Company	Sudbury, Massachusetts
Research Analysis Corporation	McLean, Virginia
Sandia Laboratories	Albuquerque, New Mexico
SCI-Tech.	Wilmington, Delaware
Sperry Rand	Huntsville, Alabama
Structural Dynamics Research Corp.	Cincinnati, Ohio
Teledyne Brown	Huntsville, Alabama
Teledyne Ryan	San Diego, California
Teledyne Computer Center	Toledo, Ohio

Table 3-3. Organizations Reported as Users of
NASTRAN (continued)

Texas Instruments	Dallas, Texas
TRW Systems	Redondo Beach, California
United Aircraft, Sikorsky Division	Stratford, Connecticut
Watervliet Arsenal, U.S. Army	Watervliet, New York
Westenhoff & Novick	Chicago, Illinois
Westinghouse Telecomputer	Pittsburgh, Pennsylvania
Westinghouse Defense and Space Center	Baltimore, Maryland
Westinghouse, Research and Development Center	Pittsburgh, Pennsylvania

Table 3-4
NASTRAN Response Sample Characteristics

Population	Total No. in Pop.	Industry		Government		Academic %	Service Bureaus %	Affiliation Unidenti- fied %
		Aero- space %	Non Aero- space %	NASA %	Non NASA %			
COSMIC Pur- chasers of Tapes and Documenta- tions (users)	69	40	28	16	6	5	5	0
Colloquium (users and non-users)	264	35	19	16	14	5	11	0
News Letter (users and non- users)	784	36	32	7	8	10	4	3
Responded to 1st News Letter (and a user)	129	35	28	8	9	4	5	11
Survey List	205	41	30	8	8	7	6	0
Response Sample	152	35	32	9	9	5	10	0

3.3 BENEFIT DATA ANALYSIS AND RESULTS

3.3.1 Current Usage of NASTRAN and the Survey Population

NASTRAN is currently being used in a wide and comprehensive variety of about 186 applications, which are listed in Appendix F. Table 3-5 shows that the aerospace industry, representing about one-third of the response population, accounted for one-half of the 186 applications, reflecting a high degree of interest and more intensive use of the program by that particular user group. With the exception of the academic institutions, the remaining applications being performed by the other users were uniformly distributed among the other groups. In addition to the 186 applications currently identified as being performed, there are an additional 55 applications either under development or planned. The distribution of these applications, shown in Table 3-6, among the various user groups roughly parallels that of applications being performed at the present time. These additional 55 applications are listed in Appendix G.

Table 3-5 also indicates that 124 of the 186 applications would not have been attempted without the availability of NASTRAN, which demonstrates a great deal of confidence in the program and its capabilities. In view of the fact that about 90 percent of these 124 applications were considered to be successful, this confidence is justified. Even for many of the 62 applications that would have been developed had NASTRAN been unavailable, users pointed out that the other programs were not as effective as NASTRAN. That is, they did not provide sufficient capacity, and the answers they provided were not as accurate.

A basic assumption was made that the 152 responses received from mail, personal interviews, and telephone surveys represent all of the major user organizations. Because of the high degree of interest expressed in the NASTRAN program it was further assumed that those who did not respond to the survey were non-users, that they had only limited NASTRAN use, or that they deemed the answers proprietary. As might be expected, service bureaus were the most reticent. This problem was partially overcome as the customers of the service bureaus provided a good portion of the information.

Data on current usage patterns of NASTRAN, along with comments on its efficacy and specific suggestions for future improvements and applications, are discussed in Section 3.4 and in the appendices.

Table 3-5. Summary of Current NASTRAN Applications,
by Type of Organization

Organization	Applications that would have been developed had NASTRAN been unavailable		Applications that would not have been attempted without NASTRAN		No. of Applications	Percent
	No.	Percent	No.	Percent		
Aerospace Industry	26	42.0	67	54.0	93	50.0
Non Aerospace Industry	10	16.1	16	12.9	26	14.0
Government-NASA	5	8.1	19	15.3	24	12.9
Government-Non-NASA	10	16.1	9	7.3	19	10.2
Service Bureaus	7	11.2	10	8.1	17	9.1
Academic Institutions	4	6.5	3	2.4	7	3.8
TOTAL	62	100	124	100	186	100

Source: Appendix H

Table 3-6. Summary of NASTRAN Applications in
Development or Planning Stage

Organization	Number of Applications	Percent
Aerospace Industry	25	45.5
Non-Aerospace Industry	12	21.8
Government - NASA	8	14.5
Government - Non NASA	5	9.1
Service Bureaus	5	9.1
Academic Institutions	0	0
TOTAL	55	100

3.3.2 Direct Economic Benefits

3.3.2.1 Cost Reduction

While the experience with NASTRAN has been relatively brief, the data derived from the mail survey indicate that current users have been able to achieve a tremendous increase in productivity. This increase in productivity has resulted in a significant reduction in real operating costs. In question 6 (Appendix C), users were asked to rank in order of importance the benefits they receive from NASTRAN. The results are presented in Table 3-7. From line one of the table it may be noted that 62 percent of the 69 users identifying their top choice indicated that the most important benefit they derived from the program was that it enabled them to perform analyses that they would not have been able to perform without NASTRAN. Six users ranked this benefit in second place, and three users ranked it third. Seven users did not rank it among the first three. The second line of the table shows that NASTRAN gives more complete results than other programs. The ranking of other benefits follow on succeeding lines.

These results provide a clear indication that the most significant direct economic benefit was the reduction in real operating costs achieved through an increase in productivity.

In order to more firmly establish the reasons for the use of NASTRAN, especially for those applications that would not have been attempted without its availability, users were asked (question 11, Appendix C) to indicate their reasons for its selection. The responses, covering a total of 77 applications, are shown in Table 3-8. NASTRAN was selected for almost 90 percent of these applications because it provided techniques not previously available and it could be applied to large complex problems. These results confirm the earlier finding about the tremendous increase in productivity and the resulting reduction in real costs.

Users have been intensively involved in developing and refining their applications of NASTRAN. Hence, they have not had sufficient time to adequately quantify their savings and increase in productivity. Some, however, were able to achieve some quantification for 12 applications, and the results

Table 3-7. NASTRAN Program Benefits, by Order of User Selection

	Benefit Ranking						Number of times mentioned, but not ranked on the questionnaire	
	First		Second		Third			
	No. Users	Percent	No. Users	Percent	No. Users	Percent		
Performed analysis that would not have been attempted without NASTRAN	43	62.3	6	8.8	3	4.9	7	10.8
Obtained more complete results than other programs	8	11.6	16	23.5	15	24.6	8	12.3
Time saving	6	8.7	6	8.8	6	9.8	10	15.4
Obtained more accurate results	2	2.9	13	19.1	10	16.4	8	12.3
Improved communications with other engineers and analysts in the field of structural analysis	4	5.8	6	8.8	9	14.8	9	13.9
Cost reduction	3	4.4	5	7.4	7	11.5	6	9.2
Work simplification	1	1.5	14	20.6	7	11.5	9	13.9
Resulted in safer product	1	1.5	0	0	4	6.6	2	3.1
Increased product reliability	1	1.5	0	0	0	0	0	0
Provides checkpoint for in-house programs	0	0	1	1.5	0	0	0	0
Resulted in better product	0	0	0	0	0	0	4	6.2
Provides additional capability	0	0	01	0	0	0	2	3.1
Provides stimulus for development of better applications	0	0	1	1.5	0	0	0	0
TOTAL RESPONSE	69	100.0	68	100.0	61	100.0	65	100.0

Table 3-8. Reasons for Using NASTRAN for Applications
That Would Not Otherwise Have Been Attempted

Reasons for Using NASTRAN	Aerospace Industry	Non- Aerospace Industry	Govt. NASA	Govt. Non- NASA	Service Bureaus	Academic Institutions	Total	Percent
Development of own programs too expensive	4	0	0	4	0	0	8	10.4
Provides techniques not previously available	34	1	3	0	8	0	46	59.7
Complexity and size of problem	6	4	8	2	1	0	21	27.3
Shortens product development time	0	0	0	1	0	0	11	1.3
Better and more accurate results acquired	0	0	0	0	0	1	1	1.3
TOTALS							77	100.0

(taken from question 16, Appendix C), are shown in Table 3-9. Two of the most significant benefits listed are the one million dollars per month savings being realized by the Ford Motor Company in improving its quality assurance in frame dynamics problems, and the 500-engineer man-hours by NASA LaRC in its Viking launch vehicle analysis.

Some users were not sufficiently informed on costs, or they considered their cost data proprietary, and did not adequately report their costs of performing NASTRAN applications. Thirty-two users, however, did report their costs in sufficient detail (question 13, Appendix C) for performing 50 NASTRAN applications. The results are summarized in Table 3-10, and the costs of performing individual applications are listed in Appendix J. The total cost of performing these 50 applications was \$529,025. On this basis, an estimate of the cost of performing the 186 current applications could be extrapolated to \$1.5 million annually. In addition, as an indication of the value the various user groups attach to their investment in NASTRAN, they have spent a total of about \$232,000 for improvements to it. These improvements are listed in Table 3-27. The individual cost components considered in the total were programmer/analysts costs, engineering costs, and computer costs. A comparative cost analysis between NASTRAN and previous computer programs used for the same application could not be made since the response to question 14 (Appendix C) was not sufficient; however, the several responses received to this question, which permitted a comparison of a few selected applications, are discussed in Section 3.4, paragraph 3.4.13. These data do indicate, however, the existence of significant cost savings, which promise to become larger as NASTRAN is improved.

Even though users could not provide enough data for a thorough cost comparison between NASTRAN and other computer programs, they did provide a clear indication that actual cost savings are the result of NASA providing NASTRAN maintenance. In Table 3-11, for example, it may be noted that 36 out of 46 user organizations achieved actual cost savings which were directly attributable to the provisions of maintenance of the program by NASA. When users were asked (question 19, Appendix C) how much they would have budgeted for maintenance if it had not been provided by NASA, the responses

Table 3-9. Examples of Typical NASTRAN Benefits

Aerospace Industry

Structural damping study	Shortened development time 8 weeks
Dynamic stress concentration analysis	Shortened development time 4 weeks

Government - NASA

Analysis of mobile service platforms	Saved 3 man weeks in safety analysis, and shortened development 10 weeks
Analysis of skylab launch pedestal	Saved 12 man weeks in safety analysis, and shortened development time 6 weeks
Viking launch vehicle and payload	Saved 12 man weeks in reliability analysis and shortened development time 3 months

Industry - Non-Aerospace

Automobile frame dynamics	Saved \$12,000,000 per year in quality assurance analysis
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Table 3-10. Costs of Performing Selected NASTRAN Applications

Type of Organization	Number of Applications	Programmer Analysts Costs	Engineering Costs	Computer Costs	Total Costs
Industry Aero-space	31	\$16,350	\$161,850	\$117,125	\$295,325
Industry Non-Aerospace	9	6,100	52,800	49,300	108,200
Government - NASA	8	21,500	40,700	57,500	119,700
Government - Non-NASA	2	0	3,400	2,400	5,800
Service Bureaus	NA*	NA*	NA*	NA*	NA*
Academic Institutions	NA*	NA*	NA*	NA*	NA*
Total	50	43,950	258,750	226,325	529,025

*Note: NA - not applicable since no applications were reported with complete cost data.

Source: Appendix J

Table 3-11. Users Receiving Cost Savings Benefits From NASA Program Maintenance

Type of Organization	Did benefit	Did not benefit
Industry Aerospace	18	4
Industry Non- Aerospace	6	2
Government - NASA	2	3
Government - Non-NASA	5	0
Service Bureaus	3	1
Academic Community	2	0
Total	36	10

in Table 3-12 show that for 27 applications they would have set aside \$324,000 for maintenance. It is emphasized that this represents only 27 applications, while a total of about 186 applications are being performed, and about 55 applications are either underway or planned. On this basis, the actual cost savings on maintenance alone for government, academic, and industry users could be conservatively extrapolated to \$2.5 million annually. NASTRAN Systems Management Office spends approximately \$400,000 per year on NASTRAN maintenance. Thus, it is clear that centralized maintenance by NASA is a very efficient method of operating and affords a considerable benefit to users.

3.3.2.2 Business Generated by NASTRAN

The responses to question 9 of the mail questionnaire (Appendix C) and question 3 of the supplementary telephone questionnaire (Appendix D) indicate that about 21 service bureaus are furnishing NASTRAN services to other organizations. These service bureaus are listed in Appendix K. While these service bureaus did not provide estimates of the revenues derived from the sale of these services; the sales would nevertheless constitute a direct benefit. That is, these sales represent revenues that would not have been received if NASTRAN had not been developed.

Only five organizations responded to question 15 (Appendix C). They were asked if they could attribute the development of any new product to NASTRAN: The responses are presented in Table 3-13. It is evident that this new business generated by NASTRAN will be substantial, and will constitute a very large, direct economic benefit.

3.3.3 Other Benefits

Analysis of the responses to the mail questionnaire provided some indication that NASTRAN will result in the development of safer structures and other products. This, of course, would be an important intangible benefit. In Table 3-7 for example, one user indicated that the most important NASTRAN benefit was that it resulted in a safer product, and three users ranked this benefit as the third most important. Also, in Table 3-9, another user indicated that his company (Ford Motor Company) is currently achieving savings

Table 3-12. Estimated Program Maintenance Budget if
Maintenance Not Provided by NASA,
Selected NASTRAN Applications */

<u>Application</u>	<u>Annual Budget Estimate</u> (thousands of dollars)
-Industry Aerospace-	
Engineering analysis	\$ 8.0
Improved math algorithms	19.0
Debug known program errors	7.5
Update system and locate errors	2.0
Upgrade SAMIS	15.0
Space shuttle studies	30.0
RAM studies	10.0
Unidentified (2 applications)	<u>60.0</u>
Total	\$151.5
-Industry Non-Aerospace-	
Annual updating and improvements of subroutines including tailoring to in-house usage	20.0
Debug programs	2.0
Static analysis of a casting	20.0
Dynamic frame analysis	
Advanced technology satellite	
Large space telescope	28.0
PAC 3	
Orbiting astronomical satellite	
Electronic product design	15.0
Front suspension lower arm analysis	
ACT arm	30.0
Frame dynamics	
Program maintenance	<u>10.0</u>
Total	\$125.0
-NASA-	
Skylab buckling	
Shuttle analysis	
Skylab and shuttle stress	<u>\$ 45.0</u>
Solar panel dynamics and statics	
Total	\$ 45.0
-Service Bureaus-	
Data preparation assistance and output analysis	<u>2.4</u>
Total	\$323.9

*/ These 27 applications are only those reported by individual users. Users not responding were probably unable to provide budget estimates. In several instances data were presented in terms of engineering or programming man-hours instead of dollars. In these cases conversions to dollars were made on the following basis: 1 engineer = \$19,000/year - 1 programmer = \$15,000 year.

Table 3-13. New Product Development Attributable to NASTRAN

Product	Type of organization	Value
More sophisticated structural analysis	service bureau	\$20,000 per month
Hypersonic wing	industry aerospace	\$650,000
Engineering support services	industry aerospace	\$40,000
Analysis of complete electronic packages without need to sub-structure	industry aerospace	\$15,000 per year
More sophisticated analytical capability	industry non-aerospace	\$5,000,000
Reel pallet	government non-NASA	unknown
Design of Toroidal antenna (earth station)	government non-NASA	unknown

of \$1 million a month in improved quality assurance. It may be that the improved level of safety achieved through the application of NASTRAN could ultimately result in the saving of lives. While this benefit cannot be quantified, it is nevertheless very important.

3.3.4 Prospects for Future Savings and User Interest in NASTRAN

As pointed out in paragraph 3.3.2.1, the current users of NASTRAN have probably spent more than \$1.5 million in running the program, and they have invested an additional \$232,000 in making improvements of their own to the program. These amounts would obviously not have been expended unless the return received, in the form of increased productivity and new product sales, exceeds these amounts. This increased return would represent the direct economic benefits resulting from the program.

As evidence of their continuing interest in NASTRAN, the current users have recommended about 116 improvements; all of these improvements would be expected to result in further cost savings. These improvements are summarized in Table 3-14, and listed in Appendix I. The distribution of these improvements by user groups, as in the current applications, reflects the more intensive application of the program by the aerospace industry.

As further evidence of their continuing interest, the users have recommended an additional 35 future applications for NASTRAN. These applications, if implemented, are also expected to result in future savings and benefits. Table 3-15 summarizes the number of these applications, and they are presented in Appendix G.

3.4 GENERAL USAGE RESULTS

3.4.1 Introduction

The questions contained in the mailed and supplementary questionnaires were also concerned with NASTRAN usage. These data are all contained in raw form on the questionnaires which have been submitted to NASA as part of this contract. The following paragraphs include tables and graphs, with applicable comments, which summarize this information. No proprietary data is included. The information is cogent and of general interest to all NASTRAN users. Selected information from this section has been included in Volume I, Executive Summary.

Table 3-14. Number of User Recommended Improvements to NASTRAN

Type Organization	Number of Improvements	Percent
Total	116	100.0
Industry - Aerospace	52	44.8
Industry - Non-Aerospace	20	17.2
Government - NASA	13	11.2
Government - Non-NASA	17	14.7
Service Bureaus	12	10.3
Academic Institutions	2	1.7

Source: Appendix I

Table 3-15. Number of Recommended Future Applications

Type Organization	Future Applications	Percent
Industry - Aerospace	18	51.4
Industry - Non-Aerospace	9	25.7
Government - NASA	2	5.7
Government - Non-NASA	5	14.3
Service Bureaus	1	2.9
Academic Institutions	0	0
Total	35	100.0

Source: Appendix G

3.4.2 NASTRAN Documentation

Tables 3-16 through 3-20 summarize the user comments on NASTRAN documentation. The users, in general, stated that this program contained more documentation than any other program of its size and complexity; this, in part supports the many "good/satisfactory" ratings. For the Demonstration Manual, Table 3-16, two of the comments which come through clearly during the interviews are emphasized. The users need a variety of simple illustrative problems with short computer running times. In addition they would like complete listings so that they can check their work. For the User's Manual, Table 3-17, the users believed the greatest need was for a good index/cross index in order to readily find specific information. For additional documentation desired (Table 3-20) most emphasis was placed on the development of a NASTRAN Students/Teachers Manual. This same comment also appeared, but to lesser extent, in comments on the existing documentation. About 50 percent of the requests for a student's manual came from the aerospace industry.

3.4.3 NASTRAN Training Courses

Table 3-21 indicates two facts about the NASTRAN program, first, it is a large and complex program with 681 people attending a training course in order to understand and use the program, second, the user organizations spent considerable money both in-house and with service bureaus to conduct these courses. Interesting side lights from the raw data showed, 1. the non-aerospace industry conducted almost exclusively in-house training, 2. the aerospace industry used service bureaus, and 3. NASA agencies were about evenly split between in-house, service bureaus, and some courses given at NASA Goddard Space Flight Center.

