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~~A~~ PRELIMINARY INVESTIGATION OF THE POTENTIAL APPLICABILITY OF THE IPAD SYSTEM TO NON-AEROSPACE INDUSTRY, FINAL REPORT (NOV 73 - JAN 75)

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16. Abstract

Under contract to the National Aeronautics and Space Administration, Battelle's Columbus Laboratores carried out a study of the applicability of the planned IPAD system to the design activities of non-aerospace industries. As a result of this study, it was determined that IPAD could be of significant benefit to a number of industries, with the most likely users being the heavy construction and the automotive industries.

Two additional short studies were initiated to investigate the possible impact of IPAD on a national energy program and on urban and regional planning activities of local and state governments. These initial studies indicated the possibility of significant payoff in these areas and the need for further investigations.

It was also determined in the study, that utilization of IPAD by non-aerospace industries will probably involve a long stepwise process, since these industries maintain a policy of gradual introduction of new technology.

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FOREWORD

In the conduct of this investigation, opinions and advice were requested from and were generously provided by specialists in many disciplinary areas at Battelle. Contributions from the following were particularly useful:

Mr. F. L. Bagby, Manager, Defense and Space Systems

Mr. W. L. Swager, Assistant Manager, Metallurgy Department

Mr. F. W. Boulger, Senior Technical Advisor

Mr. W. A. Smith, Assistant Manager, Engineering and Manufacturing Technology Department

Mr. J. Wetherbee, Manager, Space and Transportation Department (Deceased)

Mr. W. H. Browne, Manager, Safety and Security Department

Mr. T. J. Atterbury, Associate Corporate Director, Energy, Materials and Environment Research

Mr. J. M. Griffin, Environmental, Land Use, and Regional Planning Section

Mr. L. J. Kasper, Economics Analysis and Planning Section.

The results in this study could not have been obtained without the help of members of the four companies who agreed to evaluate IPAD: Ammann and Whitney, Caterpillar Tractor Company, Ford Motor Company, and Whirlpool Corporation. The contributions of these organizations are gratefully acknowledged.

EXECUTIVE SUMMARY

The IPAD computer software system is being planned by NASA to enhance the design process for aerospace vehicles. It was recognized early by NASA that IPAD (Integrated Programs for Aerospace-Vehicle Design) could have widespread application for design of complex systems outside of the aerospace fields as well. As a first step in identifying the scope of the possible non-aerospace use of IPAD, NASA initiated a small contract with the Columbus Laboratories of Battelle Memorial Institute on November, 1973.

The objectives of this research contract were twofold:

1. To identify Standard Industry Classes for which the possibility of applying IPAD appeared sufficiently promising to warrant further investigation in a subsequent more comprehensive study.
2. To develop a procedure for interesting individual companies in making direct evaluations of the applicability of IPAD to their design processes. The feasibility of this procedure was to be tested by contacting a small number of selected companies to obtain, if possible, their evaluation of IPAD.

By mutual consent between NASA and Battelle, two very brief additional studies, of about 1-2 man-weeks each, were carried out to make tentative evaluations of the applicability of IPAD to the proposed national energy program and to the general field of urban and regional planning.

Review of Standard Industry Classes

The review of non-aerospace industries by Standard Industrial Classes involved an initial screening of each class on the basis of the number and type of technologically oriented employees, and on the basis of the types of products designed and manufactured in each class. For certain industry classes that appeared to be potential users of IPAD, available data on individual companies (Moody's Industrial Manual, Company Annual Reports) were studied to obtain more detailed accounts of their various design activities. A detailed description of this survey is included in Appendix A.

Because of the limited scope of this survey, no quantitative prediction could be made of the possible number of non-aerospace companies that could use IPAD. However, a number of general industry classes were identified that appeared to be sufficiently promising to warrant further study. The most promising classes appeared to be:

1. Automotive manufacturing
2. Heavy construction
3. Engines and turbines (power plant)
4. General electric equipment manufacturing
5. Computer and electronics equipment manufacturing.

It is believed that other industries may eventually utilize IPAD, as their design functions become sufficiently automated to adopt the IPAD technology.

Finally, it appeared that service industries could be involved in development of IPAD systems for the end users. These include computer-software services (both the computer manufacturers and independent companies), engineering and architect services, and research and development laboratories.

Direct Evaluation of IPAD by Selected Industries

To obtain the assistance of selected companies in evaluating IPAD, a 1 hour presentation was formulated to explain the IPAD system as it was then being planned by NASA. The final form of the presentation arrived at, after careful review by NASA, is described in Appendix B. It was explained in this presentation that NASA planned to develop the central software while the user community was expected to develop their analysis modules and data bases. The presentation was well received, and four of the six companies that heard the presentation responded with evaluations of the applicability of IPAD to their design processes. Their evaluations were based on the information in the final reports of the NASA contracted feasibility studies, copies of which were given each company.

The results of these evaluations were:

- The Ford Motor Company, on the basis of a limited study, decided that IPAD would be very useful to the automotive industry.

- The Ammann and Whitney Company decided that IPAD would be very useful in designing and building highway systems, or industrial complexes. However, it would not be useful in building or bridge design.
- The Caterpillar Tractor Company decided that IPAD was not now useful for designing their heavy construction equipment, but that it might be very useful at a future time (10-15 years).
- The Whirlpool Corporation decided that their various appliance products were not sufficiently complex to require IPAD application. However, they believed that some of the special capabilities planned for IPAD might be useful in their design processes.

Of the two companies that declined to review IPAD, one (Cincinnati-Milacron Corporation) did not believe that IPAD would significantly help in their design problems. The second company (Xerox) did think that IPAD had potential applicability to their design functions but could not allocate manpower to study the program in the time frame allowed.

It was the unanimous opinion of the respondees that if IPAD were to be implemented into their design operations, this implementation would have to be carried out in a sequence of steps over a period of time. These companies agreed that it was absolutely necessary to thoroughly test all new technological methods and verify their cost effectiveness before incorporating them as part of the company's main operations. Each company believed that the IPAD system was too big and complex, and required too large an investment to be absorbed in one step. Further, it was agreed that a gradual process of introducing the system was necessary to allow design management to anticipate and reconcile the natural resistance of established designers to the effect of IPAD on the nature of their work. It is clear that the pace at which IPAD might be implemented would depend heavily on the state of the economic health of a given industry, and the individual company's need to maintain and improve its competitive position.

Special Studies

Two special areas of possible IPAD applications were identified by Battelle, during its research program, that seemed to merit special attention. These were the fields of urban and regional planning, and the projected national program to achieve self-sufficiency in energy. With the agreement of NASA, Battelle carried out very short studies of these two areas. Battelle specialists, thoroughly familiar with these two areas, were introduced to IPAD and asked to evaluate its applicability. In each case the evaluation made use of the specialist's prior knowledge of his field and an acquired knowledge of IPAD. It was concluded that IPAD could potentially be of substantial benefit in both areas of application.

Conclusions

As a result of carrying out its preliminary study, Battelle believes that there exists a significant potential market for utilization of the IPAD system to improve the design productivity of sectors of the non-aerospace industrial community. A number of areas of application are believed to be of sufficient promise to warrant further investigation. These include the automotive industry, the heavy construction and other energy-related industries, the computer industry, and the field of urban and regional planning. Any further investigation should involve making presentations of the IPAD story to companies in the above technical areas, or to city or state governments involved in urban and regional planning. Responses to these presentations would permit a more realistic prediction of the number of organizations that would benefit from utilization of IPAD. A second, and equally important objective of any future investigation should be the formulation of plans for the development and implementation of IPAD systems tailored to specific areas of application.

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A PRELIMINARY INVESTIGATION OF THE POTENTIAL APPLICABILITY OF THE IPAD SYSTEM TO NON-AEROSPACE INDUSTRY

By L. E. Hulbert

ABSTRACT

Under contract to the National Aeronautics and Space Administration, Battelle's Columbus Laboratories carried out a study of the applicability of the planned IPAD system to the design activities of non-aerospace industries. As a result of this study, it was determined that IPAD could be of significant benefit to a number of industries, with the most likely users being the heavy construction and the automotive industries.

Two additional short studies were initiated to investigate the possible impact of IPAD on a national energy program and on urban and regional planning activities of local and state governments. These initial studies indicated the possibility of significant payoff in these areas and the need for further investigations.

It was also determined in the study, that utilization of IPAD by non-aerospace industries will probably involve a long stepwise process, since these industries maintain a policy of gradual introduction of new technology.

INTRODUCTION

In response to the growing needs of the aerospace industry, the National Aeronautics and Space Administration is planning the development of the computer program system IPAD (Integrated Programs for Aerospace-Vehicle Design).

Under NASA sponsorship, the Boeing Airplane Company and the General Dynamics Corporation carried out two extensive studies of the feasibility of the proposed IPAD system [1,2]*. Both companies reported that the IPAD system should be of significant benefit to the productivity of the design processes of non-aerospace as well as aerospace companies.

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* References are listed on page 93.

However, since the prime concern of these studies was the planning of IPAD to attack aerospace problems, only a limited effort was spent to address non-aerospace problems. NASA believed that it was important to make a further evaluation of the possible impact of IPAD on the non-aerospace sector, and awarded Battelle's Columbus Laboratories a contract in November, 1973, to begin this evaluation.

Battelle's investigation consisted of two main activities:

1. A general survey of all non-aerospace industries by Standard Industrial Class (SIC) to identify those industries most likely to use IPAD, and a study of specific companies within these industries.
2. Selection of specific companies that might make a direct evaluation the applicability of IPAD to their design operations. A presentation of the IPAD concept was made to executives of these companies in sufficient detail for them to decide whether it would be useful for their company to make an evaluation of IPAD. Follow-up discussions were carried out with those companies that evaluated IPAD, to discuss their conclusions.

This report summarizes the results of the studies carried out. The first section describes briefly the survey of the non-aerospace industries by SIC. In this study it was determined that IPAD would be most applicable to the automobile and the heavy-construction industries, with varying degrees of applicability to a number of other industries.

As a result of contacts made with executives of six companies, four decided to make evaluations of the IPAD system. The results of these evaluations are presented in the second section of this report.

Short studies were also carried out to investigate the applicability of IPAD to the problems of urban and regional planning and to the future design problems that will be encountered as the United States attacks the problem of developing its energy resources. The results of these studies are presented in separate sections.

REVIEW OF THE NON-AEROSPACE INDUSTRY BY STANDARD INDUSTRIAL CLASS

An overall survey was conducted of the non-aerospace industry to evaluate the possibility that various types of industries might be able to make cost-effective use of IPAD in their business operations. This study was based on the Standard Industrial Class (SIC) code, which was developed by the U. S. Department of Commerce. [3] This code allows uniform cataloging of the entire field of economic activities. A brief outline of the survey is given here. A detailed description of the study is given in Appendix A.

The initial step of the survey was to evaluate the entire set of SIC listings and to eliminate those classes that were thought to have little use for IPAD. This first screening was based primarily on a publication of the numbers of workers of given occupations employed in each class as determined by the 1970 census. [4] In this screening, ten occupations were considered most relevant (architect, computer specialist, mathematician, operations and systems researchers, tool programmer (NC), and aeronautical and astronautical, civil, electronic and electrical, industrial and mechanical engineers).

This initial screening identified 20 classes of industries that employed a sufficient number of engineers and technical specialists to warrant further study. The study involved an evaluation of the products involved in each class and the identification and study of specific companies within the class, selected with the help of an unpublished report prepared by the Investors Management Sciences Inc., for Battelle. Studies of individual companies were primarily based on descriptions of the company activities given in their 1973 annual reports.* Another source of data on manufacturers was the Moody's Industrial Manual. [5] Further information was obtained from the companies making evaluations of IPAD with respect to their industries.

As a result of the assessment of industries by SIC, two industries were judged to be most probable users of IPAD technology. These were the heavy construction and automotive industries. Table 1 lists these and other industries for which it was judged the IPAD system could possibly have some benefits.

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* Battelle maintains an extensive and current library of company annual reports. The only companies considered in this study for which annual reports were not obtained were closed corporations that do not issue reports.

TABLE 1. POSSIBLE INDUSTRIAL USERS OF AN IPAD SYSTEM

SIC	INDUSTRY
1600	Heavy Construction
3510	Engines and Turbines
3520	Farm Machinery
3530	Construction, Mining, Material Handling Equipment
3573	Computer Manufacturing
3600	General Electrical Equipment Manufacture
3630	Household Appliances
3650	Communication Equipment Manufacture
3710	Motor Vehicle Manufacture
7370	Computer Software Services
7397	Commercial Research and Testing Laboratories
8910	Engineering and Architect Services
8990	Miscellaneous Business Services (Educational, Scientific, and Research Org.)
9900	Conglomerates

In addition to the construction and automotive industries, it appeared that other industries, such as engine and turbines, electrical equipment and computer manufacturers, might be possible users of IPAD. However, any attempt to make a comparison between these industries or other industries in Table 1 on the basis of the relative applicability of IPAD,would be premature. It was demonstrated by the companies performing evaluation of IPAD, that an accurate evaluation of IPAD applicability to, and possible acceptance by, an industry can only be made by members of that industry. Thus, further evaluations of IPAD by companies in these industrial classes will be recommended as one of the conclusions of this study.

DIRECT EVALUATION OF IPAD USEFULNESS IN SELECTED COMPANIES

The survey of U. S. industry described in the previous section was designed to yield an overall picture of the possible applicability of IPAD. However, it was recognized that a much more accurate evaluation of the applicability of IPAD to design problems of an industry would be made by a company in that industry. Therefore, a vital part of the program for evaluating IPAD was a plan for presenting the IPAD concept to executives of major companies along with a request that they consider making an evaluation of the possible impact of an IPAD system on their operations.

Five companies were chosen for visitation and an initial presentation of the IPAD concept. These were

1. Caterpillar Tractor Company
2. Ford Motor Company
3. Whirlpool Corporation
4. Ammann and Whitney
5. Cincinnati-Milacron Corporation.

The first four of these companies agreed to make evaluations of IPAD and their conclusions are presented below. The Cincinnati-Milacron Corporation decided that the IPAD system was too complex for their design needs and declined to make an in-depth review of the report.

As a result, Battelle contacted the Xerox Corporation which is a high-technology company with complex design problems. This company, after hearing a description of the IPAD system and making a brief evaluation of the IPAD system, decided that although IPAD looked useful for some of their problems, they could not then commit enough time to make a meaningful study of the program.

The results of the studies by the four companies is given in the following. Also included is a brief description of each company to help in understanding their conclusions.

From the results of this phase of the study, it may be concluded that very few, if any, non-aerospace companies have developed the design technology or the design management structure that would permit easy introduction of IPAD into their design function. Since a new idea that does not work costs the company money, company managements rightly regard new technology with great skepticism until its payoff can be proved. All companies that were contacted are committed to the stepwise development of design technology. Moreover, each step is deliberately taken small enough that the payoff can be demonstrated. The size of the technological advances represented by IPAD could not be digested in one step by any company although each of the companies recognize many advantages in using the system.

Nevertheless, the managements of these companies have to be aware of new technology, and develop long-range plans for their companies. Having the IPAD system as a model for considering long-range goals in design technology was thought to be a significant benefit by the various companies.

The Caterpillar Tractor Company

The Caterpillar Tractor Company is the world's largest manufacturer of construction equipment of all types. Its product line consists of a wide model range of tracked and wheeled tractors, dozers, and loaders, plus scrapers, graders, and off-highway trucks. The company supports an extensive research and development program that utilizes more than 4000 engineers, scientists, and supporting staff.

Of the $122,000,000 spent on research and development in 1973, $94,000,000 was spent on development of new products and major improvements to existing products.

The research department at the Technical Center in Peoria, Illinois, explores advanced technology related to the company's capabilities, investigates new design concepts, and develops analytical programs for evaluating design alternatives. The engineering departments apply technology developed by the research department to the design of new machines or components which are then thoroughly tested in the laboratory and in the field before the item enters production.

The extent of Caterpillar's design activities is illustrated by the fact that they increased their product line from 33 models in seven product families to 70 models in twelve product families in 10 years. Among newer products recently developed are a line of graders with articulated frames and a new beadless rubber and wire tire.

The company has been using computers in design for many years. At present, the research department owns a CDC 3000 Series digital computer and an EAI analogue computer. With the capacity of these machines, Caterpillar solves many of its design problems using programs that it has developed. When the company must solve a problem that exceeds the capacity of its computers, it engages outside consultants to obtain appropriate solutions.

Examples of structural analysis problems investigated by finite element methods are the dynamic loads on a back hoe boom in its operating cycle, for which it was demonstrated that the critical loads were starting and braking the rotation of the boom as it swings a load from the hole to the unloading position. The company has been using finite element analysis for about five years for analytical design of certain engine parts. One of the most critical components of any new engine is the crankshaft. Caterpillar utilizes three-dimensional finite element analysis to predict stresses in the crankshaft. These predictions may be checked with either plastic models or with cast-iron, strain-gaged models.

Caterpillar has been investigating the use of computer graphics and has developed a computer-aided drafting system.

It has developed an interactive graphics system for certain structural analysis. One application of this system was to display the motions on the lift arms of an end loader.

