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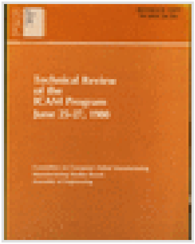

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Abstract: The Committee on Computer-Aided Manufacturing was responsible for monitoring and reviewing the progress of the Integrated Computer-Aided Manufacturing (ICAM) program of the U.S. Air Force Systems Command. The Committee's assessment is that the ICAM program performs a valuable service to the United States in bringing together government, industry, and academia to further the development of computer-aided manufacturing modules and their integration. Contributions are being made in the areas of hardware and software, enabling technologies, individual CAM modules, and integration of modules. This report offers comments on technology transfers, the level of effort of the ICAM program, and the balance of effort between projects in the ICAM program; in addition it gives detailed reviews of key ICAM projects as of June 25-27, 1980.

Descriptors: *Air force, *Project management, Technology transfer, Management analysis

Identifiers: *Computer aided manufacturing, NTISNASNRC, NTISDODAF, NTISNASNAE, NTISNASIOM

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TECHNICAL REVIEW OF THE ICAM PROGRAM

JUNE 25-27, 1980

A report

to the

Air Force Systems Command

U.S. Air Force

by the

Committee on Computer-Aided Manufacturing

Assembly of Engineering

National Research Council

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NOTICE: The project that is the subject of this report was approved by the Governing Board of the National Research Council, whose members are drawn from the councils of the National Academy of Sciences, the National Academy of Engineering, and the Institute of Medicine. The members of the committee responsible for the report were chosen for their special competences and with regard for appropriate balance.

This report has been reviewed by a group other than the authors according to procedures approved by a Report Review Committee consisting of members of the National Academy of Sciences, the National Academy of Engineering, and the Institute of Medicine.

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Committee on Computer-Aided Manufacturing
Assembly of Engineering
National Research Council
2101 Constitution Avenue, N.W.
Washington, D.C. 20418

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Chapter 1

INTRODUCTION

A major responsibility of the Committee on Computer-Aided Manufacturing (COCAM) is to perform an ongoing technical review of the Integrated Computer-Aided Manufacturing (ICAM) program of the U.S. Air Force. The committee accomplishes this task through the work of the Project Review and Technology Transfer Subcommittee, one of three COCAM subcommittees.

PURPOSE OF THE REPORT

The Project Review and Technology Transfer Subcommittee met June 25-27, 1980, at the ICAM Program Office at Wright-Patterson Air Force Base. The meeting was timed to coincide with Air Force budget decisions for the fiscal years 1981 and 1982. The subcommittee heard presentations from the ICAM program staff on the new projects and new phases planned for those years.

This report is a review of information presented at that meeting. Its purpose is to provide the ICAM Program Office and the Air Force Systems Command (AFSC) with a review of the status and quality of individual projects and the ICAM program as a whole.

The project reviews are written to provide some explanation to the reader who is not familiar with all of the details of the program. Still, this report can in no way serve as a substitute for the descriptive project material available from the ICAM Program Office.

REVIEW PROCEDURES

During the year, members of the Project Review and Technology Transfer Subcommittee monitor key decisions and milestones and attend end-of-phase or end-of-project briefings and demonstrations for major projects. Each member has responsibility for one thrust area and alternate responsibility for a second thrust area.

In the course of monitoring ICAM projects, the Project Review and Technology Transfer Subcommittee devoted three days to a thorough technical review of the entire ICAM program. The subcommittee studied ICAM plans and heard presentations from the ICAM program staff. The first day's presentations covered the ICAM program as a whole. Discussion on the second day centered on decisions about new projects and follow-ons in FY 1981-82. The description of a project included its objective, approach, deliverables, level of effort, inputs to other projects, and technology to be transferred. On the third day of the meeting, the subcommittee continued its discussion and began to draft this report.

For the most part, following discussion by the whole subcommittee, each subcommittee member wrote a review of his primary thrust area. All comments and recommendations were subject to the approval of the full committee.

Subcommittee members agreed on criteria for evaluation, so that their reviews could be similar in structure as well as in stringency. The criteria are:

- objectives of the project,
- needs likely to be satisfied by successful completion of the project,
- strategy or approach for accomplishing project objectives,
- relative importance of the project,
- quality of work completed,
- expected benefits to the industry,
- funding availability vs. need,
- sequence, current status, and interrelationships with other projects,
- critical decisions to be made regarding the project, and
- recommendations.

Projects are evaluated in the context of the goals of the total ICAM program.

AN INTRODUCTION TO ICAM TERMINOLOGY

The committee recognizes that terminology used in the ICAM program can be difficult even for those who are familiar with the program. Thus, it has included explanations of acronyms and ICAM terms in the glossary at the end of this report. The following paragraphs are meant as a brief introduction for newcomers to the world of ICAM.

The ICAM program approaches manufacturing technology through integrated sets of subsystems of the hierarchy of manufacturing functions.

Such sets are called "wedges" and are conceived to slice through manufacturing functions from broad systems definition to shop-floor implementation. Current ICAM work is in the sheet-metal fabrication wedge.

The ICAM program is divided into 10 thrust areas, so that the work is in more manageable pieces. Each thrust area is designated by a four-digit number: 1000, 2000, etc. Individual projects are also designated by a four-digit number; the first digit indicates the thrust area under which the project is organized.

The levels of manufacturing control are manufacturing process, station, cell, center, and factory. Each level has automated control of two or more operations of the level below it.

REPORT ORGANIZATION

This introductory chapter provides the background for the following chapters. Chapter 2 contains the recommendations resulting from the review of the ICAM program as a whole. The rationale for each recommendation is given in the chapter, although more complete explanation is provided in the appendices. Because this report stems from the June technical review and is not an update of the annual report, it does not cover all of the issues in the 1979 report. Recommendations from the annual report that are not repeated here should not be construed as obsolete.

Chapter 3 is the review of the ICAM program. It covers topics that cut across individual projects -- the balance of effort between thrust areas, the level of effort, and comments on technology transfer. The detailed reviews of individual projects are organized by thrust area and appended to the report.

In the course of the three-day meeting, James Mattice, Chief of the Manufacturing Technology Division, asked the subcommittee several questions about the program's management and strategy. The responses are presented in Chapter 4. There is, understandably, some overlap between the responses and the technical review and recommendations in the two preceding chapters.

Chapter 2

RECOMMENDATIONS

The Committee on Computer-Aided Manufacturing supports the fundamental objectives of the ICAM program. The program performs a valuable service to the United States in bringing together the government, industry, and academia to further the state of the art of computer-aided manufacturing (CAM) modules and their integration. Contributions are being made in the areas of hardware and software, enabling technologies, development of individual CAM modules, and integration of modules.

First and foremost, the committee recommends that the ICAM program continue to pursue the sheet metal fabrication, assembly, and following wedges; to provide technology with short-term results, such as robots; to provide the theoretical foundation for the improvements that will result from integration; and to use coalitions to stimulate an exchange of a range of ideas and to involve a large number of firms in the ICAM program.

The committee believes that the ICAM program has successfully established an architectural foundation now being used by some U.S. manufacturing firms; its future development should be limited to global architecture definition and support of the future wedges. The ICAM program should continue the program sequences in the thrust areas that industry can apply immediately (fabrication, design/manufacturing interface, group technology, assembly, and material handling); and continue to encourage the use of preliminary versions of modeling projects that could aid in future integration efforts.

The committee, while impressed with the quality of the program's work to date, believes the adoption of the following recommendations could lead to further improvements in the ICAM program. The recommendations concern the management, strategy, and balance of the program. For the most part, comments about particular projects are confined to the appendices. A few project-specific recommendations of importance are listed below. Each recommendation is followed by its rationale and commentary.

The area with greatest potential for improving the long-range value of the program is the development of methods to implement in industry beyond the involved contractors. Much excellent technical work is being sponsored by the program without adequate planning for the use of ICAM products by firms other than the developer. The success of the ICAM program will depend largely on the diffusion of its products. Therefore, the first four recommendations are ways to enhance technology transfer.

MANAGEMENT PRESENTATIONS

- A slide and tape presentation is needed that can be shown to manufacturing executives without the attendance of ICAM staff.

Managers do not have the time to read ICAM project reports. However, they usually can sit down with their manufacturing specialists, review a slide and tape presentation, and discuss the potential benefits and applications of the ICAM program. Presentations should emphasize short-term solutions and should note successful applications that have already been made. This approach not only saves time for the ICAM program and the Air Force Systems Command (AFSC) but also has a number of advantages from the viewpoint of the audience that the program is trying to reach. Managers will be able to learn about the program at their convenience, in their environments, and without the involvement of the program staff or the AFSC until after the executives are knowledgeable about the ICAM program.

SURVEY OF IMPLEMENTATION POTENTIAL

- A survey of potential users would enable the ICAM program to improve its planning for product development and implementation.

Large and small companies have varying needs for ICAM modules of capability, and have drastically different integration and implementation problems. The ability of firms to integrate the ICAM modules with their own will be debated until industry and the Air Force have greater communication and a more common understanding of the problem.

The survey should:

1. indicate the potential value of ICAM modules to industry,

2. identify the key integration problems and applicability of specific ICAM projects to the solution of such problems, and

3. identify the interface standards that must be developed and used by industry to support integration.

The survey should be supplemented with knowledgeable analysis of work going on in industry or government to establish how the Air Force program relates to industry-funded activities and compares with competitive products.

TECHNOLOGY TRANSFER SPECIALIST

- One person in the ICAM Program Office should have full-time responsibility for managing and expediting the transfer of all ICAM products.

Technology transfer is too important a concern to be relegated to the spare time of a busy staff. As the committee noted in its 1979 annual report, one person in the program office should be responsible for all technology transfer. That person should continually seek opportunities to move ICAM technology to potential users in industry. He should recognize differences among user groups and user needs and should tailor technology transfer strategies to these differing needs. Further, he should be "fluent" in the language spoken by operations executives.

ICAM VS. INDUSTRY PRIORITIES

- Modeling and simulation tools, fundamental to long-term productivity improvements, should be implemented at the earliest practical date but should not be allowed to delay the development of programs that provide immediately applicable solutions to short-term industry problems.

Industry and the ICAM Program Office appear to have different priorities among the ICAM projects. The program has spent a large portion of its funding on the development of increasingly sophisticated tools in modeling, simulation, and decision support. Manufacturing companies have a strong interest in the results of projects in fabrication, assembly, material handling, robotics, and inspection -- all areas in which industry has immediate needs and can expect short-term results. Decision support systems and other sophisticated tools will not be as readily accepted by industry. People deeply involved in the technical development of CAM appreciate the long-term value of ICAM work in architecture, data bases, manufacturing control, and simulation (thrust areas 1000, 3000, 6000, and 8000). However, top operations management generally will be slow to develop the understanding and appreciation that will lead to funding for extensive implementation.

While such projects are important for the long-term success of the ICAM program, the continued refinement of models should not be allowed to delay projects in the other thrust areas, which solve more immediate and apparent problems.

PROJECT COORDINATION

- A program management system to coordinate contractual obligations between projects is urgently needed.

The ICAM Program Office is in the process of developing the Integrated Program Information Management System (IPIMS), a program management system that will display the relationship of contractual obligation between projects. Without this analytical capability, industry cannot be confident of the schedules planned for the individual projects. Indeed, COCAM members were unable to determine the extent to which interdependent projects had conflicting schedules or overlapping events. The ICAM Program Office has contractually obligated more than 20 contractors to coordinate, exchange, and use data on a scale unprecedented in industry. A PERT net analysis system or the equivalent is necessary to determine what the impact will be of the delays or schedule incompatability encountered in developing the ICAM tools and interrelated projects. This system should be activated as soon as possible.

DATA BASE MANAGEMENT

- The ICAM program needs to specify manufacturing data base requirements.

Many of the data used in manufacturing operations are obtained from engineering. If much transformation of these data is required, the timely and efficient use of the data is jeopardized. To ensure that manufacturing needs be given consideration, we strongly recommend that ICAM prepare a manufacturing data base requirements specification. The Integrated Program for Aerospace Vehicle Design (IPAD) of NASA is approaching the issue from the viewpoint of design. An ICAM document on manufacturing data base requirements could be used by NASA to develop IPAD software that is usable by ICAM for its data management needs. To gain acceptance by the potential users, we also recommend that it be jointly demonstrated by ICAM and IPAD.

ICAM USERS

- ICAM tools should be developed with the intent that manufacturing engineers will be the primary users.