3.4.4 Interest in NASTRAN Share Library

Table 3-22 indicates a large interest in the formation of a share library even though about 30 percent of the users would not release proprietary data. This interest in a library is reinforced by the information in paragraph 3.4.14. Table 3-27 indicates that 37 significant improvements and adaptations have been made by users and that they have spent an estimated \$232,000 to accomplish them. Most of these improvements now used only by the originator,

Table 3-16. Summary User Comments On
NASTRAN Demonstration Manual

Comment	No. of Users
1. Needs more simple illustrative problems	21
2. Needs Listings	17
3. Good/Satisfactory	13
4. Needs more specific procedures	10
5. Should be written to "learn from"	7
6. Needs Index/Cross Index	3
7. Unsatisfactory	3
8. Too long, need abstracts	2

Table 3-17. Summary User Comments
on NASTRAN USER'S Manual

Comment	No. of Users
1. Good/Very good	29
2. Needs more explanation	7
3. Needs Index/cross index	12
4. Too operator oriented	4
5. Should be written to learn from	3

Table 3-18. Summary User Comments on
NASTRAN Theoretical Manual

Comment	No. of Users
1. Satisfactory/Good/Very good	40
2. Needs more explanation	8
3. Needs index/cross index	4
4. Needs more non-aerospace industrial application	2
5. Needs to be written for engineers instead of mathematicians	1

Table 3-19. Summary User's Comments on
NASTRAN Programmer's Manual

Comment	No. of Users
1. Satisfactory/Good/Very good	28
2. Requires reorganization	5
3. Needs index/cross index	4
4. Needs more explanation	2

Table 3-20. Additional NASTRAN
Documentation Desired

Documentation	No. of Users
NASTRAN Students/Teachers Manual	16
Comprehensive Index/Cross Index	8
Revised Demonstration Manual with More Problems	8
Direct Matrix Abstraction Program Manual	4

Table 3-21. Conduct of NASTRAN
Training Courses

Conducting Organization	No. of Users	Total Attendees and Course Length	
In-house	10	267 91	2 weeks 2 days
Service Bureaus	17	90 113 20	1-2 weeks 1-2 days 3 weeks
NASA Goddard Space Flight Center	5	100	1 day - 2 weeks

would have wide application among the other users. In talking to the users the biggest drawback to a library is the belief that a user who donates an improvement to the library may not get anything in return. A suggested solution is for the NASTRAN Systems Management Office to act as a clearing-house and to periodically publish the available improvements. Individual companies could then negotiate with each other for use of various routines.

3.4.5 NASTRAN Publicity

Table 3-23 lists the information concerning how users originally became aware of NASTRAN. Thirty percent reported that they learned of the program by conversation with colleagues, and about the same percentage through contact with a NASA facility. Twelve percent heard of the program through the sales effort of a service bureau. There is currently wider publicity through the NASTRAN News Letter and a colloquium.

3.4.6 Why NASTRAN was Selected

Industry and government agencies have long needed a methodology for solving a wide variety of large structural analysis problems. NASTRAN was specifically designed with such a capability. Other programs, such as SAMIS and FRAN, are preferred by certain users; however, the consensus of opinion is that NASTRAN was selected because of its ability to solve large problems and to give more accurate answers than other programs. Table 3-24 illustrates this point.

3.4.7 Ownership of Computer Used to Run NASTRAN

From the response indicated in Table 3-25 it is apparent that most companies are using their own computers for NASTRAN. This does not conflict with wide use of service bureaus as reported earlier because the bureaus set up and service the program on customers' computers as well as their own. In fact one company performing service bureau functions does not use its own computer.

3.4.8 Computers and Plotters Used for NASTRAN

NASTRAN was written for general use. However, the programs were generally only directly adaptable to the IBM, Univac, and CDC Computers

Table 3-22. User Interest in
NASTRAN SHARE LIBRARY

Comment	No. of Users
Interested	54
Would release proprietary data	16
Would not release proprietary data	17
Don't know company decision on release of proprietary data	11

Table 3-23. How Users Learned of NASTRAN Existence

Comment	No. of Users
Through colleagues	15
NASA Langley, Goddard, Marshall, Cosmic	14
Sales visit by Service Bureau	6
Technology News Letters	9
Involved in original development	6

Table 3-24. Why NASTRAN
Program Selected For Use

Comment	No. of Users
Required for large problems	29
Needed structural analysis tool	6
Prefer to other similar program	4
Customers asked for (Service Bureau)	4
Keep abreast of latest in computer programs.	2

Table 3-25. Ownership of Computer used to Run NASTRAN

Type of Organization	Own Computer	Service Bureau Computer	Both own and service bureau computer	Other computers	Total responses
Industry Aerospace	20	5	6	4	35
Industry Non-Aerospace	11	2	1	2	16
Government NASA	9	1	0	0	10
Government Non-NASA	9	0	0	0	9
Academic Institutions	2	0	0	0	2
TOTAL	51	8	7	6	72

Note: Service bureaus elected not to answer this question but since most are selling computer time it is expected that they are using own computers as much as possible.

Table 3-26. Computers and Plotters Used for NASTRAN

Computer	No. of Users	Plotter	No. of Users
IBM 360 Series	65	Stromberg Carlson 4020	21
IBM 370 Series	15		
Univac 1108	15	Stromberg Carlson 4060	1
Univac 1106	1	CalComp	19
CDC 6000 Series	34	EAI 3500	1
		DDI	2

as shown by the usage in Table 3-26. Other machines can use the program but it requires conversion. Users have expressed interest in having routines for GE, Burroughs, Honeywell, and others, but have not made this conversion themselves. As noted, the use of plotters is evenly split between CalComp and Stromberg Carlson.

3.4.9 Use of Rigid Formats

Figure 3-1 illustrates the use frequency of the rigid formats -- 1, 3, 5, and 9 are used 70 percent of the time and the response data indicates that this is true regardless of the user type; i.e., government, industry, or academic.

3.4.10 Use of NASTRAN Levels

The NASTRAN Systems Management Office (NSMO) at NASA Langley Research Center has issued the NASTRAN program with a level designation. The higher the level number, the more up-to-date and sophisticated is the program. At present, NASA levels 11, 11.1, 12, and 12.1 are in use, with 12 the latest version. Figure 3-2 shows the distribution of levels by various users. As expected, level 12 has the greatest number. The other levels are still in use because it may not be advantageous to a particular user to change the program once he has it operating on his computer.

The service bureaus buy the tapes and documentation from COSMIC and make modifications and improvements. These modifications are then sold to users with a designation indicating a service bureau version, such as 11.1.2, 11.1.4, 11.1.6, 14, and 15. In general, these versions have faster running times and some particular improvements related to type users. Figure 3-3 shows the use frequency of service bureau levels. Figure 3-4 is a cross plot presenting the use of COSMIC (NASA) and service bureau levels by the six types of user organizations.

3.4.11 Type Organization Used for Assistance

Since the NASTRAN program is large and complex, assistance is occasionally required in running the program. Users have reported getting assistance from service bureaus, an in-house computer group, or a NASA