In the development of both its analytical and experimental research and design technology, Caterpillar creates or obtains new analytical or computer-aided design procedures as it becomes evident that there is a need for the procedures, that there would be a payoff in using them, and that the capability for using them could be acquired. Thus the development of the automation of the design process for Caterpillar products has been, and is expected to be, an evolutionary process. On the basis of about 20 years'experience in applying computer analysis to design problems, Caterpillar estimates that it may take 10 to 15 years to reach the stage of total integrated design planned in the IPAD system. However, in the interim period, they believe that the IPAD system can have a beneficial effect on the design processes in their industry (and other industries) even if there were to be no direct use of the languages and the computer executive systems. They also expect that there may be elements of the system that can be more, or, less useful, such as stress analysis technique or hydraulic system design.

Caterpillar believes that full development of all of the analysis modules and data bases by single companies would probably not be cost-effective. Instead, it believes that development of a generalized industrial version of the IPAD system should be carried out. This system would include a variety of general analysis modules and widely applicable data bases such as libraries of the properties of all commonly used industrial materials. Individual companies would then be able to incorporate proprietary design methods and data into the system for use in their special problems.

Caterpillar believes that development of the generalized industrial version of IPAD should be carried out either by government agency or by a consortium of companies utilizing a university or an institution, such as Battelle, to furnish the technology for developing operating modules and data bases.

The Whirlpool Corporation

The Whirlpool Corporation is the world's largest company devoted exclusively to making home appliances. It is a primary supplier of appliances to the Sears, Roebuck and Company as well as a distributor of appliances under its own brand. Its net sales in 1973 were $1,636,000,000 with an expenditure of $27,000,000 on research and development. Whirlpool's products include home refrigeration and air conditioning, laundry appliances, home entertainment and electronics, and other household appliances.

These products are considerably simpler in mechanical design than other categories considered in the subject study. However, the design function is extremely important in this highly competitive consumer market to achieve maximum product reliability at minimum cost while producing products with esthetic appeal to the customers.

The Whirlpool Corporation maintains a corporate research and engineering laboratory at Benton Harbor, Michigan, for all of its corporate operations. The Corporate Research Department conducts applied research in six prime areas: engineering, electronic systems, computer technology, materials and processing, systems engineering, and natural sciences.

Engineering research is carried out in heat transfer, fluid dynamics, noise and vibration control and stress analysis. Electronics systems research is directed toward developing electronic controls and control systems for present and future products. It is also heavily involved in manufacturing and control systems. The computer technology group is responsible for the research computer center, including computer operation, data preparation, programming and consulting. It also provides advanced systems for use in solving current and anticipated research and engineering problems. In addition to the research center computer, the research staff can remotely access an IBM 370/165 located at the corporate data processing center, when large problems must be solved.

The materials and processing research department studies the optimum utilization of materials for Whirlpool's products. The Science Research Department is responsible for the application of various disciplines such as chemistry, microbiology, physiology, and food science to the improvement of current products or the development of new products.

In response to the description of IPAD by Battelle, The Whirlpool Corporation reviewed the summary reports of the feasibility studies. As a result of this study, it was concluded that there might be some advantages in IPAD for Whirlpool but there were also disadvantages. Thus it was recommended that the Whirlpool Corporation should wait until the IPAD system is more fully defined and developed before making any substantial commitment to become involved in evaluating the IPAD system.

The following is a discussion of some of the advantages and disadvantages the planned IPAD system as viewed by members of the Whirlpool Corporate Research Staff.

Some IPAD Advantages

1. It could provide the structure for a team approach to unify traditional product engineering, manufacturing engineering, and quality engineering into parallel, simultaneous functions rather than the present serial operation.

   That is, it could be a point for rethinking the design process as it is applied within Whirlpool. The organized, systematic approach which an IPAD type system could afford, would reduce the number of iterations required in redesign, following each step in moving a design from engineering to production. For example, a more systematic consideration of product reliability could be made so that it becomes a part of the actual design and not designed into the product later. Whereas aerospace companies have found the team approach important for engineering design, the non-aerospace companies could benefit from applying this approach into areas that would include manufacturing.

2. Much use could be made of the proposed management aspect of the IPAD system.

   A. It could first be a means of automating the paper flow comprising such things as engineering approvals, tooling releases, release for production, etc.

B. It could make it possible for engineering and manufacturing to easily communicate and consider mutual problem areas on a management level. As such, it would reinforce the team approach to design mentioned above.

C. The tools,which are primarily communications oriented (e.g., interactive video terminals with graphic capabilities),that have been proposed for management, would make it possible for managers to more directly contribute to and participate in the creative processes of design concept formulation. Similarly, it would simplify conveying the design engineers' concepts to management.

D. More emphasis could be placed on management alternatives and tradeoffs with the availability of programs to interrogate data files and then to make the necessary analyses (a natural integration of the operations research philosophy into the design process).

3. Use could be made of special computer software capabilities to be included in the IPAD system.

A. So far, the use of computerized graphics has been hindered for lack of standardized, easy to use software packages which readily take output generated by an analysis program and provide a pictoral type of display. This capability could help promote the more creative aspects of the design process. It would give engineers an opportunity to more thoroughly examine all aspects of the results of their design analysis. A pictoral summary may show an obvious, useful design trend which may otherwise have gone unnoticed.

B. A system which easily ties together existing, or future separate analysis programs into a computer aided design package could reduce programming efforts now made in developing specialized simulation packages.

However, it may be that due to the smaller number of such analysis programs (i.e.,IPAD Operational Modules) for a company such as Whirlpool, specialized programs may provide greater ease and flexibility of use by the design engineer. This would perhaps more than offset the extra development effort in structuring specialized programs and data files.

Potential Areas of Difficulty

A system of the magnitude which has been proposed for IPAD may not be suitable for an engineering design process which is less complex in nature, such as Whirlpool's. Aerospace industry is characterized by production of complex, costly,low volume items (from 1 or 2 to several hundred) which require considerable technical design considerations. Each design has a somewhat unique design objective (payload, velocity, range, etc.). Whirlpool, on the other hand, has high-volume production products whose design criterion remain relatively constant or slowly evolve over a period of time.

A typical Whirlpool design project is not so large that it must be broken into subtasks which must be coordinated, as is done in aerospace design. With smaller project magnitude, communication among design engineers is possible on an informal basis. It is not until the project is ready to proceed from engineering to manufacturing that communications becomes an important factor to consider.

2. IPAD would require a special individual as data-base administrator. This individual is almost mandatory to maintain accurate, up-to-date information for use in analytical programs. Again the magnitude of Whirlpool design projects may not be large enough to justify such a position or even the data base itself. However, selected subsets of specialized data required by individual programs (or Operational Modules) and applications may well be all that should be maintained on an as needed basis.

3. The use of analytical models in the design process at Whirlpool has been of an evolutionary nature. The development of special programs to meet specific needs encourages this evolution, but it is a relatively slow process. Unless IPAD contains specific provisions to meet the resistance resulting from the elements of change which it requires, it is not likely to result in successful application. Aerospace industries have a better starting position from which such a program may be launched. This change is itself not bad--in fact it probably represents the beneficial areas of IPAD. It does, however, place an added burden on the system which is necessary for initial use.

   The heart of the IPAD system is the operational modules. The development of these modules would still be necessary in addition to the IPAD system itself. Existing proprietary programs such as the air conditioner simulation, dryer simulation, and the refrigerator simulations could provide the nucleus of the operational modules. However, these programs are capable of independent application. Based on the experience with these programs, the huge analytical design systems envisioned for IPAD may not be needed for Whirlpool. If so, it would be better to consider each program and application on its own merits rather than the entire design system. Then, should our base of such applications approach that found today in the aerospace companies, and IPAD has been successfully formulated, we would be in a logical position to merge these programs into IPAD.

The Ford Motor Company

The Ford Motor Company is the country's second largest manufacturer of automobiles and parts. It is a vertically integrated company, producing substantial portions of the iron and steel required in its manufacturing operations. The many and varied design problems confronting the automobile industry have been well publicized in the press. In addition to the increasingly stringent safety and air pollution requirements being imposed by government regulations, the industry must be able to respond to the changing moods of the American public for different types of automobiles.

These moods are particularly changeable at the present time because of the unsettled oil supply situation. In 1974, and into the early part of 1975, the automobile industry is bearing a heavy burden of the economic slowdown in the United States.

To survive and continue to prosper in the future, the automotive industries must continue to improve their productivity in both design and manufacturing. The Ford Motor Company maintains a continuing program of research in automated design, including the application of interactive graphics and contour generation methodologies for body design, and widespread application of structural analysis codes such as NASTRAN for detailed analysis and design of automotive parts for reliable services.

The two sets of final reports of the IPAD feasibility studies [1,2] were reviewed by a number of Ford specialists in the system and design groups. Because of the economic conditions prevailing at Ford and in the rest of the automotive industry during the time this study was carried out (August, 1974-March, 1975), it was not possible to investigate the IPAD system in complete detail. Nevertheless, a number of conclusions were reached that are of significance to the possible utilization of IPAD in automotive design.

Some IPAD Advantages

1. The reasons stated in the contractor's feasibility reports for the desirability of the IPAD-like system, as stated in terms of an aerospace company's needs, are equally valid for an automotive company. The most significant reasons, restated in terms of an automotive scene are:
    A. It has become increasingly difficult to meet market and government requirements while designing better vehicles in a shorter time at a lower cost.
    B. The time required to design and develop a vehicle line cannot be significantly shortened without effectively solving existing data communications and management visibility problems. Such a solution can only be achieved by a new approach such as offered by IPAD.

C. The cost of engineering a product can be substantially reduced by increased use of available engineering disciplines, application of some new ones, and continued automation of many simple tasks that are being done manually.

2. A significant number of computer software packages, when released, and if compatible with the in-house computer system, can be directly applied in automotive engineering tasks. Those most readily adaptable to fall into operating system software or IPAD framework software categories. It can be anticipated that, due to the differences in automotive engineering approach, a substantial portion of management/engineering software, which includes most operating modules, will have to be either significantly modified or developed from the ground up.

3. IPAD would force a discipline in data creation, accurate data maintenance, and systematic data distribution.

Potential Areas of Difficulty

1. The system as planned may be too all-encompassing to be portable. If it is to become a national resource, companies other than the original developers must be able to implement it within their own facilities, as has happened with NASTRAN. A company designing electronic machinery and interfacing with circuit analysis programs would not be interested in maintaining the software overhead of a system which can also develop turbine blade geometry and compute the fatigue characteristics. There are "common threads" among all technical disciplines, but some disciplines are diverse enough that forcing an artificial similarity is an expensive luxury.

2. Many of the functions the large host computer apparently is scheduled to perform in IPAD could be handled less expensively and just as well by a carefully defined and skillfully managed system of manual procedures. This is particularly true of training. It is suggested

that initial training, cues, and prompts, beyond the usual menu and message functions, be handled in classroom or drafting room sessions, with manuals and tutoring handled during actual computer usage.

Mini- and micro computers are being more and more extensively used as elements of computer-aided manufacturing systems, either alone or in hierarchical systems with other computers. It may be desirable to use such computers for much of the designer interaction with communication to the central computer and central IPAD system only when necessary.

Comments on Implementation and use of IPAD

1. When attempting to identify which portions of a design/engineering process can be automated, the reports [1,2] recognize that the most important source of information and advice is the designer or engineer now performing that function. It is crucial that that person has an interest in a successful automation, and that he be asked to actively participate in any new system. A common initial misunderstanding is that the computer threatens to usurp that portion of his job with which he most closely identifies, namely, the creative process. The IPAD report wisely points out that this will never happen regardless of how sophisticated computer technology becomes. A subtlety, however, is that upon careful investigation, some design processes are found to be not as creative as originally thought. Although the stages in developing the design may be complex, the outcome is a function only of basic quantifiable design parameters available at the very first stage.

2. An aspect of the IPAD system which was repeatedly stressed in the reports was the compression of decisions into a continuous stream without the interference of "non creative" activities. One designer believed that performing these routine tasks often provides valuable "soak" time for ideas to be developed and decisions to be pondered, and that major design decisions should be made at one's desk while planning the day's computer activities and not debated while one is tying up an expensive computer system.

3. It is the policy of Ford Motor Company to carry out the piece-wise development of large systems, with each piece delivering a near-team economic return. It would be very difficult for Ford to undertake, on its own, a project of the scope and magnitude of IPAD. It, therefore, is happy to see the development of IPAD sponsored by NASA. It is anticipated that the acceptance and use of IPAD, once it is developed, might follow the course taken by NASTRAN. Once this program was developed, proven (with NASA sponsorship), and made available, its use in the automobile industry followed naturally. Various structural analysis tools are routinely used in automobile design and have greatly impacted the approach to product design and problem analysis.

IPAD appears to have tremendous potential and its impact on business methods within the automobile industry and elsewhere could be profound.

The Ammann and Whitney Company

The Ammann and Whitney Company is a firm of consulting engineers with a current staff of over 300. It maintains a complete design office capability with experienced personnel in structural, architectural, mechanical, electrical, civil, soils, availability-reliability, logistical analyses, computer, survey, and construction-supervision fields. The company was one of the early users of computers in engineering consulting with its own IBM 650. At present, the company owns an IBM 1130 and rents time on CDC 6600 and IBM 370 computers.

Its library of structural analysis programs includes NASTRAN, ICES-STRUDL, STARDYN, and many programs that it has developed.

The company has engaged in design of highways and bridges, buildings of all types, including blast resistant structures, mass transit facilities, airports, antennas, harbors, and other special structures such as drydocks, dams, piers, and waterfront facilities,and water storage and distribution facilities. Ammann and Whitney made an evaluation of the applicability of IPAD to the design problems in each of these areas and reached the following conclusions.

Design of Buildings

The structural design of office-type buildings is usually a straightforward procedure, with exterior shell appearance dictated by the architect and client, and interior space utilization tailored to the needs of the client. Material choices are made on the basis of preliminary configuration-cost analyses and usually do not change substantially in the design process. Structural analyses now utilize the computer heavily.

Structural design of public buildings utilizes finite element analysis, particularly if the building is a shell structure that must conform to the architect's conception of form and function. A special structure in which Ammann and Whitney was involved as a member of the design and construction team was the hardened control center for the Perimeter Acquisition Radar facilities of the SAFEGUARD system. The high-density utilization of the building space and the many design constraints in this building required a large design team and continuous interaction between all of the members of the multicompany team working on the project. Much communication and coordination was carried out by telephone and telecopier, and was slow compared to an IPAD system which might have been very helpful in developing the design of the center.

In this and each of the other areas of concern to Ammann and Whitney, the biggest need is for efficient cost-estimating procedures which might be made available in a computerized system with a complete and reliable up-to-date data bank of available parts, supplies, and labor costs.

Mass Transit

An IPAD system would be very valuable in the preliminary design of mass transit systems when all of the various alternative routes and the various trade-offs are being studied. If an IPAD model were developed for a given transit system, it would then be useful as a management tool to the construction supervisor and general contractors.

Highways and Bridges

Preliminary design of highway systems would be greatly helped with an IPAD system that would have the capability to incorporate all of the geometric terrain details, the various cost models for land acquisition, bridge design, cut and fill procedures, environmental impact, and others. As in the case of mass transit, the IPAD model of a given highway, once developed, would be useful to the contractors during its construction.

Ammann and Whitney participates in many projects involving the design of a single bridge, or short segments of highway, to replace and upgrade existing highways. Such design studies would not require an IPAD system. In particular, the design of large bridges is a nearly sequential operation, proceeding from traffic studies to general configuration, to soil and foundation studies, to design and details analysis for dead and live loads, with only a few iterations needed.

Airports and Harbors

The IPAD system would be particularly cost-effective in the design of new airports or new harbors. The complexities of the system interactions and the various necessary trade-offs result in the general type of problem for which IPAD would be most useful. The display capabilities of IPAD would be particularly useful in explaining the progress of such design studies to the public and to public officials who must oversee the development.

Use of IPAD in the design of single airport terminals or a single waterfront structure being added to existing facilities would probably not be cost-effective.

Support for Developing IPAD Systems

Ammann and Whitney believes that development of general IPAD system models in the areas of public construction (highway systems, airports, etc.) should probably be supported by an appropriate agency of the U. S. government. The alternative, if IPAD is to be developed for public construction, is for separate contractors or groups of contractors to develop IPAD systems for their own use. Only a very small percentage of the industry has resources to make this type of investment. Even then, cost of these developments would then be amortized on subsequent projects. Since the government directly or indirectly pays the major cost of such public construction, it would certainly save money and develop a better product if it were to support the development of appropriate IPAD systems and make them generally available for public benefit. With the major elements of the system developed, each contractor can add his own modules to the system to particularize it for his use. In major public construction projects, it is usual for the work to be allocated to a variety of contractors and consulting firms. Control and scheduling of these many interacting contractors could be enhanced with the features to be provided by an IPAD system.

The development of an IPAD system for certain types of heavy construction might be feasible through group support of a number of like-minded companies. This would probably be more useful than individual development of separate IPAD systems by those large engineer-contractors who would have resources to develop their own versions of IPAD. These contractors must interact with subcontractors and myriad suppliers on large construction jobs and it would be to the advantage of the prime construction contractor to have a relatively open IPAD system with appropriate accessibility for at least some of the subcontractors.