Two types of people in industry will be using ICAM tools: manufacturing engineers with strong manufacturing backgrounds but little computer training, and analysts with a strong computer background. We recommend that the ICAM tools be developed so that the manufacturing engineer as well as the computer specialist can readily use the tools.

Some ICAM tools are being developed with the expectation that a manufacturing manager will use them personally to support his decision-making process. The key to this development has been a graphics user interface that permits an unsophisticated user to perform simulation exercises. Unfortunately, the effort to simplify the user interface has limited the capability of such tools as the ICAM Decision Support System (IDSS). Directing the tool at the manufacturing engineer should enable the developers to create a more powerful tool.

The use of a simulation capability by manufacturing management is not likely. If efforts to meet the needs of the manufacturing engineer and analyst also satisfy the manager's needs, so much the better. Current manufacturing management has neither the desire nor the time to acquire the detailed level of understanding of system analysis that is required to model the system using decision support tools such as simulation, structured analysis, or linear programming. Simulation results could be misapplied if the user does not fully understand the need for correct data selection and the limitations of the simulation algorithms. Systems analysts and engineers are employed to apply these tools as their understanding of the problem dictates. It is to this user that the future IDSS prototypes and simulation work, projects in the 8000 thrust area, should be directed.

ICAM STAFF

- Individuals with manufacturing experience should be added to the ICAM program staff.

The program office is operated by a talented staff of basically computer-oriented people. The staff in June 1980 was not large enough to manage a program of this magnitude. The staff should be supplemented by the addition of more individuals with experience in line aerospace operations and program management, and these people should be given better management tools.

INTEGRATION

- Manufacturing interface standards, rather than a detailed ICAM architecture, should be the basis for integration of ICAM modules.

It appears to many in industry that ICAM architecture analysis tools are being developed according to the theory that these will define manufacturing in such detail that the resulting information can be used to ensure that ICAM developments within different companies will fit together in the end. This is an unreasonable expectation. At the higher levels of architecture analysis, the view of the companies will be generic; that will not be the case at detailed levels. The program should not spend large amounts of money to try to develop and coordinate a common architecture among companies at a detailed level.

The value of establishing standards to support the interfacing of systems in manufacturing is not known. In the graphics area, the Initial Graphics Exchange Specification, sponsored by the ICAM program, has proven to be a valuable step for industry. We recommend that a similar approach be taken for interface standards in manufacturing.

COMUTER COSTS FOR ICAM TOOLS

- The ICAM Decision Support System needs to be operable on a system less costly than CYBERNET.

One of the main problems in simulation and modeling today is the great expense incurred for data collection, model development, sensitivity analysis. The IDSS appears to be attacking the data collection and model development problems directly through the link to the manufacturing data base and the graphics user interface. The computing costs associated with IDSS, including storage and execution, are likely to increase as IDSS becomes a more powerful tool. The addition of analytic tools, data reduction modules, links to ICAM subsystems, and other planned enhancements will require considerable computing resources. The current costs accumulated by using IDSS on CYBERNET, even without the planned features, are staggering. Unless IDSS is operable on a system that achieves a reduction in analysis costs, the tool is not likely to be widely used. The program office or its contractors should consider alternative computer systems that can handle IDSS.

TEST, INSPECTION, AND EVALUATION

- Test, inspection, and evaluation (TI&E) should be a higher priority of the ICAM program than it is currently.

As a first step, thrust area 0000, test, inspection, and evaluation, needs to be re-examined and made more compatible with the other thrust areas. TI&E should not be an after-the-fact consideration. It can be an extremely serious bottleneck to production operations if it is not an integral part of the computerized manufacturing process. The ICAM program has not yet placed enough emphasis on this important area.

Part of the TI&E task is the generation of meaningful tests and, more important, meaningful results. The task of test generation is becoming sophisticated, time-consuming, and prone to error. This is equally true for assemblies, sub-assemblies, or even single parts.

We recommend, therefore, that the ICAM program approach this problem with the intent of generating tests from the design information in an automated way. The solution must incorporate checking to assure that this process is error free and consistent from part to part and assembly to assembly.

ACRONYMS

- The use of acronyms should be reduced. Acronyms that are used should frequently be explained.

The ICAM program may be difficult to understand because of its broad scope and the complexity of the problems it seeks to solve. This difficulty is exacerbated by the large number of acronyms that the program staff uses. To be transferred, the program must be understood; to be understood, the program should rely on conventional manufacturing terms, curtail the use of acronyms, and repeatedly define acronyms that are used. We have appended a glossary for the interpretation of the acronyms and jargon that we have retained.

Chapter 3

REVIEW OF THE ICAM PROGRAM

The Integrated Computer-Aided Manufacturing (ICAM) program of the U.S. Air Force is the only major program in this country advancing the state of the art of computer-aided manufacturing and involving a major segment of aerospace manufacturing in the development process. The capabilities being developed by ICAM could, if effectively implemented throughout manufacturing industries, significantly improve U.S. productivity in both military and commercial activities.

At this early stage, the ICAM program is already providing a stimulus to aerospace and other U.S. industries through direct involvement in the program and through competitive encouragement. For example, the robotics program being carried on by General Dynamics and McDonnell Douglas has stimulated the release of capital funds for similar equipment in other companies to remain competitive.

In this chapter we review three issues that are important for the success of the program as a whole:

- balance of effort between thrust areas,
- level of effort, and
- technology transfer.

A project-by-project review of the new and follow-on projects beginning in FY 1981 appears in the appendices.

BALANCE OF EFFORT BETWEEN THRUST AREAS

The committee, in the preparation of this report, had as one of its objectives to rank the thrust areas in order of priority. In this way we hoped to encourage the continued funding of the most critical projects in times of potential budget reductions. This task turned out to be significantly more difficult than the committee had anticipated.

In the first analysis, it appeared that because of current industry needs, thrust areas fabrication (2000), design/manufacturing interaction (4000), planning and group technology (5000), assembly (7000), material handling and storage (9000), and test, inspection, and evaluation (0000) should have the highest priority for funding. With further analysis of the projects, we found that the need for and long-term value of the other areas could not be ignored.

In analyzing ways to increase the stimulation of industry with ICAM seed money, the committee initially considered that the projects with the most immediate impact on productivity should be emphasized. Unfortunately, this would assign low priorities to projects involving highly sophisticated advanced computer tool development, such as simulation, modeling, and operations research (8000).

Relative to thrust area 8000, the aerospace industry lacks expertise in applying simulation and modeling techniques to manufacturing decisions and, therefore, reduces its potential for improving productivity. Manufacturing engineers and managers are reluctant to use these tools, largely because data collection procedures are inadequate. As a result, the analyst using current simulation and modeling systems spends more time collecting and validating data than performing analyses. With the improvement in data collection, this analytical capability will become more important.

The more sophisticated tools being developed by ICAM have the potential for reducing manufacturing costs significantly in the future, but their benefits are not as apparent to industry in the near term as the benefits of other thrust areas. It is very important to industry that problems arising in the development of these sophisticated ICAM tools do not delay the fundamental work in such thrust areas as fabrication (2000) and assembly (7000).

Thrust area 6000, manufacturing control and external interfaces, directed at establishing mechanisms for "on time" status information and feeding back corrective action information in a closed loop, is required for the timely management of complex manufacturing operations. This thrust identifies what information is required, where it is needed, and when it is needed in the production cycle. The challenge will be to develop the logic necessary to analyze and evaluate the information so that better, more timely decisions may be made.

The assembly thrust area (7000) offers great potential for productivity improvement. Little has been done in the United States in the last 30 years to change the methods of assembling aircraft structures. With the advent of better data from engineering in a computer-oriented format, an opportunity appears to modernize assembly operations with automatic assembly methods. This thrust, along with the fabrication thrust, presents one of the top priorities of the ICAM effort.

It is encouraging to industry that the ICAM plans have identified the enabling technology requirements. Many in industry consider some of this work to be of the highest priority and would like to have the programs expedited and given funding priority in times of fund shortages over some of the more sophisticated tool development projects.

LEVEL OF EFFORT

The ICAM program is an important way for industry to acquire the knowledge and capability to improve manufacturing productivity through the use of computers. One of the most serious problems in the industry today is that so few people in each of the companies have the knowledge, experience, and funding support to pursue computer-aided manufacturing development. The ICAM program has uniquely increased industry's interest and activity in this field during the last few years. Several important factors, however, must be considered for an orderly expansion of developmental activities.

- There is a serious shortage of computer-aided manufacturing skills in industry today. The people with such skills are rapidly becoming involved in company productivity improvement programs and the ICAM program.

- The universities in this country are not training enough manufacturing engineering students to satisfy industry's demand for these skills. No program is directed at training university professors in current manufacturing technology in anything but superficial ways.

- The ICAM program staff is skilled but short of people with experience in manufacturing operations. The program office is understaffed at the present time for the projects planned and underway. With these problems in mind, we believe that the ICAM Program Office needs to acquire additional staff knowledgeable in operations management. The ICAM staff should be increased sufficiently, to the extent possible, to cover current and planned projects.

- Both the aerospace industry and the Air Force would benefit if issuing Requests for Proposals (RFPs) were spread throughout the year. The current practice of releasing all of the RFPs in an extremely short period of time causes the industry to disrupt its work to prepare responses that are stacked in a high pile. If the Air Force could spread this effort throughout the year, it would get more and better responses to RFPs.

- The overall effort of the ICAM program at the present time is appropriate and should increase as currently planned. The technology being developed in this program is no new that future problems may be difficult to anticipate. Some of these problems may require additional funding, which should be justified on a case by case basis.

- Thrust area 0000, test, inspection, and evaluation, is extremely important to the ICAM program. We believe that its scope has been underestimated and that the area has been underfunded.

COMMENTS ON TECHNOLOGY TRANSFER

In the 1979 annual report, COCAM recommended that:

- The ICAM Program Office designate one person as a focal point for the transfer of all ICAM technology.

- One or more modules, such as Manufacturing Control - Material Management (MCMM), be transferred using normal market forces, generally through a company already in the business of packaging and implementing software.

- The program office develop an easily understood package that could communicate to corporate management the purpose and expected benefits of the ICAM program.

The ICAM Program Office has taken responsibility for technology transfer and has initiated a transfer project for the MCMM module. But the program manager is overloaded with other duties. Accordingly, we recommend that he be assisted in the specific assignment.

In general, the transfer of technology from the ICAM projects, particularly the software tools being developed, requires a well-planned communications effort to gain acceptance by corporate management. The software packages are not understood by, or used by, the top operations people in most of the aerospace industry today. For this reason, the ICAM Program Office needs to prepare presentations to be used inside the companies in the industry to convey to management the expected output and benefits of the ICAM program. The format and language should be clear enough that the Air Force personnel do not have to accompany the presentation of information. It is most important that the presentations about the modules or tools being developed by the ICAM program be put in terms that can be readily understood by the potential customers. The information in the management presentation should be directed toward non-technical line management. They will be expected to review the information with systems developers and operators so that they can readily understand how the modules of capability developed under the ICAM program can be used with the existing systems in the company.

We recommend that the program office develop an introductory management package that describes the program in depth and in the language of corporation senior management -- i.e., for the most part non-technical English. If need be, a separate package should be developed for non-aerospace industrial managers.

Chapter 4

RESPONSE TO QUESTIONS BY J. MATTICE

In the course of the review of the ICAM program June 25-27, 1980, the subcommittee members were addressed by James J. Mattice, Chief of the Manufacturing Technology Division of the Air Force Materials Laboratory. He asked a series of questions on the overall strategy and future management style of the ICAM program. The subcommittee's responses, as amended and approved by the entire committee, are presented in this chapter.

Question 1. What are the benefits of the simulation and modeling projects* sponsored by the ICAM program? How critical is the need for these projects?

Response. The overall goal of the ICAM program is to develop a systematic base for large and highly integrated systems for defense manufacturing. The prerequisite for this knowledge base is a widely encompassing architecture that clearly describes the functions of aerospace systems manufacturing and their interrelations. Such a model is too basic and general to be developed in industry using corporate funds and would not become available without the sponsorship of ICAM in the reasonably foreseeable future. Without this model the work on specific hardware and software modules would be disconnected and impossible to consolidate into a whole greater than the sum of its parts.