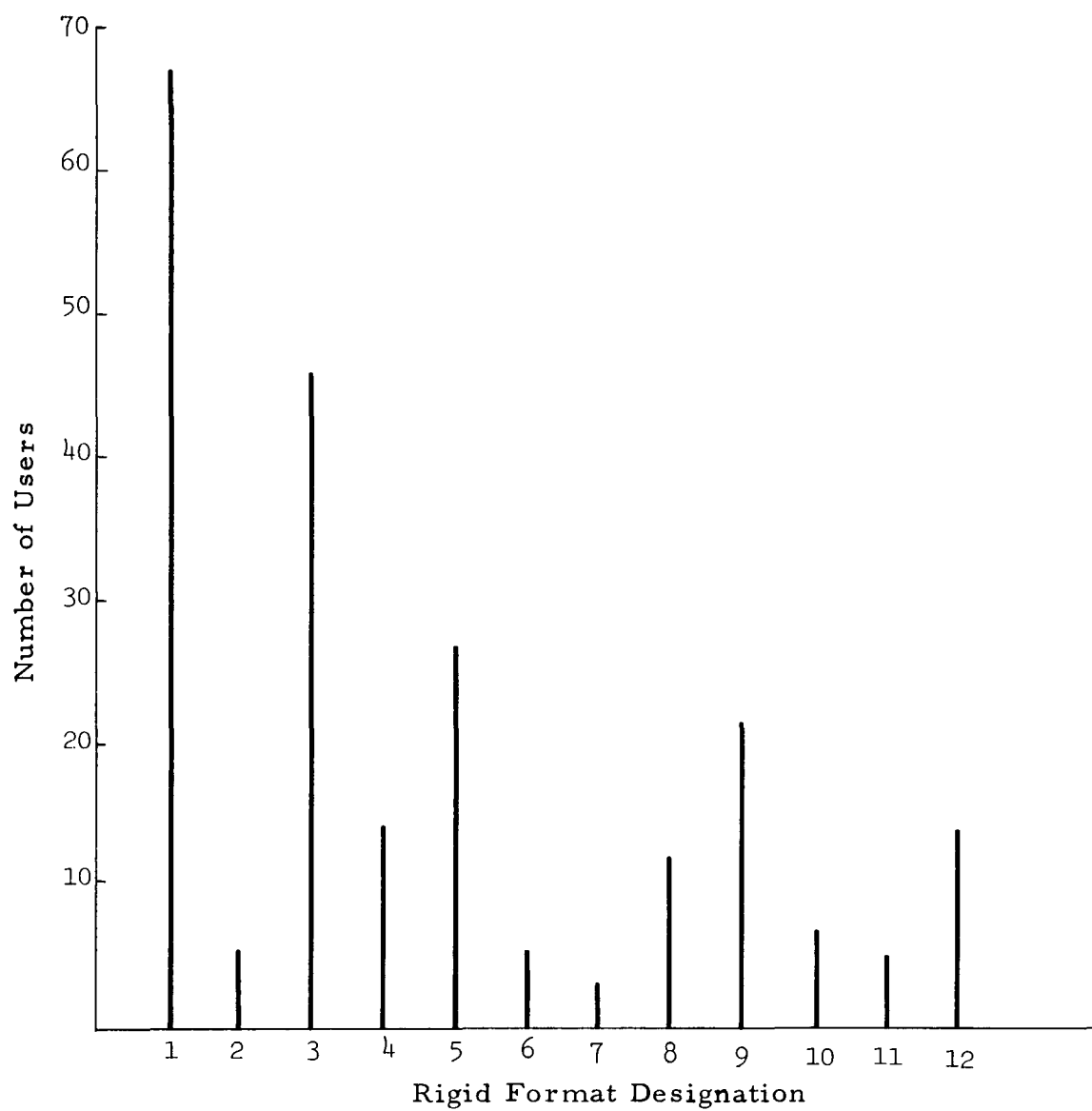


Figure 3-1. Use of Rigid Formats

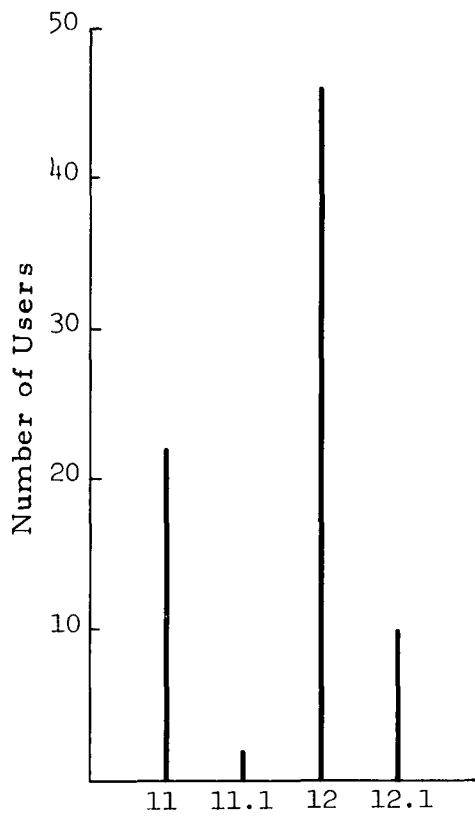


Figure 3-2. Use of COSMIC (NASA) Levels

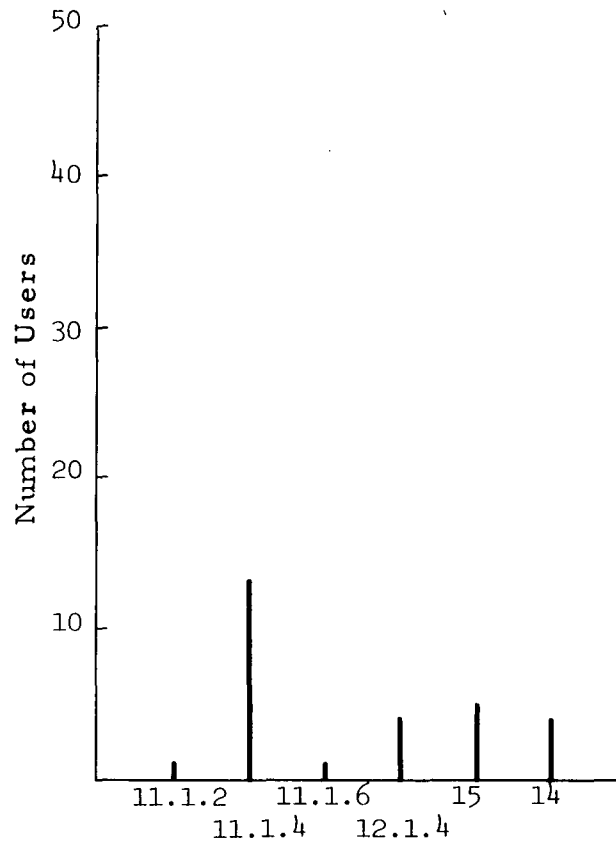


Figure 3-3. Use of Service Bureau Levels

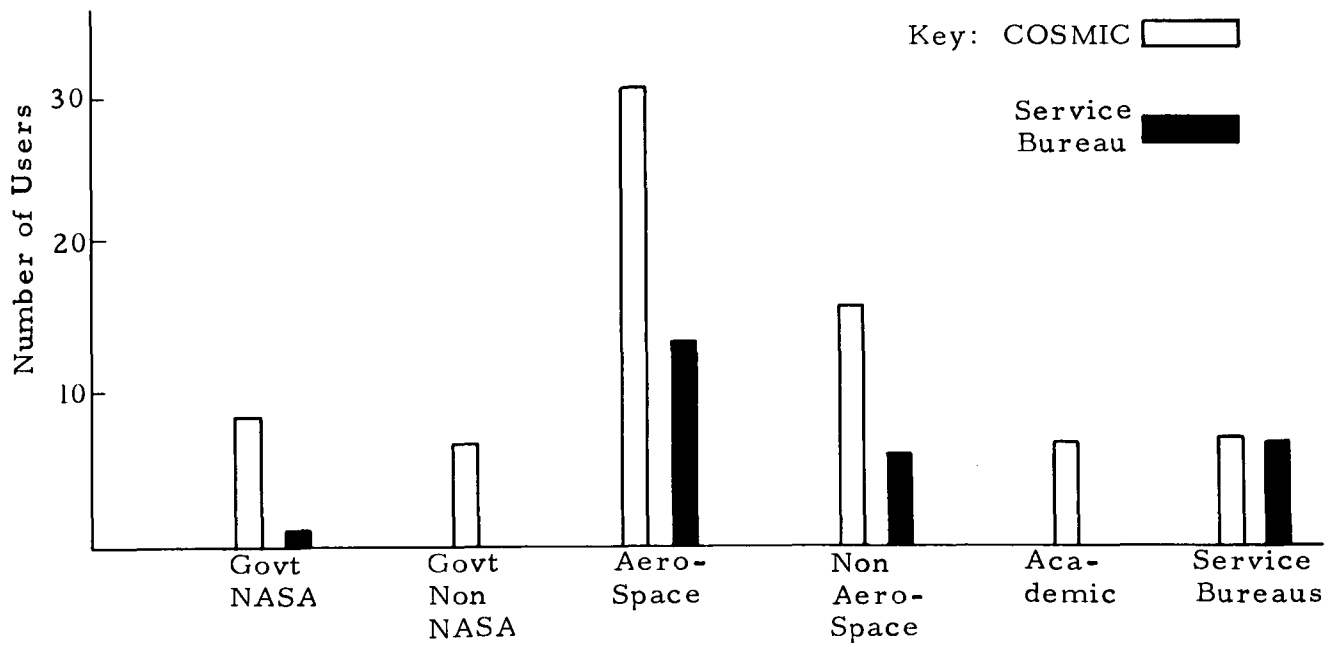


Figure 3-4. Use of Level Versions by Type Organizations

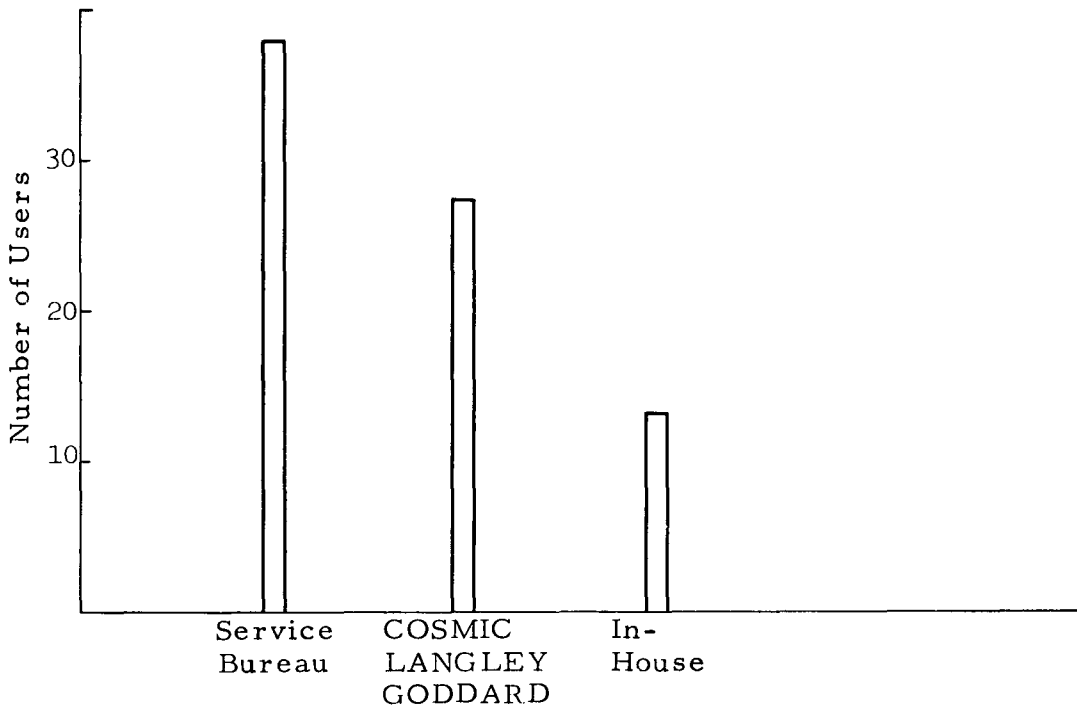


Figure 3-5. Type Organization Used for Assistance in Program

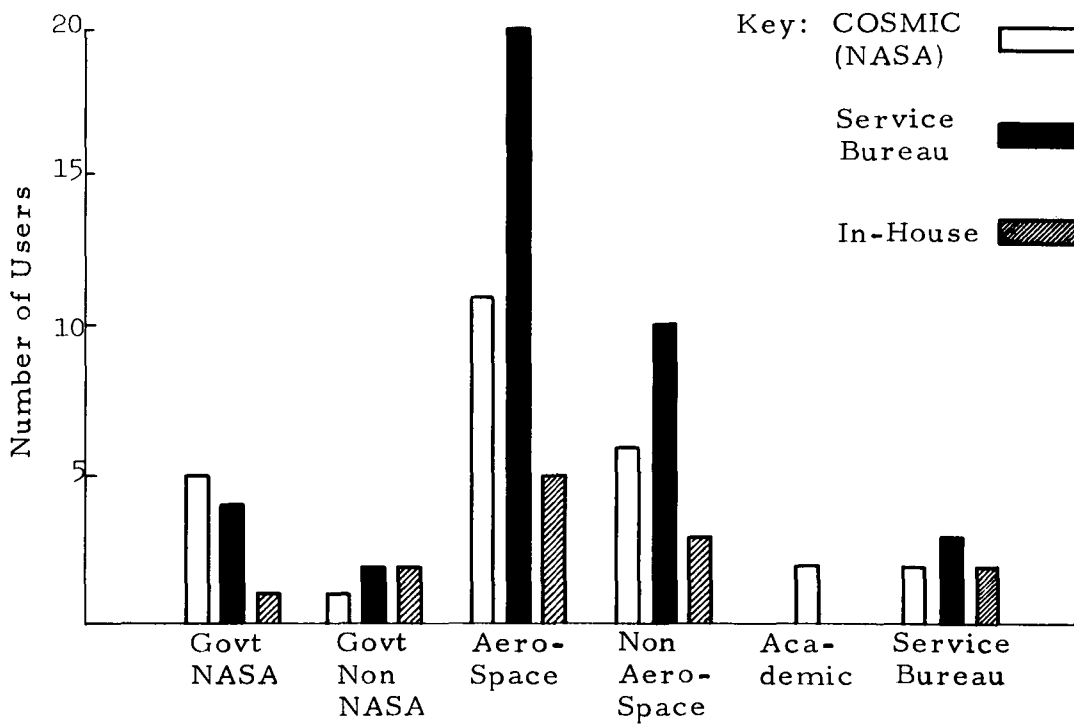


Figure 3-6. Assistance by Type User Organization

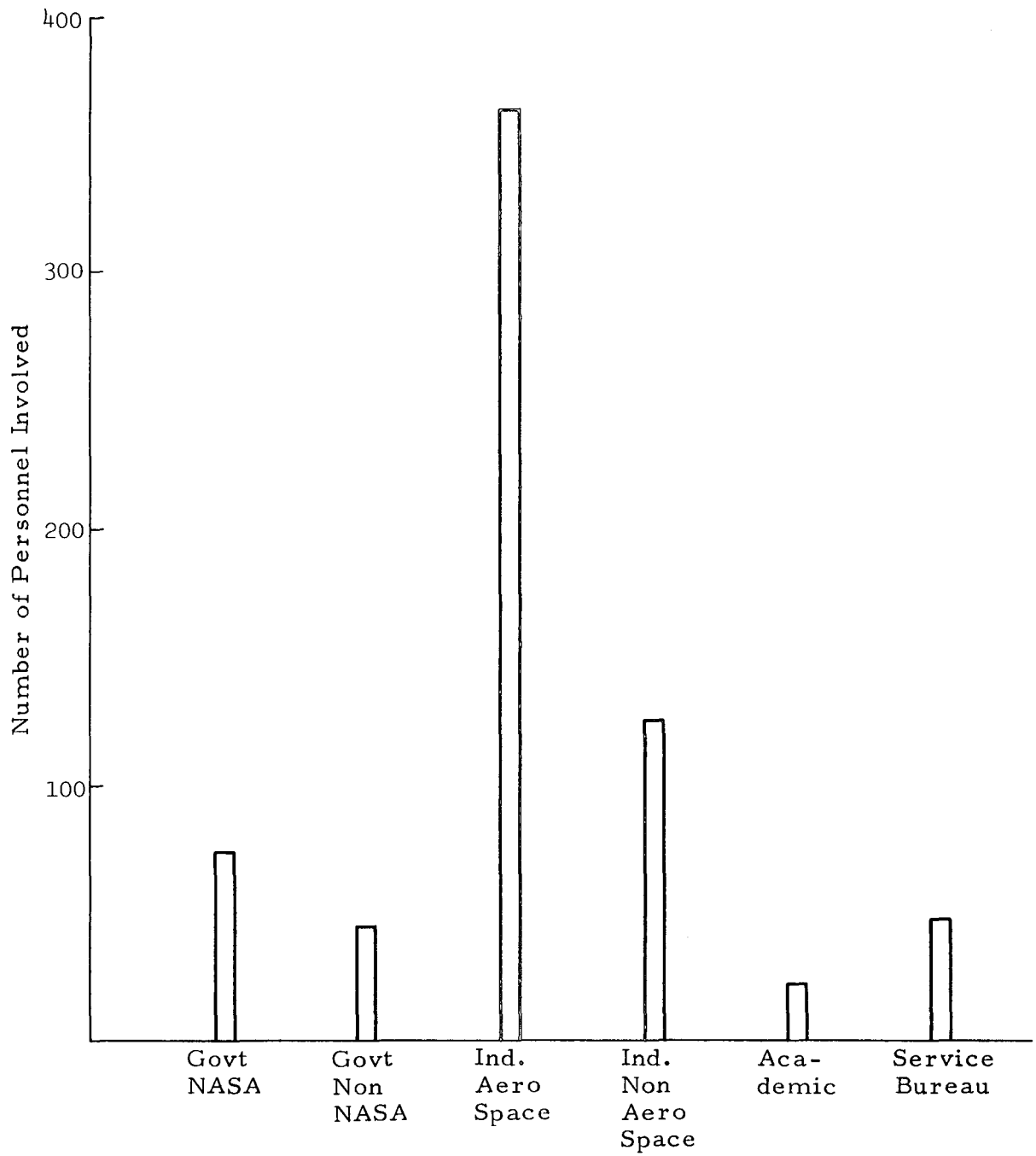


Figure 3-7. Number of Personnel Involved in NASTRAN by Type Organization

organization (COSMIC, Langley Research Center, and Goddard Space Flight Center). Figure 3-5 shows that the service bureaus do most of the assistance work. Figure 3-6 is a cross plot by type user illustrating what organizations are called upon for assistance.

3.4.12 Personnel Involved in NASTRAN

Users reported 667 persons involved in using the NASTRAN program, the majority being engineers. The number reported by service bureaus is undoubtedly low since the information was deemed proprietary by some bureaus. Two of the academic institutions stated that they needed to know the extent of NASTRAN usage so they could increase the number of students who were taking the NASTRAN courses. The non-aerospace corporations, who are newcomers to the program, expect to expand the number of personnel involved; Ford Motor Corporation expected to double its number by the end of 1972. There are a group of 25 potential users listed in Appendix B some of which will undoubtedly become active in 1972. Figure 3-7 illustrates the number of persons involved by type of organization.

3.4.13 Cost Comparison - NASTRAN versus Other Programs

Questions 13 and 14 of the mailed questionnaire (Appendix C) requested comparative data for the same structural analysis application as run by both NASTRAN and another computer program. The respondees in general claimed that such data was not available and the response was limited to only five returns -- two NASA and three aerospace companies. The results for these examples cannot be considered conclusive. There is a faint trend indicated: with NASTRAN, a number of man hours are usually saved but the additional computer running time tends to offset this saving. With the advent of level 15 in the near future, which speeds up running time, the savings by NASTRAN will be more substantial. Some of the returns have indicated that service bureau versions of current COSMIC tapes are faster by a factor of 6 to 1. A significant question for a future benefit survey would be a comparison of old and new NASTRAN running times for the same application. Eight comparison examples follow. No summary table has been prepared because the data is too meager.

(1) Application - 3D Propellent Response

Program	Eng. Cost	Computer and Cost
NASTRAN	\$1500	\$400 - 6600
ANALOG	\$3000	\$100 - 1108
Saving	\$1500	-\$300
Net Saving	\$1200	

(2) Application - 3D Propellent Strain

Program	Eng. Cost	Computer and Cost
NASTRAN	\$1500	\$400 - 6600
2D-APPROX	\$1500	\$100 - 1108

In this case the 2D-APPROX did not give correct answers and therefore the company lost \$1600.

(3) Application - Mobile Service Structure

Program	Eng. Cost	Computer and Cost
NASTRAN	\$1320	(No time or \$) 360/50
FRAN	\$10100	(No time or \$) GE 635
Net Savings	\$8780	

(4) Application - Vertical Assembly Bldg.

Program	Eng. Cost	Computer and Cost
NASTRAN	\$380	(No time or \$) 360/50
FRAN	\$7600	(No time or \$) GE 635
Net Savings	\$7320	

(5) Application - Antenna Quad

Program	Eng. Cost	Computer and Cost
NASTRAN	\$1140	\$500 - 1108
SAMIS	\$1140	(No time or \$) 7094 (Date 1965)
Savings - Both programs approximately the same.		

(6) Application - CH53 Sponson (Helicopter)

Program	Eng. Cost	Computer and Cost
NASTRAN	\$8000	\$4000 - 360/67
ASKA	\$11500	\$3000 - 1108
Savings	\$3500	\$1000
Net Savings	\$2500	

(7) Application - ATM Solar Array

Program	Eng. Cost	Computer and Cost
NASTRAN	\$26200	\$24000 - 1108
SAMIS	\$31600	\$9600 - 7094
Savings	\$5400	-\$14400
Net Loss	-\$9000	

(8) Application - ATM Solar Array (Dynamic)

Program	Eng. Cost	Computer and Cost
NASTRAN	\$5400	\$3000 - 1108
SAMIS	\$8900	\$6000 - 7094
Savings	\$3440	\$3000
Net Savings:	\$6440	

3.4.14 In-House Initiated NASTRAN Improvements and Adaptations

Question 20 of the mailed questionnaire (Appendix C), requested information on in-house initiated improvements and adaptations of the NASTRAN program and the estimated cost to the organization concerned. The significance of this information is that the users consider the program to be of such value that they spend their own funds for improvements. These improvements are in fact an investment made to increase productivity and/or to increase profits over the longer term other wise they would not be made. These improvements are probably considered proprietary by the organization which made them, which may account for the small amount reported by service bureaus. Table 3-27 lists the adaptations, improvements, and their costs by type organization.

Table 3-27. Improvements and Costs

Type Organization	Improvements/Adaptations	Estimated Cost
Industry - Aerospace	1. Implemented rigid formats 3.5, 3.6, and 3.7.	2500
	2. Developed pre-processor wavefront (active column) sequencing.	1500
	3. Developed input data checking and plotting	5000
	4. Symmetric decomposition in inverse power, level 12.1.	150
	5. Fixed inverse power errors.	300
	6. Iterative graphic display for debugging geometric errors	6000
	7. Converter IBM 360 to 7090.	100
	8. Corrected error margin of safety routine.	250
	9. Linked with in-house matrix algebra system	*NR
	10. Converted NASTRAN Stress output to matrix format.	*NR
	11. Developed drive for static analysis from externally generated load matrix.	*NR
	12. Developed iterative computer graphics for input/output processing.	50000
	13. Linked flutter analysis using FORTRAN and job step to existing aeroelastic solution program.	100
	14. DATRAN program converts NLOAC program input data to NASTRAN input data deck.	*NR
	15. Improved mass matrix reduction.	*NR
	16. Developed pre-processor to translate FRAN data to NASTRAN data.	5000
	17. Developed pre-processor to translate ELAS data to NATRAN.	3000
	18. Developed static casting.	5000
	19. Developed dynamic frame.	2000
Subtotal		80900
Government - NASA	1. Developed substructure analysis.	*NR

Table 3-27. Improvements and Costs (continued)

	2. Improved 360 input/output routines.	*NR
	3. Developed load preparation pre-processor.	*NR
	4. Developed detrigging routine.	2000
	5. Developed SKYLAB buckling analysis improvement.	40000
	6. Developed element improvement.	80000
	7. Made improvements to format 12.1 which reduced CPU and input/output charges by 25%	2500
	8. Added test to evaluate percent of region actually used on each link.	2000
	9. Made changes to allow use of either 026 or 029 card punch.	500
	10. Recompiled level 12.1.	500
	11. Developed VIKING launch vehicle and payload analysis.	20000
	Subtotal	147500
Government - Non-NASA	1. Developed new element definition.	*NR
	2. Developed bandwidth minimization program.	*NR
	3. Developed data generator.	*NR
	Subtotal	*NR
Service Bureaus	1. Developed flutter analysis using 360 job step to existing aeroelastic solution program.	100
	2. Developed input generator.	2000
	3. Wrote routine to extract data from weak points.	1000
	4. Developed data preparation programs.	500
	Subtotal	3600
	GRAND TOTAL	\$232000

* NR = Not reported

Appendix A
Survey Mailing List

Mr. G.A. Abbott
North American Rockwell Corporation
12214 Lakewood Blvd.
Downey, California 90241

Dr. H.N. Abramson
Southwest Research Institute
San Antonio, Texas 78206

Mr. S.H. Adams
Pratt and Whitney Aircraft
Florida R and D Center
P.O. Box 2691
West Palm Beach, Florida 33400

Mr. M.G. Allen
General Dynamics Corporation
Convair Aero Division
P.O. Box 748
Ft. Worth, Texas 76101

Mr. V.L. Alley Jr.
Systems Engineering Division
NASA Langley Research Center
Mail Stop 314
Hampton, Virginia 23365

Mr. H.E. Andreas
SCI-TEK Computer Center Inc.
1707 Gilpin Avenue
Wilmington, Delaware 19806

Mr. A.B. Atchley
Lockheed Georgia Company
Scientific Programming Division
Dept. 87-10 Zone 288
Marietta, Georgia 30060

Mr. M.U. Ayres
Corporate Engineering
3755 E. Marginal Way
The Boeing Company
Seattle, Washington 98124

Mr. W.R. Baca
Structural Sys. Specialists
P.O. Box 903
5400 Rosemead Blvd.
Pico Rivera, California 90640

Mr. E.F. Baird
Grumman Aerospace Corporation
Bethpage, New York 11714

Mr. Allan P. Bakke
Research Engineering
NASA Ames
Moffett Field, California 94086

Mr. B.T. Bata
Westinghouse Electric Corporation
Mail Stop 463
P.O. Box 746
Baltimore, Maryland 21203

Mr. Helmut F. Bauer
Georgia Inst. of Technology
School of Eng. Science and Mechanics
225 N. Avenue, N.W.
Atlanta, Georgia 30332

Bell Telephone Laboratory
Indian Hill
Naperville, Illinois 60540

Mr. R.D. Bennett
Vought Aeronautics Corporation
Dallas, Texas 75222

Mr. Richard Benton
Atlantic Research Corporation
3333 Harbor Blvd.
Costa Mesa, California 92626

Dr. H. Bergman
North American Rockwell
Science Center
1049 Camino Dos Rio
Thousand Oaks, California 91360

Mr. J. Berman
Grumman Aircraft Engr. Corporation
Bethpage, New York 11714

Mr. J.H. Best
LTV Aerospace Corporation
P.O. Box 5907
Dallas, Texas 75222

Dr. J. Blackman
AM Elec. Power Service Corp.
2 Broadway
New York, New York 10004

Dr. F.K. Bogner
University of Dayton Research Inst.
300 College Park Avenue
Dayton, Ohio 45409

Mr. L. E. Bothell
Kaman Aerospace Corporation
Kaman Nuclear
1700 Garden of the Gods Road
Colorado Springs, Colorado 80907

Mr. J. D. Bower
Teledyne Ryan Aeronautical
Structural Mechanics
2701 Harbor Drive
San Diego, California 92112

Dr. W. F. Bozich
McDonnell Douglas
Astronautics Co.
5301 Bolsa Avenue
Huntington Beach, California 92647

Mr. L. Brand
NNS and DD Company
4101 Washington Avenue
Engineering Laboratory
Newport News, Virginia 23600

Mr. R. J. Broliar
Teledyne Brown Engineering
Strength Analysis Branch
Mail Stop 190
Huntsville, Alabama 35807

Mr. Eugene Burch
Technology Applications Center
University of New Mexico
Albuquerque, New Mexico 87106

Mr. R. Butler
NASA-Langley Research Center
MS 125
Hampton, Virginia 23365

Mr. T. G. Butler
Code 406
NASA-Goddard Space Flight Center
Greenbelt, Maryland 2071

Mr. J. M. Carlson
NASA Headquarters
TU Division
Code UT
Washington, D. C. 20546

Mr. S. H. Chang
Beech Aircraft Company
Department 884
9709 East Central Avenue
Wichita, Kansas 67201

Mr. L. E. Chaump
VFSTC Room U7038
GE Company
P. O. Box 8555
Philadelphia, Pennsylvania 19101

Mr. L. I. Chasen
General Electric Company
Valley Forge Space Center
P. O. Box 8555
Philadelphia, Pennsylvania 19101

Mr. R. Chiapetta
IIT Research Institute
10 East 35th Street
Chicago, Illinois 60616

Mr. William Cho
Sargent & Lundy Engineers
140 S. Dearborn
Chicago, Illinois 50606

Mr. W. L. Cook
Communications Satellite Corporation
950 L-Enfant Plaza South S. W.
Washington, D. C. 20024

Mr. L. C. Corrington
Assistant Chief for Technical Operations
SNPO-C
NASA-Lewis
21000 Brookpark Road
Cleveland, Ohio 44125

Mr. R.E. Criste
Research Analysis Corporation
Westgate Research Park
McLean, Virginia 22101

Mr. M.J. Cronk
Convair Division
General Dynamics
5001 Kearney Villa Road
San Diego, California 92112

Dr. E.H. Cuthill
Naval Ship Res and Dev Center
Code 805
Washington, D.C. 20034

Mr. R.E. Davis
McDonnell Automation Company
Box 516
St. Louis, Missouri 63166

Mr. P. DeSantis
Chi Corporation
11000 Cedar Avenue
Cleveland, Ohio 44106

Mr. B.J. Donham
Los Alamos Scientific Lab
Group Eng/Do
Box 1663
Los Alamos, New Mexico 87544

Dr. D. Dudley
Aerojet Solid Prop Co
P.O. Box 13400
Sacramento, California 95813

Mr. W.H. Dukes
Bell Aerospace Co.
P.O. Box One
Buffalo, New York 14240

Mr. John Dutton
McDonnell Douglas Corporation
St. Louis, Missouri 63166

Mr. R. Ebrus
Grumman Data Systems Corporation
Plant 35 Dept. 502
Bethpage, New York 11714

Dr. F. England
Westinghouse Electric Corporation
Friendship International Airport
Box 746
Baltimore, Maryland 21203