In summary, IPAD systems of certain types would probably be cost-effective to some segments of the heavy-construction industry. However, initial development of these sytems will be a real problem, probably requiring government subsidy.

POTENTIAL APPLICATION OF IPAD TO URBAN AND REGIONAL PLANNING

The original objectives of the contract being described in this report were to investigate the applicability of IPAD to non-aerospace industry. Although NASA has considered the possible use of IPAD by other agencies of the Federal Government, it was determined during the course of Battelle's study that little consideration had been given to the possible benefits of applying IPAD to problems faced by state and local governments. Clearly, taking into account all of the complex interactions between the factors involved in any major urban or regional plan, is a problem as complex as the design of an aircraft. With the approval of the technical monitor, Battelle conducted a brief study of the possibility of using IPAD in urban or regional planning.

Simply stated, urban and regional planning consists of those activities necessary to sustain a city or region as it evolves through time. As such, functions like problem definition, goal formation, alternatives development, evaluation, implementation, administration, and monitoring must be accomplished by a team of people representing many disciplines. Because city management and planning functions are complex and require considerable effort, functionally organized city departments and agencies have been formed. These organizations partition the problems of managing and planning a city into manageable pieces. However, the problems of cities do not fall into these clear-cut organizational lines. Common problems, common data needs, and highly integrated decisions characterize urban and regional planning.

The highly interrelated, multidisciplinary nature of urban and regional planning lends itself well to the conceptual structure of the IPAD system. Most decisions within a city are made in conjunction with a data base that describes the conditions and characteristics of the urban area. Decision makers will require different data and different

combinations of data but there is sufficient commonality of needs between decision makers that a master data-base library would prove useful. Similarly, the decisions of one agency or department often affect operations in others. Considerably more efficient and effective management could be achieved if knowledge about decisions and actions were available to all departments on a current basis. Finally, decisions require that alternatives be evaluated. Special-purpose models are available to aid in these evaluations, but their historical costs and maintenance problems have kept them from being used effectively. Additionally, these evaluation models need input of data from many disciplines and require an appreciation of the interactions of the many urban functions. IPAD offers one means for addressing these planning needs and a means for integrating some of the more mechanical functions of a city.

Large-scale computer systems are not new to the urban and regional planning field. Transportation and land use planning models were popular during the 1960's. More recently, special purpose, real time systems are being developed to aid in the provision of police and fire protection. Fully operational systems for accounting, payroll administration, and budgeting have been adopted by most cities. Finally, a whole new class of information and analytical models are being used. These historical experiences lead to the conclusion that IPAD can be accepted and used in urban and regional planning.

Potential Uses of IPAD

There are three main types of applications for which IPAD can provide assistance to urban areas. First, the system can be used to organize a multidisciplinary data base that can be accessed by all departments and agencies in a city. Second, general, and special purpose models requiring input from several departments can be constructed to aid in evaluating alternative plans and programs.

The data organizational potential of IPAD should not be viewed as an end product. Rather, the data-base storage and retrieval capabilities of IPAD are an intricate part of other, more sophisticated capabilities. The IPAD system is designed to be more than a large data storage and retrieval system and, as such, should not be underutilized. Also, the cost of the IPAD system would prohibit the exclusive use of the system for data manipulation.

The data organization potential of IPAD could focus on constructing a data base containing relevant data on current urban characteristics and conditions that can be used for analytical and mechanical functions. These data should be classified geographically, chronologically, and hierarchically in terms of detail. The retrieval system should be capable of aggregating or disaggregating data to the desired level of subject detail and geographic scope, and organizing the data in the proper chronological frame.

The content of these data is practically infinite. Some representative types of data are

- Population by age, sex, color, and income for Census blocks
- Sewer and water system configuration including location, size, age, and condition
- Transportation routes by types, location, capacity, use, and condition
- Air quality data by pollutant type, location, concentration, and duration
- Budget and expenditure data by department, program, and date
- Land valuation by location, type of land use, and ownership
- Vital statistics (births, deaths, marriages, divorces) by location, demographic characteristics, and time
- Education statistics by location, school district, type of school
- Crime and fire statistics by location, type, severity.

Care should be exercised to include all potentially useful data without overburdening the system with trivial data sets. Also, in order to be effective, the update of the data base should be made part of the regular routine of the city so that no duplication of effort is required.

The second major potential use of the IPAD system is for special modeling activities. As conceptualized, the IPAD system will have the capacity to accept special models. IPAD will serve as the interface between the user and the model and between the model and the data base. A host of special-purpose models, most being simulation and stochastic in nature, are used in urban and regional planning. Transportation models, land-use models, population-projection models, location/allocation models, demand models, social-impact models, and many other models have been developed for special functions. Significant effort has been expended by cities to develop these models and IPAD should be designed to accommodate them without requiring major revision.

The third area in which IPAD can contribute to the urban and regional planning profession relates to performing mechanical functions. Administrators of large cities must spend countless hours in the processing of forms, applications, records, and other miscellaneous data. IPAD could serve as a central depository for these data and could help standardize the process by which they are generated. Examples of functions that IPAD could serve include :

- Maintaining and displaying repair and maintenance records for streets, sewers, traffic control devices, etc.
- Processing and storing crime reports
- Processing and storing fire run reports
- Processing and storing tax records
- Maintaining and displaying current budget and expenditure data by department and agency
- Maintaining inventory and purchasing records.

These mechanical functions could be made more efficient through the use of IPAD and, at the same time, the data would be available for use by other agencies and departments. The value of IPAD is its ability to systematize the collection process and to display the data and records in a format compatible for their use. For example, fire run reports can be used in at least two ways. First, the aggregate data can be used for determining budget requirements, capital purchases, and cash-flow

requirements. Second, the same data can be used in a spatially disaggregated manner for determining allocations of men and equipment between fire stations, for identifying new fire stations, and for identifying areas of potential high fire rates. A similar situation exists for police and crime reports. These data can be used for determining aggregate demand for police protection, for analyzing spatial location of crime, and for aiding in criminal investigations where trends, patterns, and suspect characteristics can be searched and cross-classified to aid the investigators.

In summary, the IPAD system appears to provide the general capability for integrating data, performing analyses, and conducting routine functions of a city. The ultimate design that is being worked with is the city, its spatial properties, and situational characteristics. This design is quite different than an aerospace vehicle; yet the capabilities of the system can bridge the differences.

Potential Problems

The introduction of IPAD, or any large-scale system, into an urban area can result in several problems. These problems revolve around user acceptance, subject matter adaptibility, and security.

First, city governments will have to be convinced that the IPAD system is a feasible alternative to the status quo and that the system offers cost savings and increases in effectiveness. Resistance to change is characteristic of many of the civil-service-type functions of a city. Additionally, recent trends toward unionization of state, county, and municipal employees could prove a problem if the IPAD system is used to replace current manual labor. Training programs and job placement programs would be mandatory companions of the IPAD system.

A second problem facing the implementation of IPAD in cities is whether sufficient information exists to effectively link the various functions of a city into an integrated design model. Much is known about individual urban functions. Models, data, and evaluation techniques are available to aid decision makers. However, the relationships between

urban functions are not well understood and the theory behind the linkages does not exist in many cases. For example, the strong linkage between land-use planning and transportation planning has long been known and many different models exist that attempt to quantify this linkage. Recently, planners have been realizing that land use, transportation, social conditions, and environmental conditions are all highly interrelated. Few models, however, are available to describe these linkages and those that do exist are open to criticism. In fact, due to the dynamics of change inherent in the city system, planners may never know the relationships between these elements, although interactions through an IPAD model should offer increased hope of evaluating these relationships. The main point is that the urban system cannot yet be partitioned into pieces, analyzed, and reconstructed the way an aerospace vehicle can. Care must be taken not to superimpose a deterministic system on a system that is far from being deterministic.

The final concern rests with the security of the IPAD system for applications involving information about individuals. Three basic factors need to be considered. First, the system must protect against the possible permanent destruction of irreplaceable data. Second, the system must insure the anonymity of individuals. Third, provisions should be made to prohibit abuse of data by non-authorized individuals. Data security provisions in the planned IPAD system should at least ease this problem.

Initial Steps for IPAD Implementation in Urban and Regional Planning

If the feasibility is established for developing a version of IPAD for urban and regional planning purposes, a transitional implementation program must be undertaken. Such a program should focus on two points. First, demonstration efforts with existing software and information systems currently in operation in cities should be made. Special emphasis should be given to gaining the support of the Urban Information Systems Interagency Committee (USAC). This committee is led by the Department of Housing and Urban Development and has participants from the Departments

of Health, Education, and Welfare; Transportation; Labor; Commerce, Justice; National Science Foundation; and the Defense Civil Preparedness Agency.

Second, the initial demonstration projects should seek to overcome some of the traditional problems of large scale systems. Early release versions of IPAD should contain models and utilities that are simple and noncontroversial so that constructive criticisms of IPAD can be obtained. Additionally, the model should be developed with a specific policy or problem orientation. It should not be sold as a cure-all for urban problems. In the early stages, the users should be shown the potential of the model, not forced to deduce its potential from broad capability statements. The models contained in IPAD should be made usable and efficient. Long-term benefits from the system can be lost if too much criticism exists about the individual models. The first versions should focus on applications that are deterministic rather than stochastic.

It appears that the IPAD system does hold significant potential for applications in city planning and management. This potential is keyed to the system's ability to handle data, to perform integrated analytical tasks, and to efficiently execute mechanical jobs. Although an urban area has an infinite number of possible applications, care must be taken to introduce the IPAD system in applications where the systems capabilities can best be manifested.

IPAD AND THE U. S. ENERGY PROGRAM

The Battelle Memorial Institute has been deeply involved in research related to the production and distribution of various forms of energy for many years. As a further recognition of the critical problems facing the U. S. in the energy field, Battelle initiated the Battelle Energy Program in 1973. Utilizing the background accumulated in the Battelle Energy Program, the following evaluation was made of the possible impact of IPAD on the U. S. energy problems.

Although, as yet, no clearly defined long-range plan has been developed for attacking the energy problems of the U. S., several points are becoming clear.

- There are no easy or short-term routes to totally U. S. controlled energy sources
- In the short time period, 1980 to 1985, energy conservation and more efficient utilization must be considered as absolutely necessary
- Energy conservation will probably not free sufficient energy supplies to achieve national goals and rising aspirations of U. S. citizens.

Thus, it appears that a parallel policy of conservation and strong commitment to developing new sources and supplies of energy will be necessary. The latter will require better definition and commitment to long-range goals than has ever been true of the U. S. society.

In reviewing the various alternatives open to the United States, the following steps appear to be necessary to the development of a self-sufficient energy industry.

In the next decade, using already existing technology for the most part, significant effort will have to be put forth to develop oil and gas supplies controlled by the U. S., such as:

- Exploration and development of Alaska resources such as NPR No. 4, Prudhoe Bay, and other Arctic finds
- More rapid development of outer continental shelf resources, including Atlantic and Pacific coasts

- Move toward more rapid development of the U. S. indigenous tar sands and oil shale.

While this is being implemented in the next decade, technology development, plant design and construction should move forward to provide a massive network of coal-gasification and coal-liquefaction plants for needed gaseous and liquid fuels necessary to replace diminishing crude and natural gas supplies in the 1985-2000 time period. Parallel with this, and already under way, is the development of base-load, light-water, nuclear power plants. Time lags and the need for an unparalleled influx of capital will probably prevent construction of all the nuclear plants desirable. Fossil-fueled power plants will probably always be needed for peaking and swings in power requirements. Alternative sources of energy (such as solar power) may be added to this energy mix.

It was noted above, that solution of the energy problems will require an enormous long term commitment. It has already been recognized by the Office of the President that such a program will probably be the largest single commitment ever attempted by this country.

A review of the industrial classes described in Appendix A shows that the main load of meeting the construction goals outlined above will fall on four types of industries:

- Heavy Construction
- Engines and Turbines
- Engineering and Architect Services
- General Electrical Equipment Manufacturers.

The pool of technical manpower within these industries now and in the near future will be inadequate to cope with the scope and magnitude of the design problems that will have to be overcome if the United States does indeed embark on a full-scale energy-development program. Even at the present time, one of the major causes of delay in construction of an atomic energy plant is the massive manpower requirements for plant design. The FEA estimates 100,000 man-years/year of technical personnel will be required to build projected nuclear power plants. If one adds to the technical man-hour requirements for nuclear plants to similarly massive investments of time for coal-conversion

plants, it becomes easy to see that delays in new plant construction caused by shortages of design-function manpower could be massive.

It would appear that the only realistic way in which this shortage of engineers is to be overcome would be to automate the design function through the development of appropriate IPAD or IPAD-like systems. Further, any investment now in tools and techniques to increase the efficiency, decrease the total time required (because of capital committed), and decrease the chance for error in the design of energy plants will have massive payoffs in each new energy plant constructed.

When one multiplies this by the large amount of plant and equipment necessary, an integrated design tool like IPAD should be accorded a national priority. To whatever extent possible, the U. S. energy industry should not wait for the tool to be completely developed before applying it to new energy plants. Any increases in designer efficiency as the program is developed might very well pay handsomely for the program on a "pay-as-you-go" basis.

In this short study, consideration was given to many practical problems encountered in designing and constructing major plants, and how these might be affected by an IPAD system. This study revealed that one of the most amazingly costly and time-consuming problems of building energy plants has been the transfer of design technology and detailed information to the "construction trailer". An unbelievable amount of time is spent and lost during construction in finding and studying the massive stack of drawings provided by the millions of man hours of design time. If visual displays of construction detail, part numbers and materials could be available at a terminal in the construction shack by an IPAD system, it is quite possible that reduction of construction delays could save all the developmental costs of IPAD.

Because of time constraints, the evaluation reported here had to be very superficial. It is clear that an in-depth study to develop a plan for applying IPAD to a program of the apparent complexity and magnitude of the projected U. S. Energy Program is a substantial task. However, based on the apparent future needs for design technology and the promise of IPAD, as identified above, it is strongly recommended that this study be initiated. This plan must provide both for developing the appropriate analysis modules and data bases, and for encouraging use of the resulting system by the affected industries.

CONCLUSIONS AND RECOMMENDATIONS

On the basis of the preliminary study reported here, it was concluded that a significant potential may exist for the application of IPAD to design problems in the non-aerospace sector. However, because of the limited scope of the study, no quantitative estimate could be made of the amount of use that might be made of IPAD by this sector. The two industries most likely to benefit from application of IPAD are the heavy construction and the automotive industries. Many companies believed to be involved in the manufacture of power generation equipment, such as engine and turbine manufacturers, and the general electrical equipment manufacturers should also find IPAD to be useful. It is believed that other industries will begin to implement IPAD in the years after its development, as their needs and design technologies require it.

Implementation of IPAD into individual companies, particularly those in the manufacturing sector, will undoubtedly take place as an evolutionary process, that may span a period of years. This will be necessary to give the company time to evolve the organizational structure and to take care of any personnel problems as they arise. It also is necessary to give the company time to validate the economic benefits of each facet of the design automation before it is adopted as an operating procedure. Nevertheless, having the IPAD system as a potential future goal for planning the evolution of the design functions is seen as a benefit by most companies.

Two brief studies were carried by Battelle as supplements to the planned study. These were directed at investigating the applicability of IPAD to the U. S. energy problems and to urban and regional planning problems. Both of these studies have identified enormous potential opportunities for utilization of IPAD. Problems were also identified in these areas with regard to obtaining acceptance of the IPAD system. It appears that incorporation of IPAD technology into existing company (or government) organizations must be a well-planned evolutionary process spread over a period of years.

Such a process, if begun now, would gain valuable time in applying the IPAD benefits to wider sectors of the U. S. community. It is, therefore, recommended that NASA institute a program or programs (possibly in cooperation with other Government agencies) to plan for and begin to work for the application of automated design technology in non-aerospace sectors of the economy.

APPENDIX A

REVIEW OF U. S. INDUSTRY BY STANDARD INDUSTRIAL CLASS (SIC)

The Standard Industrial Classification system was developed to promote comparison of statistics describing various facets of the economy of the nation. The SIC defines industries in accordance with the composition and structure of the economy and covers the entire field of economic activities. The SIC code consists of four digits. The first two digits are used to indicate major groups and the second two digits are used to define specific subgroups. The two-digit major groups are classified under 11 divisions as shown in Table A-1. This Table was prepared from the 1972 Standard Industrial Classification Manual[3], which lists and describes all of the industry classes that were defined at that time.

A review was made of the non-aerospace sector by Standard Industrial classes to identify types of industries that might be able to use IPAD to enhance their business operations. Within each industry class, specific industries were studied to make an evaluation of the possibility that such industries might be able to use IPAD.

The first step in determining which SIC groups might use IPAD was to eliminate those groups most unlikely to need the IPAD system. This initial elimination process was based on the study of the occupational distribution by industry given in Reference[4]. Tables in this report list the numbers of reported employees of every kind, employed by various industry groups. The most meaningful occupations for this study were judged to be the following:

1. Architect
2. Computer Specialist
3. Aeronautical, Astronautical Engineers
4. Civil Engineers
5. Electronic and Electrical Engineers
6. Industrial Engineers
7. Mechanical Engineers
8. Mathematicians
9. Operations and Systems Research
10. Tool Programmer, Numerical Control.