The question that concerns COCAM now is not whether the architecture is needed but rather how detailed it should be. A finely detailed model will not be appropriate for all firms; it may not even be appropriate for any firm. Simulation and modeling provide benefits, particularly in manufacturing operation systems planning. The use of these techniques can enable managers to make more informed decisions. However, to be useful, ICAM modules should be flexible enough to apply to a variety of situations. We caution the program office against developing overly rigorous and detailed models, especially at the expense of more applications-oriented projects.

Many of today's manufacturing managers resist the use of simulation and modeling techniques. If the ICAM program provides these tools in a flexible form and requires their use by ICAM contractors,

*The question refers to the ICAM Decision Support System (thrust area 8000) and to the manufacturing architecture (thrust area 1000).

then the program can perform a great service to industry -- not only from the particular models, but also by acquainting industry with these techniques.

Question 2. At present, approximately 60 percent of the ICAM projects are software and 40 percent are hardware. Is this an appropriate balance?

Response. It would be difficult to specify the ideal balance between hardware and software. Although hardware is more easily evaluated and transferred, the development and implementation of software is necessary to demonstrate that productivity improvements can result from the hardware tools of the ICAM program and to contribute to productivity improvements in the overhead activities. To the best of the committee's knowledge, the current balance between hardware and software projects is not causing any problems in the rate of development or transfer of ICAM modules.

In the near future, the emphasis on equipment and "current art software" should gradually increase so that prototype manufacturing cells and centers can be installed, tested, and seen by potential adopters. Actual productivity improvement will be realized when more efficient manufacturing equipment and their supporting software systems are widely implemented. It is recommended that there be a shift in focus toward manufacturing cells and centers in the near future.

Question 3. Will the software developed in the ICAM program make current computer hardware systems obsolete?

Response. The committee understands the following to be true:

- The standard ANSI languages, Fortran and Cobol, will be used in the development of all software. These may be augmented by an industry "standard" language such as Pascal.

- A set of distributed computer systems from several manufacturers will be used in the overall systems -- i.e., a set of heterogeneous computer systems.

- The computer systems will be connected with a standard wideband trunk on a serial channel interconnection system. The committee holds that a standard should be developed for a serial channel in the years 1983-1984.

- The data base developed will be executable on a standard, general purpose computer; it will not require a special data base processor.

- The data base, in general, will be centralized at the factory for control and update (the data administration function) and distributed for access and utilization to the various centers, cells, and stations.

Assuming the above, the general purpose systems sold by several of the main-frame manufacturers should be stable in the ICAM environment. If a standard data management interface is developed, then the individual modules should be executable on either large or small processors of any supplier, depending upon the individual factory center, cell, or station configuration.

Question 4. What needs to be done to encourage operations executives to include ICAM products and ideas in their plants?

Response. First, the ICAM Program Office needs one person to act as a focal point for all technology transfer activities. The ICAM program manager and Computer-Integrated Manufacturing (CIM) Branch chief have many demands on their time as they oversee the day-to-day program operations. The technology transfer job, if done properly, requires more effort than they have time to give. An individual is needed to make continuing contact with industry and to work full-time for the transfer of ICAM technology. The selection of a person with nationally recognized operations technology and management credentials would facilitate the accomplishment of this task.

Second, a marketing study could provide a basis for the ICAM program to make informed decisions in developing a strategy for diffusing its products and ideas. Such a study could:

- identify potential customers,
- determine customers' needs,
- describe the nature of their operating environments in terms of envisioned ICAM capabilities, and
- describe the procedures used to make decisions relating to the adoption of new manufacturing technology.

Because of the variation in critical operating problems and levels of operating sophistication, firms will have differing needs and will respond to differing "sales pitches." A marketing study will enable the ICAM program to tailor its technology transfer approach to both the needs and the styles of individual firms.

Third, new presentations to industry should be prepared. Based on the information obtained from the marketing study, several systems or system modules should be selected and used to prepare presentations, using commonly understood manufacturing language. The focus in each case should be on shorter-term problem-solving and the expected benefits of the technology with specific economic goals where possible. Successful applications should be well publicized, so that the implied or demonstrated competitive advantage of the new technology -- or the competitive "disadvantage" of failure to consider such technology -- will be a spur to other companies to adopt or develop similar technology. The presentations prepared by the program office can gradually form a library from which further presentations to industry can be selected. Goals for ICAM demonstration centers should be defined and publicized to begin directing industry attention to the real world results of the ICAM program. A slide and tape presentation should be prepared to explain the ICAM projects in individual plants. The presentation should be usable without ICAM office participation, so that company CAM specialists can sit down with top company operations executives and show how the ICAM modules of capability will mesh with, enhance, or improve existing or proposed systems in their own plants. When executives are able to understand how ICAM's results can aid and benefit them, they will be in a position to decide on the expenditure of company funds for the investigation or implementation of individual ICAM modules.

Question 5. Are ICAM program RFPs structured and written in a form that will encourage excellent responses? Are contract requirements too restrictive?

Response. The standard RFP format used by the ICAM program is not appropriate for all projects. Often, the tasks appear to be required only for the sake of standardization. Consider two examples: In the case of enabling technology, much time and manpower are associated with the early stages of the life cycle, when such projects could begin with the development of data for the detailed design. Using the Manufacturing Control - Material Management sequence as a second example, project 6103 is a follow-on to 6101. Yet, rather than build on the needs analysis, requirements definition, and preliminary design of the earlier project, project 6103 repeats these steps.

The contract requirements are so detailed that little room is left for original thinking. Requiring a structured response inhibits creative approaches and discourages the contractors from being innovative. The responses become stereotyped and lack the originality so important to such a complex program as ICAM. The structure can also be a barrier to the small organizations and universities with unique ideas and prevent them from participating.

Some potential contractors are discouraged from responding because of the extensive architecture, modeling, and simulation requirements. They don't want their talented, scarce technical staff spending a lot of time, effort, and money to reach conclusions or provide information that they already know from being close to the operation for many years. The ICAM requirement to demonstrate the technology at someone else's plant also causes reluctance.

In short, more flexible RFPs should lead to more creative and higher quality responses. Respondents will be able to focus on the heart of the subject instead of on the lengthy standard sections.

Question 6. Are contractor coalitions well balanced? Are they being dominated by software firms?

Response. In the view of the committee, the contractor coalitions do not appear to be dominated by software firms. Hardware and software firms, aerospace and non-aerospace, industry and universities are all represented in appropriate numbers on the various coalitions. The coalition concept is praiseworthy for its involvement of a wide range of users and developers. Coalitions should be structured so as to encourage active participation by all members.

Question 7. Are the ICAM acronyms a problem?

Response. The ICAM program has tremendous potential for improving productivity and, along with related efforts in U.S. industry, can strengthen the position of U.S. industry in world markets. Accordingly, it is vital that, to the extent possible, all elements of our society -- particularly those outside the Air Force and the aerospace industry, including the Congress and the public -- should know about and understand the ICAM program and how it can affect them.

Acronyms, already seemingly a well-established part of the American version of the English language, serve a limited purpose in this communications effort. While it is understandable that those inside the ICAM program might find useful this verbal shorthand, the use of abbreviations that are not descriptive technical terms or part of the idiom should be curtailed when the ICAM staff communicates with outsiders, including COCAM. At the very least, care must be taken to define repeatedly the newer, more esoteric acronyms until their meanings become clear.

Precise terminology is sometimes necessary, but excessive and unwarranted use of highly specialized terminology or jargon does a disservice to the ICAM program. It tends to hinder understanding of the program's context and objectives and antagonizes potential users of ICAM products.

ICAM leadership should demand, receive, and promote written and spoken ICAM communications in simple, clear words that are easily understood by those who are not part of the program.

Question 8. Is the program being managed responsibly? What needs to be done better?

Response. The program, which is the first of its kind in this country, has been managed as well as could be expected in a government environment where considerable management time is consumed in budget justification and complex contracting procedures. A cadre of talented young people has been welded together into an effective program management team. This team is well versed in theoretical knowledge but somewhat short on industrial manufacturing experience. They need to develop a greater awareness of what is important to manufacturing management by increasing their interaction with industry and adding, where possible, manufacturing experience to the staff.

The program staff should recognize that its priorities do not coincide completely with those of manufacturing management. High on the manufacturing priority list are the individual modules of computer-aided manufacturing capability that the executive can integrate immediately on the shop floor with operating systems. Low on his priority list are complicated methods to visualize manufacturing.

The current generation of manufacturing executives will be slow to accept the theory that they are going to change their company's method of planning and controlling production in the near future. Such systems will change gradually when individual ICAM tools are developed and proven in the industrial environment -- when the changes are evolutionary, not revolutionary.

Question 9. Should the Air Force sponsor basic research in the areas underlying the ICAM software?

Response. As more funds become available, some basic research should be supported by the Air Force Manufacturing Technology program. The more immediate needs are to identify software capabilities that the ICAM program as currently defined will need in the near term as well as in the more distant future. After longer-term software needs are identified, a comparison of these with the state of the art will suggest gaps in to consider sponsoring research to close those gaps in support of ICAM software. It would also be advisable to explore joint efforts with other federal agencies such as the National Science Foundation and the Department of Commerce, and with research work associated with manufacturing technology programs at universities.

APPENDICES

In reviewing the ICAM program, committee members paid particular attention to projects that begin or that have follow-on options in FY 1981. Each project was examined in the context of its thrust area -- that is, relative to similar work that has preceded it in the ICAM program.

The 10 appendices correspond to the 10 thrust areas of the program. In the appendices we cover the objectives of the thrust area and the new starts, the strategy for thrust area development, the relative importance of the area and its projects, the quality of the work done in the thrust area, expected benefits to industry resulting from successful completion of the projects, the sequence or current status of thrust area development, critical decisions to be made, and recommendations on the area.

Thrust Area 1000

MANUFACTURING ARCHITECTURE

INTRODUCTION

The goal of this thrust area is to establish a generic framework (manufacturing model or architecture) that displays all of the functions, information types, and interactions typical of aerospace batch manufacturing. Different models are being prepared for the factory of today (called the "AS IS architecture") and the factory of the future ("TO BE architecture"). The framework is intended to form the basis for the computer-integrated factory.

These are currently four major elements to the architectural thrust: generic architecture (1000), program support (1300), program integration techniques (1500), and systems design techniques (1700). According to the June 1980 road maps, three new starts are planned for FY 1980-81 supporting the development of manufacturing architecture. These projects are 1104, ICAM architecture part III; 1501, configuration management for ICAM requirements analysis/design phase; and 1701, system engineering methodologies.

OBJECTIVES

Project 1104 is to establish the TO BE architecture of the factory of the future, of which the sheet metal center and assembly center will be demonstrated parts. Prior architecture projects established the AS IS framework of aerospace manufacturing. This project is important because its intent is to ensure that the individual cells and centers can be integrated into an effective whole.

Project 1501 is directed at establishing formal configuration management policies and procedures that will evolve standards for various disciplines of integrated manufacturing.

Project 1701 will develop tools to aid in the design, creation, and integration of ICAM systems and subsystems. A second objective is to evaluate the state of the art in systems development support tools and to compare it with the ICAM requirements. The third task is to provide for technology transfer.

STRATEGY

Project 1102 established the AS IS architecture of manufacturing, followed by 1104 directed at establishing the TO BE baseline for the subsystem development for the factory of the future. The architectural thrust will establish mechanisms for the integration of ICAM projects. Configuration management systems will be developed and standards evolved.

An analysis will be made of the systems development support tools available to industry today in light of ICAM need. Tools development plans will be evolved to support this analysis, and industry training in those tools will be provided.

CURRENT STATUS

The ICAM Definition (IDEF) method for describing manufacturing functions has been established and is being automated to create, edit, display, plot, and verify diagrams and models in support of the analysis of manufacturing. The development of the Information Model ($IDEF_1$) and Dynamic Model ($IDEF_2$) of manufacturing is continuing. A variety of people in industry, government, and academia are being trained in the use of IDEF tools.

The requirements for future manufacturing systems will be documented as the TO BE architecture to guide future systems development effort. This work is being initiated with FY 1980 funds, with much of the work funded in FY 1981.

Under the title of systems engineering methodology, tools and analytical methods will be evolved with FY 1981 funds to aid in the design, construction, and integration of CAM systems.

The first phase of human factors project 1303 has been completed. The significant human factors that can affect ICAM implementation have been identified.