Mr. W.M. Flannely
Kaman Aerospace Corporation
Old Windsor Road
Bloomfield, Connecticut 06002

Dr. K. Forsberg
Lockheed Aircraft Co
Lockheed Research Lab.
Palo Alto, California 94304

Dr. R.E. Fulton
NASA-Langley Res. Center
MS 1880
Hampton, Virginia 23365

Mr. T. Furuike
North American Rockwell
Space Division
12214 Lakewood Blvd.
Downey, California 90241

Mr. J. Fuscoe
Rohr Corporation
Library
P.O. Box 878
Chula Vista, California 92012

Mr. A.M. Garber
General Electric Company
Tech. Engr.
3198 Chestnut Street
Philadelphia, Pennsylvania 19101

Mr. H.B. Garland
General Dynamics
Convair Aerospace Division
Fort Worth, Texas 76101

Dr. R.A. Gellatly
Bell Aerospace Co.
P.O. Box One
Buffalo, New York 14240

Mr. R.K. Gieseke
General Dynamics/Convair
Mail Stop 585-0
P.O. Box 1128
San Diego, California 92112

Mr. R. Gluck
TRW Systems Group
One Space Park
Redondo Beach, California 90278

Mr. T.M. Gmitro
CDC
223 W. Jackson
Chicago, Illinois 60606

Mr. J. Go
Computer Sciences Corp.
Federal Bldg., Room 514
Richland, Washington 99352

Prof. M. Goldberg
Polytechnic Inst. of Brooklyn
Aerospace Engr/Appl Mech
208 Violet Street
Massepeque Park, New York 11762

Mr. David Gregory
Grumman Aerospace Corporation
Bethpage, New York 11714

Mr. R.B. Gregory
Research Analysis Corp.
Marketing Consultant
McLean, Virginia 22101

Mr. C. Gunn
The University of Chicago
Argonne National Laboratory
9700 Cass Avenue
Argonne, Illinois 60439

Mr. G.W. Haggemacher
Lockheed Aircraft Corp.
D/74-41 B/63 P/A-1
Burbank, California 91503

Mr. W.C. Hamann
Ford Motor Co.
Village Plaza 3rd Floor
23,400 Mich Avenue
Dearborn, Michigan 48124

Mr. J.E. Hansen
Thiokol Chemical Corp.
Waspac Division
Brigham City, Utah 84302

Mr. S.D. Hansen
The Boeing Company
Commercial Airplane Div.
P.O. 3707
Renton, Wa. 98124

Mr. J. Harrell
Tech. Utilization Officer
JFK Space Center, NASA
Kennedy Space Center, Florida 32899

Mr. T.J. Harvey
Lockheed Missile and Space Co.
P.O. Box 504
Sunnyvale, California 94088

Mr. Joseph A. Heinrichs
Fairchild Industries
Germantown, Maryland 20767

Dr. R.F. Henke
Structural Dynamics Research Corp.
5729 Dragon Way
Cincinnati, Ohio 45227

Mr. C.W. Hennrich
The Macneal-Schwendler Corp.
3217 North Armistead Avenue
Hampton, Virginia 23366

Mr. Richard F. Hess
Perkin-Elmer Corporation
Danbury, Connecticut 06810

Mr. Reid Hopkins
Hercules
Bacchus Works
USAF Plant 81
Magna, Utah 84044

Mr. R.J. Holcshuh
Bell Laboratories Inc.
Room 2D262
Whippany, New Jersey 07054

Mr. Lo-Ching Hua
CDC
Chicago Data Center
223 West Jackson Blvd.
Chicago, Illinois 60606

Dr. S.H. Huang
Applied Mechanics Res GP
Aero Mechanics Dept.
Naval Air Development Center
Warminster, Pa. 18974

Dr. F.C. Hung
North American Rockwell Corp.
General Offices
1700 East Imperial Highway
El Segundo, California 90245

Mr. R. Hunter
Bell Telephone Labs
Department 6515
Room 2D-168
Whippany, New Jersey 07981

Mr. C. Hwang
Northrop Corporation
Norair Division
3901 W. Broadway
Hawthorne, California 90250

Mr. M. Ice
Boeing Company
MS 8C-43
P.O. Box 3999
Seattle, Washington 98124

Mr. J.R. Johnson
Air Force Flight Dyn Lab.
Wright-Patterson AFB
Dayton, Ohio 45433

Mr. Terrence P. Kane
Puget Sound Naval Shipyard
Seattle, Washington 98114

Mr. M. Kaser
Midwest Applied Sci. Corp.
Box 2157
West Lafayette, Ind. 47906

Mr. S. Katow
Jet Propulsion Labs
Bldg. 125 Box 22
4800 Oak Grove Drive
Pasadena, California 91103

Mr. I. Kenigsberg
Sikorsky Aircraft
Stratford, Connecticut 06075

Dr. J.M. Kennedy
Argonne National Labs
Reactor Analy/Safety Division
9700 S. Cass Avenue
Argonne, Illinois 60439

Mr. P.J. Kertesz
Lockheed Missile/Space Company
Dept. 6262 Bldg. 156A
P.O. Box 502
Sunnyvale, California 94088

Mr. W.M. Kethley
Cosmic
Barrow Hall
University of Georgia
Athens, Georgia 30601

Mr. S. Key
Sandia Corporation
Division 1541
P.O. Box 5800
Albuquerque, New Mexico 87115

Mr. G.W. Knobeloch
Structural Dynamics Research Corporation
5729 Dragon Way
Cincinnati, Ohio 45227

Mr. P.K. Korwek
Ford Motor Car Company
Box 2053
Dearborn, Michigan 48121

Mr. J.C. Kostelec
Ford Motor Company
Engineering Tech. Office
Village Plaza Tower
Dearborn, Michigan 48124

Mr. W.P. Kunkel
Westinghouse Tele-Computer
Systems Corporation
2040 Ardmore Blvd.
Pittsburgh, Pennsylvania 15220

Mr. P. Kuo
AVCO
Lycoming Division
560 South Main Street
Stratford, Connecticut 06497

Mr. Henry S. Kwoh
CDC-MEISCON
223 N. Jackson
Chicago, Illinois 60606

Mr. Stewart J. Lammers
Ford Motor Company
Bldg. 1, Room 2149
20000 Rotunda Drive
Dearborn, Michigan 48121

Dr. L.A. Larkin
A.O. Smith Corporation
Dept. 9731
P.O. Box 584
Milwaukee, Wisconsin 53201

Dr. G. Lasker
General Dynamics
P.O. Box 2507
Pomona, California 91766

Mr. J.R. Laubach
Bell Laboratories Inc.
Room 3A-211A
Whippany Road
Whippany, New Jersey 07981

Dr. H. Lee
Westinghouse R and D Center
Bulah Road Churchill Boro
Pittsburgh, Pennsylvania 15221

Mr. John E. Leonard
NASA MSC
Code FD12
Houston, Texas 77058

Dr. R.S. Levy
Fairchild Hiller Corporation
Republic Aviation Division
Farmingdale, Long Island
New York 11735

Mr. R. Levy
Jet Propulsion Lab.
California Inst. of Tech.
4800 Oak Grove Drive
Pasadena, California 91103

Mr. W.E. Lorensen
Watervliet
Maggs Research Center
Bldg. 115
Watervliet New York 12189

Mr. G.A. Lynch
E.I. Dupont De Nemours Co. Inc.
Engineering Department
Bldg. 304
Wilmington, Delaware 19898

Dr. R.H. MacNeal
MacNeal Schwendler Corporation
7422 North Figueroa Street
Los Angeles, California 90041

Dr. R.H. Mallett
Bell Aerospace Company
P.O. Box One
Buffalo, New York 14240

Mr. Marburger
U.S. Army
USAMERDC Bldg.
Ft. Belvoir, Virginia 22060

Mr. Curtis Martin
LTV Aerospace Corporation
Dallas, Texas 75222

Mr. R.A. Marx
Goodyear Aerospace Corporation
Dept. 428
1210 Massillon Road
Akron, Ohio 44315

Dr. J.B. Mason
Goddard Space Flight Center
908 South Wick Drive
Towson, Maryland 21204

Mr. P. Mason
Grumman Aerospace Company
Dept. 35-460
Bethpage, New York 11714

Mr. C.B. Mayforth
VFSTC Room U2704
General Electric Co.
P.O. Box 8555
Philadelphia, Pennsylvania 19101

Mr. R.L. McComas
Sand E-ASTN-AA
NASA/Marshall Sp. Flt. Ctr.
Marshall Sp. Flt. Ctr., Alabama 35812

Mr. C.T. McCormick
Raytheon Co.
Missile Systems Div. Box 900
Hartwell Road
Bedford, Mass. 01730

Dr. R.W. McLay
University of Vermont
Mechanical Engineering
Burlington, Vermont 05401

Dr. F.G. McLean
Westenhoff & Novick
222 W. Adams
Suite 1100
Chicago, Illinois 60606

Dr. R.J. Melosh
Philco-Western Dev. Labs
3825 Fabian Way
Palo Alto, California 94304

Mr. J. Midgley
Federal Building
Room 581 A
825 Jadwin Avenue
Richland, Wa. 99352

Mr. W. Mikesell
Chicago Bridge and Iron
Analysis Group
901 West 22nd Street
Oakbrook, Illinois 60521

Dr. R. Miller
The Boeing Company
Commercial Airplant Div.
P.O. Box 3707
Renton, Wa. 98124

Mr. Robert B. Morgan
Texas Instruments
P.O. Box 5474
Dallas, Texas 75222

Mr. G. Morosow
Martin Marietta Corporation
P.O. Box 179
Denver, Colorado 80201

Mr. J.W. Morrison
Teledyne Ryan Aeronautical
Structural Mechanics
2701 Harbor Drive
San Diego, California 92112

Dr. R.W. Mortimer
Mechanical Engineering
Drexel University
Philadelphia, Pennsylvania 19104

Mr. L.I. Nagy
Ford Motor Company
ADV Analytical Tech.
23400 Michigan Avenue
Dearborn, Michigan 48124

Dr. O.S. Narayanaswamy
Ford Motor Company
Scientific Lab
Room 51077
Dearborn, Michigan 48121

Dr. N.W. Nelson
Esso Research and Engr. Co.
P.O. Box 101
Florham Park, New Hampshire 07932

Mr. L. Nieh
Stone and Webster Engineering Corp.
225 Franklin Street
Boston, Massachusetts 02107

Mr. J.S. O'Connor
John Hopkins University
8621 Georgia Avenue
Silver Spring, Maryland 20910

Mr. L. L. Olbrys
Raytheon Company
Sudbury Engineering Facility
528 Boston Post Road
Sudbury, Massachusetts 01776

Mr. A. J. Oster
ITEK Corporation
Optical Systems Division
10 Maguire Road
Lexington, Massachusetts 02173

Owens Illinois Company
North Technical Center
1700 N. Westwood
Toledo, Ohio 43601

Mr. M. Pakstys
General Dynamics
Electric Boat Division
Dept. 411 R and D
Groton, Connecticut 06340

Mr. L. F. Parson
Westinghouse Electric Corporation
P. O. Box 746
Baltimore, Maryland 21203

Dr. J. Payne
Bldg. A-2 Rm. 225
Aerospace Corporation
P. O. Box 95085
Los Angeles, California 90045

Mr. R. P. Peloubet
General Dynamics Corporation
Forth Worth, Texas 76101

Mr. D. Pengelley
General Dynamics Corporation
Convair Division
P. O. Box 1128
San Diego, California 92112

Mr. C. H. Perisho
McDonnell Aircraft Co.
St. Louis, Missouri 63166

Mr. J. S. Pektas
Lockheed Georgia Co.
D/72-26 Zone 457
Marietta, Georgia 30060

Mr. N. S. Phillips
Chief Engineer
Beta Industries Inc.
2763 Culber Avenue
Dayton, Ohio 45429

Mr. L. D. Pinson
MS 244
NASA Langley Research Center
Hampton, Virginia 23365

Mr. P. Polentz
Code Fan
NASA-Ames Res. Ctr.
Moffett Field, California 94035

Mr. R. F. Porter
Westinghouse Defense and Space
Baltimore, Maryland 21203

Dr. A. B. Potvin
Senior Research Engineer
Esso Production Research Co.
P. O. Box 2189
Houston, Texas 77001

Mr. R. Pyle
Computer Sciences Corporation
9841 Airport Blvd.
TAC 3 2nd Floor
Los Angeles, California 90045

Mr. Leon Rafaelian
Teledyne CAE Computer Center
1606 Laskey Road
Toledo, Ohio 43601

Mr. L. L. Reed
La Jolla, California 92037

T.E. Reed
Pamona, California 91768

Mr. W.E. Roberts
Texas Instruments Inc.
P.O. Box 5012
Dallas, Texas 75222

Mr. H.W. Robinson
Hughes Aircraft Co.
P.O. Box 3310
Fullerton, California 92634

Mr. W.I. Robkin
Itek Corporation
10 Maguire Road
Lexington, Massachusetts 02173

Commanding Officer
Rock Island Arsenal
Rock Island, Illinois 61201

Mr. R.A. Rosanoff
North American Rockwell Corp.
North American Aviation
12214 Lakewood Blvd.
Downey, California 90241

Dr. A. L. Ross
General Electric Co.
Room U3140
P.O. Box 8555
Philadelphia, Pennsylvania 19101

Mr. R.A. Rousos
Ford Motor Co.
Advanced Anal. Tech.
23400 Michigan Ave.
Dearborn, Michigan 48124

Mr. K. L. Rowan
Goodyear Aerospace Corp.
Dept. 478 Plant G-1
Akron, Ohio 44300

Dr. C.P. Rubin
Hughes Aircraft Co.
Mail Station 626
P.O. Box 92919
Los Angeles, California 90009

Mr. Edward Russell
P.O. Box 179
Martin Marietta Corp.
Denver, Colorado 80201

Mr. J.E. Ruzicka
Barry Research and Dev.
700 Pleasant Street
Watertown, Massachusetts 02171

Dr. J.B. Sainsbury-Carter
Sikorsky Aircraft
Structures and Materials
North Main Street
Stratford, Connecticut 06497

Mr. A Scapilauskas
Pioneer Services
2N Riverside Plaza
Chicago, Illinois 60606

Dr. F.P. Schauer
US Atomic Energy Commission
Division of Reactor Stds
Structural Engineering Br.
Washington, D.C. 20545

Mr. R.P. Schmitz
Space Support Division
Sperry Rand
716 Arcadia Circle
Huntsville, Alabama 35801

Ms E. Schram
Cessna Aircraft Company
Commercial Aircraft Division
5800 Pawnee
Wichita, Kansas 67201

Dr. D. Schwerzler
General Motors Research Labotatory
12 Mile and Mound Roads
Warren, Michigan 48090

Miss C. Scott
Bell Com Inc.
955 L-Enfant Plaza North SW
Washington, D.C. 20024

Mr. David H. Seitz
Mail Stop 1613
P. O. Box 179
Martin Marietta Corporation
Denver, Colorado 80201

Dr. A. V. Setlur
Pioneer Services
2N Riverside Plaza
Chicago, Illinois 60606

Shell Pipe Line Corporation
Library
P. O. Box 35335
Houston, Texas 77035

Dr. Simkins
Watervliet Arsenal
Watervliet, New York 12189

Mr. J. H. Simmons
Piper Development Center
P. O. Box 1328
Vero Beach, Florida 32960

Dr. H. Simpson
Simpson Gumpertz and Heger Inc.
1696 Massachusetts Ave.
Cambridge, Massachusetts 02138

Mr. J. Smayda
IBM
Systems Development Division
Rt. 17C and Glendale Drive
Endicott, New York 13760

Mr. K. P. Snodgrass
Ford Motor Co.
Design Analysis Group
Room 2149 Bldg. 1
Truck Operations
Dearborn, Michigan 48121

Mr. D. Stanley
Lockheed California Co
Dept. 80-31
Burbank, California 91503

Dr. E. L. Stanton
McDonnell Douglas Corp/
Douglas Missile and Space Missile Div.
Santa Monica, California 90496

Mr. E. C. Steeves
Engineering Science
GEPL
US Army Natick Labs
Natick, Massachusetts 01762

Mr. G. Stevens
Portsmouth Naval Ship Yard
Portsmouth, New Hampshire 03801

Mr. D. Strome
Boeing Company
MS 8C-43
Box 3999
Seattle, Washington 98124

Mr. R. S. Swanson
Science and Technology Div.
Inst. for Defense Analyses
400 Army-Navy Drive
Arlington, Virginia 22202

Systems Science and Software
11662 Sorrento Valley Road
San Diego, California 92121

Dr. F. Tabaddor
The B. F. Goodrich Co.
500 South Main Street
Akron, Ohio 44318

Mr. M. Tamulionis
IIT Research Institute
3719 South Shields
Chicago, Illinois 60609

Mr. L. Thoreson
North American Rockwell
Rochetdyne
D/086-313-Zone 7
Canoga Park, California 91300

Dr. E.A. Thornton
Old Dominion Univ. Res. Foun.
School of Engineering
P.O. Box 6173
Norfolk, Virginia 23508

Dr. M.C. Todd
EI Dupont De Nemours Co. Inc.
Engineering Department
Bldg. 304
Wilmington, Delaware 19898

Mr. J. Tomassoni
General Electric Corp.
Missile and Space Div.
3198 Chestnut Street
Philadelphia, Pennsylvania 19101

Mr. D.A. Turner
General Motors Corp.
Allison Division
P.O. Box 894
Indianapolis, In. 46206

Dr. A.A. Vicario
Hercules Incorporate
P.O. Box 210
Cumberland, Maryland 21502

Mr. G.K. Virooman
Chief Tech. Inf.
Watervilet Arsenal
Watervilet, New York 12189

Mr. B. Vonoy
Boeing Company
4735 E. Marginal Way South
Seattle, Washington 98134

Mr. D.C. Walker
Control Data Corp.
Scientific Services Dept.
8100 34th Avenue S. HQWO5G W 32
Minneapolis, Minnesota 55440

Mr. J.F. Werner
Goodyear Aerospace Corporation
1210 Massillion Road
Akron, Ohio 44315

Dr. M.T. Wilkinson
Louisiana Technical University
Box 4875 Tech. Station
Ruston, Louisiana 71270

Mr. H.E. Wilson
Bell Helicopter
P.O. Box 482
Ft. Worth, Texas 76101

Dr. R. Wingate
NASA-Langley
Hampton, Virginia 23365

Mr. S. Yahata
North American Rockwell
Space Div.
12214 Lakewood Blvd.
Downey, California 90241

Mr. C.H. Yeh
Harza Engineering Co.
150 S. Wacker Drive
Chicago, Illinois 60606

Mr. M. Yoshioko
NASA Ames
Moffett Field, California 94087

Mr. M.J. Vlissides
RAC
McLean, Virginia 22101

Mr. Stanely E. Zager
B.F. Goodrich
MGMT and Computer Science
500 South Main Street
Akron, Ohio 44318

Dr. Z. Zudans
Franklin Institute Res. Lab
20th and Race Streets
Philadelphia, Pennsylvania 19103