TABLE A-1.-- LISTING OF TWO-DIGIT MAJOR GROUPS OF THE STANDARDS INDUSTRIAL CLASS CODE

Division A.	Agriculture, forestry, and fishing	
	Major Group 01.	Agricultural production--crops
	Major Group 02.	Agricultural production--livestock
	Major Group 07.	Agricultural services
	Major Group 08.	Forestry
	Major Group 09.	Fishing, hunting, and trapping
Division B.	Mining	
	Major Group 10.	Metal mining
	Major Group 11.	Anthracite mining
	Major Group 12.	Bituminous coal and lignite mining
	Major Group 13.	Oil and gas extraction
	Major Group 14.	Mining and quarrying of nonmetallic minerals, except fuels
Division C.	Construction	
	Major Group 15.	Building construction--general contractors and operative builders
	Major Group 16.	Construction other than building construction--general contractors
	Major Group 17.	Construction--special trade contractors
Division D.	Manufacturing	
	Major Group 20.	Food and kindred products
	Major Group 21.	Tobacco manufactures
	Major Group 22.	Textile mill products
	Major Group 23.	Apparel and other finished products made from fabrics and similar materials
	Major Group 24.	Lumber and wood products, except furniture
	Major Group 25.	Furniture and fixtures
	Major Group 26.	Paper and allied products
	Major Group 27.	Printing, publishing, and allied industries
	Major Group 28.	Chemicals and allied products
	Major Group 29.	Petroleum refining and related industries
	Major Group 30.	Rubber and miscellaneous plastic products
	Major Group 31.	Leather and leather products
	Major Group 32.	Stone, clay, glass, and concrete products
	Major Group 33.	Primary metal industries
	Major Group 34.	Fabricated metal products, except machinery and transportation equipment
	Major Group 35.	Machinery, except electrical
	Major Group 36.	Electrical and electronic machinery, equipment, and supplies
	Major Group 37.	Transportation equipment

TABLE A-1.-- LISTING OF TWO-DIGIT MAJOR GROUPS OF THE STANDARDS INDUSTRIAL CLASS CODE - Continued

	Major Group 38.	Measuring, analyzing, and controlling instruments; photographic, medical and optical goods; watches and clocks
	Major Group 39.	Miscellaneous manufacturing industries
Division E.	Transportation, communications, electric, gas, and sanitary services	
	Major Group 40.	Railroad transportation
	Major Group 41.	Local and suburban transit and interurban highway passenger transportation
	Major Group 42.	Motor freight transportation and warehousing
	Major Group 43.	U.S. Postal Service
	Major Group 45.	Transportation by air
	Major Group 46.	Pipe lines, except natural gas
	Major Group 47.	Transportation services
	Major Group 48.	Communication
	Major Group 49.	Electric, gas, and sanitary services
Division F.	Wholesale trade	
	Major Group 50.	Wholesale trade--durable goods
	Major Group 51.	Wholesale trade--nondurable goods
Division G.	Retail trade	
	Major Group 52.	Building materials, hardware, garden supply, and mobile home dealers
	Major Group 53.	General merchandise stores
	Major Group 54.	Food stores
	Major Group 55.	Automotive dealers and gasoline service stations
	Major Group 56.	Apparel and accessory stores
	Major Group 57.	Furniture, home furnishings, and equipment stores
	Major Group 58.	Eating and drinking places
	Major Group 59.	Miscellaneous retail
Division H.	Finance, insurance, and real estate	
	Major Group 60.	Banking
	Major Group 61.	Credit agencies other than banks
	Major Group 62.	Security and commodity brokers, dealers, exchanges, and services
	Major Group 63.	Insurance
	Major Group 64.	Insurance agents, brokers, and service
	Major Group 65.	Real estate
	Major Group 66.	Combinations of real estate, insurance, loans, law offices
	Major Group 67.	Holding and other investment offices

TABLE A-1.-- LISTING OF TWO-DIGIT MAJOR GROUPS OF THE STANDARDS INDUSTRIAL CLASS CODE - Continued

Division I.	Services	
	Major Group 70.	Hotels, rooming houses, camps, and other lodging places
	Major Group 72.	Personal services
	Major Group 73.	Business services
	Major Group 75.	Automotive repair, services, and garages
	Major Group 76.	Miscellaneous repair services
	Major Group 78.	Motion pictures
	Major Group 79.	Amusement and recreation services, except motion pictures
	Major Group 80.	Health services
	Major Group 81.	Legal services
	Major Group 82.	Education services
	Major Group 83.	Social services
	Major Group 84.	Museuums, art galleries, botanical and zoological gardens
	Major Group 86.	Membership organizations
	Major Group 88.	Private households
	Major Group 89.	Miscellaneous services
Division J.	Public administration	
	Major Group 91.	Executive, legislative, and general government, except finance
	Major Group 92.	Justice, public order, and safety
	Major Group 93.	Public finance, taxation, and monetary policy
	Major Group 94.	Administration of human resources programs
	Major Group 95.	Administration of environmental quality and housing programs
	Major Group 96.	Administration of economic programs
	Major Group 97.	National security and international affairs
Division K.	Nonclassifiable establishments	
	Major Group 99.	Nonclassifiable establishments

9. Operations and Systems Research
10. Tool Programmer, Numerical Control.

A detailed breakdown of employees by industry to the third SIC digit was given in[4]. A list showing the numbers of employees in the above 10 categories was compiled from this report, and is given in Table A-2.

Study of this table shows that many of the classes may easily be eliminated on the basis of the small number of engineers or scientists in the group. Generally, if the number of included engineers and scientists totaled less than 10,000, the group was deleted. In each case, the occupational description given in[3] was checked to verify that the IPAD system was unlikely to be used in the industry. This initial elimination process resulted in 24 SIC groups shown in Table A-3.

Three groups were retained in which there were less than a total of 10,000 engineers and other technical specialists listed. The Engine and Turbine group was retained because it contained the major steam turbine manufactures (Babcock and Wilcox, Combustion Engineering, and Foster Wheeler). The Farm Machinery category was included because of the overlap with the construction equipment field. The Household Appliances category was included since it was one of the initial groups studied. Four groups (Ordinance, Electronic Computing,* Aircraft and Parts, and Colleges and Universities) were included in this table for statistical comparison with the other groups, even though they were believed to be outside the scope of the study.

A comparison of Table A-3 with Table A-1 shows that the 20 groups selected for further study are devoted to construction, manufacturing, communication, and business services. This further study involved the evaluation of the activities of each group as defined in the SIC Manual[3] and a study of the activities of individual companies in certain of the groups. The results of this evaluation will be discussed for each of the 20 industry classes.

The study of individual companies was based on the information contained in Moody's Industrial Manual[5] and on 1973 annual reports published by each company. A large current file of these reports is routinely maintained by Battelle as part of its industrial marketing operations. All of the companies discussed in this Appendix had supplied Battelle with 1973 annual reports except for those closed corporations that do not issue annual reports.

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* Computer design and manufacture, although not specifically studied in this survey, is believed to be a likely candidate for use of IPAD.

TABLE A-2.- OCCUPATIONAL DISTRIBUTION BY INDUSTRY FOR SELECTED PROFESSIONAL AND KINDRED WORKERS (1970)

SIC	INDUSTRY	ARCHITECT	COMPUTER SPECIALIST	AERO.ASTRO ENGINEERS	CIVIL ENGINEERS	ELECTRO ENGINEERS	INDUSTRIAL ENGINEERS	MECHANICAL ENGINEERS	MATH-EMATICIANS	OPER.SYST. RESEARCHER	TOOL PGMR. NUM CONTR
100	AGR.PROD.,LIVESTOCK	4901	313	0	1810	171	229	346	5	34	11
1000	METAL MINING	5	201	0	142	99	258	136	0	70	0
1200	COAL MINING	11	40	0	126	34	117	80	0	19	0
1300	OIL,GAS EXTRACTION	34	2187	9	867	725	709	986	72	321	11
1400	NONMETAL MINING	5	145	0	160	109	195	151	0	32	0
1500	BUILDING CONSTRUCT.	1135	275	15	8961	547	551	782	0	68	6
1600	CONSTRUCT EX.BLDGS.	719	1530	14	50640	2069	1462	2289	68	309	25
1700	SPEC. CONSTR. TRADES	469	548	8	12940	3514	1065	3104	5	99	12
1900	ORDINANCE	57	4571	3932	896	8739	5893	8511	277	2837	53
2010	MEAT PRODUCTS	8	271	0	69	55	759	240	7	81	11
2020	DAIRY PRODUCTS	14	228	4	39	38	480	169	0	70	0
2030	CANNING, PRESERVING	0	348	4	49	148	697	348	9	169	0
2040	GRAIN MILL PRODUCTS	5	181	0	59	35	421	116	0	138	0
2050	BAKERY PRODUCTS	0	99	0	69	58	351	142	0	88	0
2080	BEVERAGES	22	303	0	88	135	544	306	0	286	4
2099	FOOD PREP N.E.C.	34	902	45	139	170	1077	578	6	367	0
2100	TOBACCO MANUFACTURE	12	206	0	23	72	174	108	0	53	0
2200	TEXTILE PRODUCTS	14	1361	0	104	208	3334	962	9	991	0
2270	FLOOR COVERINGS	0	194	0	15	28	244	51	0	100	0
2300	APPAREL AND ACCESS.	0	990	16	34	60	2027	190	4	499	13
2400	LUMBER EX. FURNITURE	118	390	0	235	253	762	260	7	190	0
2500	FURNITURE FIXTURES	24	461	83	44	56	1331	260	5	279	5
2610	PULP,PAPER MILLS	14	923	6	363	557	1451	1101	9	557	10
2640	MISC.PAPER PRODUCTS	0	327	0	35	154	712	357	6	319	0
2650	PAPERBOARD PRODUCTS	20	189	9	48	83	633	271	0	503	0
2710	NEWSPAPER PUBLISHING	5	523	12	10	127	73	65	0	97	5
2799	ALL OTHER PRINTING	41	2445	6	55	199	1120	374	13	1330	30
2810	IND.INORG.CHEMICALS	40	1261	0	511	1243	1402	1589	60	617	4
2820	PLASTICS, SYNTHETICS	16	518	12	215	440	959	1000	10	378	0
2830	DRUGS AND MEDICINES	20	912	0	90	95	848	249	21	509	9
2840	SOAP AND COSMETICS	5	416	6	85	52	625	353	5	345	0
2850	PAINTS	13	184	0	6	31	202	48	11	131	0
2870	AGRICULT. CHEMICALS	13	124	0	52	40	101	166	0	66	0
2890	MISC. CHEMICALS	57	1611	29	423	557	1387	1351	44	715	15
2910	PETROLEUM REFINING	60	2473	4	921	577	733	1368	88	855	11
2950	PAVING, ROOFING	0	33	0	25	21	143	73	0	35	0
3010	RUBBER PRODUCTS	36	956	9	149	336	435	1090	0	790	23
3070	MISC. PLASTICS	6	259	0	93	155	361	828	0	312	0
3100	LEATHER PRODUCTS	0	333	0	6	23	613	99	0	161	12
3210	GLASS PRODUCTS	24	365	0	84	269	1050	548	8	301	15

TABLE 4-?.- OCCUPATIONAL DISTRIBUTION BY INDUSTRY FOR SELECTED PROFESSIONAL AND KINDRED WORKERS (1970)-CONTINUED

SIC	INDUSTRY	ARCHITECT	COMPUTER SPECIALIST	AERO.ASTRO ENGINEERS	CIVIL ENGINEERS	ELECTRO ENGINEERS	INDUSTRIAL ENGINEERS	MECHANICAL ENGINEERS	MATH-EMATICIANS	OPER.SYST. RESEARCHER	TOOL PGMR. NUM CONTR
3270	MISC NON-METALLIC	33	503	11	837	330	1540	734	6	383	4
3310	BLAST FURNACE,MILLS	24	1513	5	891	1041	3406	1381	31	1171	20
3320	OTH. PRIM IRON STEEL	6	459	5	167	313	1861	789	0	537	22
3330	NON-FERROUS INDUSTRY	26	1021	5	268	1058	2460	1474	40	778	26
3420	HARDWARE-HAND TOOLS	0	313	11	37	54	874	1041	6	243	16
3440	STR.METAL PROD.FABR.	58	726	60	1207	781	1991	2226	0	471	46
3450	SCREW MACHINERY	5	116	0	4	19	540	425	0	138	5
3460	METAL STAMPING	9	222	0	33	32	914	593	0	228	5
3490	MISC.METAL PROD.-AB.	16	681	15	232	436	505	2006	0	791	30
3510	ENGINES AND TURBINES	5	485	95	53	549	1122	1948	25	154	58
3520	FARM MACHINERY	18	605	5	61	235	1355	1359	0	385	3
3530	CONSTR.,MINE EQUIP.	18	1237	0	331	963	2513	4195	0	891	68
3540	METALWORKING MACH.	0	928	5	30	802	1888	4583	9	559	282
3570	OFFICE EQUIPMENT	95	19626	23	54	8550	3583	3268	113	375	41
3573	COMPUTER MFG.	32	3179	0	61	2036	1708	526	21	766	25
3599	MIS.NONELEC. MACH.	49	2763	124	475	3107	6954	14864	44	2178	291
3630	HOUSEHOLD APPLIANCES	0	622	5	72	1879	1699	795	0	406	10
3650	COMMUNICATIONS MFG.	30	6130	528	330	36440	8943	5263	134	3188	102
3699	MIS.ELECTRICAL MACH.	89	8399	290	464	52736	14374	7725	167	4340	113
3710	MOTOR VEHICLE MFG.	117	583	108	434	1654	8966	15196	74	2071	81
3720	AIRCRAFT AND PARTS	90	8469	50519	2339	14479	13199	12745	286	7382	374
3730	SHIP AND BOAT BLDG.	783	759	124	361	2611	1726	4467	18	969	19
3740	RAILROAD EQUIPMENT	0	151	14	58	214	452	473	5	232	0
3810	SCIENTIFIC MEAS.INST	16	853	231	47	2613	2083	1456	42	681	43
3830	OPTICAL,HEALTH INSTR	0	529	24	34	791	177	763	5	347	5
3860	PHOTO EQ.,SUPPLIES	28	1034	8	119	1029	1736	1173	14	749	4
3870	WATCHES,CLOCKS	0	71	0	0	100	190	71	0	70	5
4010	RAILROAD TRANSPORT	56	277	0	2236	739	649	468	4	418	11
4210	TRUCKING SERVICES	8	684	0	152	155	362	188	0	94	0
4220	PUBLIC WAREHOUSES	0	126	0	30	18	90	76	0	4	11
4400	WATER TRANSPORT	87	224	0	179	104	127	7099	0	33	0
4500	AIR TRANSPORT	131	2014	1087	301	607	784	322	19	749	23
4600	PIPELINES EX. GAS	0	109	0	96	138	42	106	0	38	0
4700	TRANSPORT SERVICES	40	294	0	251	94	70	128	0	72	8
4810	PHONE COMMUNICATION	146	4628	5	1244	29658	1234	365	42	1154	25
4830	RADIO,TV BROADCAST	9	190	10	134	272	102	151	0	38	7
4890	TELEGRAPH,MISC.COMM.	12	413	0	45	1159	65	51	9	88	0
4910	ELECTRICAL UTILITIES	187	2657	21	2856	21156	1140	3144	39	814	10
4920	GAS,STEAM SUPPLIERS	16	769	6	472	231	384	696	11	207	10
4940	WATER SUPPLIERS	4	213	0	2988	429	127	289	0	42	0