RELATIVE IMPORTANCE

A fundamental description and understanding of the architecture of manufacturing is mandatory for the economical and timely development of manufacturing systems. $IDEF_0$, a graphic method of displaying manufacturing functions and showing their relationships, will be a very important tool to industry when it is in a form that can be used by the engineers normally involved in systems development. It is particularly useful for introducing computer specialists to manufacturing activities so that they can gain a fundamental understanding of manufacturing. The IDEF capability will become more valuable as it becomes more automated. These tools should be developed in such a way that manufacturing engineers can use them for requirements definition and communication.

The Information Modeling ($IDEF_1$) and Dynamic Modeling ($IDEF_2$) tools are just starting to be used, but they appear to have significant potential as useful tools for industry if they can be automated and kept simple. The tools are so new that their value is difficult to determine at this time.

Some in industry have expressed concern about the emphasis on architecture in the ICAM program. Further funding of project 1104 should not be directed at developing and coordinating a common architecture between companies at a detailed level but should be directed at the interface of the individual thrust areas.

For the timely introduction of CAM developments into a company, planning and preparation are needed. Human factors project 1303 is expected to provide a good foundation of data to industry for planning the introduction of new systems.

Part of the manufacturing architecture thrust area is directed towards developing configuration management methods and standards to manage the development of CAM systems. This effort is important for managing the ICAM projects and for developing systems that can be integrated with others.

QUALITY OF WORK

The quality of the basic work in this thrust has been quite good. However, we believe the thrust direction is overly driven by computer science considerations rather than the needs of manufacturing and design. Industry has a strong desire for early development and demonstration of cells and centers using available and understood tools wherever possible. The ICAM program is developing a large number of needed modeling, simulation, manufacturing control, decision support, information management, and other tools for immediate use by industry and for integrated cells, centers, and factories of the future. Industry's past experience in developing these kinds of tools indicates that the development is difficult, seldom completed on time, and in need of iterative improvements and direct experience by the user before the tool is finally evolved. The ICAM program appears to expect scheduled success in the development of tools that most of industry has never seen achieved. Until the Integrated Project Information Management Systems (IPIMS) tool is developed and used, the committee is not in a position to understand the magnitude of this problem.

The work being done in this area is important but should not be overemphasized. The architecture projects need to provide tools that are understandable and readily used by the manufacturing engineer. Sophisticated tools that are not understood will not be implemented by industry.

EXPECTED BENEFITS

Industry needs efficient methods of developing software systems that will improve productivity. The architecture thrust is intended to provide a structure for understanding relationships among systems and to help ensure that ICAM products can be transported and integrated.

The architecture provides for a more complete understanding of the functions performed in manufacturing, the information requirements, and the dynamics of the manufacturing operation. Modeling methods are being developed that could, when available, materially aid in the analysis of manufacturing functions.

In-depth analysis of a complex aerospace activity -- for example, the automatic assembly of a major structure such as a wing spar -- is a time-consuming task when methods available to industry today are used. To provide economic justification for the automation of the assembly of this structure, all relevant activities performed by every organization need to be identified, understood, and evaluated for the conventional and automated production methods. Today, much of this information is not collected or evaluated because of the costs and time involved.

If the ICAM program can develop easy-to-use tools that manufacturing engineers, who have a good knowledge of manufacturing, can use in such studies, the cost savings can be enormous. Preliminary indications are that with user-oriented, automated tools, the costs of this type of analysis could be reduced by 10 to 30 percent or more. As the trend toward automation of manufacturing operations increases, the savings increase and could in a single company amount to million dollar figures. No reliable aerospace cost-comparison data are available today because the tools are not well enough developed.

FUNDING

A large portion of the ICAM funds has been directed at this thrust area. In the opinion of many people in industry, a disproportionate share of the budget is being spent in this thrust area. It is the opinion of COCAM that this money will have been well spent if it results in tools that the average manufacturing engineer can use to communicate manufacturing requirements to the system developer.

CRITICAL DECISIONS

One of the most critical decisions that has to be made in the ICAM program is related to the design/manufacturing interface. The NASA Integrated Program for Aerospace Vehicle Design (IPAD) is developing computerized methods of handling engineering data. Many of the same data are required in manufacturing. A program needs to be developed and supported by IPAD and ICAM that will provide a common understanding of the design/manufacturing interface, to ensure that data processed by the IPAD system will be usable for manufacturing.

The acceptance of ICAM tools by industry will be directly related to whether the tools are oriented toward computer scientists or manufacturing engineers. The user must view the tools as straightforward. Managers want their manufacturing engineers to solve production problems, not to take time to learn computer science.

The new tools that are being developed should be evaluated under well understood existing conditions before they are applied to the development of new systems such as the ICAM wedges. It will be difficult to determine when these new tools should be brought into use in the ICAM projects. Some ICAM contractors will tend to avoid the use of these new tools. However, it is important that the tools be used and modified as early as practical <u>without</u> delaying the cell and center development programs.

RECOMMENDATIONS

Industry's acceptance of the ICAM program and its tools is dependent on the ease with which program results can be understood and applied. If they are to be widely used in industry, they must be understood and used by the average manufacturing engineer. We strongly recommend that the tools being developed by the ICAM program be developed for the needs and use of the manufacturing engineer, not the computer specialist.

The ICAM architecture analysis tools are being developed with the apparent expectation that they will define manufacturing in enough detail to enable ICAM developments by different companies to fit together. Many in industry believe this to be an unreasonable expectation. Companies will be similar in some ways, but not necessarily at levels of detail. Significant amounts of money should not be spent to try to develop and coordinate a common architecture among companies at a detailed level.

The value of establishing standards to support the interfacing of systems in manufacturing is not known. In the graphics area, the Initial Graphics Exchange Specification (IGES) sponsored by the ICAM program has proven valuable for industry. It is recommended that a similar approach be taken for interface standards for manufacturing.

Thrust Area 2000

FABRICATION

OBJECTIVES

Project 2105 is to establish or enhance currently deficient hardware and software enabling technologies needed for sheet metal fabrication. These capabilities will be used to support the overall needs of the integrated sheet metal center.

Project 2106, manufacturing technology for sheet metal fabrication cell construction and demonstration, will result in the demonstration of three such cells. The effort will concentrate on the final specifications and construction of the cells, followed by the physical implementation and use of the fabrication system.

The objective of project 2201 is to complete the detailed and optimized design for a sheet metal fabrication center. The effort will address the broad outline of the preliminary design and will provide the required level of detailed design for building the fabrication center.

STRATEGY

These projects are the building blocks for the computer-integrated sheet metal center. Therefore, the basic strategy should be for contractors to obtain production shop expertise in the development of these projects. The computer systems development for these projects needs to be able to work with work flow, scheduling, and other typical shop operations. Also, automated planning should provide adequate part data to enable blanking, forming, and identification of parts as required.

SEQUENCE

The overall timing relative to industry needs appears excellent. The relationship of its schedule to that of other projects will not be fully understood until the Integrated Project Management Information System is implemented.

EXPECTED BENEFITS

The expected deliverables are (1) enabling software and hardware for automation of blanking, forming, and processing parts, and (2) three sheet metal fabrication cells. Also, a sheet metal center design should evolve and be incorporated in the deliverables.

The major benefit to industry should be better success in the development of an operational sheet metal fabrication center. Operation of the center will result in reduced labor costs, shorter total cycle time to fabricate parts, and inventory reductions. Potential industry users are aerospace and other fabrication shops with low quantity production runs.

POTENTIAL BARRIERS TO SUCCESSFUL COMPLETION

First, the state of the art in the fields of automated inspection, material handling, and the use of robots for short production run jobs may be limiting factors in the near future for the construction of integrated sheet metal fabrication cells and centers. Second, there is a shortage of manpower for systems engineering development in these fields and in automated planning and production control. Finally, software systems and hardware that will function satisfactorily in a production shop need to be developed.

RECOMMENDATIONS

Fabrication is an essential thrust area from the viewpoint of industry. We strongly recommend that these projects not be delayed by any problems that arise in the development of ICAM tools being developed in thrust areas such as 1000 and 8000.

The results of project 2105 will be particularly important to industry. These advancements in enabling technology are needed today and, in many cases, are likely to be applied as soon as available, regardless of the extent of computerization. This project is needed more urgently than the development of some of the more advanced simulation tools and, if necessary, should be given funding priority. This project is a cornerstone of sheet metal cells and centers.

Thrust Area 3000

DATA BASE AND DATA AUTOMATION

Project 3101. Computer-Based Information System Requirements for Sheet Metal Center

OBJECTIVES

The objective of project 3101 is to produce a computer-based information system (CBIS) that will become an integral part of the ICAM sheet metal center design. The project will address the information handling requirements (distributed processing, transaction processor, data base management, etc.) and preliminary design of a CBIS needed to support the ICAM sheet metal center demonstration in FY 1985. The results:

- will form a solid basis for designing the requirements for a transaction processor to support the CBIS, and
- will enhance portability and reliability of ICAM subsystems as they are transferred to the aerospace industry.

STRATEGY

In phase I (AS IS), manufacturers who use computer transactional techniques will be surveyed to understand current information systems, transaction techniques, and data bases and to identify distributed network controls that are being used. It is expected that phase I will be completed in May 1981.

In phase II (TO BE), the needs of the Manufacturing Cost/Design Guide, Manufacturing Control - Material Management, and robotics projects that will be included in the sheet metal center will be consolidated and evaluated. The scheduled completion date is January 1982.

Preliminary design and validation via prototyping is scheduled for phase III and is not covered in this fiscal year. The phase III prototype will begin January 1982 and is to be completed in January 1983.

STATUS

This project is currently in phase I, the requirements definition to outline the AS IS environment. A statement of work, which has just been issued for multi-source solicitation, will result in a single award.

RELATIVE IMPORTANCE

This is the critical project to industry integration of the thrust area application systems identified in the ICAM program.

FUNDING

	FY 1980	FY 1981	FY 1982	FY 1983	
ICAM	703	1400	1150		(in thousands
CIM		150	150	100	of dollars)

Funding should be adequate for the first two phases but may not be adequate in phase III if a full working prototype is required.

COMMENTS

1. The statement of work calls for the establishment of a master plan that defines the functions necessary to obtain project objectives. This is key for this phase of the program.

2. The statement of work requires a continuous review of and coordination with project 1104, the architecture for the integrated sheet metal center. This interaction is essential to the success of the thrust area.

3. The statement of work requires the establishment of an interface with projects 3301 and 3302, the General Utility System. Development and standardization of a data base management system is listed in the ICAM roadmap for this project, but not in the statement of work. It should be. As the user interface results are expected from 3301 and 3302, the project should also consult previously published material and research in this area. One good source is IFIP working group 2.6 on data bases (1976, 1977, 1979), available from the North Holland Publishing Company, Amsterdam.

4. In phase II, the task for incorporating the needs of the Manufacturing Control - Material Management system and the robotics for the sheet metal center is not specified in the statement of work. If that is still an objective, it should be explicit.

5. Review of the IPAD Information Processor (IPIP) is required in the statement of work. This is the only clear statement to address the key design-to-manufacturing interface.

6. A recommendation from the Data Base Panel of the Manufacturing Technology Advisory Group workshop in Detroit was to unify the efforts of the IPIP data management system and this project. As of August, an IPIP prototype will be demonstrable. It could provide a much safer vehicle to accomplish the demonstration of the sheet metal center.

RECOMMENDATIONS

The ICAM program should prepare a manufacturing data base requirements specification for NASA, to ensure that the IPAD software is usable by ICAM for its data management needs. The compatibility needs to be demonstrated for both engineering and manufacturing to encourage industry acceptance.

Project 3201. Data Administration System Assessment

OBJECTIVES

The objectives for project 3201 are:

- to define the characteristics of the life cycle of data in manufacturing,
- to enhance the portability of ICAM systems that will be transacting with the data administrative system,
- to accommodate both business and engineering information in the same system, and
- to study the relationships of data flow and data as they exist during the life cycle of information in the data base.

STRATEGY

In phase I, the project will survey aerospace manufacturers to collect the data necessary to establish the requirements of data support systems. A key input to this project will be 3101, to be completed in January of 1982. This will be required before the phase II TO BE program (FY 1982) can be performed. Phase III (FY 1983) programs, i.e., prototyping, will be completed only after 3101 phase III in FY 1982.

STATUS

This thrust area is currently in the phase I requirements definition to outline AS IS environment. It will be issued for multi-source solicitation, which will result in a single award.

EXPECTED BENEFITS

It is necessary to understand the life cycle of data to build data support systems for manufacturing. None of the existing systems support the ICAM needs, according to assessments performed by individual aerospace companies that are under current contract with ICAM.