Appendix B
Modified Mailing List

Key

U = User
P = Potential User
I = Interested, but non-user
T = Telephone contact
M = Mail return
Per = Personal contact
NR = No mail return and no telephone contact
D = NASTRAN distributor
C = Consultant
N = Definite non-user

Adjusted Address List	NASTRAN Participation	Comment
Mr. G. A. Abbott North American Rockwell Corp. 12214 Lakewood Blvd. Downey, California 90241	T, U	
Mr. D. J. Ahrens Cessna Aircraft Company Commercial Aircraft Division 5800 Pawnee Wichita, Kansas 67201	M, I	Replace Miss E. Schram
Mr. M. G. Allen General Dynamics Corp. Convair Aero Division P. O. Box 748 Ft. Worth, Texas 76101	M, T, U	
Mr. V. L. Alley Jr. Systems Engineering Division NASA Langley Research Center Mail Stop 314 Hampton, Virginia 23365	NR	
Mr. Brig Agrawal Communication Satellite Corp. Clarksburg, Maryland	Per. U	
Mr. A. B. Atchley Lockheed Georgia Company Scientific Programming Division Dept. 87-10 Zone 288 Marietta, Georgia 30060	T, U	
Mr. W. R. Baca Structural Sys. Specialists P. O. Box 903 5400 Rosemead Blvd. Pico Rivera, California 90640	NR	
Mr. E. F. Baird Grumman Aerospace Corp. Bethpage, New York 11714	NR	
Mr. Allan P. Bakke Research Engineering NASA Ames Moffett Field, California 94086	M, U	

Adjusted Address List	NASTRAN Participation	Comment
Mr. B. T. Bata Westinghouse Electric Corp. Mail Stop 463 P. O. Box 746 Baltimore, Maryland 21203	Per. U	
Mr. Helmut F. Bauer Georgia Inst. of Technology School of Eng. Science and Mechanics 225 N. Avenue, N.W. Atlanta, Georgia 30332	M, T, U	
Bell Telephone Laboratory Indian Hill Naperville, Illinois 60540	NR	
Mr. R. D. Bennett Vought Aeronautics Corp. Dallas, Texas 75222	M, T, U M, T, U	
Dr. H. Bergman North American Rockwell Science Center 1049 Camino Dos Rio Thousand Oaks, California 91360	NR	
Mr. J. Berman Grumman Aircraft Engr. Corp. Bethpage, New York 11714	NR	
Mr. J. H. Best LTV Aerospace Corporation P. O. Box 5907 Dallas, Texas 75222	NR	
Dr. J. Blackman AM Elec. Power Service Corp. 2 Broadway New York, New York 10004	NR	
Mr. Winston Blackman NASA MSC Code FD12 Houston, Texas 77058	M, T, U	Replace Mr. John E. Leonard

Adjusted Address List	NASTRAN Participation	Comment
Dr. F.K. Bogner University of Dayton Research Inst. 300 College Park Avenue Dayton, Ohio 45409	NR	
Mr. L.E. Bothell Kaman Aerospace Corp. Kaman Nuclear 1700 Garden of the Gods Road Colorado Springs, Colorado 80907	T, I	
Mr. J.D. Bower Teledyne Ryan Aeronautical Structural Mechanics 2701 Harbor Drive San Diego, California 92112	M, U	
Dr. W.F. Bozich McDonnell Douglas Astronautics Co. 5301 Bolsa Avenue Huntington Beach, California 92647	M, T, U	
Mr. R.J. Broliar Teledyne Brown Engineering Strength Analysis Branch Mail Stop 190 Huntsville, Alabama 35807	M, T, U	
Mr. Eugene Burch Technology Applications Center University of New Mexico Albuquerque, New Mexico	M, U	
Mr. R. Butler NASA-Langley Research Center MS 125 Hampton, Virginia 23365	C	
Mr. T.G. Butler Code 406 NASA-Goddard Space Flight Center Greenbelt, Maryland 20771	C	
Mr. J.M. Carlson NASA Headquarters TU Division Code UT Washington, D.C. 20546	C	

Adjusted Address List	NASTRAN Participation	Comment
Mr. S. H. Chang Beech Aircraft Company Dept. 884 9709 East Central Ave. Wichita, Kansas 67201	M, P	
Mr. L. E. Chaump VFSTC Rm. U7038 GE Company P. O. Box 8555 Philadelphia, Pennsylvania 19101	M, P	
Mr. R. Chiapetta IIT Research Institute 10 East 35th Street Chicago, Illinois 60616	T, P	
William Cho Sargent & Lundy Engineers 140 S. Dearborn Chicago, Illinois 50606	NR	
Mr. R. L. Circle Lockheed Georgia Co. D/72-26 Zone 457 Marietta, Georgia 30060	M, U	Replace Mr. J. S. Pektas
Mr. John Cleary Itek Corp 10 Maguire Rd. Lexington, Massachusetts 02173	T, U	Replace W. I. Robkin
Mr. J. Conaway Sikorsky Aircraft Structures and Materials North Main St. Stratford, Connecticut 06497	M, T, U	Additional Name
Mr. William A. Cook Thiokol Chemical Corp. Waspac Division Brigham City, Utah 84302	M, P	Replace J. E. Hansen
Mr. W. L. Cook Communication Satellite Corp. 950 L-Enfant Plaza South, S. W. Washington, D. C. 20024	M, T, U	

Adjusted Address List	NASTRAN Participation	Comment
Mr. L. C. Corrington Assistant Chief for Technical Operations SNPO-C NASA-Lewis 21000 Brookpark Road Cleveland, Ohio 44125	M, U	
Mr. H. Cox NNS and DD Company 4101 Washington Ave. Engineering Laboratory Newport News, Virginia 23600	T, I	Replace Mr. L. Brand
Mr. Bruce Cramer McDonnell-Douglas Astronautics Corp. East St. Louis, Missouri 63166	M, U	Additional Name
Mr. D. G. Cross Atlantic Research Corporation 3333 Harbor Blvd. Costa Mesa, California 92626	M, T, U	Replace Mr. Richard Benton
Mr. R. E. Criste Research Analysis Corp. Westgate Research Park McLean, Virginia 22101	M, U	
Mr. M. J. Cronk Convair Division General Dynamics 5001 Kearney Villa Road San Diego, California 92112	NR	
Dr. E. H. Cuthill Naval Ship Res and Dev Center Code 805 Washington, D. C. 20034	T, U	
Mr. R. E. Davis McDonnell Automation Company Box 516 St. Louis, Missouri 63166	T, P	

Adjusted Address List	NASTRAN Participation	Comment
Mr. P. DeSantis Chi Corporation 11000 Cedar Avenue Cleveland, Ohio 44106	M, T, U	
Mr. Melvin Dickover Teledyne Computer Center 1606 Laskey Road Toledo, Ohio 43601	M, T, U	Additional Name
Mr. B. J. Donham Los Alamos Scientific Lab Group Eng/Do Box 1663 Los Alamos, New Mexico 87544	M, T, U	
Dr. D. Dudley Aerojet Solid Prop Co P.O. Box 13400 Sacramento, California 95813	M, T, U	
Mr. W. H. Dukes Bell Aerospace Co. P.O. Box One Buffalo, New York 14240	NR	
Mr. John Dutton McDonnell Douglas St. Louis, Missouri 63166	M, U	(Combined with Mr. Bruce Cramer
Mr. R. Ebrus Grumman Data Systems Corporation Plant 35 Dept. 502 Bethpage, New York 11714	NR	
Dr. F. England Westinghouse Electric Corp. Friendship International Airport Box 746 Baltimore, Maryland 21203	Per. U	
Mr. W. M. Flannely Kaman Aerospace Corporation Old Windsor Road Bloomfield, Connecticut 06002	NR	
Dr. K. Forsberg Lockheed Aircraft Co. Lockheed Research Lab. Palo Alto, California 93404	T, I	
	B-7	

Adjusted Address List	NASTRAN Participation	Comment
Mr. Walter E. Fried Pioneer Services 2N Riverside Plaza Chicago, Illinois 60606	M, U	Replace Mr. A. Scapilauskas
Dr. R. E. Fulton NASA-Langley Res. Center MS 1880 Hampton, Virginia 23365	NR	
Mr. T. Furuike North American Rockwell Space Division 12214 Lakewood Blvd. Downey, California 90241	NR	
Mr. J. Fuscoe Rohr Corporation Library P. O. Box 878 Chula Vista, California 92012	NR	
Mr. S. Gabrielse Westinghouse R and D Center Bulah Road Churchill Boro Pittsburgh, Pennsylvania 15221	T, U	Replace Dr. H. Lee
Mr. A. M. Garber General Electric Company Tech. Engr. 3198 Chestnut Street Philadelphia, Pennsylvania 19101	T, I	
Mr. H. B. Garland General Dynamics Convair Aerospace Division Fort Worth, Texas 76101	NR	
Mr. A. D. Gilbertson McDonnell Douglas Corp. Douglas Missile and Space Division Santa Monica, California 90496	M, T, U	Additional Name
Mr. Billy Gregg Pratt and Whitney Aircraft Florida R and D Center P. O. Box 2691 West Palm Beach, Florida 33400	T, U	Replace Mr. S. H. Adams

Adjusted Address List	NASTRAN Participation	Comment
Mr. Robert Guyan North American Rockwell Space Division 12214 Lakewood Blvd. Downey, California 90241	M, U	Additional Name
Mr. T.M. Gmitro CDC 223 W. Jackson Chicago, Illinois 60606	NR	
Mr. J. Go Computer Sciences Corp. Federal Bldg., Room 514 Richland, Washington 99352	M, T, U	
Prof. M. Goldberg Polytechnic Inst. of Brooklyn Aerospace Engr/Appl Mech 208 Violet Street Massepeque Park, New York 11762	NR	
Mr. David Gregory Grumman Aerospace Corp. Bethpage, New York 11714	M, T, U	
Mr. R.B. Gregory Research Analysis Corp. Marketing Consultant McLean, Virginia 22101	NR	
Mr. James E. Grove The B.F. Goodrich Co. 500 South Main Street Akron, Ohio 44318	M, U	Replace Dr. F. Tabbador
Mr. C. Gunn The University of Chicago Argonne National Laboratory 9700 Cass Avenue Argonne, Illinois 60439	NR	
Mr. G.W. Haggemacher Lockheed Aircraft Corp. D/74-41 B/63 P/A-1 Burbank, California 91503	M, T, U	

Adjusted Address List	NASTRAN Participation	Comment
Mr. W. C. Hamann Ford Motor Co. Village Plaza 3rd Floor 23,400 Mich Avenue Dearborn, Michigan 48124	M, T, U	Return combined with J. C. Kostelec and L. I. Nagy
Mr. S. D. Hansen The Boeing Company Commercial Airplane Div. P. O. Box 707 Renton, Wa 98055	NR	
Mr. Henry J. Harris Tech. Utilization Officer JFK Space Center, NASA Kennedy Space Center, Florida 32899	M, T, U	Replace Mr. J. Harrell
Mr. R. J. Harvey Lockheed Missile and Space Co. P. O. Box 504 Sunnyvale, California 94088	NR	
Mr. Joseph A. Heinrichs Fairchild Industries Germantown, Maryland 20767	M, U	
Mr. C. W. Hennrich The MacNeal-Schwendler Corp. 3217 North Armistead Ave. Hampton, Virginia 23366	T, U	
Mr. Richard F. Hess Perkin-Elmer Corporation Danbury, Connecticut 06810	T, U	
Mr. Reid Hopkins Hercules Bacchus Works USAF Plant 81 Magna, Utah 84044	M, T, U	Combined with Mr. John C. Tsamisis

Adjusted Address List	NASTRAN Participation	Comment
Mr. R. J. Holcshuh Bell Laboratories Inc. Room 2D262 Whippany, New Jersey 07054	T, U	
Mr. Lo-Ching Hua CDC Chicago Data Center 223 West Jackson Blvd. Chicago, Illinois 60606	M, T, U	
Dr. S. H. Huang Applied Mechanics Res GP Aero Mechanics Dept. Naval Air Development Center Warminster, Pa. 18974	M, T, U	
Dr. W. F. Hubka Kaman Aerospace Corp. Kaman Nuclear 1700 Garden of the Gods Road Colorado Springs, Colorado 80907	T, I	Additional Name
Dr. F. C. Hung North American Rockwell Corp. General Offices 1700 East Imperial Highway El Segundo, California 90245	NR	
Mr. R. Hunter Bell Telephone Labs Department 6515 Room 2D-168 Whippany, New Jersey 07981	M, T, U	
Mr. M. Ice Boeing Company MS 8C-43 P. O. Box 3999 Seattle, Washington 98124	M, T, U	
Mr. J. R. Johnson Air Force Flight Dyn Lab. Wright-Patterson AFB Dayton, Ohio 45433	T, I	
Mr. Basil Jordan LTV Aerospace Corp. Dallas, Texas 75222	T, U	Additional Name

Adjusted Address List	NASTRAN Participation	Comment
Mr. Steven Jordan Bell Aerospace Co. P.O. Box One Buffalo, New York 14240	T, U	Replace Dr. R.A. Gellatly
Mr. M. Kaser Midwest Applied Sci. Corp. Box 2157 West Lafayette, Ind. 47906	NR	
Mr. S. Katow Jet Propulsion Labs Bldg. 125 Box 22 4800 Oak Grove Drive Pasadena, California 91103	M, T, U	
Mr. I. Kenigsberg Sikorsky Aircraft Stratford, Connecticut 06075	T, P	
Dr. J.M. Kennedy Argonne National Labs Reactor Analy/Safety Division 9700 S. Cass Avenue Argonne, Illinois 60439	M, T, U	
Mr. P.J. Kertesz Lockheed Missile/Space Company Dept. 6262 Bldg. 156A P.O. Box 502 Sunnyvale, California 94088	T, P	
Mr. W.M. Kethley Cosmic Barrow Hall University of Georgia Athens, Georgia 30601	M, D	
Mr. G.W. Knobeloch Structural Dynamics Research Corp. 5729 Dragon Way Cincinnati, Ohio 45227	M, T, U	Replace Dr. R.F. Henke
Mr. P.K. Korwek Ford Motor Car Company Box 2053 Dearborn, Michigan 48121	NR	

Adjusted Address List	NASTRAN Participation	Comment
Mr. J.C. Kostelec Ford Motor Company Engineering Tech. Office Village Plaza Tower Dearborn, Michigan 48124	M, T, U	Return combined with W. C. Hamann and L.I. Nagy
Mr. W.P. Kunkel Westinghouse Tele-Computer Systems Corporation 2040 Ardmore Blvd. Pittsburgh, Pennsylvania 15220	M, T, U	
Mr. P. Kuo AVCO Lycoming Division 560 South Main Street Stratford, Connecticut 06497	M, T, U	
Mr. Henry S. Kwoh CDC-MEISCON 223 N. Jackson Chicago, Illinois 60606	M, U	
Mr. Stewart J. Lammers Ford Motor Company Bldg. 1, Room 2149 20000 Rodunda Drive Dearborn, Michigan 48121	T, U	
Dr. L.A. Larkin A.O. Smith Corporation Dept. 9731 P.O. Box 584 Milwaukee, Wisconsin 53201	T, U	
Mr. Edward Larson North American Rockwell Rocketdyne D/086-313-Zone 7 Canoga Park, California 91300	T, P	Replace Mr. L. Thoreson
Dr. G. Lasker General Dynamics P.O. Box 2507 Pomona, California 91766	T, P	

Adjusted Address List	NASTRAN Participation	Comment
Dr. Raymond La Tona Simpson Gumpertz and Heger Inc. 1696 Massachusetts Ave. Cambridge, Massachusetts 02138	M, P	Replace Dr. H. Simpson
Mr. J.R. Laubach Bell Laboratories Inc. Room 3A-211A Whippany Road Whippany, New Jersey 07981	T, U	
Dr. R.S. Levy Fairchild Hiller Corporation Republic Aviation Division Farmingdale, Long Island New York 11735	NR	
Mr. R. Levy Jet Propulsion Lab. California Inst. of Tech. 4800 Oak Grove Drive Pasadena, California 99103	T, U	
Mr. W.E. Lorensen Watervliet Maggs Research Center Bldg. 115 Watervliet, New York 12189	M, T, U	
Mr. Joseph Lowe Itek Corporation 10 Maguire Road Lexington, Massachusetts 02173	M, T, U	Additional Name
Mr. G.A. Lynch E.I. Dupont De Nemours Co. Inc. Engineering Department Bldg. 304 Wilmington, Delaware 19898	M, T, P	
Dr. R.H. MacNeal MacNeal Schwendler Corp. 7422 North Figueroa Street Los Angeles, California 90041	M, U	

Adjusted Address List	NASTRAN Participation	Comment
Dr. R.H. Mallett Bell Aerospace Company P.O. Box One Buffalo, New York 14240	NR	
Mr. Marburger U.S. Army USAMERDC Bldg. Ft. Belvoir, Virginia 22060	M, T, P	
Mr. Curtis Martin LTV Aerospace Corporation Dallas, Texas 75222	T, U	
Mr. R.A. Marx Goodyear Aerospace Corp. Dept. 428 1210 Massillon Road Akron, Ohio 44315	M, U	
Dr. J.B. Mason Goddard Space Flight Center 908 South Wick Drive Towson, Maryland 21204	M, U	
Mr. P. Mason Grumman Aerospace Company Dept. 35-460 Bethpage, New York 11714	NR	
Mr. Petro Matula Naval Ship Res and Dev Center Code 805 Washington, D.C. 20034	M, T, U	Additional Name
Mr. C.B. Mayforth VFSTC Room U2704 General Electric Co. P.O. Box 8555 Philadelphia, Pennsylvania 19101	NR	
Mr. James McAndrew SCI-TEK Computer Center Inc. 1707 Gilpin Avenue Wilmington, Delaware 19806	M, U	Replace Mr. H.E. Andreas

Adjusted Address List	NASTRAN Participation	Comment
Mr. R. L. McComas S and E-ASTN-AA NASA/Marshall Sp. Flt. Ctr. Marshall Sp. Flt. Ctr., Alabama 35812	M, T, U	
Dr. R. W. McLay University of Vermont Mechanical Engineering Burlington, Vermont 05401	M, P	
Dr. F. G. McLean Westenhoff & Novick 222 W. Adams Suite 1100 Chicago, Illinois 60606	M, T, U	
Dr. J. McMunn TRW Systems Group One Space Park Redondo Beach, California 90278	M, U	Replace Mr. R. Gluck
Dr. R. J. Melosh Philco-Western Dev. Labs 3825 Fabian Way Palo Alto, California 94304	T, I	
Mr. J. Midgley Federal Building Room 581 A 825 Jadwin Avenue Richland, Wa. 99352	NR	
Mr. W. Mikesell Chicago Bridge and Iron Analysis Group 901 West 22nd Street Oakbrook, Illinois 60521	M. P	
Dr. R. Miller The Boeing Company Commercial Airplant Div. P. O. Box 3707 Renton, Wa. 98124	M, P	
Mr. Joseph Minkel Itek Corp. 10 Maguire Road Lexington, Mass. 02173	T, U	