TABLE A-2.- OCCUPATIONAL DISTRIBUTION BY INDUSTRY FOR SELECTED PROFESSIONAL AND KINDRED WORKERS (1970)-CONTINUED

SIC	INDUSTRY	ARCHITECT	COMPUTER SPECIALIST	AERO.,ASTRO ENGINEERS	CIVIL ENGINEERS	ELECTRO ENGINEERS	INDUSTRIAL ENGINEERS	MECHANICAL ENGINEERS	MATH-EMATICIANS	OPER.SYST. RESEARCHER	TOOL PGMR. NUM CONTR
5010	MOTOR VEH. WHOLESALE	21	439	0	23	16	224	193	6	143	11
5050	METALS.MINERALS	0	217	6	128	39	209	121	4	39	0
5060	ELECTRICAL GOODS	12	601	9	44	1824	445	336	0	262	10
5070	HARDWARE.PLUMB.,HEAT	20	189	0	19	50	144	397	0	0	0
5080	MACH.EQUIP.,SUPPLIES	43	5466	92	220	1391	817	360	45	596	42
5093	SCRAP.WASTE MATERIAL	5	12	0	8	4	33	10	0	0	0
5120	DRUGS AND CHEMICALS	21	473	0	51	100	94	161	7	147	0
5130	DRY GOODS APPAREL	0	234	0	0	6	45	13	0	10	0
5150	RAW FARM MATERIALS	0	115	0	29	7	42	16	0	19	0
5170	PETROLEUM PRODUCTS	24	529	3	355	55	195	212	14	174	7
5200	LUMBER AND HARD ARE	76	171	6	63	54	56	175	0	5	0
5300	GEN. MERCHANDISE	158	2473	0	132	139	509	196	0	495	19
5400	FOOD STORES	43	672	0	157	75	298	139	5	99	5
5500	MOTOR VEH.,RET.SALES	24	502	0	214	116	179	150	6	117	4
5600	APPAREL SALES	26	239	0	27	0	40	27	0	47	0
5700	HOME FURNISHINGS	21	344	0	38	275	82	118	0	54	5
5800	EATING AND DRINKING	37	161	0	71	9	89	23	0	80	17
5900	MISC. RETAIL SALES	75	1383	10	176	448	310	432	12	222	21
6000	BANKING	56	10472	0	87	52	348	62	28	2220	50
6100	CREDIT AGENCIES	26	1324	0	58	36	70	12	0	199	16
6200	SECURITY BROKER.EXCH	5	1802	5	48	53	108	28	6	505	15
6300	INSURANCE	205	13542	10	572	99	4770	115	492	2783	143
6500	REAL ESTATE	501	421	0	722	102	169	201	6	120	5
7000	HOTELS AND LODGING	75	117	0	106	174	68	200	0	43	0
7200	PERSONAL SERVICES	133	330	0	103	105	210	185	14	18	0
7310	ADVERTISING	6	333	10	15	52	42	29	6	76	4
7370	COMPUTER SERVICES	59	24120	15	68	1092	536	264	143	409	20
7392	BUS. MGT. CONSULTING	179	2610	15	238	354	7460	198	74	522	11
7397	RES.,DEV.,TEST LABS.	64	3415	632	692	5544	1024	2504	472	1066	31
7399	MISC. BUS. SERVICES	22	1156	60	271	2214	661	513	101	559	20
7500	AUTO REP.,REL. SERV.	0	234	0	35	26	115	44	0	57	18
7900	AMUSEMT.,RECREATION	20	78	6	108	62	28	108	7	21	0
8060	HOSPITALS	77	2382	5	406	468	676	509	10	361	4
8220	COLLEGES AND UNIV.	839	12074	147	1135	3127	495	1211	329	798	30
8910	ENGR.,ARCH. SERVICES	38242	1819	479	30849	11297	2528	10883	137	504	18
8930	ACCT.,AUDIT SERVICES	270	8782	0	115	232	262	53	21	352	13
8990	MISC.PROF SERVICES	427	2221	724	756	4445	754	2165	743	787	48

TABLE A-3.- OCCUPATIONAL DISTRIBUTION FOR SELECTED INDUSTRIES

SIC	INDUSTRY	ARCHITECT	COMPUTER SPECIALIST	AERO.ASTRO ENGINEERS	CIVIL ENGINEERS	ELECTRO ENGINEERS	INDUSTRIAL ENGINEERS	MECHANICAL ENGINEERS	MATH-EMATICIANS	OPER.SYST. RESEARCHER	TOOL PGMR. NUM CONTR
1500	BUILDING CONSTRUCT.	1135	275	15	8961	547	551	782	0	68	6
1600	CONSTRUCT EX.BLDGS.	719	1530	14	50640	2059	1462	2289	68	309	25
1700	SPEC. CONSTR. TRADES	489	548	8	12940	3514	1065	3104	5	99	12
1900	ORDINANCE	67	4571	3932	696	8799	5893	8511	277	2837	53
3510	ENGINES AND TURBINES	5	485	95	53	549	1122	1948	25	154	58
3520	FARM MACHINERY	18	605	5	61	235	1355	1359	0	385	3
3530	CONSTR.,MINE EQUIP.	18	1237	0	331	953	2513	4195	0	891	68
3540	METALWORKING MACH.	0	928	5	30	802	1868	4583	9	559	282
3573	COMPUTER MFG.	32	3179	0	61	2036	1708	626	21	766	25
3599	MIS.NONELEC. MACH	49	2763	124	475	3107	6954	14864	44	2178	291
3630	HOUSEHOLD APPLIANCES	0	622	5	72	1879	1699	795	0	406	10
3650	COMMUNICATIONS MFG.	30	6130	528	330	36400	8943	5283	134	3188	102
3699	MIS.ELECTRICAL MACH.	69	8399	290	464	52786	14374	7725	167	4340	113
3710	MOTOR VEHICLE MFG.	117	588	108	434	1634	8966	15196	74	2071	61
3720	AIRCRAFT AND PARTS	90	8469	50519	2339	14479	13199	12745	286	7382	374
3730	SHIP AND BOAT BLDG.	793	759	124	361	2611	1726	4487	18	969	19
4810	PHONE COMMUNICATION	146	4628	5	1244	29658	1234	365	42	1154	25
4910	ELECTRICAL UTILITIES	157	2657	21	2856	21156	1140	3144	39	614	10
7370	COMPUTER SERVICES	59	24120	15	68	1092	536	264	143	409	20
7392	BUS. MGT. CONSULTING	179	2610	15	238	354	7460	198	74	522	11
7397	RES.,DEV.,TEST LABS.	64	3415	632	692	5544	1024	2504	472	1066	31
8220	COLLEGES AND UNIV.	839	12074	147	1135	3127	495	1211	329	798	30
8910	ENGR.,ARCH. SERVICES	38242	1819	479	30849	11237	2528	10883	137	504	18
8990	MISC.PROF SERVICES	427	2221	724	756	4445	754	2165	743	787	48

The listings of 1973 Net Sales and R & D were obtained from the company annual reports and from a list prepared for Battelle by Investor's Management Sciences Inc. For closed companies, other sources were mined (such as magazine articles). The results of the evaluation of the industry groups and of companies within certain of these groups will be described.

Building Construction (SIC 1500)

This group includes general building contractors and operative builders, primarily engaged in the construction of residential, farm, industrial, commercial or other buildings. Potential users of IPAD in this group would include primarily large companies who design and build large industrial or commercial complexes. The two largest members of this group are Turner Construction and Daniel International both with Sales of about $600 M. Almost no company in this group reported any research and development activity in either 1972 or 1973. According to the evaluation by Ammann and Whitney, described elsewhere in this report, design of buildings is a fairly straight-forward procedure. Much of the design procedure is now automated, but its complexities are not great enough to require IPAD. Therefore, it is believed that this group represents a low probability for use of IPAD.

Construction Other than Buildings (SIC 1600)

This group includes general contractors engaged in heavy construction such as highways, bridges, airports, railroads, light and power plants, oil refineries, and miscellaneous types of construction other than buildings. It is expected that construction of major new plants for energy conversion (coal gasification or liquifcation, etc.) would be carried out by this group. Most of the larger companies in this field provide architectural and design services in addition to construction contracting. However, it is not unusual on many large jobs for these companies to engage the services of architectural and engineering consulting firms in addition to using their own staffs. It is this group of companies together with architects, engineers, and other technical specialists that will provide the basic technical know-how to build the energy facilities that will be created under the U. S. energy program. Those firms that provide architectural and engineering services, but do not provide construction contracting services, are described in a later section.

The Engineering News-Record listed the top 400 construction contractors of 1973 in its issue of April 11, 1974,[16] in terms of the total volume of construction contracts awarded each company. (This figure includes monies to be paid to subcontractors and, as such, is considerably larger than net sales for the company.) On this basis, the two largest contractors were Brown and Root Inc. (a subsidiary of Halliburton Company), and Bechtel. Ebasco Services, Inc., a second subsidiary of the Halliburton Company was listed as fifth largest in terms of 1973 contracts awarded.

The Halliburton Company
(1973 Net Sales, $2131 M; R&D $12.22 M)

This company, through its subsidiaries, provides for a broad line of construction services, including heavy construction of all types, highways, buildings, and manufacturing process plants. The Brown and Root Company was awarded a total of $4740 M in construction contract awards, to top all firms in this category. Ebasco Services Inc. was awarded contracts totaling $1,700 M. These companies provide engineering and construction services for industrial plants (such as refineries, petrochemical and petroleum facilities, pulp and paper mills) and for other heavy construction, such as off-shore drilling platforms. Brown and Root is managing contractor for construction of four off-shore platforms for the British Petroleum Company for drilling in the North Sea oil fields. The first of these is a 475-foot-high structure standing in 416 feet of water. In addition, it has designed platforms for this oil field being built by other firms.

Bechtel

This three-company group provides engineering-constructing services to the pipeline, oil-production and mining industries; nuclear and thermal power projects; and other heavy construction. It is a closed corporation and, as such, need not report its sales. Engineering News-Record estimates that its contract awards in 1973 were $3564 M. An estimate of the net sales or research and development expenditure is not available.

Projects carried out by the company include the logistics study and construction management of the Alaskan pipeline and design of pipeline systems

and refineries in Russia. It is involved in design-construction efforts for about 20 nuclear power plants. It is currently developing plans for coal liquifaction and gasification plants provided that they prove feasible. It is also constructing hotels. However, about 2/3 of the company's work is in energy related fields which will be crucial to this country's future.

Construction, Special Trades (SIC 1700)

This group includes contractors who undertake specialized activities for general contractors, performing only part of the work required by the general contractor. Activities include painting and decorating, industrial machinery and equipment installation. Thus, even though a substantial number of engineers are employed in this area, it is not believed to be a candidate for IPAD applications.

Engines and Turbines (SIC 3510)

Establishments in this group engage in manufacturing steam turbines, hydraulic turbines, gas turbines (except aircraft), complete steam, gas, and hydraulic turbine generator set units. Major companies included in this group are Babcock and Wilcox Company, Combustion Engineering, Inc., Foster Wheeler Corporation, and Westinghouse-Turbine Division (Westinghouse Electric Company is described under SIC 3600). This manufacturing category involves complex products with a high technology orientation. Therefore, it is believed that these manufacturers could have a significant interest in IPAD.

Babcox & Wilcox Company
(1973 Net Sales $1,063 M; R&D $21.0 M)

This company makes individually engineered complete fossil-fuel boilers, nuclear steam systems and nuclear fuel assemblies for electric utilities and marine application, as well as fossil-fuel boilers for industrial processes and for industrial processing and power generators. Steam generating equipment includes specially engineered accessories and components, such as automatic controls, control and performance computers, heat exchangers, special control valves, and centrifugal pumps.

Other products include individually engineered computers for industrial processes, individually engineered transfer or multistation machines and a line of production tools (grinders,lathes, etc.). Babcox and Wilcox has participated in developing a stack-gas cleaning process and has designed a system for burning municipal refuse to generate steam, one of which is in operation.

Combustion Engineering, Inc.
(1973 Net Sales $1,272 M; R&D $24 M)

Combustion Engineering's power systems group designs and manufacturers fossil and nuclear fueled steam generating systems and components, nuclear fuel, and air-quality-control systems for the electric utility industry. It also designs and makes boilers for a broad range of industrial customers, chemical-recovery systems,and steam generating equipment for Canadian and overseas markets.

Combustion Engineering's engineering group is made up almost entirely of scientists and engineers. It offers design engineering and construction supervision services for the petroleum, petrochemical, chemical, and other process industries.

Foster Wheeler Corporation
(1973 Net Sales $540 M; R&D $4.0 M)

This company's operations consist of design, manufacture, sale and installation of power plant, chemical plant and oil refinery equipment, and of specially engineered industrial apparatus. Steam power plant equipment is made for industrial plants, public utilities and commercial installations.

It provides engineering and construction for process plants, including complete oil refineries, substitute natural gas plants, lube oil processing, fertilizer,and other petrochemical processing plants. In this activity it purchases most of the equipment and materials from suppliers.

Farm and Garden Machinery and Equipment (SIC 3520)

These establishments engage in manufacturing farm machinery and equipment (including wheel tractors) for use in planting and harvesting of crops,

preparing crops for market, or for use in performing other farm operations and processes. In addition to tractors, equipment includes combines, spraying machines, and haying machines. Companies in this category maintained an average of 2.8% of total 1973 sales for R & D. However, as illustrated by the Caterpillar Tractor Company evaluation described elsewhere in this report, the analytical design technology development in this area may not be amemable as yet to IPAD utilization. This might be a function of management philosophy in each company which could be determined through interviews.

One of the largest companies in this category is the Allis-Chalmers Corporation.

Allis-Chalmers Corporation
(1973 Net Sales $1166 M; R&D $35 M)

This company manufactures and markets a full line of farm tractors and related implements, combines, and engines. It manufactures and markets cement processing equipment, and a variety of industrial machinery, pumps, valves, and other nuclear components. It manufactures and markets crawlers, wheel tractors, graders, scrapers, and related equipment. It manufactures and markets lift trucks and other material-handling devices. It manufactures and markets steam-turbine generator units and equipment, in part, as a partner with Kraft-work Union AG of West Germany.

Construction, Mining and Materials Handling Machinery and Equipment (SIC 3530)

Although under the same three digit SIC code, construction-equipment and mining equipment manufacturers will be discussed separately here. (Materials-handling equipment includes elevators, conveyors, etc.,and is not believed to be separately a subject for IPAD application.)

Construction equipment manufacturers primarily engage in making heavy machinery,and equipment such as bulldozers, concrete mixers, cranes, dredging machinery and power shovels. This group averaged 2.8% of sales expended on R&D in 1973. Because of the nature of the product, structural design is an important problem. The design objectives for this type of equipment must be strength and durability and, in some cases, a need for minimum-deformation

structural design in this environment. Structural analysis through finite element methods is an important tool in solving such design problems.

Two large construction equipment manufacturers are Caterpillar Tractor Company and FMC Corporation.

Caterpillar Tractor Company
(1973 Net Sales $3182 M; R&D $122 M)

This company manufactures 274 models of 24 prime products such as tracked and wheeled tractors, wheel dozers, tracked and wheeled loaders, off-highway trucks and bulldozers. It makes engines for itself and others. Its products are used in agriculture, construction, logging, mining, petroleum, industrial warehousing and public service markets. This company was chosen to make an evaluation of IPAD. The results of its study are reported in an earlier section of this report.

FMC Corporation
(1973 Net Sales $1719 M; R&D $43 M)

Products of this conglomerate include construction and mining equipment, defense equipment, and environmental equipment. Specific construction equipment includes power cranes, shovels, draglines, and coal-preparation plants. Defense products include tracked personnel carriers, naval ordnance equipment, and automated guided-missle-launching systems. Environmental equipment includes pollution-control equipment for municipal and industrial water treatment, and air-pollution control equipment.

Oil Field Machinery and Equipment (SIC 3533)

Establishments in this area are primarily engaged in manufacturing machinery and equipment for use in oil and gas fields. This includes design and manufacture of pipe-laying equipment. With the need to drill at increasing water depths on the continental shelf, the design problems for such equipment are becoming more complex. Many of the companies making oil field equipment are also classified under the heavy construction group (SIC 1700). These include the Halliburton Company and Bechtel, which were discussed earlier. One company

operating in the oil field machinery area almost exclusively is the J. Ray McDermott & Company, Inc.

J. Ray McDermott & Co., Inc.
(1973 Net Sales $425 M; R&D $.81 M)

This company provides comprehensive engineering, fabricating and construction services to industry involved in offshore drilling for gas and oil. It produces and installs offshore drilling rigs, making both lay barges and jet burying barges. It maintains a fleet of heavy marine construction equipment.

Metalworking Machinery (SIC 3540)

This category includes companies primarily engaged in manufacturing machines that shape metal by cutting, stamping, pressing, extruding, or other means. Design objectives of these machines are related to their function with an emphasis on low distortions under load. The more complex machine tools are produced in very small numbers and are custom-made to order. However, they are assembled as much as possible from standard parts, so that the complex design capabilities to be provided by IPAD are not considered necessary in their design.

Although such companies may not use IPAD to design their machines, it is clear that this industry is and will be a significant factor in Computer Aided Manufacturing and developing Numerically Controlled Machines. As IPAD is developed and used in design, these companies will probably become involved whenever the interface is developed between integrated design and integrated manufacturing activities.

Two machine tool companies described here are The Sundstrand Corporation and the Cincinnati Milacron Corporation.

Sundstrand Corporation
(1973 Sales $383 M; R&D $16 M)

The company is engaged in design, manufacturing, and sale of an extensive and highly diversified line of equipment, systems, and components requiring a high degree of research, development, and engineering. High-technology products include automated multiunit-machinery centers, and standard machine tools, and nuclear-fuel-handling mechanisms for nuclear-reactor-power-generating systems.

Cincinnati-Milacron Corporation
(1973 Sales $370 M; R&D $11 M)

This company manufactures machine tools, related machinery and products, including milling, grinding, broaching, and drilling machines, automated lines, automated and process control systems, metal working presses, service parts and accessories. It makes a line of process control minicomputers which it uses with its computer controlled machine tools or sells separately.

Miscellaneous Machinery (Except Electrical)
(SIC 3550, 3560, 3580, 3590)

This combined category includes a great variety of special industrial equipment for textile manufacture, wood working, paper and printing. It also includes general industrial machinery such as pumps, ball bearings, compressors and fans, refrigeration and service industry machinery. Apparently, the large number of mechanical engineers reported in Table A-3 for this category is a result of including a large number of small companies making a great variety of products. It does not appear that any particular area in this category would call for the application of IPAD. The two largest companies in this group are Ingersol-Rand Company and USM Corporation.