The primary benefit of this project will be that different types of data -- engineering, business real-time, and non-real-time -- will be stored in the same system for ease of access. As more data representing product manufacturing are put into digital form, the need for management and administration of the data becomes more acute. This project will attempt to define the functions and procedures needed to perform this service.

FUNDING

	FY 1981	FY 1982	FY 1983	
ICAM	400	800	800	(in thousands
CIM	100	100	100	of dollars)

Funding appears adequate through FY 1983.

COMMENTS

1. The project is intended to prevent data duplication and ensure the availability of necessary data.

2. The key to the project is the combination of geometric and process control data with operational data (material and production control) while maintaining the integrity of the information base. This project should lead to a clear specification of the information types allowed in the CBIS.

3. Projects 3101 and 3201 need to be executed together. No mention is made of how to integrate 3201 and 3101. It is not clear why 3101 and 3201 are separate projects, and we suggest combining them.

4. Portability is a stated requirement not necessarily assured through this project. The updates in data will originate from different application programs and will be of different information types. Thus, in addition to describing data flows and data relationships, the project needs to define a set of rules that completely and exclusively prescribe the dynamic transition of the information base through its life cycle. The definition and enforcement of this set of rules is key to meeting the requirement of portability and the maintenance of integrity of the information base.

Project 3302. General Utilities System (GUS) Design Analysis and Build

OBJECTIVES

The objectives of project 3302 are:

- to establish a prototype general pre- and post-processing system to support other ICAM analytical software for the ICAM sheet metal center,
- to create tools for structured analysis,
- to provide support for simulations, software, and geometic modeling, and
- to provide a user friendly interface.

STRATEGY

The General Utilities System (GUS) requirements developed in project 3101 are used to establish the GUS preliminary design. The design parameter and application scenarios of a GUS are established from the requirements determined from: Manufacturing Control - Material Management, the Manufacturing Cost/Design Guide, robotics task B, AUTOIDEF, and the ICAM Design Support System. The design will be validated by building a prototype to support the systems listed above.

STATUS

This new start is phase I of a two-phase project. It will result in a TO BE General Utilities System and preliminary design document in FY 1981. Phase II (FY 1982) will develop a GUS prototype and an updated design document. It will be a multi-source solicitation with a single award.

EXPECTED BENEFITS

As ICAM subsystems are established, many different graphic user interfaces will also be established. These user interfaces will contain similar user features but will be established under separate contracts. This project is needed to avoid duplication of effort under each project.

This project will establish the design and build of a generic, user friendly graphics interface support system which will allow many users (from shop floor manager to system design engineers) to interact with the different ICAM subsystems being built. GUS will allow much more efficient and effective use of all ICAM modules because of the generic user interface established. It will provide savings by training users to learn only <u>one</u> user language to access many different application systems. Further savings will result from the establishment of new subsystems that use this software as its user interface.

FUNDING

	FY 1981	FY 1982	
ICAM	600	900	(in thousands of dollars)
CIM	200	200	

Funding appears adequate for FY 1981.

COMMENTS

1. The Initial Graphics Exchange Specification should be incorporated into the project.

2. In the establishment of data relationships, the project will need 3201 as an input to fully describe the information types and relationships and understand the rules that are prescribed.

3. The output will define user interfaces to project 3101, the CBIS prototype system. The statement of work of 3101 requires close cooperation with project 3201; a similar requirement should be included in this statement of work.

4. This program is state-of-the-art. No current systems provide the capabilities outlined in the objectives. A great deal of research is taking place in this area. A summary of research projects is available in the procedings of the IFIP Working Group 8.1 Conference held in 1979 in Oxford. The proceedings are available from the North Holland Publishing Company, Amsterdam.

Thrust Area 4000

DESIGN/MANUFACTURING INTERACTION

INTRODUCTION

The goal of this thrust area is to "establish subsystems and procedures which will integrate design engineering and manufacturing engineering as a routine business practice." The 4000 thrust area has three major elements: design architecture (4100), design/manufacturing interface (4200), and production interaction tools (4500).

According to the ICAM road map, four projects were to have been funded in the 4000 thrust area during FY 1980:

4101 Baseline design architecture
4204 Initial Graphics Exchange Specification
4502 Manufacturing Cost/Design Guide (MCDG)
4503 MCDG computerization

Project 4101 was deferred during FY 1980 and is now scheduled to start in FY 1981; however, much of the basic design architecture work was completed under project 1102T6. Since that is part of another thrust area, it will not be reviewed in this appendix.

OBJECTIVES

The 4000 series projects are intended to provided the integration between computer-aided design and computer-aided manufacturing systems. If the objectives are fully realized, a complete interaction of design and manufacturing systems to yield fully optimized products would occur.

STRATEGY

The strategy for developing the integration of design and manufacturing has three relatively straightforward elements. These elements recognize the current status of CAD systems being developed in industry and the major production-related consideration for designers -- namely, cost. Because CAD programs developed by aerospace industries are built around different software subsystems and data bases, an integrated data base is more easily evolved than implemented at once. The evolution of an integrated data base would permit each of various industry-developed entities to be incorporated into a CAD system. As part of this effort, the first strategic element is to identify data base elements required by CAD systems that are different from those required by CAM systems.

A second strategic element is the identification of costs associated with alternative production processes and the computerization of that cost information in such a way as to make it usable by designers at a fairly early stage. Finally, to attempt to assure that the integration processes cover the spectrum, the project will identify, as completely as possible, the full range of interactions between design and manufacturing.

STATUS

In general, the progress in the 4000 thrust area appears satisfactory. The Initial Graphics Exchange Specification (project 4204) attacks the data base problem described above and seeks to enhance communication of basic geometry, drafting, and other entities among CAD/CAM systems. Version 1 was delivered in January 1980 and has been accepted by the American National Standards Institute for release as a national standard in August 1980. This is a significant achievement. Version 2 is to be delivered in January 1981 and appears to be on schedule.

The Manufacturing Cost/Design Guide (project 4502) appears to have been a worthwhile project conducted by Battelle. The evolution of the initial cost/manufacturing data is now being followed by computerization of that information (project 4503). At this juncture it is too early to evaluate how this system will be received by industry. It is noteworthy that ICAM has planned training sessions to familiarize industry with its use.

The baseline design architecture (project 4101) will be initiated during FY 1981. Some of this work has already been accomplished under project 1102T6.

RELATIVE IMPORTANCE

Industry appears to have made relatively little progress in integrating the analytical portions of its CAD systems with CAM systems; therefore, the ICAM efforts in this area could be highly significant to industry. While the integration with CAD systems need not restrain the development of CAM systems, certainly the integration of those systems with CAD processes would enhance the effectiveness of the ICAM program.

In the design/manufacturing interface area, the ICAM program efforts will substantially enhance the state of the art in industry simply because of the traditional separation of these activities that has prevailed. The evolution of a proper design/manufacturing data base and a functioning computerized manufacturing cost/design guide could be very useful to industry. In general the 4000 series thrust area must be regarded as very important to the ultimate realization of integrated design/manufacturing systems.

QUALITY OF WORK

The work done to date on the design architecture seems to be good. The accomplishments of the Manufacturing Cost/Design Guide and of the Initial Graphics Exchange Specification appear to be excellent.

EXPECTED BENEFITS

In order for the Air Force to reduce the cost of weapons systems, not only is it necessary to develop more efficient manufacturing systems but it is essential that production-related matters be incorporated into the design process. In the past, one designed, then produced with a seemingly endless number of following iterations. The integration of design and manufacturing systems could not only reduce costs but also lead to improved product design. The need for such integration is therefore obviously great. The evolution of new technologies that would tend to integrate CAD and CAM systems is the primary benefit of this area. Significant increases in productivity are expected to result therefrom.

FUNDING

The proposed funding for the development of the design architecture appears excessive compared to the funding needs in the graphics exchange area, an effort which is slated to receive funding of approximately $100,000 in FY 1981. Additional funding for modularizing the computerized Manufacturing Cost/Design Guide system could enhance its use by subcontractors, especially the smaller ones.

CRITICAL DECISIONS

The Integrated Program for Aerospace Vehicle Design is a critical element on the design side of the CAD/CAM interface and should be continued in close coordination with ICAM in order to develop a total system. A decision must be made as to how far the ICAM effort will "back into" the design area. Clearly, ICAM cannot take on the IPAD task. The ICAM Program Office needs to develop guidelines on the extent to which it wishes to bridge the CAD/CAM interface.

A decision also should be made as to how far to pursue the design architecture. Manufacturing alternatives are relatively easy to define and describe. Moreover, they are limited in number. Design alternatives are, however, more numerous and considerably "softer" in their description. Care must be taken to avoid attempting to define design architecture in too much detail.

The manufacturing/design interface will also be substantially influenced by decisions regarding wedges. If the composite wedge is selected for emphasis by the Air Force, an entirely new series of 4000 thrust area projects will be required simply because designing with composites is rather less well understood and more complex than designing with metals.

The Manufacturing Cost/Design Guide has tremendous potential for technology transfer, especially to non-aerospace industry. In spite of that potential, the ICAM program is not likely to undertake any serious efforts to effect that transfer, nor does there seem any likelihood that another government agency will make the effort.

RECOMMENDATIONS

1. Based on the achievements accomplished and the projects funded during FY 1980, it is recommended that those projects proposed for FY 1981 be pursued.

2. A very close watch must be maintained over the design architecture project (4101) to ensure that it does not penetrate excessively into the design arena and become bogged down.

3. Proposed second year funding for the graphics exchange specification (4204) would seem to be less than is needed for this most important endeavor. A follow-on project may be needed to assure attainment of the objectives.

4. A significant effort should be made to obtain an industrial evaluation of the Manufacturing Cost/Design Guide. Such an evaluation may reveal shortcomings that would require additional development funding.

5. The ICAM Program Office should be alert to changes in the concerns for the design/manufacturing interface that might attend the selection of new wedges, particularly the impact of a composite wedge.

Thrust Area 5000

PLANNING AND GROUP TECHNOLOGY

Project 5202. Group Technology/Characterization Code (GTCC)

OBJECTIVES

The first objective of ICAM's work in this area is to develop a framework for classifying and storing information in concentrated form and a system for retrieving and transferring the descriptive data among persons involved in various phases of manufacturing. The classification system is based on group technology (GT), which is a systematic method for classifying things into groups based on their similarities in geometrical, processing, or other characteristics. The second goal is to establish and test one module, for sheet metal parts, of the complete characterization code (CC). The final goal is to implement and demonstrate the GTCC module for sheet metal in a working environment, the sheet metal cell or center, by January 1983.

STRATEGY

The GTCC effort is not intended to develop a standard code to compete with proprietary codes already available. Instead, the work is expected to provide a structure (taxonomy) based on hierarchical relationships of part characteristics to which a user can fit any coding system based on a hierarchy. A successful GTCC should simplify the effort needed to implement an integrated system by providing a framework for compatible modules.

EXPECTED BENEFITS

The Group Technology/Classification Code project will collect pertinent information from the coalition and through interacting with other ICAM projects. The project effort is being described in quarterly reports, and a final report will be issued.

The project is entering the last phase of a three-phase effort. The deliverables include definitions of the requirements for a complete classification code for sheet metal parts (SMCC), preliminary and detailed designs of a group technology support system (GTSS), software and documentation for the GTSS, and a demonstration of the system.

If successful, this project will benefit industry and government suppliers by providing a major tool for simplifying the effort of part designers and planners of manufacturing operations. The software being developed is expected to reduce repetitive work by those specialists, minimize paperwork, shorten lead times, and reduce in-process inventories.

STATUS AND SEQUENCE

After some time was lost in phase I, the GTCC project seems to be on schedule and to have met its recent interim objectives. The reports mention no problems in funding or timing.

Partly because the subject is specialized, the project reports are difficult for those outside the field to understand. The information presented is probably intended to help in implementing GTCC, but the style is not likely to attract converts to the ICAM approach to manufacturing.

The Group Technology/Classification Code project interacts with many other ICAM projects, particularly in providing inputs to the following:

- 1104 - Architecture
- 3301 - Requirements analysis of General Utilities System
- 5501 - Requirements for an integrated plannning system to handle materials requirements, scheduling, shop loading, and process planning
- 6201 - Manufacturing Control - Material Management for the sheet metal center
- 4503 - Computerization of the Manufacturing Cost/Design Guide. (This will require collaboration because work on the MC/DG started before the work on the architecture and group technology.)