Adjusted Address List	NASTRAN Participation	Comment
Mr. Robert B. Morgan Texas Instruments P.O. Box 5474 Dallas, Texas 75222	M, T, U	
Mr. J.W. Morrison Teledyne Ryan Aeronautical Structural Mechanics 2701 Harbor Drive San Diego, California 92112	M, T, U	
Dr. R.W. Mortimer Mechanical Engineering Drexel University Philadelphia, Pennsylvania 19104	M, P	
Mr. A.F. Muller Southwest Research Institute San Antonio, Texas 78206	M, P	Replace Dr. H.N. Abramson
Mr. L.I. Nagy Ford Motor Company ADV Analytical Tech. 23400 Michigan Ave. Dearborn, Michigan 48124	M, T, U	
Dr. O.S. Narayanaswamy Ford Motor Company Scientific Lab Room 51077 Dearborn, Michigan 48121	M, U	
Dr. N.W. Nelson Esso Research and Engr. Co. P.O. Box 101 Florham Park, New Hampshire 07932	T, P	
Mr. L. Nieh Stone and Webster Engineering Corp. 225 Franklin Street Boston, Massachusetts 02107	T, P	
Mr. J.S. O'Connor John Hopkins Univ. 8621 Georgia Ave. Silver Spring, Maryland 20910	M, T, U	

Adjusted Address List	NASTRAN Participation	Comment
Mr. G. Peter O'Hara Watervliet Arsenal Maggs Research Center Bldg. 115 Watervliet, New York 12189	M, T, U	New Name
Mr. L. L. Olbrys Raytheon Company Sudbury Engineering Facility 528 Boston Post Road Sudbury, Massachusetts 01776	M, T, U	
Mr. A. J. Oster ITEK Corporation Optical Systems Division 10 Maguire Road Lexington, Massachusetts 02173	NR	
Owens Illinois Company North Technical Center 1700 N. Westwood Toledo, Ohio 43601	NR	
Mr. L. F. Parson Westinghouse Electric Corp. P. O. Box 746 Baltimore, Maryland 21203	NR	
Dr. J. Payne Bldg. A-2 Rm. 225 Aerospace Corporation P. O. Box 95085 Los Angeles, California 90045	T, P	
Col. M. Pearson Chief Dynamics Branch Northrop Services. Inc. 3025 Technology Drive Huntsville, Alabama 35806	M, U	Replace Mr. C. Hwang
Mr. R. P. Peloubet General Dynamics Corporation Fort Worth, Texas 76101	M, U	
Mr. D. Pengelley General Dynamics Corp. Convair Division P. O. Box 1128 San Diego, California 92112	NR	

Adjusted Address List	NASTRAN Participation	Comment
Mr. C. H. Perisho McDonnell Aircraft Co. St. Louis, Missouri 63166	M, T, U	
Mr. N. S. Phillips Chief Engineer Beta Industries Inc. 2763 Culber Ave. Dayton, Ohio 45429	M, U	
Mr. L. D. Pinson MS 244 NASA Langley Research Center Hampton, Virginia 23365	M, T, U	
Mr. P. Polentz Code Fan NASA-Ames Res. Ctr. Moffett Field, California 94035	M, U	
Mr. R. F. Porter Westinghouse Defense and Space Baltimore, Maryland	Per. U	
Dr. A. B. Potvin Senior Research Engineer Esso Production Research Co. P. O. Box 2189 Houston, Texas 77001	M, P	
Mr. R. Pyle Computer Sciences Corp. 9841 Airport Blvd. TAC 3 2nd Floor Los Angeles, California 90045	M, U	
Mr. Leon Rafaelian Teledyne CAE Computer Center 1606 Laskey Road Toledo, Ohio 43601	M, T, U	
Mr. T. E. Reed Pamona, California 91768	NR	
Mr. William Renegan NASA MSC Code FD12 Houston, Texas 77058	T, U	Additional Name

Adjusted Address List	NASTRAN Participation	Comment
Mr. James E. Richardson NASA Lewis 21000 Brookpark Road Cleveland, Ohio 44135	M, U	Additional Name
Mr. R.M. Rivello Johns Hopkins University 8621 Georgia Ave. Silver Spring, Maryland 20910	M, T, U	Additional Name
Mr. W.E. Roberts Texas Instruments Inc. P.O. Box 5012 Dallas, Texas 75222	NR	
Commanding Officer Rock Island Arsenal Rock Island, Illinois	NR	
Dr. A. L. Ross General Electric Co. Room U3140 P.O. Box 8555 Philadelphia, Pennsylvania 19101	M, P	
Mr. R.A. Rousos Ford Motor Co. Advanced Anal. Tech. 23400 Michigan Ave. Dearborn, Michigan 48124	NR	
Mr. K. L. Rowan Goodyear Aerospace Corp. Dept. 478 Plant G-1 Akron, Ohio 44300	NR	
Dr. C.P. Rubin Hughes Aircraft Co. Mail Station 626 P.O. Box 92919 Los Angeles, California 90009	NR	
Mr. J.E. Ruzicka Barry Research and Dev. 700 Pleasant Street Watertown, Massachusetts 02171	NR	

Adjusted Address List	NASTRAN Participation	Comment
Dr. J. B. Sainsbury-Carter Sikorsky Aircraft Structures and Materials North Main Street Stratford, Connecticut 06497	M, T, U	
Dr. F. P. Schauer US Atomic Energy Commission Division of Reactor Stds Structural Engineering Br. Washington, D.C. 20545	T, I	
Mr. R. Scheller McDonnell Automation Co. P.O. Box 516 St. Louis, Missouri 63166	T, P	Additional Name
Mr. R. P. Schmitz Space Support Division Sperry Rand 716 Arcadia Circle Huntsville, Alabama 35801	M, T, U	
Mr. P. R. Schrantz Comsat Corp. Clarksburg, Maryland 20734	Per. U	Additional Name
Dr. D. Schwerzler General Motors Research Laboratory 12 Mile and Mound Roads Warren, Michigan 48090	M, T, U	
Mr. David H. Seitz Mail Stop 1613 P.O. Box 179 Martin Marietta Corporation Denver, Colorado 80201	M, U	
Dr. A. V. Setlur Pioneer Services 2N Riverside Plaza Chicago, Illinois 60606	M, T, U	
Mr. George E. Walker Shell Pipeline Corp. P. O. Box 35335 Houston, Texas 77035	M, I	Additional Name

Adjusted Address List	NASTRAN Participation	Comment
Dr. Simkins Watervliet Arsenal Watervliet, New York 12189	M, U	
Mr. K.P. Snodgrass Ford Motor Co. Design Analysis Group Room 2149 Bldg. 1 Truck Operations Dearborn, Michigan 48121	T, U	
Mr. D. Stanley Lockheed California Co. Dept. 80-31 Burbank, California 91503	NR	
Dr. E. L. Stanton McDonnell Douglas Corp/ Douglas Missile and Space Missile Div. Santa Monica, California 90496	M, T, U	
Mr. E.C. Steeves Engineering Science GEPL US Army Natick Labs Natick, Massachusetts 01762	T, I	
Mr. D. Strome Boeing Company MS 8C-43 Box 3999 Seattle, Washington 98124	NR	
Mr. R.S. Swanson Science and Technology Div. Inst. for Defense Analysis 400 Army-Navy Drive Arlington, Virginia 22202	M, P	
Systems Science and Software 11662 Sorrento Valley Road San Diego, California 92121	NR	
Mr. Ali Abu Taho Comsat Corp. Clarksburg, Maryland 20734	Per. U	

Mr. M. Tamulionis IIT Research Institute 3719 South Shields Chicago, Illinois 60609	NR	
Dr. E.A. Thornton Old Dominion Univ. Res. Foun. School of Engineering P.O. Box 6173 Norfolk, Virginia 23508	M, U	
Mr. John C. Tsamisis Design Engineer Hercules Inc. Box 98 Magna, Utah 84044	T, P	
Dr. M.C. Todd El Dupond De Nemours Co. Inc. Engineering Dept. Bldg. 304 Wilmington, Delaware 19898	M, U	
Mr. David Utterback McDonnell Aircraft Co. P.O. Box 516 St. Louis, Missouri 63166	M, T, U	Additional Name
Dr. Curtis Vail General Motors Research Lab. 12 Mile and Mound Roads Warren, Michigan 48090	M, T, U	Additional Name
Dr. A.A. Vicario Hercules Incorporate P.O. Box 210 Cumberland, Maryland 21502	M, T, U	
Mr. G.K. Virooman Chief Tech. Inf. Watervliet Arsenal Watervliet, New York 12189	NR	
Mr. David L. Vitello Raytheon Co. Missile Systems Div. Box 900 Hartwell Road Bedford, Massachusetts 01730	M, U	Replaced Mr. C. T. McCormick

Adjusted Address List	NASTRAN Participation	Comment
Mr. B. Vonoy Boeing Company 4735 E. Marginal Way South Seattle, Washington 98134	NR	
Dr. W.A. Von Riesenmann Sandia Corporation Division 1541 P.O. Box 5800 Albuquerque, New Mexico 87115	M, T, U	Replaced Mr. S. Key
Mr. D.C. Walker Control Data Corp. Scientific Services Dept. 8100 34th Ave. S. HQWO5G W 32 Minneapolis, Minnesota 55440	M, T, U	
Dr. V.B. Watwood Franklin Institute Res. Lab 20th and Race Streets Philadelphia, Pennsylvania 19103	M, U	Replaced Dr. Z. Zudans
Mr. J.F. Werner Goodyear Aerospace Corporation 1210 Massillion Road Akron, Ohio 44315	NR	
Mr. Leslie White Lockheed Georgia Co. Scientific Programming Div. Dept. 87-10 Zone 288 Marietta, Georgia 30060	T, U	Additional Name
Dr. M.T. Wilkinson Louisiana Tech. Univ. Box 4875 Tech. Station Ruston, Louisiana 71270	M, T, U	
Mr. H.E. Wilson Bell Helicopter P.O. Box 482 Ft. Worth, Texas 76101	M, T, U	
Dr. R. Wingate NASA-Langley Hampton, Virginia 23365	M, U	

Adjusted Address List	NASTRAN Participation	Comment
Mr. Richard Wohlen Martin Marietta Corp. P.O. Box 179 Denver, Colorado 80201	M, T, U	Replaced Mr. G. Morosow
Mr. S. Yahata North American Rockwell Space Div. 12214 Lakewood Blvd. Downey, California 90241	M, U	Return combined with G.A. Abbott and R. Guyan
Mr. C.H. Yeh Harza Engineering Co. 150 S. Wacker Drive Chicago, Illinois 60606	M, U	
Mr. M. Yoskoko NASA Ames Moffett Field, California 94087	M, U	
Mr. M.J. Vlissides RAC McLean, Virginia 22101	NR	
Mr. Stanley E. Zager B.F. Goodrich MGMT and Computer Sciences Corp. 500 South Main St. Akron, Ohio 44318	T, P	

Adjusted Address List	NASTRAN Participation	Comment
Mr. M. U. Ayres Corporate Engineering 3755 Marginal Way The Boeing Co. Seattle, Washington 98124		Delete - Terminated Company
Mr. L. I. Chasen General Electric Co. Valley Forge Space Center P. O. Box 8555 Philadelphia, Pennsylvania 19101	M, N	Delete-Librarian
Mr. Edward Fernald Portsmouth Naval Ship Yard Portsmouth, New Hampshire 03801	T, N	Delete - Both Mr. Edward Fernald and Mr. G. Stevens who was on original list
Mr. Terrence P. Kane Puget Sound Naval Shipyard Seattle, Washington 98314	T, N	Delete
Mr. M. Pakstys General Dynamics Electric Boat Division Dept. 411 R and D Groton, Connecticut 06340	T, N	Delete
Mr. L. L. Reed La Jolla, California 92037		Delete - Address unknown
Mr. H. W. Robinson Hughes Aircraft Co. P. O. Box 3310 Fullerton, California 92634		Delete-Address unknown
Mr. R. A. Rosanoff North American Rockwell Corp. North American Aviation 12214 Lakewood Blvd. Downey, California 90241		Delete - Address unknown
Mr. Edward Russell P. O. Box 179 Martin Marietta Corp. Denver, Colorado 80201		Delete - Address unknown

Adjusted Address List	NASTRAN Participation	Comment
Miss C. Scott Bell Com Inc. 955 L-Enfant Plaza North SW Washington, D.C. 20024		Delete - Address unknown
Mr. J.H. Simmons Piper Development Center P.O. Box 1328 Vero Beach, Florida 32960	M,N	Delete
Mr. J. Smayda IBM Systems Development Div. Rt. 17C and Glendale Drive Endicott, New York 13760	T,N	Delete
Mr. J. Tomassoni General Electric Corp. Missile and Space Div. 3198 Chestnut Street Philadelphia, Pennsylvania 19101		Delete - Terminated Company
Mr. D.A. Turner General Motors Corp. Allison Div. P.O. Box 894 Indianapolis, Indiana 46206	T,N	Delete

Appendix C
Mailed Questionnaire

NASTRAN QUESTIONNAIRE

If you wish to discuss this questionnaire, please feel free to call Mr. E. T. (Pete) Steen, Project Manager, telephone (703) 533-8877, Ext. 6282.

RESPONDENT INFORMATION

1. Name, title, and telephone number of person completing questionnaire:

Name: _____

Title: _____

Telephone: Area Code () No. _____ Ext. _____

2. Name and address of company/organization:

Name: _____

Address: _____

3. Nature of company/organization business:

PROPRIETARY INFORMATION

4. Do you regard any portion of your response to this questionnaire as containing proprietary information? Yes _____. No _____. If so, please indicate such information so that its proprietary nature may be respected.

REMARKS AND COMMENTS

5. Please use this space for any amplifying remarks or comments.

INFORMATION REGARDING NASTRAN PROGRAM BENEFITS

6. Please indicate with a checkmark (✓) the benefits or advantages that have accrued to you as a result of using the NASTRAN Program, and rank on a 1-2-3 scale the three benefits you regard as the most important.

<u>Benefit</u>	<u>Check Here</u>	<u>Three Most Important</u>
Cost Reduction	_____	_____
Work Simplification	_____	_____
Time Saving	_____	_____
Obtained more accurate results	_____	_____
Obtained more complete results	_____	_____
Performed analysis that would not have been attempted without NASTRAN	_____	_____
Provides for improved communications with other engineers and analysts in the structural analysis field	_____	_____
Resulted in a safer product	_____	_____
Other (describe) _____	_____	_____
_____	_____	_____
Other (describe) _____	_____	_____
_____	_____	_____
Other (describe) _____	_____	_____
_____	_____	_____

INFORMATION REGARDING THE COMPUTERS YOU HAVE USED FOR RUNNING THE NASTRAN PROGRAM

7. Please indicate the computer or computers you have used to run the NASTRAN Program.

	<u>Used</u>	<u>Specific Computer Model</u>
IBM 360 Series	_____	_____
CDC 6000 Series	_____	_____
Univac 1108	_____	_____
(Other) _____	_____	_____

8. Did you run the NASTRAN Program --

	<u>Yes</u>	<u>No</u>
On your own (company's) computer ?	_____	_____
Computer service bureau's computer ?	_____	_____
Other computer ?	_____	_____

9. If you ran the NASTRAN Program on a computer service bureau's computer, please indicate the name and location of the bureau providing that service.

Name: _____

Location: _____

INFORMATION REGARDING THE APPLICATIONS FOR WHICH YOU
HAVE USED THE NASTRAN PROGRAM

10. Please list below the applications you have made of the NASTRAN Program. Also for each application, please indicate whether you would have developed a program, at your own expense, for doing this work if NASTRAN had not been available.

	Application	Would Have Developed Program	Would <u>NOT</u> Have Developed Program
a			
b			
c			
d			
e			

11. Please list below the applications you would NOT have attempted WITHOUT NASTRAN and a brief reason as to why NASTRAN made the attempt possible. Also, was the NASTRAN application successful ?

	Application	Reason	Successful	
			Yes	No
a				
b				
c				
d				
e				

12. Do you have underway (or planned) any new NASTRAN applications which are not yet completed? Yes _____. No _____. If "yes", list below:

13. For each NASTRAN application used, please estimate your operational cost (or man-hours).

	NASTRAN Application	Programmer/Analyst Cost (man-hours or \$)	Engineering Cost (man-hours or \$)	Type Computer Used and Cost
a				
b				
c				
d				
e				

14. If any of the above applications have been accomplished by alternate methods (for example, prior to the availability of NASTRAN or by another program) please estimate your operational costs for the alternative method and the date used.

Line No. From Preceding Table	Alternate Method	Programmer/Analyst Cost (man-hours or \$)	Engineering Cost (man-hours or \$)	Type Computer Used and Cost	Date Used

15. What new product development can be attributed to the NASTRAN Program? Please estimate the value of the business that this development generated for you.

Product	Business Value

16. For each product or service development in which NASTRAN was used, estimate cost or time savings which can be attributed to NASTRAN for the parameters in the table below. (An example is shown.)

Product/ Service	Value Parameter	NASTRAN Used	Benefits (Savings)	Product/ Service	Value Parameter	NASTRAN Used	Benefits (Savings)
Analysis of Sandwich Plate	Safety Analysis	Yes	40 man/hr Eng.		Safety Analysis		
	Reliability Analysis	Yes	20 man/hr Eng.		Reliability Analysis		
	Qual. Assurance Analysis	Yes	\$500		Qual. Assurance Analysis		
	Development Time	Yes	6 weeks		Development Time		
	Other				Other		
	Other				Other		
Product/ Service	Value Parameter	NASTRAN Used	Benefits (Savings)	Product/ Service	Value Parameter	NASTRAN Used	Benefits (Savings)
	Safety Analysis				Safety Analysis		
	Reliability Analysis				Reliability Analysis		
	Qual. Assurance Analysis				Qual. Assurance Analysis		
	Development Time				Development Time		
	Other				Other		
Product/ Service	Value Parameter	NASTRAN Used	Benefits (Savings)	Product/ Service	Value Parameter	NASTRAN Used	Benefits (Savings)
	Safety Analysis				Safety Analysis		
	Reliability Analysis				Reliability Analysis		
	Qual. Assurance Analysis				Qual. Assurance Analysis		
	Development Time				Development Time		
	Other				Other		
Product/ Service	Value Parameter	NASTRAN Used	Benefits (Savings)	Product/ Service	Value Parameter	NASTRAN Used	Benefits (Savings)
	Safety Analysis				Safety Analysis		
	Reliability Analysis				Reliability Analysis		
	Qual. Assurance Analysis				Qual. Assurance Analysis		
	Development Time				Development Time		
	Other				Other		

INFORMATION REGARDING THE OFFERING OF NASTRAN SERVICES

17. Do you offer NASTRAN services to other companies or agencies? Yes _____. No _____.
If you do, please estimate the value of the business generated for you by this service.
-

INFORMATION REGARDING NASTRAN PROGRAM MAINTENANCE AND MODIFICATION

18. Does the provision of NASTRAN maintenance by NASA result in any cost savings because you do not have to provide this in-house capability? Yes _____. No _____.
19. If NASA did not provide maintenance, please estimate how much you would budget for such work?