Ingersol Rand Company
(1973 Net Sales $1038 M; R&D $39 M)

This is one of the largest makers of non-electrical machinery products. It manufactures compressors, rock drills, hoists, turbines, bearings, pumps, pneumatic drills, tunneling and quarrying machinery, hand held-tools, pulp paper, and plastic-forming machinery.

USM Corporation
(1973 Net Sales $634 M; R&D $13 M)

This company makes an extensive line of shoe machinery and related parts, machinery for rubber and plastic products, metal working machinery for milling, boring, grinding, and extruding metals. It produces industrial

adhesives, sealants,and coatings and an extensive line of blind rivets made of various metals.

General Electrical Manufacturing Companies (SIC 3600)

This group includes three large conglomerate makers of electrical equipment: General Electric Company, Westinghouse Electric Company and RCA Corporation.

General Electric Company
(1973 Sales $11,575 M; R&D $330 M)

This company is the leading manufacturer of apparatus, equipment, supplies and appliances for generation, transmission, utilization and control of electrical power. Major categories of business products are consumer--appliances, air conditioners, radio and TV receivers,etc.; power equipment--gas turbines, marine turbines, nuclear-power reactors and fuel; industrial components--adjustable constant speed drives, batteries, communications, computer time sharing, medical systems,etc.; aerospace--aerospace instruments, aircraft jet engines, armament systems, flight controls, re-entry systems; product service--radar, sonar, and space-flight systems.

It maintains research and development laboratories that serve the entire company. The research and development center at Schenectady, New York, conducts studies across most technological disciplines. Other laboratories include aerospace business group labs at Valley Forge, Pennsylvania, and Electronics Laboratory at Syracuse, New York. With a major involvement in nuclear and non nuclear power-generation equipment and turbines of all kinds, it would appear that this company is faced with many complex design problems that could benefit from IPAD.

Westinghouse Electric Corporation
(1973 Sales $5702 M; R&D $146 M)

The company's principal activity is the manufacture and sale of equipment and appliances for the generation, transmission,and control of electricity. It manufactures and sells products ranging from commercial nuclear

power plants to home appliances. It makes steam and gas turbines, all types of electrical equipment used by power companies, nuclear and non-nuclear propulsion equipment for the Navy and marine industry, electrical and electronic instrumentation, and other equipment for the aerospace industry.

It designs, develops, and furnishes nuclear-power-plant equipment and fuel for the generation of electricity. It is prime contractor for the development of the demonstration plant for the Liquid Metal Fast Breeder Reactor. It also designs and manufactures offshore nuclear power plants in a joint venture with Tenneco Inc.

The Westinghouse Central Research Laboratories in Pittsburgh, Pennsylvania, conducts a broad program of basic and applied research, advanced development, and creative engineering in areas of present and future importance to the company. Recent results of these efforts include innovations in water purification, solid-state power conditioning, electrochemical-energy storage. Research is carried out in materials, equipment, processes, and systems of traditional interest to the company and in new technology such as air-pollution monitors and control, coal pretreatment for sulfur removal, high-power gas lasers, and improved waste-treatment techniques, among others.

The RCA Corporation
(1973 Sales $4246; R&D $104 M)

This company pioneered in the development of radio, black and white and color television, and allied products. It manufactures and distributes all types of consumer and commercial electronic systems. Subsidiaries include the National Broadcasting Company. For space, defense, and other Government business, the company designs, develops, and manufactures a variety of military and space electronics equipment for U. S. defense and space programs. Products include radio products and systems, transmission systems, electronic warfare systems, command and control systems, avionics integration, space data and guidance, aeronautical and navigational satellites, and many others.

The Company conducts substantial amounts of basic research in electronics, physics, chemistry, optics, metallurgy, and quantum electronics. It has engaged in development programs for new techniques of image pickup, storage, and display. Substantial research activities are also devoted to lasers and holography and new solid-state devices for use separately or in integrated circuits.

Household Appliances (SIC 3630)

Establishments in this group are primarily engaged in manufacturing household equipment for cooking, regrigeration, and laundry, as well as making other electric housewares and fans. None of this equipment approaches the complexity of industrial machinery. This is reflected in the small number of engineers employed in this field as shown in Table A-3.

The Whirlpool Corporation was chosen from this category to evaluate IPAD on the basis that while home appliances represented a minimum design complexity for possible application of IPAD, it might be useful in designing for this highly competetive, consumer oriented market. A detailed report of the conclusions reached by Whirlpool Corporation are presented in another section of this report.

Whirlpool Corporation
(1973 Net Sales $1636 M; R&D $27 M)

This company manufactures major home appliances, some commercial products, and residential products featuring central air conditioners and furnaces. It markets gas and laundery equipment, gas and electric ranges, refrigerators, air conditioners, furnaces,and other appliances under its own brand name. Many appliances are made for the Kenmore and Coldspot brand names sold by Sears such as gas and electric laundry equipment, trash compactors, vacuum cleaners, refrigerators, freezers, air conditioners,and dehumidifiers.

The Singer Company
(1973 Net Sales $2527 M; R&D $36 M)

Approximately 59% of this company's 1973 sales was sewing machines. Other consumer products include furniture, power tools, floor care,and home-knitting machines. It also markets gas metering and control systems for the natural gas industry. About 10% of its 1973 sales or $253 M was in information systems and aerospace electronics. It markets computers and point-of-sale equipment. Aerospace products include Doppler navigation equipment, a/d converters, stellar-inertial guidance systems and others.

Radio and T.V. Communications Manufacturing (SIC 3650, 3660)

As reported in Table A-3, no distinction was made between radio and TV receiver manufacturers and makers of communication equipment. The bulk of engineers in this category are electronic as would be expected. However, a significant number of computer specialists as well as mechanical engineers were included. The principal areas of interest with regard to IPAD applicability is the communications equipment manufacture. This may be wire telephone and telegraph equipment, or radio or television transmitting, signaling, or detection equipment.

Telephone and telegraph apparatus includes all central station switching equipment in addition to telephones, teletypewriters, and other simple equipment. The largest manufacturer of telephone equipment is the Western Electric Corporation as a subsidiary of A. T. & T. It's 1973 Sales were $6551 M and R&D was $560 M. Research by this company in switching equipment and computers has been well-publicized. However, it is not possible to decide whether the IPAD system would be useful in this area.

The electronic communication equipment manufacturers, in addition to radio and TV broadcasting equipment, make electronic-field detection devices, light- and heat-emission-operating apparatus, object-detection devices, navigational electronic equipment, and aircraft-and missile-control systems. Complexity of avionics systems and variety of performance trade-offs in electronics systems makes design problems for such systems an interesting candidate for IPAD applications.

Two companies making electronic systems are E-Systems Inc. and Collins Radio. Other companies making such devices include the companies in SIC 3600 described earlier.

E-Systems Inc.
(1973 Net Sales $166 M; R&D $3 M)

E-Systems developed from LTV Electrosystems Inc. when it was divested from LTV Corporation in 1972. The company is primarily engaged in design, development, production, and servicing electronic systems and products for Department of Defense, NASA, and other Government agencies, general industry,

and foreign governments. Products and services include electronic systems, subsystems components and equipment. These are used to carry out reconnaissance, surveillance, and intelligence, command, control, and communications functions; and navigation guidance and control.

Collins Radio Co. (Subsidiary of Rockwell International)
(Sales figures not available)

Collins Radio designs, manufactures, and services electronic communications systems and equipment used in government, commercial and business aviation. Principal market for Collins products include avionics, government telecommunications, microwave, and communications switching.

Motor Vehicles and Motor Vehicle Equipment (SIC 3710)

This group includes manufacturers of motor vehicles, including passenger cars, trucks, and buses. It also includes makers of truck and bus bodies and all related parts and accessories. Outside of the aircraft industry, it would appear that the automobile industry will be the industry most able to make use of the IPAD capability. This is based on a number of observations: (1) the evaluation of IPAD applicability by Ford Motor Company, (2) General Motors has been developing and successfully using an integrated design system, (3) the big-three automobile manufacturers invested four times more in R&D ($2012 M) in 1973 than the 9 largest aircraft companies combined* ($510 M). Moreover, the automobile industry had a higher R&D as a percent of sales than any aircraft company except for United Aircraft Corporation. Curiously, the number of engineers and technical personnel shown in Table A-3 for the automotive area is less than 1/3 that of the aircraft industry.

* Boeing, General Dynamics, Grumman, Lockheed, Martin Marietta, McDonnel-Douglas, Northrop, Rockwell International, United Aircraft Corporation.

General Motors Corporation
(1973 Net Sales $35798 M; R&D $945 M)

This is the worlds largest automobile manufacturing company. It primarily engages in manufacture, assembly, and distribution of motor-driven products for the transportation market. Through various divisions and subsidiaries, it makes automotive products, consisting of passenger cars, trucks, and coaches and major components for these, as well as parts and accessories. It also makes substantial amounts of components and accessories sold to other manufacturers of automobiles, trucks, and coaches.

General Motors is a large maker of diesel engines for trucks, construction, lumbering, mining, and petroleum equipment. It makes gas turbines for military and commercial aircraft, and industrial gas turbines for electricity generation, construction equipment, marine, and transportation applications.

General Motors conducts research and development at its technical center at Warren, Michigan. Research is directed toward improving product line. Significant recent research has been directed toward meeting emission standards and improving power plant efficiency. A substantial investment has been made in development of the rotary engine.

The company began research into computer-aided design in the late 1950's and early 1960's, and has developed an integrated design program with substantial graphics capability.[7] It has been demonstrated that the system greatly increased the productivity of the designer.[8] However, an exceedingly important lesson was learned that the development and implementation of automated design methods must be painstakingly planned and carried out.[9] The way in which the new technology is introduced into the design environment, may spell the difference between success and failure of an IPAD implementation.

The Ford Motor Company
(1973 Net Sales $23,015 M; R&D $826 M)

This is the second ranking manufacturer of automobiles. In addition to its line of automobiles, it manufactures wheel-type tractors, farm equipment, home appliances, and electronics equipment. However, the manufacture, assembly and sale of cars, trucks, and related parts and accessories constituted 91% of its sales volume in 1973.

The company is highly integrated in that it produces substantial portions of the steel and iron required in its manufacturing operations. It manufactures all of its requirements for gasoline engines, most of its glass, most of its transmissions, body stampings, trim sets, frames, radiators, and other parts and accessories.

The Ford Motor Company conducts research and development at its Dearborn research center, primarily directed toward improvement of its products and development of new products. In 1973, Ford invested a larger percent of sales in R&D than any other American automotive manufacturer. This is one of the companies selected to conduct an evaluation of IPAD applicability. The results of this evaluation is described in an earlier section of this report.

The Chrysler Corporation
(1973 Net Sales $11,774 M; R&D $247 M)

The Chrysler Corporation is the smallest of the "Big Three" in terms of sales and R&D investment. Like GM and Ford, the bulk of Chrysler's business is in manufacture of automobiles, trucks, parts and accessories. However, it also makes tractors, outboard motors, air conditioning and heating equipment, and defense-space products, including tracked and wheeled vehicles and space boosters.

As with other automotive manufacturers, R&D is being directed toward achieving better fuel economy through trying to develop lighter structures by design and use of lightweight metal substitutes (aluminum, magnesium, plastics). They also are designing for lower wind resistance and friction.

A considerable effort is being expended in research on emission controls, on stratified charge engines, and on other types of engine designs.

American Motors Corporation
(1973 Net Sales $1739 M; R&D $33 M)

Although small by automotive standards, AMC is still a very large corporation, with sales and R&D expenditures larger than all but five of the aerospace companies. Thus, it is still a viable candidate to consider application of IPAD. The company's product is virtually all in automobiles and motorized vehicles, parts, and accessories, although it has a subsidiary making injection molded plastic parts for non-automotive applications.

As the smallest of the major automotive manufacturers, AMC has tried to grow by responding more quickly to the changes in the automobile market than its larger competitors. Thus it could be quite interested in utilizing integrated design programs to further reduce its response time. Balancing this fact would be the smaller resources that it would have to invest in developing such a system.

International Harvester Company
(1973 Net Sales $1192 M; R&D $110 M)

The company is a leading producer of farm machinery and tractors as well as of motor trucks and construction equipment. Its principal products include motor trucks and service parts, agricultural implements, wheel-type tractors, crawler tractors,and allied construction equipment, pig iron and steel products. Its Solar Division produces gas turbine engines for electric power generation and other uses, and components for aircraft and missiles.

Its research and development activities include product improvement and new product development. It is conducting significant research in development of gas turbines.

Ship and Boat Building and Repair (SIC 3730)

This group includes companies primarily engaged in building and repairing all types of ships, barges and boats. As shown in Table A-3, this group included nearly 12,000 engineers and technical workers, primarily mechanical electronic and industrial engineers. Design of ship structures is clearly very complex and could benefit from integrated design programs. This is recognized by the Naval Ship Research and Development Center, which is developing the COMRADE System. It would seem that this system could be used for design of all varieties of ships once it is developed. It is not possible to determine at this time whether it would be useful to incorporate the various analysis modules and the data bases being developed into an IPAD system for ship design.

Telephone Communications (Wire and Radio) (SIC 4810)

This category includes utilities furnishing point-to-point communication services by telephone. Since manufacture of telephones and switching equipment was covered in SIC group 3650, category 4810 applies to providing services to the user. In this area, American Telephone and Telegraph Company has a dominant position with 1973 sales of $23,527 M and R&D of $170 M. Western Electric is the manufacturing subsidiary of AT&T and furnishes essentially all of its equipment. Its activities were described earlier. The second largest American telephone company is General Telephone and Electronics with 1973 sales of $5105 M and R&D of $95 M. About half of this was telephone operations. There are a number of smaller telephone companies with revenues ranging from $15 M to $2000 M.

In providing interconnection service to millions of customers, the American telephone system must solve enormously complex systems problems. The telephone companies have developed specialized computer-controlled switching devices, systems-control computers, and data-base storage techniques in providing this service. With such systems in place and growing, these companies may not have any need for the IPAD system, which is not being directed toward their specific needs.

Electric Services (SIC 4910)

This category includes establishments engaged in the generation, transmission and/or distribution of electricity. As shown by Table A-3 those electric industries employ a substantial number of engineers, of which electro-engineers are the largest group. In the problem of providing service to customers with existing capacity, the electric utilities are in somewhat the same position as the telephone companies in that they have developed specialized equipment and procedures for taking care of their problems. However, the electric companies must build the capacity to generate the electricity that they provide. For the most part, a company will have a generating plant built by contractors of SIC 1600 class. It may be, however, that some companies might find an IPAD system useful for conducting preliminary design studies. Perhaps the best contact for the electric industry is the Electric Power Research Institute, at Palo Alto, California, which was recently established

to conduct research into industry problems for the entire electric power industry.

Computer and Data Processing Services (SIC 7370)

This group includes establishments engaged in providing services in computer programming, systems design and analysis, and other computer software. Companies in this group may become an important element of the non-aerospace application of IPAD, since they can provide computer-related technology that a company may be lacking in trying to apply IPAD. A number of companies in this group specialize in data base technology, which is an important part of IPAD system applications.

Most companies in this category are quite small (annual sales of under $50 M) and would probably not be capable of developing an IPAD applications package except under contract to a user organization. The largest organization in this group is the Computer Sciences Corporation.

Computer Sciences Corporation
(1973 Net Sales $147 M; R&D $2.22 M)

This company provides, principally on a contractual basis, a wide range of services utilizing its capabilities in analysis, design and implementation of computer and communications systems. Its services include design of software systems, translation of complex scientific and engineering problems into forms suitable for solution by computer, design of data systems for scientific applications,and development of mathematical models and management information systems.

The company offers high-level engineering services in the design of conventional and satellite communications services. It provides consulting services in fields of environmental sciences, regional planning, oceanography, and geophysics management. It develops proprietary computer based products and services for marketing to industry. These range from packaged computer applications programs to *INFONET*, a nationwide remote computing system for information processing and scientific computation.

Business Management Consulting (SIC 7392)

This category includes establishments providing a variety of general or specialized management consulting or public relations services on a contract or fee basis. It does not include professional design and related consultant engineering (SIC 8910) or computer-related services (SIC 7370). Examples of the types of activities included in this group are business analysis, business economics, city planners except for professional engineers, efficiency experts, lobbyists, market analysis, operations research (except for computer systems) and opinion research. Except for city planning, these activities are judged to be low-probability users of IPAD technology. The possible use of IPAD in urban and regional planning is discussed elswhere in this report.

Research, Development,and Testing Laboratories (SIC 7391, 7397)

These categories include establishments engaged in research and development or testing on a contract or fee basis. as in the case of companies providing computer and data processing services, companies in this group, for the most part, do not have sufficient resources to develop IPAD applications systems on their own. However, they will provide a vital interface to the industrial community in helping develop applications packaged under contract to industrial users.

The largest company in this group is the Planning Research Corporation.