RECOMMENDATIONS

The reliability and discriminating characteristics of the system should be evaluated by coding an appropriately large number of sheet metal parts. The coding exercise should be conducted by several people representative of the expected users of the system.

Project 5501. Integrated Planning System

OBJECTIVES

The objectives of this project are to define the requirements of a system for planning and scheduling some of the manufacturing functions in the aerospace industry and to demonstrate its capabilities in supporting the operations of the sheet metal center.

STRATEGY

The first three tasks in developing an integrated planning system (IPS) should provide a good understanding of methods now used by the aerospace industry for scheduling manufacturing operations, planning the process details, and identifying the resources (labor, material, and equipment) needed for production. That information will define the requirements of an integrated computerized system and help in selecting a suitable architecture for the system. The subsequent effort will pull that information into a detailed design of the architecture of the IPS. Presumably, the IPS will evolve from the ICAM hierarchy of process, station, cell, and center. It will classify the attributes of activities, decisions, and actions taken in the different planning functions. The final option calls for constructing hardware and software and demonstrating that the IPS system could provide planning support for the sheet metal manufacturing center.

STATUS AND SEQUENCE

This project is the second phase of a three-phase effort to develop an integrated planning system for manufacturing. Although the goal is ambitious, no technical barriers to progress are foreseen. Some COCAM members experienced in developing software for planning believe that the $4.8 million appropriation will not cover the cost of development. The IPS may avoid this problem by building on available systems and inputs from other projects or through cost sharing by coalition members.

Projects related to the integrated planning system include:

- 1104 - Architecture
- 3101 - Computer-Based Information Systems requirements
- 3302 - Design analysis of General Utility System (FY 1981)
- 5202 - Group Technology/Classification Code
- 5204 - Planning support for GTCC (FY 1982)
- 6201 - Design Manufacturing Control - Material Management system for a sheet metal center

8205 - Build first version of ICAM Decision Support System
9302 - Design Materials Handling/Storage System for sheet metal cell and center.

EXPECTED BENEFITS

A successful integrated planning system would provide consistent, reliable, and efficient plans and schedules for three subsystems in the complete manufacturing system. The subsystems are manufacturing planning, process planning, and production planning. The IPS could be expected to lower the costs for those tasks and the amount of unproductive time of equipment and associated labor. Operating the system with a sheet metal center would permit quantitative cost/benefit analyses.

A successful integrated planning system might be useful in the cruise missile, F-16, and F-18 programs. The IPS and its individual modules are of potential use in manufacturing firms.

The IPS project will be documented in a final report. It can be expected to describe the current planning practices for the three subsystems of interest and the composite architecture of the integrated planning system. The deliverables include preliminary and detailed designs of the IPS architecture for a sheet metal center and the aerospace industry. Presumably, they wil be documented according to standard practice.

Less specific forms of technology transfer will result from interchange of information among members of coalitions working on the IPS project and other ICAM projects.

RECOMMENDATIONS

One of the stated objectives is to build and demonstrate an integrated planning system to support the sheet metal cell and center, but that goal is not mentioned specifically in the statement of work. It should be.

Thrust Area 6000

MANUFACTURING CONTROL AND EXTERNAL INTERFACES

OBJECTIVE

The objective of the thrust area is to provide a closed-loop factory management system based on obtaining "on-time" status information within and between factory operations with corrective feedback action.

EXPECTED BENEFITS

A large percentage of industry acts and reacts through manual systems in handling production control and shop load problems in the factory environment. To improve productivity of batch manufacturing where flexibility for design and production change is desired, computerized systems appear to have the potential for significantly improving timeliness and reducing manpower requirements.

STRATEGY

The plan is to develop three levels of manufacturing control: a cell manufacturing control system, a center manufacturing control system, and a factory manufacturing control system.

The 6100 series will develop manufacturing control systems for cells. Project 6101 will determine the requirements for and design of the cell Manufacturing Control - Material Management system for an air launch cruise missile engine production cell.

The 6200 series projects have been planned to develop the center Manufacturing Control - Material Management system. The manufacturing center in the ICAM program is considered to be made up of several cells that require interacting control systems. Project 6201 establishes the requirements for and design of the cell Manufacturing Control - Material Management system. Project 6202 provides for building and demonstrating the system at the factory level involving several manufacturing centers. Project 6301 provides for the design of the factory control system and project 6302 for the development and demonstration in support of air launch cruise missile engine programs.

The ICAM strategy has been to use a coalition of industry representatives to describe current manufacturing systems and identify their deficiencies. From these data, they are proceeding with the development of the requirements for the future. The industry coalition considered the Manufacturing Control - Material Management concept being developed as applicable to a wide range of manufacturing such as sheet metal, assembly, and composites.

Project 6101. Integrated Manufacturing Control - Material Management Requirements Definition, and Design

OBJECTIVES

The objectives for the ICAM contract awarded to General Electric were to produce preliminary and detailed designs of a complete closed-loop factory management system. The focus of the projects is on the control of the shop in the sheet metal center.

EXPECTED BENEFITS

The coalition has found that this type of capability is not available today and that, if developed, this capability would be generic in nature and applicable to much of manufacturing in the future.

STRATEGY

The basic strategy is as outlined for the 6000 thrust development. In addition, three concepts act as the basis for ICAM's design:

- Four Plane Concept - divides the manufacturing process into four distinct functions: planning, control, material flow, and process. This aids the designer in determining the control activities, which are the project's prime concern.

- Generic Control Module - defines the elements required for a "closed-loop" manufacturing control system: plan work, load resource, implement plan, obtain feedback control data, and measure performance.

- Hierarchical Control - defines structure of manufacturing control: factory, center, cell, station, and process.

STATUS

The ICAM team has developed a composite functional model of the existing factory management systems based on data from Northrop, Lockheed, Vought, Boeing, and General Electric.

Some of the weaknesses identified in the current systems are poor schedule realization, poor utilization of resources, long manufacturing cycles, much work-in-process, and high control costs.

Control features deemed missing from the model of existing systems relate to three functions: plan detail work, load resources, and measure performance. It was found that plan detail work and load are often performed manually without automation, while measure performance is in most instances missing. The system design of the factory of the future is being evolved and the information model is being developed.

RELATIVE IMPORTANCE

Many of the production problems in industry today result from the lack of timely and accurate data on the status of work in progress. The manual effort in meeting changing production requirements is extensive. Recent information in one company indicates that the cost of expediting special shop orders alone can be reduced by at least 30 percent.

DELIVERABLES

This project will result in the definition and design of a future system for integrated Manufacturing Control - Material Management that later will be demonstrated in the sheet metal cell.

QUALITY OF WORK

The coalition team working on this project has taken a very practical approach to developing the integrated MCMM capability. It appears that for this reason industry will be able to make good use of this system at an early date.

RECOMMENDATIONS

This project is a key step in the development of supporting technology for the operation of sheet metal cells and center. The schedule of this project should be closely coordinated with those of the fabrication thrust projects to ensure that the output of this project can be used directly by the sheet metal cells and center.

Project 6103. Integrated Cell MCMM System for Sheet Metal Fabrication

OBJECTIVES

The objective of this project is to design, build, and demonstrate a subsystem that can provide manufacturing control and material management at the cell level. The requirement for this subsystem is established in project 6101. The subsystem is to be installed and demonstrated in an aerospace sheet metal fabrication environment.

This MCMM subsystem is intended to provide the means for planning work to be done, loading resources, implementing the plan, obtaining feedback to monitor performance, and determining corrective action necessary to obtain results. The project will identify what information is required, where it is needed, and at what time in the production cycle. Principal challenges for the contractor will be acquiring and timing information input, processing and evaluating information to produce corrective measures that will optimize the production process, and interfacing this subsystem with other subsystems and with other systems within the ICAM architecture.

EXPECTED BENEFITS

In a multi-variable environment such as a manufacturing cell, all significant variables need to be monitored to observe variations from the chosen plan and to identify and evaluate alternate production plans so that appropriate corrective action can be taken to optimize the use of materials and resources.

This has been the goal of material and production control systems for many years. The risk in this program does not seem to be in the acquisition of information or in making this information available in any desired format in a timely fashion. The challenge will remain the development of the logic to analyze and evaluate the information so that better, more timely decisions can be made. A logic system that will make such decisions automatically is likely to be beyond present capabilities except in a highly structured, narrowly constrained environment or in extremely simple situations that would not benefit from computer-based assistance in any case.

The benefits of this project will be found in two areas: (1) identification and measurement of the significant variables in the production environment that affect manufacturing results, and (2) an increased understanding of the relationships among these variables (or lack of relationships) to make improved planning possible and to increase the planner's ability to deal with unpredictable occurrences on the production floor. This project and associated projects should be vigorously pursued for these reasons.

SEQUENCE

This subsystem is intended to be the basis for project 6201, an integrated MCMM system at the center level. It provides the first (station) and second (cell) level material control and manufacturing management system for the manufacturing operation. It must interface with project 1104, ICAM architecture.

POTENTIAL BARRIERS TO SUCCESSFUL COMPLETION

This project appears to have manageable constraints. Data acquisition activities such as process monitoring, tracking material movement, and checking resource availability are within the capabilities of current technology. The principal problem area is likely to be in developing analytical logic to evaluate actual shop floor activities and the implications of altering the manufacturing plan.

The contract specifications also require construction of $IDEF_1$ and $IDEF_2$ models. In view of the fact that no $IDEF_1$ or $IDEF_2$ modeling systems currently exist, this may be impossible to achieve.

STRATEGY

The project is divided into two phases. Phase I, task 1 is to establish requirements for and design of an MCMM station and an MCMM cell. Phase II, task 2, option 1 is to implement and use an MCMM station in an aerospace sheet metal manufacturing environment. Phase II, task 3 is to build and demonstrate an MCMM cell in an established manufacturing environment.

DELIVERABLES

Deliverables of this project are:

- a successful strategy for implementation of ICAM subsystem,
- demonstration in a major aerospace company,
- an operating hardware/software system,
- complete documentation for the system, and
- a return-on-investment benchmark.

Project 6104. Build and Demonstrate An Integrated Cell Manufacturing Control - Material Management (MCMM) Subsystem For Small Business

OBJECTIVE

Project 6104 will build station- and cell-level MCMM controllers, using the design from project 6101. These subsystems are then to be installed and operated in a small aerospace manufacturing environment to demonstrate the portability of ICAM systems into the small business portion of the aerospace industry.

EXPECTED BENEFITS

A substantial number of aerospace companies are small and lack resources to develop or adapt complex, sophisticated, computer-aided manufacturing systems. If ICAM is to be successful, it needs to create portable modules and subsystems that can be used by small aerospace companies without incurring excessive costs or requiring excessive resources.

Most small aerospace companies are subcontractors to large or medium-sized companies. Their manufacturing systems (information management systems, information transmission systems, and manufacturing scheduling and control systems, to name a few) should be integrated with those used by the prime contractor to the greatest degree possible. Some of the potential benefits of such integration are reduced costs, greater use of assets, shorter response time, and greater capacity to accommodate changes without incurring excessive costs.

SEQUENCE

This project will use as a point of departure the requirements definitions and designs for an integrated MCMM up to and including cell level established in project 6101 and experience gained from project 6103. It will then focus on the modifications, if any, necessary for successful installation and operation in a selected small aerospace manufacturing company. The system initially will be stand-alone. Interfaces will be verified and modified on site. The ultimate goal is full integration with an existing manufacturing environment. The system will then be operated under real-life conditions and evaluated for user acceptability and benefits.

POTENTIAL BARRIERS TO SUCCESSFUL COMPLETION

The greatest potential problem for project 6104 appears to be the difficulty of adapting a highly abstract, idealized control system to an existing environment without significantly modifying the system, the environment, or both. If the results of project 6104 need to be radically modified for small aerospace companies, successful adaptation will not be a conclusive demonstration of the the worth of the unmodified system; it will demonstrate only that one modification was successful.

STRATEGY

Task 1 is to define the scope of the MCMM subsystem within the aerospace environment in which implementation is proposed (in this case, an Air Launch Cruise Missile Facility). Task 2 is to construct, install, integrate, and test an MCMM station. Task 3 is to construct, install, integrate, and test an MCMM cell.

DELIVERABLES

Deliverables of this project are:

- an operating hardware/software system,
- complete documentation for the system,
- ICAM demonstration in small aerospace business, and
- training for technology transfer.