Applications	Budget Allotment

20. If you have initiated improvements, short cuts, or adaptations for new applications using your own funds, please indicate the applications and estimated costs.

Applications	Cost

21. Exclusive of computer operating time, what improvements do you recommend for the NASTRAN Program?

22. Do you have any suggestions, based on your experience with NASTRAN, for areas in which new applications could potentially be developed, but where no work is currently underway?

Your cooperation in responding to this questionnaire is sincerely appreciated. For your convenience a postpaid self-addressed envelope is enclosed for mailing your reply to Computer Sciences Corporation.

Appendix D

Supplementary Questionnaire

Supplementary List of Questions
for Personal/Telephone Interviews

RESPONDENT INFORMATION

Name, title, and telephone number of person interviewed.

Name: _____

Title: _____

Telephone: Area Code () No. _____ Ext. _____

Name and address of company/organization.

Name: _____

Address: _____

Nature of company/organization business.

Interviewer Information

Name: _____

Title: _____

Telephone No. _____

Address: _____

Date and Time/Interview _____

SUPPLEMENTAL QUESTIONS

1. Please indicate the NASTRAN formats you have used.

<u>Format</u>	<u>Used</u>	<u>Not Used</u>
1. Static Analysis	_____	_____
2. Static Analysis with Inertia Relief	_____	_____
3. Normal Mode Analysis	_____	_____
4. Static Analysis with Differential Stiffness	_____	_____
5. Buckling Analysis	_____	_____
6. Piecewise Linear Analysis	_____	_____
7. Direct Complex Eigenvalue Analysis	_____	_____
8. Direct Frequency and Random Response	_____	_____
9. Direct Transient Response	_____	_____
10. Modal Complex Eigenvalue Analysis	_____	_____
11. Modal Frequency and Random Response	_____	_____
12. Modal Transient Response	_____	_____

2. Please indicate the NASTRAN levels you have used.

<u>Level</u>	<u>Used</u>	<u>Not Used</u>
8	_____	_____
9	_____	_____
10	_____	_____
11	_____	_____
12	_____	_____

3. Are you using NASTRAN as furnished by a Service Bureau or an industrial company providing this type service? Yes____, No____. If yes, please indicate the service bureau or industrial company and the level or other designation used to describe the program.

4. Please comment on NASTRAN Documentation as listed below. Is it clear, consise; what changes (improvements) would you recommend?

a. NASTRAN Demonstration Problem Manual

b. NASTRAN Users Manual

c. The NASTRAN Theoretical Manual

d. The NASTRAN Programmer's Manual

e. NASTRAN levels

5. Do you use NASTRAN Tapes as obtained from COSMIC? Yes ____,
No _____. If yes, what changes or improvements would you recommend?

6. What other NASTRAN documentation do you believe necessary or
desirable?

7. Do you use the Computer Software Management and Information Center
(COSMIC) for NASTRAN information? Yes ____, No _____. If yes, please
comment upon how this service can be improved for your benefit.

8. If a problem has arisen in the use of NASTRAN documentation and tapes, who or what agency did you contact for clarification and advice?

9. After making contact with COSMIC, a Service Bureau, or other agency for advice in use of the NASTRAN program, or concerning an apparent discrepancy, what response did you obtain?

10. Have you used a training course for NASTRAN users. Yes ____, No ____.
If yes estimate number of attendees _____.

11. What NASTRAN plotters do you use?

12. What is the maximum amount of main memory on any of your computers on which you run NASTRAN?

Computers

Max. Main Memory (Bytes or Words)

13. Estimate number of company/organization personnel involved in NASTRAN usage.

Programmer/Analyst _____; engineers _____,
other _____.

14. When using NASTRAN do you require outside personnel support?

Yes ____, No ____. If yes indicate numbers below.

_____ programmers; _____ analysts;
_____ engineers.

15. Did you have to develop and use personnel training programs prior to NASTRAN usage? Yes ____, No ____. If yes, indicate the number and type of people trained, cost and length of the training course.

_____ programmers, _____ analysts,
_____ engineers, _____ other.
_____ length of training program.
_____ estimated cost of program.

16. Are you interested in forming a NASTRAN "SHARE Library" where users can send corrections, improvements, short cuts, etc. to a central agency where they are available for all purchasers of the program. Yes ____, No ____. If yes, would you release applications now considered proprietary? Yes ____, No ____.

17. How did you learn of NASTRAN and what was the primary factor in its initial selection for use?

18. If a change in NASTRAN format were made, indicate change desired and benefits you would derive.

Change in Format	Benefit: manhours saved, computer time saved, others.

19. Voluntary observations or comments by respondent.

20. If a call back is required, indicate person to be called, subject to be discussed, date and time of expected call.

Person _____

Phone No. _____

Subject _____

Date and Time _____

21. Comments by CSC interviewer.

Appendix E

Sample Forwarding Letters

December 14, 1971

KT

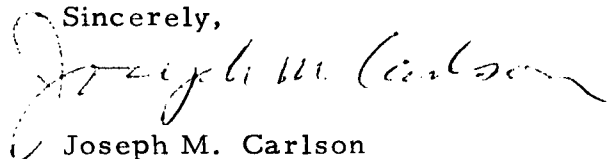
Dear Sir:

The National Aeronautics and Space Administration is responsible for managing, maintaining, and improving the NASTRAN system for use by NASA centers and industry. The NASTRAN Systems Management Office (NSMO) located in the Structures Division of the Langley Research Center was formally established Oct. 4, 1970 concurrent with the first release of level 12 of NASTRAN to the public. NASA is currently in the process of reviewing the progress of the program and in determining its usefulness and value to the user population.

Computer Sciences Corporation has been engaged to aid in this analysis task. As part of their study a questionnaire has been developed to explore and document the uses, capabilities, limitations, and benefits of the NASTRAN program to its users. We realize that some of the questions may not bear directly on your work but it is necessary to include a wide variety in order that the questionnaire be applicable to the broad spectrum of users. Those of you who have received a NASTRAN news letter directly from NASA-Langley in September, 1971 may note some duplication of a few questions. These have been reduced to a minimum consistent with the needs of this study.

In order that your information and opinions may be reflected in NASA planning and future development work, we request your assistance in completing the applicable portions of the questionnaire and returning it at your earliest convenience in the enclosed post-paid envelope. Since the study response time is short, information should be received prior to January 14, 1972 to be of value in the study. A small percentage of users may be further contacted for telephone or personal interview. Your cooperation is earnestly solicited.

Sincerely,



Joseph M. Carlson
Chief, Dissemination and Program
Evaluation Division
Technology Utilization Office

December 14, 1971

Dear Sir:

Would you please take a few minutes of your time to aid in an assessment of usefulness of the NASA Structural Analysis (NASTRAN) Program. For this purpose we seek your cooperation in furnishing the information indicated in the attached questionnaire. The questionnaire makes it easy for you to respond; however, if you desire to supplement your response or append explanatory material, please feel free to do so. A postpaid self-addressed envelope is enclosed for your convenience in replying. NASA had indicated a special need to receive replies by January 14, 1972. Your cooperation will be appreciated.

Computer Sciences Corporation and NASA will respect the proprietary nature of any information so designated. If you have any questions please do not hesitate to call Mr. E. T. Steen (Ext. 6282), Mr. C. V. Wilson (Ext. 6302) or Mr. R. Benny (Ext. 6573) at the above address.

Sincerely yours,

A handwritten signature in cursive script that reads "Charles V. Wilson".

Charles V. Wilson
Manager
Technology Utilization Program

Appendix F

NASTRAN Applications

This appendix contains a detailed listing of 186 NASTRAN applications as requested by questions 10 and 11 of the mailed questionnaire (Appendix C). The structural analysis applications are divided into two large categories: (1) those 62 which would have been developed by the organization concerned had NASTRAN not been available, and (2) those 124 which would not have been attempted without NASTRAN. Each category has been further subdivided into the six type user organizations used throughout the study, thus twelve tables follow. It should be noted that although there are in existence a number of other programs for performing some of the applications listed, many users indicated they preferred NASTRAN since it gave better and more complete results; therefore, these applications are included in category (2) above. On the other hand, a few users have developed a special program which they prefer over NASTRAN because it is tailored to their needs and computer hardware, and in general has a faster running time.

Table F-1
Aerospace Industry - Structural Analysis Applications
That Would Have Been Developed Had
NASTRAN Been Unavailable

Applications	No. of Users
Acoustic Analysis of motor voids	1
Acoustic response of honeycomb plates	1
Dynamic stress concentration	1
Static loads analysis	3
Thermal analysis	1
Shell analysis	1
Aircraft static stress analysis	1
3-D hydroelastic analysis (small sized problems)	1
Aircraft wings and stabilizers	3
Aircraft fuselage	2
Aircraft control linkage	1
Aircraft test structure	1
Dynamic analysis	1
Buckling analysis	2
Static analysis with differential stiffness	1
Space antennas	1
Natural frequencies	1
Differential stiffness	1
Analysis of space vehicle and mechanisms	1
Large telescope	1
Total Applications	26

Table F-2
Aerospace Industry - Structural Analysis Applications
That Would Not Have Been
Attempted Without NASTRAN

Applications	No. of Users
Structural analysis (static and dynamic)	2
Structural dumping study	1
Structural response	1
Thermal deformation and loads	1
Static loading	1
Wing carry thru box stress and buckling	1
Aircraft canopy normal modes	2
Advanced technology transport stiffness matrices and normal modes	1
Anisotropic plate normal modes	1
Internal loads analysis of NASA hypersonic airplane research	1
Thermal stress analysis of curved panel	1
Stress analysis of beaded panel	1
3-D propellant stress	1
3-D frequency response of propellant	1
Differential stiffness of motor	1
Buckling of motor case	1
ATM solar array large displacement analysis	1
Static eigenvalue and frequency response of antenna reflectors	1
Static eigenvalue and frequency response of miscellaneous structures	1
Static analysis, $\frac{1}{2}$ reflector - pin jointed	1
Antenna Quad - Static analysis and natural frequency	1
Antenna range test tower	1
Control and display logic assembly	1
ATM X-ray telescope vacuum diameter	1
ATS/EME-stress and mechanical deflector	1
Miscellaneous in-house structures	1
Dynamic analysis of electronic assemblies	1
Detailed stress analysis of solar array	1
Vibration isolation of sensitive electronics	1
Aircraft empennage	1
Helicopter sponson analysis	1
Aircraft fuselage studies and analysis	3
Shuttle interface shear lag analysis	1
Solar array support analysis	1
ATM cannister bulkhead	1
OWS cover plate analysis	1

Table F-2
Aersospace Industry - Structural Analysis Applications
That Would Not Have Been
Attempted Without NASTRAN (continued)

Applications	No. of Users
Composite shear web beam	1
Skylab door buckling analysis	1
Orbital workshop stress analysis	1
Apollo telescope mount analysis	1
CVT docking structure	1
Fine loads on shuttle cylinder	1
Composite wing vibrator analysis	1
Truss buckling and beam column analysis	1
Hypersonic wing	1
Missile fin	1
Aircraft droops	1
ASIP program - normal modes	1
Space Shuttle - normal modes	1
Space Shuttle - transient response	1
RAM program - normal modes	1
Apollo panel	1
Impulse response ring ARC	1
Blast response - radar array support beams	1
Jet engine turbine blade and disk analysis	1
Elastic buckling analysis	1
Matrix abstraction	1
Transient response	1
Engine components	2
Skylab water bottle storage tank vibrations	1
Stiffened membrane analysis	1
Total Applications	67

Table F-3

Non-Aerospace Industry - Structural Analysis Applications
That Would Have Been Developed Had
NASTRAN Been Unavailable

Applications	No. of Users
Static analysis of trussed structure	3
Static analysis of shells	1
Vehicle static and dynamic models	1
Frame analysis	1
Static analysis of large beam frames	
Modal analysis of trubines and blades	1
Shell structure	1
Mirror analysis	1
Total Applications	10

3

Table F-4
Non-Aerospace Industry - Structural Analysis Applications
That Would Not Have Been Attempted
Without NASTRAN

Applications	No. of Users
Static analysis of a shell type structure	1
Axisymmetric buckling analysis	1
Asymmetric shell buckling analysis	1
Shell transient analysis	1
Modal solutions for time solutions to complex problems	1
Column buckling analysis	1
Electronic product designs	1
Static analysis of a casting	1
Dynamic frame analysis	2
Front suspension lower arm analysis	1
ACT arm	1
Forced vibration response of electronic cabin entry	1
Non-conventional railroad track structures for high speed test track	1
Shell buckling - symmetric load	1
Shell buckling - asymmetric load	1
Total Applications	16

Table F-5
 NASA - Structural Analysis Applications That Would
 Have Been Developed Had NASTRAN
 Been Unavailable

Applications	No. of Users
Skylab buckling	1
Shuttle modal analysis	1
Satellite spin dynamics	1
Viking - Titan III - Centaur static and dynamic analysis	1
Firebee II Wing	1
Total Applications	5

Table F-6
NASA - Structural Analysis Applications That Would
Not Have Been Attempted
Without NASTRAN

Applications	No. of Users
Structural analysis (static and dynamic)	1
Skylab launcher pedestal	1
Mobile service structures platforms	1
Vertical assembly building platforms	1
Check output of other programs	1
Engine dynamics	1
Piping flexibility	1
Exhaust system dynamics	1
Static and dynamic analysis of YF-12 A/P	1
Dynamic analysis of W/T models	1
Advanced technology satellite	1
Large scale telescope	1
PAC 5	1
Orbiting astronomical observatory	1
Viking launch vehicle and payload	1
Wind tunnel bottle field and piping	1
F8-1 wing leading edge	1
Aircraft equipment mount	1
Supercritical wing	1
Total Applications	19

Table F-7
Non-NASA Government Agencies - Structural Analysis
Applications That Would Have Been Developed
Had NASTRAN Been Unavailable

Applications	No. of Users
Intelsat IV modes	1
Lumped mass dynamics	1
Traveling pressure/time pulse in gun tube	1
Finned tube analysis	1
Anisotropic plates	1
Submarine structure	1
Aircraft carrier structure	1
Electronic equipment	1
Sonar components	1
Weapons analysis	1
Total Applications	10

Table F-8
Non-NASA Government Agencies - Structural Analysis
Applications That Would Not Have Been Attempted
Without NASTRAN

Applications	No. of Users
Earth station antenna design	1
Solar panel modes	1
Safety analysis of reactor structures	1
Static and dynamic analysis of building frames	1
Solids of revolution	1
Thread stress analysis	1
Pallet stress analysis	1
Checking S/C bearing retainer (dynamic)	1
Plotting routine to aid draftsmen	1
Total Applications	9

Table F-9
Service Bureaus - Structural Analysis Applications That
Would Have Been Developed Had NASTRAN
Been Unavailable

Applications	No. of Users
Study FSAA second lab	1
MVM 73-dynamic analysis	1
S/C buckling analysis	1
Vibration analysis	1
Static analysis	1
Buckling analysis	1
Jet engine turbine blade and disk analysis	1
Total Applications	7

Table F-10

Service Bureau - Structural Analysis Applications That
Would Not Have Been Attempted
Without NASTRAN

Applications	No. of Users
Concrete shell analysis	1
Vessel support structure	1
FFTF Fuel pin vibration	1
FFTF mechanical core mockup	1
FFTF hydraulic core model	1
Super elliptical shell	1
Large buildings	1
Aerospace structures	1
Nuclear structures	1
Machinery structures	1
Total Applications	10

Table F-11
Academic Institutions - Structural Analysis Applications That
Would Have Been Developed Had NASTRAN
Been Unavailable

Applications	No. of Users
Light aircraft wing	1
Railroad tank car	1
Modal program	1
Other structural load programs	1
Total Applications	4

Table F-12
Academic Institutions - Structural Analysis Applications That
Would Not Have Been Attempted
Without NASTRAN

Applications	No. of Users
Car windshield	1
Diesel connecting rod	1
Chicken egg	1
Total Applications	3

Appendix G

Planned NASTRAN Applications

This appendix contains a listing of the results of question 12 in the mailed questionnaire (Appendix C). The distinction between the applications listed here and those in Appendix F is that these are in a developing or planning stage and are not yet available for current use. The benefits to the prospective users are not tangible as yet. These important and interesting applications are listed in the following tables.

Table G-1
Aerospace Industry - NASTRAN Applications in Developing
or Planning Stage

Applications	No. of Users
Buckling analysis of Minutemen interstage	1
Various applications utilizing dynamic analysis	1
Various applications utilizing static analysis	1
Thermal effects on $\frac{1}{2}$ antenna reflector	1
Thermal analysis of field temperature readings on full size 25 M antenna	1
Analysis of 12 x 60 foot thermal vacuum chamber	1
Analysis of 6 foot diameter mirror and support structure during grinding operation	1
AWACS antenna	1
NASA space shuttle	2
Analysis of shuttle booster	1
Skylab fwd skirt at solar array interface	1
Four or five small to medium sized structures	1
Control surfaces, pylon and stores on wing	1
Other formats such as non-linear analysis and dynamic field	1
Replacement of FAMAS by NASTRAN	1
Strength optimization	1
Replacement of in-house programs with NASTRAN for most structural and dynamic analysis	1
Viking proof payload	1
Complete large space telescope structure	1
Fuselage dynamics	1
Small component analysis	1
AARS fuselage	1
Static and dynamic analysis in future space programs	1
Dynamic response of a rotating blade	1
Total Applications	25

Table G-2
Non-Aerospace Industry - NASTRAN Applications in Developing
or Planning Stage

Applications	No. of Users
Energy in each element	1
Perturbation analysis for eigenvalues	1
Stiffness matrix input to dynamic routines	1
Stress analysis of complex tabular joint intersection (after availability of level 15)	1
Transient analysis of 600 DOF problem	1
Random analysis problem	1
Elastic instability analysis (shells of revolution)	1
Body dynamic analysis	1
Shock and vibration response - analysis of additional cabinets	1
Replace STARDYNE with NASTRAN for structural design	1
Analysis of an active support control system for connection of mirror	1
Dynamic analysis of a bridge	1
Total Applications	12

Table G-3
Government, NASA - NASTRAN Applications in
Developing or Planning Stage

Applications	No. of Users
Space shuttle facilities	1
Fluid mechanics applications	1
Investigations and applications related to elasticity problems, specifically stability and control of flexible A/P, buffet response, active controls and gust response	1
Wind tunnel balance frame	1
Addition of heat transfer capability	1
Certain additions and modifications to take advantage of various symmetry conditions	1
Pressure fed booster design analysis	1
Viking proof payload	1
Total Applications	8

Table G-4
Government - Non-NASA - NASTRAN Applications in
Developing or Planning Stage

Applications	No. of Users
Dynamics of lumped masses with non-linear coupling	1
Interactive computer graphics finite element analysis	1
Bridge analysis	1
Turbine blade design	1
Container stresses	1
Total Applications	5

Table G-5
Service Bureaus - NASTRAN Applications in
Developing or Planning Stage

Applications	No. of Users
Plastic deformation	1
Truss roof	1
Cooling tower analysis	1
Heat stress analysis	1
Other FFTF structural analysis	1
Total Applications	5

Appendix H

User Recommended Future Applications of NASTRAN

This appendix contains a listing of the results of question 22 of the mailed questionnaire (Appendix C). Since these recommendations have been made by each particular user group they are probably biased towards that group and no priority of accomplishment can be justified without additional study. These applications are listed in the following tables. Note these applications are for work where it is believed no effort is currently underway. If such effort is in fact being accomplished, it is recommended that NSMO publish this information in a subsequent NASTRAN News Letter.