Planning Research Corporation (1973 Net Sales $98 M; R&D $.04 M)

This company provides a variety of services to industry and government on a contract basis. Somewhat over half of its revenues derived from work for commercial clients. Approximately 39 percent of its activities were in systems analysis and data processing, 19 percent in management consulting and market research, and 42 percent in planning, architecture,and engineering. It performs the design engineering function at Kennedy Space Center for the space shuttle program and other launch missions. A partial list of its

activities includes the following: It is developing a computerized regulatory information system for the Federal Power Commission. It is preparing specifications and final design plans for the Iranian Port of Bandor Abbas on the Persian Gulf, providing design and construction management of a crude-oil terminal at the Port of Rotterdam,and supervising construction of off-shore terminals for oil tankers in Iran, Canada, and the Bahamas. It is providing ocean engineering, design and testing of a mammouth breakwater for the New Jersey Public Service Electric and Gas company's proposed floating nuclear power plant. It is conducting a planning study of the Sacremento, San Francisco Bay Area travel corridor. It is assisting Federal agencies and a number of cities in studies relating to environmental protection, urban and regional transportation,and/or energy use and conversion.

Engineering and Architecture Services (SIC 8910)

This category includes those establishments that primarily provide services of a professional nature in the fields of engineering and architecture. Many other establishments that carry out engineering and design activities as a part of their construction of manufacturing activities are described under other categories. These include the SIC 1500 construction firms, steam, gas and hydraulic turbine firms (SIC 3510), and the oil field machinery and equipment firms (SIC 3533). In contrast to these firms, some of which have total annual sales of one billion dollars or more, firms providing exclusively AE services are much smaller, with only three firms reporting more than $50 M sales. Nevertheless, total reported design billings were $2.5 billion for 1973. [10]

The largest firm in terms of total 1973 billings apparently was the Gilbert/Commonwealth Companies and Sargent and Lundy Corporation. The Ammann Company was one of the companies chosen to make evaluations of the IPAD system.

Gilbert/Commonwealth Companies

This a privately owned company and so does not report its earnings. It was estimated by Engineering News Record[10] that Gilbert's 1973 annual billings were somewhat in excess of $50 M. Gilbert provides engineering and architecture services for a variety of fields such as nuclear and fossil-fueled power plants, energy-transport systems, industrial processes, and municipal environmental systems.

Ammann and Whitney

The Ammann and Whitney Company provides engineering services in the design of buildings, bridges, highways, airports, and other types of heavy construction. Since the company is privately owned, it does not disclose its annual billings volume. This was estimated by Engineering News Record to be between $7.5 M and $10 M in 1973.[10]

The engineering services offered by Ammann and Whitney include preliminary investigations, master planning engineering and economic feasibility studies, project planning reports, research and development, and construction supervision. These services have been provided for various projects such as highways, bridges, airports, mass transportation facilities, commercial and industrial buildings, antennas, harbors, and military installations.

Examples of projects that this company has been involved are:

(1) Bridges--prepared preliminary feasibility report final contract plans and supervised construction of the Verrazano-Narrows Bridge in New York Harbor.

(2) Airports--prepared master plan, final design, contract plans and supervised construction of Dulles International Airport.

(3) Provided structural design for the Albany Mall office tower (42 stories) and other buildings in the Albany South Mall for the State Government of New York.

(4) It provided final contract plans for the initial section of the Washington, D.C., subway.

A report of this company's evaluation of IPAD applicability in the design engineering area is presented in an earlier section of this report.

Miscellaneous Professional Services (SIC 8920, 8990)

This group includes establishments primarily engaged in noncommercial research into and dessimenation of, information for public health, education, or general welfare. It includes noncommercial scientific agencies such as Battelle Memorial Institute and Stanford Research Institute, as well as agencies that operate primarily on funds from endowments, contributions,or grants.

Battelle Memorial Institute (1973 Sales $99 M)

This company is the world's largest contract research organization, with two laboratories in the United States at Columbus, Ohio and Richland, Washington, and two laboratories in Europe: Geneva, Switzerland and Frankfurt, Germany. Battelle was established under the will of Gordon Battelle as a not-for-profit organization, as one of the pioneers of contract research. Its fields of activities span essentially all fields of modern technology and it conducts research under contract to both governmental and industrial organizations. Fields of study include advanced materials and processes, engineering systems and technology, environmental quality, management of natural resources, social systems, information systems, education,and many others.

Stanford Research Institute

This Institute conducts problem-solving research in the physical and life sciences, radio sciences,information science, urban and social systems, economics, management sciences,and engineering systems. It was founded under the auspices of the Stanford University and a group of west coast industrialists, but it is now a completely independent self-contained research organization. Stanford operates as a nonprofit corporation, with income derived almost entirely from conducting contract research for clients. Its reported revenue in 1970 was over $65 M. Later revenue figures were not available.

Conglomerate Corporations (SIC 9997)

This group includes a number of large conglomerate corporations whose operations span a broad range of activities so that they are not listed in single classifications. This category includes many famous large corporations such as Gulf and Western, International Telephone and Telegraph, LTV Corporation, Litton Industries, Teledyne, Inc., Tenneco, Inc., and Textron, Inc. We will discuss here Tenneco, Inc., and Teledyne, Inc.

Tenneco, Incorporated
(1973 Net Sales $3910 M)

This company is engaged in oil production, refining, and marketing; natural gas producing and marketing; chemical manufacturing; shipbuilding, machinery and equipment manufacturing; automotive parts manufacturing, and airport support activities. Operations of interest for possible IPAD applications include shipbuilding, through its control of the Newport News Shipbuilding and Dry Dock Company and the subsidiary J. I. Case Company, which manufactures construction and farm equipment.

Teledyne, Incorporated
(1973 Net Sales $1455 M; R&D $23 M)

This company operates five lines of business: industrial products and services, aviation and electronics, specialty metals, consumer products and services, and insurance and finance. In its industrial products area, it manufactures industrial engines for automotive and stationary applications, machine tools, and automated manufacturing equipment. It conducts geophysical exploration and off-shore drilling on a contract basis for oil companies. In its aviation and electronics activities, the company designs and manufactures a variety of unmanned aircraft used by the military services. It produces gas turbines for both manned and unmanned aircraft. It manufactures computer, radar, and other electronic systems for aircraft navigation, control, and communications.

APPENDIX B

DESCRIPTION OF THE IPAD PRESENTATION MADE TO SELECTED INDUSTRIES

One fundamental objective of this research contract was to obtain the direct evaluation by selected companies of the applicability of the IPAD system to their design problems. To accomplish this, it was necessary that a careful and detailed description of the IPAD system be presented to the research management of these companies. In addition to this presentation, each of the companies was given a copy of the executive summaries of the contractors' studies made by General Dynamics/Convair Aerospace Division and by the Boeing Commercial Aircraft Company.[1,2]

Those companies that expressed interest in studying the IPAD system were furnished copies of the complete set of feasibility reports [1,2] for detailed study.

It was recognized that the initial presentation of the IPAD story to each company was vitally important as the basis on which the company management might decide whether to make an in-depth study of IPAD. Therefore, the initial task of Battelle's research contract was the development of this presentation. A team of Battelle scientists and management personnel was assembled, including those most familiar with the problems and people of the selected companies. With the help of this team, a presentation was formulated which was then reviewed with the Langley Research Center. As a result of this review, a number of changes were suggested in the presentation to make it more accurately reflect the IPAD development program at that time (April, 1974). Finally, as a result of further refining by the Battelle team, a presentation was developed that, it was believed, met the dual objectives of accurately representing NASA's development plans for IPAD and relating the planned IPAD system capabilities to the design problems of each company. After giving the presentation to six companies and evaluating responses by each company to the presentation, it was concluded that these objectives had been achieved.

The results of the evaluations made by each company were described in the main sections of the report. These evaluations were based partly on the presentation by Battelle and partly on studying the feasibility contract reports. Although the Battelle presentation as well as the feasibility studies accurately represented the status of IPAD planning at the time each was prepared, NASA's plans have evolved and will probably continue to evolve during the course of the IPAD development program. Therefore, to provide the proper perspective for the evaluations made by the various companies, a short description is given here of the Battelle presentation. Together with the feasibility contract studies, [1,2] this documents the material used by each company for its evaluation of IPAD.

The presentation utilized a number of slides. However, an important and effective part of the presentation was the movie developed by General Dynamics.

In the following, the slides are given with a very short discussion of each on facing pages.

Slide 1

The National Aeronautics and Space Administration has been considering the development of a major computer software system called IPAD. This system, as planned, will provide the team designing complex structures with a significant design tool. This program is expected to greatly assist the team solve its data communication problems, and promote the interdisciplinary interaction between members of the design team. It is also expected to help in managing the design process. Analysis modules will be included for carrying out analysis of the various facets of the design problem.

The planned IPAD development program is expected to begin in FY75 and is planned to take about 6 years at a total cost of $9,000,000.

IPAD

INTEGRATED PROGRAMS FOR AEROSPACE-VEHICLE DESIGN

- ✓ SOFTWARE SYSTEM
- ✓ A TOOL TO ASSIST A LARGE DESIGN TEAM WITH
  - DATA COMMUNICATION
  - MULTIDISCIPLINARY INTERACTION
  - ANALYSIS
- ✓ DEVELOPMENT TO BEGIN IN FY 75
  - 6 YRS,$9M

Slide 2

This slide shows the outline of the Battelle presentation,

OUTLINE

SUMMARY OF IPAD DEVELOPMENT PROGRAM

- IPAD Development Plan
- Initial Studies
- IPAD Critiques

DESCRIPTION OF THE PLANNED IPAD SYSTEM

- Overview
- Executive
- Data Base Manager
- Utilities

PRESENTATION OF IPAD MOVIE

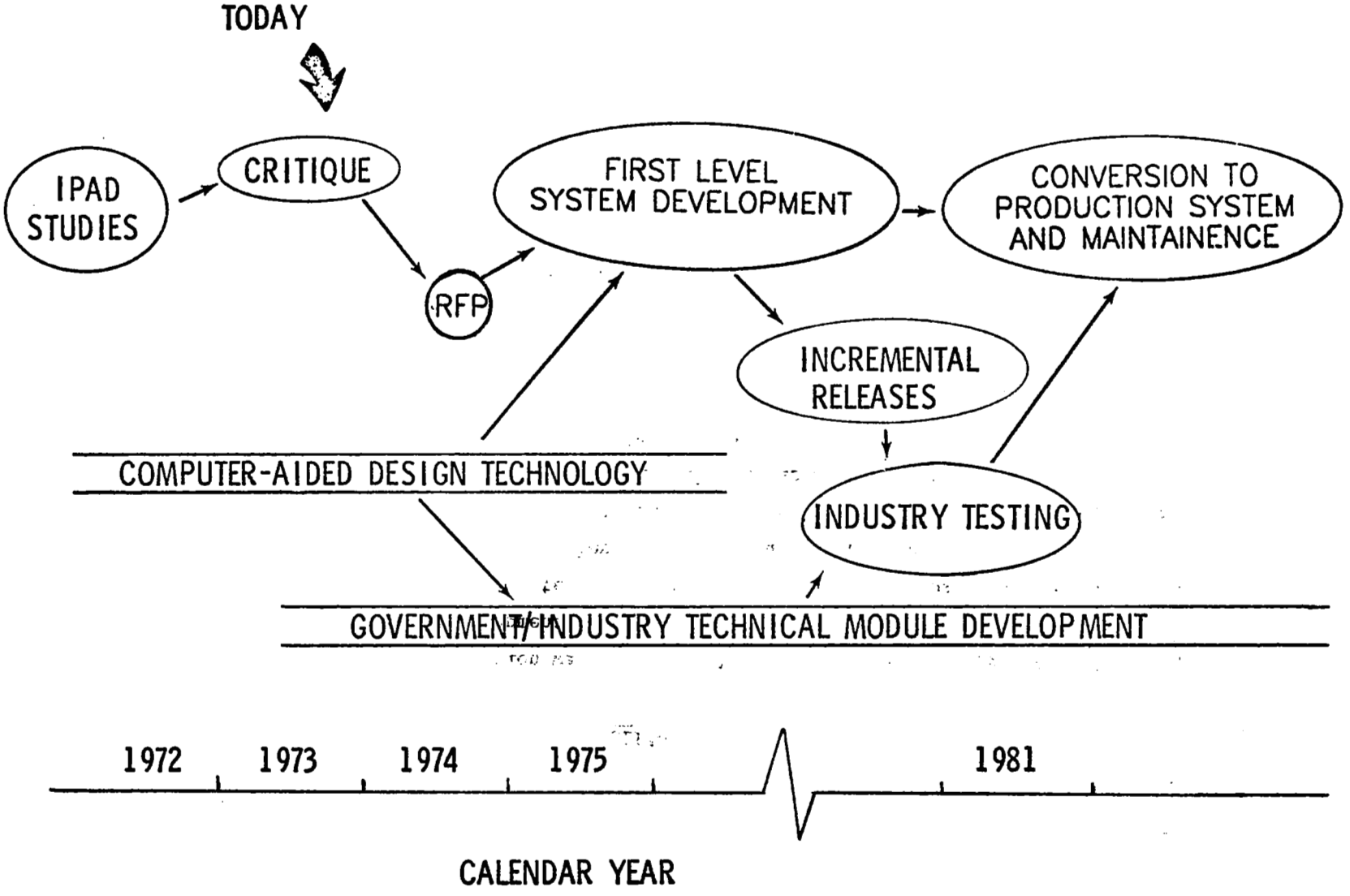
PROJECTED IPAD BENEFITS

SUGGESTIONS FOR AN IPAD EVALUATION

Slide 3

At the time the presentation was made, the NASA plan for developing IPAD called for issuing the RFP for the IPAD development late in 1974. The IPAD feasibility studies have been completed and critique of the IPAD system by Aerospace and computer industries have just been completed. It is planned that the first level of system development would proceed over a number of years with several incremental releases, the first one taking place approximately 2 years after awarding the contract. It is planned that a period of program maintenance will follow the issuance of the first release version of IPAD.

IPAD DEVELOPMENT PLAN



Slide 4

Beginning in May, 1973, two contractors were funded to develop detailed definition of the IPAD system and to investigate whether the system, so defined, is feasible for implementation on current computer machines. As the result of these studies, the contractors(Boeing Commercial Airplane Company and General Dynamics/ Convair Aerospace Division) independently concluded that the planned IPAD system was feasible and would be highly beneficial for the design of aircraft. In the process of designing the IPAD system, the contractors conducted analyses of the design process for aerospace systems, and tried to estimate possible benefits from using the system. Voluminous reports were prepared describing, in detail, the studies carried out and the projected IPAD system design [1,2].

INITIAL STUDIES

- **OBJECTIVES**

  Conceptual Definition
  Feasibility Investigation

- **TWO INDEPENDENT STUDIES CONTRACTED**

  Boeing
  General Dynamics

  $625K Total, 17 Months Duration

- **RESULTS**

  Analyzed Design Process For Aerospace Vehicles
  Characterized Software System
  Assessed Benefits And Spinoff

Slide 5

The feasibility study reports developed by Boeing and General Dynamics were studied by the aircraft and computer manufacturing companies shown on Slide 5. The major conclusions of these reviewers were that IPAD development was indeed feasible, and that use of the system would save time and money in carrying out complex design studies. They also agreed that developing IPAD was a formidable task and that Government sponsorship was needed to insure that a system was developed.