Project 6201. Establish Requirements and Design of An Integrated Center Manufacturing Control - Material Management System

OBJECTIVES

Project 6201 is to establish requirements definitions, preliminary design, and detailed design of an integrated center-level manufacturing control and material management system. The successful completion of this project will depend on the design, development, and demonstration of effective MCMM station and cell subsystems because a center is defined as the automated control of two or more cells.

EXPECTED BENEFITS

There is a need to develop and demonstrate a working example of integrated computer-aided manufacturing. The Air Force has chosen an integrated sheet metal center to be this example. Before an integrated sheet metal center can be demonstrated, a Manufacturing Control - Materials Management system for center-level control must be available. It is hoped that the control system to be developed under project 6201 will be applicable to a large variety of center configurations common to aerospace manufacturing, including composite centers and assembly centers.

It is commonly believed that more accurate, timely information on operations is required to improve manufacturing performance and costs. Increasingly flexible manufacturing systems now becoming available will require sophisticated, real-time control systems to perform at all. The establishment of an integrated sheet metal center should lead to much greater understanding of the benefits and limitations of the computer-controlled factory. Project 6201 is a basic subsystem required for demonstration of the sheet metal center.

SEQUENCE

The successful completion of this project is one of the essential steps to achieve the principal ICAM goal, which is to demonstrate in production that "ICAM, properly formatted and structured, synergistically raises efficiencies and can be harnessed to provide very substantial benefits at all levels of manufacturing management and operations."

It is the next-to-last step in a bottom-up development from process control to factory control and depends on the results of project 6103.

POTENTIAL BARRIERS TO COMPLETION

The stated purpose of this project is to create a closed-loop system to control and manage the flow of material through and operation of a manufacturing center. It is not possible to determine clearly, from the available documentation, in what physical environment this system is expected to operate. There is a strong implication that it will be some version of the automatic, computer-operated factory. When the ICAM concepts of group technology, geometric modeling systems, and generic computer-aided process planning are considered, that implication becomes stronger.

To the degree that the successful development of an MCMM closed-loop system depends on manufacturing and material handling hardware that does not now exist, the successful application to a real-world situation could be delayed or possibly fail.

The committee sees five areas of concern: the availability of manufacturing equipment and processes with the required range of flexibility and adaptability; the availability of material handling and storage systems that can become part of the integrated factory of tomorrow; the availability of measuring and sensing devices to provide information to the system; the economic practicality of these elements, hence availability, upon which an integrated MCMM may depend; the problem of developing a satisfactory system of control and decision-making logic, especially for complex, highly variable manufacturing environments.

STRATEGY

Task 1 will be to establish a factory view of the MCMM subsystem that is representative of large aerospace manufacturers. Factory views for large and medium-sized businesses established in project 6101 will be the basis for this effort.

Task 2 is to establish a composite factory view. A coalition of large, medium, and small aerospace manufacturers will modify the factory view established in task 1 to accommodate each coalition member's deviations. From this model a list of improvements will be developed and a preliminary design for the MCMM center created.

Task 3 is to establish a detailed design for the center and provide documentation.

DELIVERABLES

Deliverables of this project are:

- an operating hardware/software system,
- complete documentation,
- ICAM demonstration in a major aerospace company, and
- an ICAM implementation benchmark.

Thrust Area 7000

ASSEMBLY

OBJECTIVE

The objectives of the 7000 series projects are to analyze the requirements and establish the preliminary design for an assembly center for sheet metal, composites, or both products. From these requirements, an assembly cell, then a center, will be constructed and demonstrated.

EXPECTED BENEFITS

Product assembly, at either the subassembly or final assembly level, is characteristically a labor-intensive operation in aerospace manufacturing. Unlike parts fabrication, which has received considerable attention for productivity improvement in recent years, basic assembly techniques, equipment, and processes remain virtually the same with minor changes in the details of the process.

Assembly offers greater leverage for productivity improvement than fabrication. The Air Force has recognized this and is pioneering development in the application of computer-integrated technology in assembly.

STRATEGY

The assembly thrust consists of four projects:

- 7101 Assembly requirements and design
- 7102 Enabling technology for assembly
- 7103 Assembly cell construction and demonstration
- 7201 Final assembly

The thrust began with a nearly two-year project (7101) to establish the requirements and preliminary design of an assembly center. This project will start in FY 1980.

From the needs analysis and requirements definition of 7101, current voids in assembly process or equipment technology will be defined. These voids will be addressed as technical issues starting FY 1982 in project 7102.

Also in FY 1982, the detailed design and construction of a selected assembly cell will commence. The cell will be for the assembly of sheet metal, composite products, or both. In FY 1984, an assembly center will be started for final assembly operations.

Project 7101 is in procurement. No contract award has yet been made.

RELATIVE IMPORTANCE

Assembly is a varied manufacturing discipline consisting largely of manual activity. Assembly is a major target for future productivity improvement.

The ICAM program's concentration on assembly can be expected to initiate a major industrial movement to improve the efficiency of assembly operations much the same as productivity improvement was spawned in the machining arena with the advent of numerical control. ICAM has the potential to act as a catalyst in initiating this productivity movement. Short-term results may appear minuscule relative to the improvements that will evolve over the next decade.

Care needs to be taken not to confuse the objectives of basic computer-integrated technology. It must be recognized that automation technology is in its infancy. Much is to be gained through the development of more efficient equipment and processes; however, further leverage exists in the computer integration of the equipment and processes.

Early results of ICAM should focus on demonstrable results to kindle the interests of top industry management.

QUALITY OF WORK

Contracts have not been awarded in the 7000 series, so no comment on performance or quality can be made at this time.

FUNDING

The funding of the 7000 series appears adequate to complete a selected assembly cell and center. This demonstration will be only one of multitudes of typical applications of computer-aided manufacturing technology that can be expected to come to fruition in the next decade.

CRITICAL DECISIONS

It is too early in the thrust to comment on the many critical issues that will arise in assembly. But, briefly, the key issues to be faced will include:

- selection of a meaningful demonstration project to heighten the awareness of industrial management of the potential of computer-integrated assembly, and

- the relation of the assembly thrust to other ICAM projects. Assembly is fundamentally a manual effort today and new equipment and processes will be developed before an assembly in total will be ready for computer integration. The need for enabling technology development should not be overshadowed by the requirements for integration at an early phase of the thrust.

RECOMMENDATIONS

Assembly holds, perhaps, more potential for productivity improvement than parts fabrication. The Air Force, in recognizing this potential, is taking a lead that will ultimately result in a changing of the techniques of product assembly.

The 7000 series projects are but a first step toward that improvement. The committee wholeheartedly endorses the assembly thrust and its direction primarily at technology development.

Thrust Area 8000

SIMULATION, MODELING, OPERATIONS RESEARCH

OBJECTIVE

The objective of this thrust is to establish a decision support capability for manufacturing. This capability includes both the analytic tools and the methodology to support using those tools to aid in manufacturing decision-making. The results of this thrust will provide:

- the requirements and preliminary design for an ICAM Decision Support System (IDSS),
- characteristic performance measures for evaluation and optimization of manufacturing systems, and
- demonstration of a working prototype system for the ICAM sheet metal center.

EXPECTED BENEFITS

Industry needs improved methods to simulate shop-floor production conditions and aid the decision process. In many cases, manufacturing management has resisted the use of present modeling techniques. The lack of good collection procedures in manufacturing usually forces the simulation analyst to spend the majority of his time collecting and validating data, not performing the analysis. As a result, the flow time to execute a simulation study is increased and the credibility of the results of the study may be questioned.

As IDSS is integrated with the results of other ICAM contracts, it will demonstrate the need for improvement and automation of data collection procedures to support quantitative analyses. The key to increasing the use of simulation in industry is the reduction in time and effort required to acquire valid data. A decision support system tied into the manufacturing data base is a step toward meeting that goal.

However, the data base for other management purposes may not be adequate for simulation, and industry may choose not to expend the funds for data collection, management, and retention required to support effective simulation application.

STRATEGY

The 8000 thrust area is aimed at the development of a decision support system integrated with the sheet metal center. In the interim, IDSS 1.2, the current version developed under project 8201, will be enhanced to subsequent versions 1.3 and 1.4. The new versions will have considerably more simulation capability.

Project 8202 is to progress in parallel with 8201 and is responsible for defining the requirements for IDSS as a decision support system, not just as a simulation tool.

Follow-on projects 8203 and 8205 will add analytic tools to IDSS 2.0 and provide for integration with the sheet metal center, respectively. A number of analytic tools such as linear programming, project management support, financial planning, statistical modeling, and structured analysis will be included. The integration of the IDSS 2.0 prototype into the sheet metal center will permit access to the manufacturing data base and the ability to be invoked by the General Utility System developed under projects 3301 through 3305.

STATUS

The main result of the 8000 area to date is the IDSS 1.2 simulation language. IDSS 1.2 is an enhanced version of the original IDSS 0.0 prototype developed under project 8201. Further refinements of IDSS 1.2 will lead to versions 1.3 and 1.4, which should be comparable in capability to simulation methods presently in use in industry.

Following development of the IDSS 0.0 prototype, a number of steps were taken to tailor the version 0 method to the needs of ICAM and industry. These tasks are to:

- assess manufacturing needs for modeling and simulation support,
- determine ICAM subsystem contractor needs,
- survey state-of-the-art modeling and simulation capabilities, and
- develop $IDEF_1$ model of making manufacturing decisions.

Some of these needs have been incorporated into the 1.2 edition and will be addressed in IDSS 1.3 and 1.4. All ICAM subsystem contractors have been required to use IDSS to support their contracts. Feedback for future IDSS improvements has resulted from the subsystem use and user training sessions.

RELATIVE IMPORTANCE

Industry needs - There is no doubt that the aerospace industry lacks expertise in appying simulation and modeling techniques to manufacturing decisions. It is not apparent, however, that the resistance to simulation today is due to the deficiencies of the techniques used. A number of proven simulation methods are available to address manufacturing problems, and more are being developed. The main problems are encountered in the data required to support a simulation study.

The IDSS work to date has been to develop a simulation capability that a manager could use to support his decision making. The key to this development has been a graphics user interface that permits an unsophisticated user to perform simulation exercises. Unfortunately, the emphasis on a user interface has left the IDSS tool deficient in technical areas. The use of a simulation capability by manufacturing management is not likely in the foreseeable future. To address the needs of the aerospace industry, IDSS must be a tool that benefits analysts, who could apply it immediately, rather than managers, who have no desire to use simulation. If IDSS is to satisfy the systems analyst, then it must be superior to the techniques the analyst currently uses. To date, IDSS continues to be subject to the same problems in data acquisition, and will encounter the same resistance, as current techniques.

Near-term and long-range importance to overall ICAM success - The use of simulation, modeling, and operations research methods will be instrumental in the eventual success of the demonstration of the sheet metal center. The use of simulation and modeling should provide the insight into system performance that will allow the design of center subsystems to be optimized. The present ICAM contracts require the use of IDSS as the simulation tool. At its present state of development it does not have the capability of some other systems for the technical analyst. For this reason, its use is being resisted by some in industry. Until IDSS is developed to the point that it is a least comparable to current techniques, its use by contractors should be optional.

Advancing the industry state-of-the-art - The IDSS tools created so far do not provide any advancement in the technical state-of-the-art simulation capability. The graphics interface is a step forward in allowing an unsophisticated user access to simulation, but in the hands of an experienced simulation analyst, the much slower graphics version hinders the simulation analysis process and is used primarily for documentation.

The goal of the IDSS to become a total decision support system with many analytic modeling and simulation techniques is notewcrthy and should contribute to the field. The extent to which this goal is accomplished by use in industry depends largely on how much effort is directed toward making IDSS a high-level rather than a low-level tool.

Transfer of technology to industry - The eventual transfer of IDSS to the aerospace industry will depend on its technical merit. Key elements of IDSS, such as the graphics interface, are an outgrowth of the current thinking in the simulation and modeling community, which is concerned with minimizing development and analysis costs in simulation studies. Numerous techniques are developed every year that attempt to improve the current method of simulating. IDSS must address these same concerns as it will be competing against the new and existing techniques for use in industry. If IDSS cannot meet or exceed the capability and power of the competing techniques, IDSS will continue to be used only on Air Force contracts -- for political, not technical, reasons.

QUALITY OF WORK

Development of IDSS should continue to improve upon the simulation capabilities of other present methods until IDSS is superior to current techniques. The improvement to date has been substantial and should proceed.