Table H-1
Recommendations by Aerospace Industry

Applications	No. of Users
Incorporate thermal analysis into NASTRAN	1
Incorporate crack growth	1
Develop more refined triangular and quadrilateral membrane elements	1
Develop new rigid format for large displacement analysis where solution is iterative	1
Develop Aeroelastic capability	1
Include technology for analysis of structure containing composite	1
Develop fatigue and aerodynamic analysis	1
Expand usage of NASTRAN to encompass more sophisticated elements and both types of "higher order" elements; for example,	1
a. Stiffness equations for higher order derivatives at apex-nodal points	
b. Stiffness equations for conventional translations and rotations at "mid-side" nodes of special elements sets.	
Develop new merge routine. If freedoms sets. never introduced there should be no need to constrain them. 6 degrees of freedom per node restriction is too restrictive	1
Include layering of plate elements to allow analysis of orthotropic shells and selectively reinforced structures	1
Develop structural optimization	1
Develop automated model generation	1
Develop interactive graphics (generating model and outputting data on cards, tape or disk)	1
Develop conditional simultaneous equation DMAP capability which would allow for conditional structural constraints. This would require a normal execution of rigid format 1.0 with a DMAP interface for solution of conditional constraint load values, followed by a restart of rigid format 1.0 using the DMAP solution as a second load condition. Superposition of the two solution would complete the analysis.	1
Develop stress contour mapping	1
Combine static and dynamic stresses	1
Include stiffening effects due to rotation	1
Include quadrilateral plate based on quadratic displacement function	1
Total Applications	18

Table H-2
Recommendations by Non Aerospace Industry

Applications	No. of Users
Develop automatic data generation from surface geometry	1
Relax 6 degrees of freedom per node constraint	1
Increase number of nodes allowed per element	1
Develop special purpose elements to eliminate decomposition times	1
Develop a general purpose circuit analysis program	1
Include three-dimensional and finite elements	1
Include applications for hydrodynamic problems	1
Develop transient heat transfer analysis	1
Develop sophisticated civil engineering applications for movable bridges and other dynamically loaded structures.	1
Total Applications	9

Table H-3
Recommendations by NASA

Applications	No. of Users
Develop local buckling of plates and local buckling of structural members by methods other than differential stiffness or piecewise linear analysis	1
Develop contact stresses as related to structures pressure vessel design in order to meet ASME code	1
Total Applications	2

Table H-4
Recommendations by Government Agencies, Non-NASA

Applications	No. of Users
Develop Interactive graphics routines	1
Provide a greater variety of transient loads	1
Provide faster integration routines	1
Develop routines for structural steel design of buildings (natural frequency determination for earthquake analysis)	1
Develop geometric non-linearity (large deflection analysis)	1
Total Applications	5

Table H-5
Recommendation by Service Bureau

Applications	No. of Users
Develop applications for building structures, bridges and non aerospace impact absorbing structure	1
	1

Appendix I
User Recommended Improvements Within
Current Applications

This appendix contains a listing of the results from question 21 of the mailed questionnaire (Appendix C). These improvements have been recommended by users for implementation within the current program applications, whereas Appendix H recommends future applications. Admittedly the distinction is occasionally hazy. If some of these recommendations are currently underway, it is recommended NASA so indicate in a subsequent NASTRAN News Letter.

Table I-1
Industry - Aerospace Recommendations for Improvement
Within Current NASTRAN

Applications	No. of Users
Include more refined triangular and quadrilateral membrane elements	1
Include solid elements for non-axisymmetric structures	1
Develop automated design capability	1
Develop automatic substructuring using direct stiffness method or modal synthesis for dynamic analysis	1
Include plotting of stress or forces on subset of geometry for shell and plates.	1
Develop a new large displacement theory format which would update the stiffness matrix for increments of load	1
The output should be grouped by member or grid point number, not by loading condition. At present it is difficult to compare the many loading conditions which can occur in a fuselage type analysis	1
If more than two loading conditions are present, the maximum and minimum loads for each member should be available as output	1
The shear panel output should be changed to give a "force type" output consisting of shear flows (#/in.) along all four sides and cap forces on adjacent rods or beams (#). (see Reference 7)	1
Rod and Beam elements should have cap or grid point forces printed out, not average forces	1
The Quadrilateral Membrane element should have a force type output, consisting of shear flows along all four sides, and resultant cap forces along imaginary rod elements	1
The optional Margin of Safety output should be deleted. This is a misleading output as it assumes a <u>uniaxial</u> stress field based upon <u>average stress in idealized</u> members	1
The length of all sides of all panels should be output, together with their direction cosines in the global coordinate system	1
A check on the free body equilibrium of the structure should be available as output. This is an essential check which the structural analyst must make before using any other results	1

Table I-1

Industry - Aerospace Recommendations for Improvements
Within Current NASTRAN (continued)

Applications	No. of Users
Provide variable structural clamping with each degree of freedom associated with structural elements	1
Correct shell of revolution capability for dynamics	1
Include 3 peripheral software to facilitate more rapid problem input data preparation	1
Automate optimal grid-point resequencing	1
Provide shear flows along each side of CSHEAR elements	1
Provide the arithmetic sum of all components of each load vector	1
Provide corner forces for CQDMEM and CTRMEM elements	1
Provide forces at the ends of ROD's in addition to the average ROD force	1
Build pre-processors such as:	1
1. Automated modal generators	
2. Automated sizing of elements	
3. Automated computation of nodal point loads simulating aerodynamic, fuel structural mass and concentrated mass.	
Build post processors to do critical search of elements and margin of safety calculation	1
Build interactive graphic capability	1
Include option to allow stress output and margins of safety for each element for all load conditions to be output at one location or on one page	1
Include capability to handle plates which are offset from their grid points	1
Add automatic calculation and location of maximum moment on beams	1
Revise the MPC (multi-point constraint) handling algorithms to reduce its computer time, realizing that the majority of the MPC equations of a structure are uncoupled	1
Operate single point constraints (SPC) before multipoint constraints (MPC) to reduce <u>matrix</u> size on which costly MPC have to be performed	1
Set definition for ASET, OMIT and SUPPORT data to permit their use by reference in CASE control language analogous to SPC, MPC and load sets	1

Table I-1
Industry - Aerospace Recommendations for Improvements
Within Current NASTRAN (continued)

Applications	No. of Users
Change loads buckling analysis to include: • General 3-dimensional capability • Large geometric deformation capability • Shell elements • Offset plate elements • Capability to input prestressed elements • Quad plate element based on 4 triangles with mid-node reduced (node 1 reduced)	1
Document methods for estimating job running time	1
Automatic banding of the stiffness matrix (as an integral part)	1
Provide for checking of all data in one run	1
Include summation of applied load vectors	1
Include initial conditions for modal transient response	1
Implement capability for accumulating modes from several runs	1
Provide source code compatible with CDC RUN compiler	1
Provide source code on update tape	1
Provide following additional specifications: • Field length requirements for each module • Field length required for no spill operations • Execution time estimates for more modules • 6400 time constraints • identification of all diagnostic capability	1
Include capability for writing any selected array on disc or tape to a documented format to utilize IBM 360 job step capability	1
Include single precision option for CDC computers	1
Improve matrix abstraction capability	1
Develop new discrete elements for general shells, solids, fluids	1

Table I-1

Industry - Aerospace Recommendations for Improvements
Within Current NASTRAN (continued)

Applications	No. of Users
Improve buckling analysis for symmetry pre-stress eigenvalue modules, and matrix reduction	1
Include cross-module restart capability	1
Improve inverse iteration technique	1
Remove unsymmetric eigenvalue requirement when not required	1
Include stiffening effects due to rotation	1
Assemble best numerical analysis techniques in element library, especially the plate elements	1
Develop good quadrilateral plate which allows for linearly varying stresses	1
Total Improvements	52

Table I-2

Industry - Non-Aerospace Recommendations for Improvement
Within Current NASTRAN

Applications	No. of Users
Include more up-to-date and extensive element library	1
Develop more sophisticated approach to elastic-plastic analysis (c.f. , Pedro Marcal's work)	1
Include data generation and contour plotting of stresses and displacements, particularly for large plate analysis	1
Include single precision for CDC	1
Make RUN object code and FORTRAN object code compatible	1
Develop automatic grid generator	5
Include input of loads and output of section forces at points other than member ends	1
Include input of temperature gradients across members and elements	1
Include force envelopes for nodes and points of members (beam elements)	1
Include worst combination of axial force and bending moment (among all combinations formed) or check against section 1.6 of the AISC-specifications	1
Include aeroelastic capability	1
Develop distributed loads on bar elements	1
Develop node resequencing capability	1
Include contour plotting capability of shear stresses	1
Include ability to print strain values	1
Improve plotting format in following manner:	1
a. Only preselected elements or grid points would be labeled instead of every point in the set	
b. No overlap of members would occur	
Add automatic generation programs for meshes of a simple nature, i. e. , pre-processor and post-processor modules.	1
Add substructuring capability	1
Add bi-linear or non-linear material capabilities	1
Add elements for solids	1
Include bandwidth optimization routine	1
Total Improvements	25

Table I-3
Government - NASA Recommendations for Improvement
Within Current NASTRAN

Recommendations	No. of Users
Include AISC specification checking post processor	1
Develop easier and more accurate MPC constraints	1
Include load matrix input	1
Develop better method of reducing size of static matrix for dynamic calculations	1
Retain comment cards and original order of bulk data deck on restart tape	1
Develop more reliable method of checking stiffness matrix for singularity	1
Add more degrees of freedom	1
Develop routines for curved beam elements and curved shell elements	1
Include mix of 3-D elements axi-symmetric elements, beam elements, plate elements and shell type elements	1
Include input/output options	1
Include thermal capability	1
Include non-linear capability	1
Develop motion picture plot output for visualization of deformation of complex structures	1
Include general treatment of contained liquids	1
Total Improvements	14

Table I-4
Government - Non-NASA Recommendations for Improvement
Within Current NASTRAN

Recommendations	No. of Users
Include dynamic (direct transient) elastic-plastic capability	1
Include 3 dimension finite elements	1
Improve non-linear element connectors for dynamic problems	1
Include curved bar elements and B-31.7 pipe code stress calculator	1
Reduce core requirements	1
Increase plotting capability for axisymmetric elements	8
Include internal restart and checkpoint in some DMAP modules, specifically TRD for transient response problems	1
Allow subcase structure to alter material properties	1
Include CTRIARG and CTRAPRG elements (Format 6)	1
Include time variations in the stiffness and mass matrix (Format 9)	1
Improved restart capability (Format 9)	1
Include ability to plot grid points for CTRIARG and CTRAPRG elements (axisymmetric points)	1
Reduce core size for static and dynamic models	1
Include displacement force capability	1
Include multiple subcases for rigid formats 3 and 5	1
Provide an option to Given's method of eliminating zero entries in the mass matrix	1
Total Improvements	23

Table I-5
Academic Institution Recommendations for Improvement
Within Current NASTRAN

Recommendation	No. of Users
Develop graphical presentation of results (stresses and strains) superimposed upon structural modes	1
Develop routine for recovery of strains. It is necessary to know strains in order to correlate with experimental results	1
Total Improvements	2

Table I-6
Service Bureau Recommendations for Improvement
Within Current NASTRAN

Recommendation	No. of Users
Develop graphic display of element words and stresses	1
Develop sub-structuring	1
Develop ability to input load columns at time of transient analysis	1
Include beam member load capabilities	1
Develop data generation routines	1
Develop better documentation of output results	1
Modify plotting package to allow use of 9 track tape drives as well as 7	1
Develop plastic analysis capabilities	1
Include NASTRAN programs for other computer systems such as Burroughs and Honeywell	1
Include additional elements for solids and non linear capabilities	1
Improve description of update procedure	1
Reduce number of cards to describe a problem	1
Total Improvements	12

Appendix J
Operating Costs of Various
NASTRAN Applications

In response to question 13 of the mailed questionnaire (Appendix C), there were 50 applications which listed sufficient information to determine the cost of reported NASTRAN applications. In order to change man hours to dollars when it was assumed that typical programmer/analyst earnings were \$15000 per year, and engineers, \$19000 per year. The following typical computer hourly costs were assumed, considering no high priority runs and overnight delivery:

IBM 360 series	\$300
IBM 370 series	\$500
Univac 1108	\$600
CDC 6600	\$600

Table J-1 following lists the information.

Table J-1. Costs of Performing Selected NASTRAN Applications
by Application and Industry

Application	Programmer / Analyst Costs	Engineer Cost	Computer Model	Computer Cost	Total
Industry - Aerospace					
Structural response	\$ 0	\$4,400	CDC 6600	\$9,000	\$13,400
Buckling of motor case	0	10,000	CDC 6600	4,000	14,000
3-D propellant stress and response	400	3,000	CDC 6600	800	4,200
Differential stiffness	50	350	UNIVAC 1108	100	500
1/2 reflector with some rigid joints	700	2,700	UNIVAC 1108	4,000	7,400
Antenna quad: static analysis and natural frequency	100	900	UNIVAC 1108	500	1,500
Antenna structure	0	1,400	UNIVAC 1108	500	1,900
Dynamic stress concentration	4,600	5,800	IBM 360/ 65	13,000	23,400
ATM solar array (static)	0	25,300	UNIVAC 1108	24,000	49,300
ATM solar array (dynamic)	0	5,200	UNIVAC 1108	3,000	8,200
C&D logic assembly (dynamic)	0	7,200	UNIVAC 1108	3,000	10,200
Antenna range tower	0	16,800	UNIVAC 1108	6,000	22,800
Drone fuselage	3,300	12,000	IBM 370/ 155	2,850	18,150
Drone wing	1,500	5,250	IBM 370/ 155	2,150	8,900
Drone wing modification	0	250	IBM 370/ 155	60	310
Truss buckling	0	11,700	IBM 360	4,500	16,200
Aircraft canopy	0	1,500	IBM 360/ 75	600	2,100
Aircraft wing	0	500	IBM 360/ 75	75	575

Table J-1. Costs of Performing Selected NASTRAN Applications
by Application and Industry (continued)

Application	Programmer/ Analyst Costs	Engineer Cost	Computer Model	Computer Cost	Total
Aircraft fuselage	0	700	IBM 360 / 75	150	850
Test structure	0	700	IBM 360 / 75	300	1,000
Composite speedbrake	0	1,100	CDC 6600	300	1,800
ASIP program - normal modes	0	1,100	CDC 6600	1,000	2,100
Space shuttle - normal modes	0	6,400	CDC 6600	8,000	14,400
Space shuttle - transient response	0	2,300	CDC 6600	1,500	3,800
RAM program modes	0	500	CDC 6600	600	1,100
Antenna study modes	0	1,400	CDC 6600	2,500	3,900
CH53 sponsor analysis	2,000	6,000	IBM 360 / 67	4,000	12,000
Fuselage center section CH53E	1,000	6,000	CDC 6600	2,000	9,000
AARS fuselage studies	0	5,000	CDC 6600	4,000	9,000
UTTAS fuselage	0	6,000	CDC 6600	10,000	16,000
	Total 16,350	161,850	—	117,125	295,325
Industry - Non-Aerospace					
Buckling analysis	400	900	IBM 360	500	1,800
Static casting	4,300	9,100	UNIVAC 1108	5,000	18,400
Dynamic frame	1,400	5,500	UNIVAC 1108	5,000	11,900
Front suspension lower arm analysis	0	4,400	CDC 6600	10,000	14,400
ACT arm	0	14,600	IBM 360	12,000	26,600
Frame dynamics	0	14,600	IBM 360	15,000	29,600
Truss structure	0	700	CDC 6600	500	1,200
Mirror analysis	0	1,500	CDC 6600	650	2,150
Shell structure	0	1,500	CDC 6600	650	2,150
	Total 6,100	52,800	—	49,300	108,200

Table J-1. Costs of Performing Selected NASTRAN Applications
by Application and Industry (continued)

Application	Programmer/ Analyst Costs	Engineer Cost	Computer Model	Computer Cost	Total
Government - NASA					
ESSA second CAB	1,500	4,600	IBM 360 / 65	2,500	8,600
Balance frame	0	2,700	IBM 360 / 67	5,000	7,700
Simulator CAB	0	2,700	IBM 360 / 67	5,000	7,700
Viking launch vehicle and payload	20,000	18,300	CDC 6600	30,000	68,300
Wind tunnel	0	4,600	CDC 6600	4,500	9,100
F 8-1 wing leading edge	0	900	CDC 6600	1,500	2,400
Aircraft equipment mount	0	2,300	CDC 6600	3,000	5,300
Supercritical wing	0	4,600	CDC 6600	6,000	10,600
Total	21,500	40,700	—	57,500	119,700
Government - Non-NASA					
Thread stress analysis	0	2,700	IBM 360 / 44	1,800	4,500
Pallet stress analysis	0	700	IBM 360 / 44	600	1,300
Total	0	3,400	—	2,400	5,800
Grand Total		43950	-----	258750	529025

Appendix K

Service Bureaus

The following service bureaus or organizations performing service bureau functions were identified as providing NASTRAN Services:

- (1) Boeing Computer Services
Kent, Washington
- (2) CHI Corp.
Cleveland, Ohio
- (3) Computer Centers Inc.
Santa Barbara, California
- (4) Computer Sciences Corporation
Los Angeles, California
- (5) Control Data Corporation
Minneapolis, Minnesota (Hqts.)
- (6) COSMIC, University of Georgia
Athens, Georgia
- (7) ISD Data Center
Oakland, California
- (8) MacNeal-Schwendler Corp.
Los Angeles, California
- (9) McDonnell Douglas Automation
St. Louis, Missouri
- (10) NASA Goddard Space Flight Center (Limited)
Greenbelt, Maryland
- (11) NASA Langley Research Center (NSMO)
Hampton, Virginia
- (12) National CSS Inc.
Stamford, Connecticut

- (13) Northrup Services Inc.
Huntsville, Alabama
- (14) Optimum Systems Inc.
Palo Alto, California
- (15) Research Analysis Corp.
McLean, Virginia
- (16) Satellite Computer Center
Philadelphia, Pennsylvania
- (17) SCI-Tech Computer Center Inc.
Wilmington, Delaware
- (18) Systems Science and Software
San Diego, California
- (19) Teledyne Computer Center
Toledo, Ohio
- (20) UAH Research Institute
Huntsville, Alabama
- (21) Westinghouse Telecomputer Systems Corp.
Pittsburgh, Pennsylvania