IPAD CRITIQUES

AEROSPACE AND COMPUTER INDUSTRIES

(OCT.73– MAR.74)

MCDONNELL DOUGLAS

LOCKHEED

GRUMMAN

ROCKWELL INTERNATIONAL

IBM

CONTROL DATA

UNIVAC

NON–AEROSPACE INDUSTRIES

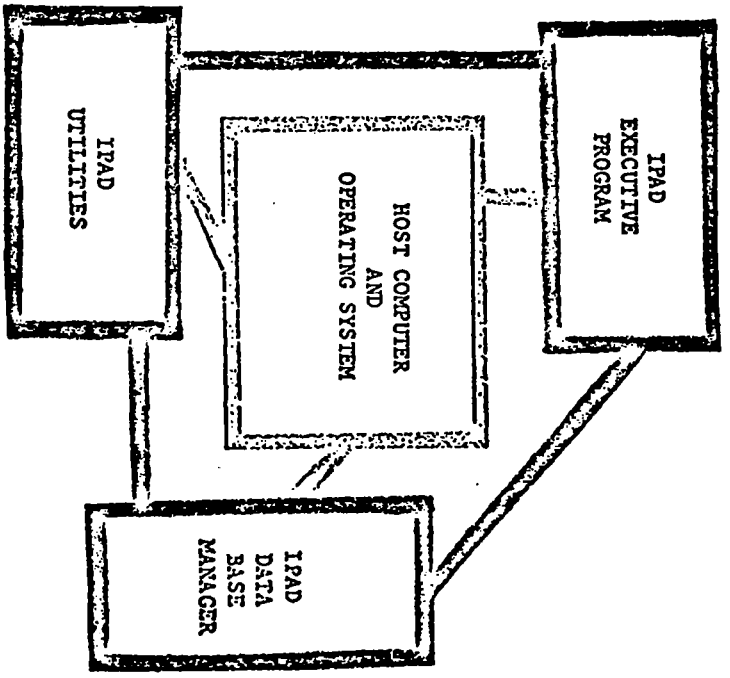
(NOV.73– APRIL 75)

BATTELLE

Slides 6
(A set of overlaid slides)

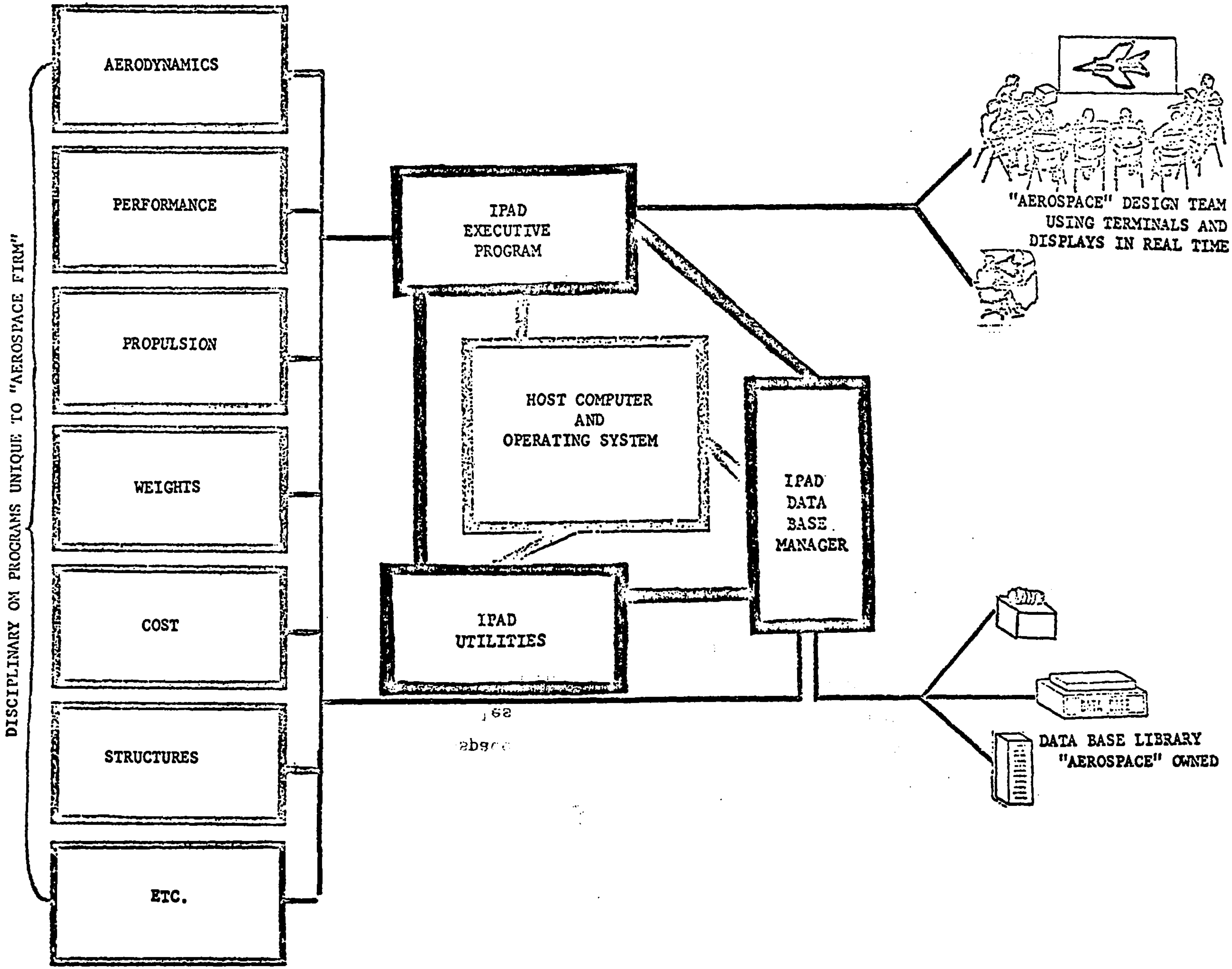
Slide 6a

The IPAD system, planned for development by NASA, consists of 3 main elements--the Executive, the Data Base Manager, and the set of IPAD utilities. This system interfaces with the host computer operating system and essentially turns it into an engineering-oriented interactive design system. As planned, this IPAD system will be very general and could be used to support a great variety of design studies.


IPAD
EXECUTIVE
PROGRAM
IPAD
UTILITIES
HOST COMPUTER
AND
OPERATING SYSTEM
IPAD
DATA
BASE
MANAGER

Slide 6b

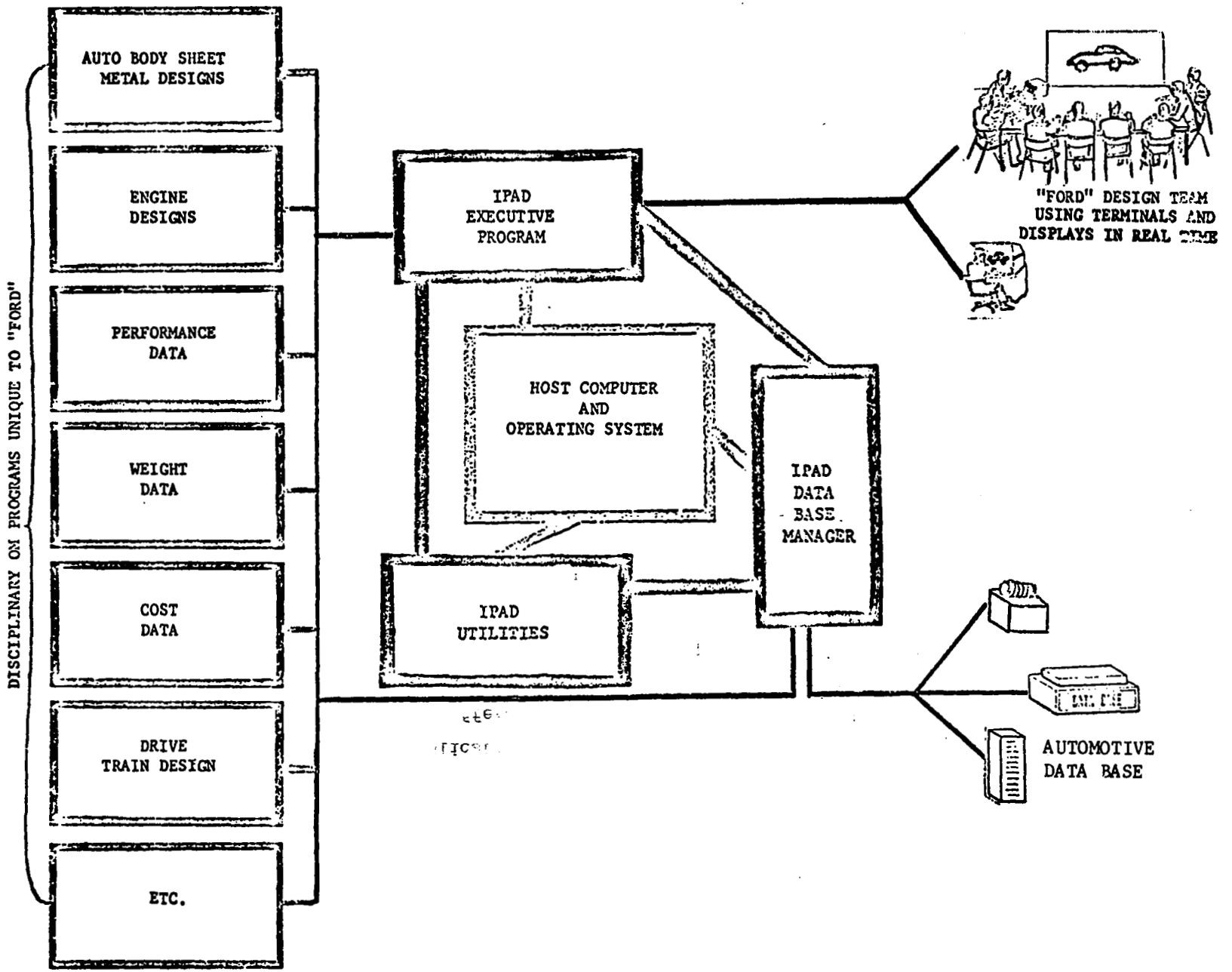
In the design of an aerospace vehicle, the design team (including the design management) will access the set of analysis modules on the left through the IPAD Executive. These modules will be supplied data, as required, from the design data base, by the Data Base Manager. The set of IPAD utilities supports both the Executive and the Data Base Manager in executing their tasks.


DISCIPLINARY ON PROGRAMS UNIQUE TO "AEROSPACE FIRM"
AERODYNAMICS
PERFORMANCE
PROPULSION
WEIGHTS
COST
STRUCTURES
ETC.
IPAD EXECUTIVE PROGRAM
HOST COMPUTER AND OPERATING SYSTEM
IPAD DATA BASE MANAGER
IPAD UTILITIES
"AEROSPACE" DESIGN TEAM USING TERMINALS AND DISPLAYS IN REAL TIME
DATA BASE LIBRARY "AEROSPACE" OWNED

Slide 6c

For a non-aerospace application, such as the design of an automobile, it is clear that different analysis modules and a different design data base will be required than for aerospace design. Once these items are developed, the automotive design team could use the IPAD system in much the same way for the design of an automobile as it is to be used in the design of an aircraft.

As indicated in the Slide, the central IPAD software system would be the same in both aerospace and non-aerospace versions and would support both types of design activities.


AUTO BODY SHEET METAL DESIGNS
ENGINE DESIGNS
PERFORMANCE DATA
WEIGHT DATA
COST DATA
DRIVE TRAIN DESIGN
ETC.
DISCIPLINARY ON PROGRAMS UNIQUE TO "FORD"
IPAD EXECUTIVE PROGRAM
HOST COMPUTER AND OPERATING SYSTEM
IPAD UTILITIES
IPAD DATA BASE MANAGER
"FORD" DESIGN TEAM USING TERMINALS AND DISPLAYS IN REAL TIME
AUTOMOTIVE DATA BASE

Slide 7

This slide and the next two slides show some examples of the functions planned for incorporation into the three main components of the IPAD system. These lists of functions are not complete, but are intended to convey an impression of the purposes planned for each part of the system.

As shown in Slide 7, the function of the Executive is to receive the commands of the user, to interpret them, and to carry out the requested actions by interfacing with the host operating system, or by calling other parts of the IPAD system. The Executive will have many self-contained "creature comforts" to make the IPAD system easier to use, such as those shown. It can also call for specific routines from the utilities section shown on the next slide.

IPAD EXECUTIVE

OVERALL SOFTWARE CONTROL

Executive Functions
Interface to Host Operating System

INTERACTIVE TERMINAL SUPPORT

Command Language
Text Editor
Management Functions

USER SUPPORT

Prefabricated Procedures
Library Search
Program Integration Checks

Slide 8

The IPAD utilities section contains general purpose utilities to help implement the Executive control functions. Other general utilities include a very general graphics package and standard mathematical routines. Special purpose utilities will also be included to provide various interfaces between the data base and the analysis modules or the Executive. This section will also include various aids for adding user's analysis modules, such as provisions for converting input-output formats of the analysis module into the IPAD data language. Many diagnostics will be provided to help the user detect errors in his modeling attempts.

IPAD UTILITIES

GENERAL PURPOSE UTILITIES

CONTROL FUNCTION IMPLEMENTATION

GENERAL GRAPHICS PACKAGE

STANDARD ROUTINES

- Optimization
- Statistics

SPECIAL PURPOSE UTILITIES

INTERFACE WITH DATA BASE MANAGER

AIDS FOR INSERTING MODULES INTO IPAD

DIAGNOSTICS

Slide 9

The Data Base Manager is perhaps the most complex section of the IPAD system, and the most difficult to develop. It will have to provide many control functions, with a data definition language, and a data manipulation language. Provision for security of the software from unauthorized access will be one of the necessary developments. The problems associated with providing computer data base security are currently receiving considerable study, and it is generally agreed that absolute data security may be extremely difficult to guarantee.

Other data base management activities will provide the design management team with many aids for program planning and scheduling, and for generating various project reports.

It is planned that there will be a variety of types of data bases that may be implemented on various types of storage devices as appropriate. The data may range between that used by a single individual to general data that may be used by everyone. Historical data libraries may be stored in off-line devices for possible recall to trace the history of a particular design process. Control of these various types of libraries will require considerable complexity in the Data Base Manager.

DATA BASE MANAGER

OVERALL CONTROL FUNCTIONS

Data Definition Language
Data Manipulation Language
Security Control Software
Data Structure Transformations

PROJECT MANAGEMENT

Planning
Communicating
Reporting

TECHNICAL DATA BASE DICTIONARIES

Community Data
Historical Data
Standard Data
Individual User Data

The IPAD Movie

The IPAD movie was developed by the General Dynamics/Convair Aerospace Division to dramatically demonstrate many of the planned features of the IPAD system. The movie is particularly effective in indicating the planned open-endedness of the system and how a design project management team will directly use the IPAD system for real-time project management. The movie also effectively demonstrates how individual engineers will use IPAD for carrying out design functions through interactive graphics terminals. By dynamically demonstrating many of the operations involved in an IPAD design process, the movie has an impact that could not be provided by a standard slide talk.

Slide 10

An important phase of the IPAD feasibility studies carried out by Boeing and General Dynamics was the study of possible benefits that may be obtained from application of IPAD to the design of aircraft. The conclusions of both contractors was that utilization of IPAD would drastically reduce both the time and cost of designing aerospace vehicles.

As shown on the slide, other benefits that could accrue from using IPAD include obtaining improved designs. Project management using IPAD would have greater control of the design process so that problems could be anticipated and solved more quickly, with the result that the final design can be achieved within the scheduled time. It is further believed that utilization of IPAD will enable greater attention to be given to designing parts for ease of manufacture at the same time that they are designed to perform their required function. Each integration of function and manufacturability, together with the increased attention given to improving the design, should lead to a reduced need for design changes during production.

PROJECTED BENEFITS

- **IMPROVED DESIGNER PRODUCTIVITY**
  - SHORTER TIME
  - IMPROVED DESIGN
  - INCREASED CONFIDENCE

- **BETTER VISIBILITY FOR PROJECT MANAGEMENT**

- **REDUCED RISK AND COST**
  - DESIGN ON–TIME
  - PARTS DESIGNED FOR EASE OF MANUFACTURE
  - FEWER DESIGN CHANGES DURING PRODUCTION

Slide 11

The approach that an individual company might take to evaluate the applicability of IPAD to its design processes can vary greatly, depending on the products of the company and its particular design problems. However, Battelle believed that some general suggestions for making such an evaluation would be helpful to those companies that would decide to investigate IPAD.

Each of the contacted companies that expressed an interest in evaluating IPAD were furnished complete copies of the feasibility studies.[1,2] Since these studies were devoted to the application of IPAD to aerospace design, it was necessary for the non-aerospace designer to study the reports and to make a mental transformation of the IPAD system objectives from an aircraft design to his company products.

It was believed that this could be best done if the designer concentrated on a single product initially and made an evaluation of whether IPAD could help in its design. Once an understanding, or understanding of the IPAD impact on a single product design was attained, it would then be easier to evaluate whether IPAD could help in design of other company products.

For those companies that carried out the IPAD evaluations, it was requested that follow-up meetings would be held to discuss the conclusions reached. After listening to Battelle's presentation and studying the Executive summaries of the feasibility studies, four companies made evaluations of the IPAD system. The results of these evaluations are described earlier in the report.

SUGGESTIONS FOR AN IPAD EVALUATION PROCEDURE

- STUDY IPAD REPORTS
- EVALUATE APPLICATION OF IPAD TO A DESIGN PROBLEM
  - Select a Specific Design Problem
  - Consider a Possible IPAD System Design for the Problem
  - Estimate Effort to Develop Needed IPAD Design
  - Estimate Possible IPAD Improvement of Design Productivity
- CONSIDER OTHER DESIGN FUNCTIONS FOR WHICH IPAD MIGHT BE USED
- EVALUATE WHETHER USING IPAD COULD BE COST-EFFECTIVE FOR YOU
- MEET WITH BATTELLE (OR NASA) TO DISCUSS YOUR CONCLUSIONS

1. Miller, R. E., Jr., Southwell, A. W., and Redhed, D. D., "Feasibility Study of an Integrated Program for Aerospace Vehicle Design (IPAD)", NASA Report Numbers CR-132391-7, by Boeing Commercial Airplane Company, (September 21, 1973).

2. Garrocq, C. A., Hosek, J. J., et al., "Feasibility Study of an Integrated Program for Aerospace-Vehicle Design (IPAD) System, Volumes I through VI, NASA Report Numbers CR-132401-6, by General Dynamics/Convair Aerospace Division (August 30. 1973).

3. "Standard Industrial Classification Manual," U. S. Government Printing Office, pp. 649, (1972).

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10. "The ENR 500", Engineering News Record, pp. 57-70, (May 16, 1974).

*U.S. GOVERNMENT PRINTING OFFICE: 1975 - 635-275/31