The IDSS system must be made portable enough to be installed at ICAM contractor facilities. The current access through CYBERNET is too expensive and time consuming. Considering the limited amount of ICAM funding available, large fractions of contract funds should not be spent for CYBERNET use. This can be avoided only by making IDSS transportable to ICAM user installations.

FUNDING

The funds allocated for projects 8201, 8202, 8203, and 8205 appear consistent with the tasks to be performed. Potential problems could arise with the extensive amount of coordination with other ICAM contracts that is required. The parallel development planned could strain the allocations, especially in project 8205, which has many integration requirements.

CRITICAL DECISIONS

A number of events must occur before the IDSS demonstration can be successful. Perhaps the most critical is the interface with the manufacturing data base to allow automated data entry into the IDSS models. The extent to which IDSS can be matched to the manufacturing data base will depend largely on the results of the 3000 thrust area projects to develop the General Utility System (GUS) and the Group Technology

Support System (GTSS). These are among the many tools that need to interact to provide IDSS with the capability to be demonstrated.

Some of the tools to be developed by ICAM will also be driven towards the 1985 demonstration. Manufacturing Control - Material Management, Computer-Based Information System, and GTSS are all required to operate the sheet metal center and will be directed to that purpose. Because the demonstration of the integrated sheet metal center is perhaps the single most important result of the ICAM program, the projects required to directly support the center could be provided with more resources and visibility. The projects not required to operate the center, such as IDSS and GUS, may as a result not receive the same level of attention. Only upon the completion of each of the life cycle steps for all of these projects will the demonstration of a decision support system be achieved. Since the projects will be carried out in parallel, the eventual success of IDSS as a decision support system will likely be subject to the results of non-8000 thrust projects and the level of coordination between projects.

The future use of IDSS in industry is limited if it is accessible only via the CYBERNET computer network. For the purpose of the ICAM program, where inter-project communication is paramount, a computer network is justified. However, as more people, both managers and analysts, use a decision support system, the costs associated with CYBERNET, or any other large scale system, will prove prohibitive. Already the trend is toward mini- and micro-computers, for which execution and storage costs are lower.

RECOMMENDATIONS

Although the 8000 thrust developments are directed towards a worthy goal and have progressed significantly, some recommendations should be considered for future 8000 thrust projects.

Manager Interface - The user that IDSS should address is the systems analyst, not the manager. The user interface should be structured in such a manner that it is easy for an engineer/analyst to access and use all of the IDSS tools. If in meeting the needs of the engineer/analyst the approach also satisfies a manager's need, then that is an additional benefit. The problem with defining a management user interface is that current management has neither the desire nor the time to acquire the detailed level of understanding of a system that is required to model the system using IDSS tools like simulation, structured analysis, or linear programming. Simulation results could be misapplied if the user does not fully understand the need for correct data selection and the limitations of the simulation algorithms. These constraints favor the analyst rather than the manager as user. Systems analysts and engineers are employed to use these tools and apply them as their understanding of the problem dictates. It is to this user that future IDSS prototypes should be directed.

Installation - One of the main drawbacks to simulation today is the considerable expense of data collection, model development, and sensitivity analysis. IDSS appears to be attacking the data collection and model development problems directly through the link to the manufacturing data base and the graphics user interface, respectively. The computing costs associated with IDSS, including storage and execution, will only increase as IDSS becomes a more powerful tool. The addition of analytic tools, data reduction models, links to ICAM subsystems, and the other planned enhancements will require considerable computing resources. The current costs accumulated by using IDSS on CYBERNET, without the planned features, are staggering. To be used by industry, IDSS needs to be operable on a system where a reduction in analysis costs can be achieved.

Some additional IDSS versions for specific machinery have been planned, but these systems do not appear to have been selected to maximize potential industry use. We recommend that the 8000 thrust projects conduct a survey of users of tools to be contained in IDSS to determine which computer systems are used today or are likely to be used in the future. Obviously, an IDSS version cannot be developed for every computer system; however, a few of the most common ones could have individual versions. For the computer systems that do not support IDSS, the 8000 thrust should at least provide documentation on the requirements to implement IDSS and procedures to modify IDSS to specific computer systems.

Simulation Capability - The simulation capability of IDSS 1.2 is a significant improvement over the initial version of IDSS. The IDSS developers should continue to strive to provide the maximum simulation capability. When conflicts between the addition of simulation power and the graphics interface occur, we recommend that the simulation capability be added even if it cannot be implemented in a graphics structure.

Thrust Area 9000

MATERIAL HANDLING AND STORAGE

OBJECTIVES

The objectives of the 9000 series projects are to:

- develop the integrated Material Handling and Storage System (MHSS) requirements and detail designs for sheet metal cell(s) and center,
- design and demonstrate enabling technologies for the MHSS,
- enhance robotic technology by development of higher order robotic languages and incorporation of vision, sensors, and pattern recognition,
- design and demonstrate a robot cell, and
- design and demonstrate computer-aided imaging.

EXPECTED BENEFITS

The application of programmable, flexible, or automated material handling and storage systems in aerospace manufacturing is in its infancy. Except in applications in highly hazardous environments and a very few aerospace applications, robotics and other sophisticated techniques have not yet been implemented in manufacturing. High costs and inflexible equipment have contributed to the apparent lack of progress in introducing new technology to the material handling and storage functions.

The Air Force recognizes that for integrated material handling and storage to become viable technologies, further requirements, specifications, and development must occur. Until such work is accomplished, a fully integrated sheet metal center is not possible.

Industry has not readily integrated or adopted any automated material handling and storage systems because of the relative inflexibility of currently available systems. If ICAM can stimulate concepts, techniques, and technology to accomplish flexibility, that will be the program's greatest contribution to promoting the automation of material handling and storage.

STRATEGY

The material handling and storage thrust consists of three subgroups:

9100 Robotics

- 9104 Aerospace robotic applications
- 9107 Factory robotic applications
- 9108 Computer-aided vision system

9300 Cell/Center MHSS

- 9301 Material flow characteristics
- 9302 Enabling technology for integrated MHSS
- 9303 Construction and demonstration of integrated MHSS

9400 Factory MHSS

- 9401 Factory MHSS requirements and preliminary design

The 9100 series projects began in FY 1978 with three concurrent projects to demonstrate the feasibility of robotics, identify additional robotic applications, and define the requirements for additional technology. Project 9108 is planed for a FY 1980 start and will involve the application of laser technology to pattern recognition and vision requirements. In FY 1982 the major task to design and demonstrate robotics for shop applications will begin.

The 9300 series projects began in FY 1979 with a study of the characteristics of material flow and handling in aerospace manufacturing. In FY 1980, project 9302 will develop the requirements, detailed designs, and enabling technologies for an MHSS system for a sheet metal cell(s) and center. The construction and demonstration project 9303 will begin in FY 1982 and conclude in FY 1984.

The 9400 series begins in FY 1982 with project 9401 to define the requirements and preliminary design of factory MHSS systems. No demonstration project is yet planned.

Robotics are perceived to play a major role in MHSS and appropriately precede the 9300 and 9400 series.

STATUS

Preliminary work has been completed or nearly completed in the following projects:

9104 - Robotic applications - task A
9104 - Robotic applications - task B

9104 - Robotic applications - task C
9301 - Material flow characteristics

Proposals for project 9302 are being evaluated by the Air Force.

RELATIVE IMPORTANCE

Material handling and storage systems are important components of flexible manufacturing systems and are necessary elements of factory cells and centers. The state of the art of integrated MHSS systems is not yet to the refinement required in the cells and center of ICAM. Requirements definition, enabling technology, and demonstrable concepts are important before cells and centers can become a reality.

QUALITY OF WORK

The work done to date has been largely exploratory and preliminary investigations to provide a foundation upon which to develop the structure of an integrated MHSS. The work accomplished to date in the robotics projects has been satisfactory. The work accomplished in project 9301 has yet to be seen by the committee.

FUNDING

No single solution to MHSS problems is applicable in all firms. ICAM can, at best, demonstrate viable and productive concepts of MHSS to encourage further industry development. To this end, the ICAM funding seems adequate.

CRITICAL DECISIONS

A common assumption is that robotics has a major role in MHSS. Much work remains to be done before the economic possibilities of robotics in aerospace applications will be understood. An integrated MHSS demonstration should be carefully planned to include several MHSS concepts while avoiding complexities that might cause the demonstration to fail. The integrated MHSS demonstration will motivate the adoption of the technology if it shows what can be done successfully and economically, not what can technically be achieved sparing no cost.

RECOMMENDATIONS

Integrated MHSS is a key to the success of the demonstration of cells and centers. The committee supports the 9000 thrust area as currently structured.

Thrust Area 0000

TEST, INSPECTION, AND EVALUATION

OBJECTIVE

The objective of the 0000 thrust is to provide the requirements, enabling technology, and demonstration of test, inspection, and evaluation (TI&E) concepts for a sheet metal cell, center, and assembly operations.

EXPECTED BENEFITS

As technology moves more into the era of automation, in-process TI&E will become an essential ingredient of manufacturing systems. Without integral TI&E, inspection can be a serious bottleneck to the production lines.

STRATEGY

The ICAM program appears to have little or no strategy for TI&E. The significance of TI&E seems to have been underestimated.

STATUS

Other than concepts that have been incidental to projects in the 2000, 3000, 5000, 6000, 7000, and 9000 series regarding TI&E, no development has occurred.

RELATIVE IMPORTANCE

Quality assurance of all aspects of automated cells and centers is essential to the successful operation of those elements resulting in hardware production. Among these elements are:

- data validation,
- data transfer verification,
- equipment performance validation,
- process sequencing,
- tooling,
- cutting tools,
- material handling and positioning,
- process controls,

- dimensional inspection, and
- non-destructive tests.

All of these elements must be controlled to result in a cell or center that operates properly. Without controls, a catastrophic failure could occur, producing large quantities of discrepant products at a significant cost incurrence.

QUALITY OF WORK

No work has yet been accomplished, so this section is not applicable.

FUNDING

The scope of the 0000 thrust area has been grossly underestimated, both in scheduling and in funding. TI&E concepts should be evolved concurrent with the other ICAM thrust areas. Funding of $5 to 7 million would seem more appropriate.

CRITICAL DECISIONS

The 0000 thrust should be reexamined and more definitively planned than currently. This is a major issue and a decision that the ICAM program must face in the near future.

RECOMMENDATIONS

TI&E is important to ICAM systems. The scope and importance of the 0000 thrust have been underestimated. This thrust area should be developed concurrently with the others. We recommend that the entire 0000 series be reevaluated and replanned to be compatible and concurrent with the other thrust areas. TI&E should not be an afterthought.

GLOSSARY

This glossary contains the acronyms and special terms used by the ICAM program and included in this report. When an acronym refers to an ICAM project, the thrust area of that project follows the definition.

Architecture	Model of manufacturing systems (1000)
AUTOIDEF	A computerized version of the ICAM Definition (IDEF) method for depicting manufacturing functions (1000)
CBIS	Computer-Based Information System (3000)
Cell	Automated control of two or more stations, including material handling
Center	Automated control of two or more cells
CIM	Computer-Integrated Manufacturing branch of the Manufacturing Technology Division of the Air Force Materials Laboratory
GTCC	Group Technology and Characterization Code (5000)
GUS	General Utilities System, a generic "user friendly" graphics interface support system for ICAM analytical software (3000)
ICAM	The Integrated Computer-Aided Manufacturing program
IDEF	The ICAM Definition method for depicting the functions, information, and dynamics of manufacturing (1000)
IDSS	ICAM Decision Support System (8000)
IGES	Initial Graphics Exchange Specification (4000)
IPAD	Integrated Program for Aerospace Vehicle Design, of the National Aeronautics and Space Administration
IPIMS	Integrated Program Information Management System, a management tool of the ICAM Program Office
IPIP	IPAD Information Processor
IPS	Integrated Planning System (5000)

MCDG	Manufacturing Cost/Design Guide, to provide manufacturing cost information to the design process (4000)
MCMM	Manufacturing Control - Material Management (6000)
Roadmap	A program management schematic diagram used by the ICAM office to show project schedules
Station	Lowest level of automated control of manufacturing processes
Thrust area	A group of related projects that form a subdivision of the ICAM program; the 10 thrust areas are designated by a four-digit number: 1000, ..., 9000, 0000
Wedge	An integrated set of subsystems of manufacturing functions, from broad systems definition to shop-floor implementation; current ICAM work is in the sheet metal fabrication wedge