The Role and Application of Data Base Management in Integrated Computer-Aided Design

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A relational data base management system has been used for managing engineering data in a computerized integrated design system. The resulting system has been applied to the analysis of various structures to demonstrate and evaluate the ability to store, retrieve, query, modify, and manipulate data. Key software used includes data management software resulting from the NASA CAD/CAM project, Integrated Programs for Aerospace-Vehicle Design (IPAD), several applications programs, and selected integrating software developed during the study. Results discussed include system development, system use, and performance and advantages of an integrated data management system.

Introduction

THE amount of data and/or information developed or obtained for a product from its inception until production can be voluminous, even for very simple products. For aerospace vehicle systems, the "archival type" handbook data, design criteria data, scheduling and contract data, and data generated during the design process are sizable and require large amounts of resources to store and retrieve it. Since a major part of product design work is the management of design data, significant improvements in designer efficiency are possible through development of better ways to manage such data.

References 1 and 2 indicate that, through efforts over the past five years of a joint industry government program denoted Integrated Programs for Aerospace-Vehicle Design (IPAD), progress is being made in development of technology to manage engineering data. IPAD reports and prototype software provide a basis for defining and assessing data management approaches for a spectrum of engineering applications.[3-7] The present paper reports on a relational approach to managing engineering data for use in a computerized integrated design system. The data management approach has been implemented into an experimental integrated software system and the resulting system used to demonstrate and evaluate such data management functions as storage, retrieval, query, manipulation, and modification of data. The development and organization of the experimental integrated design system, the application of the system to selected test problems, and insights into data management issues gained from the study are discussed.

Engineering Data Management Issues

One of the most critical elements in an effective integrated design system is data management. The IPAD project has focused on development of data management technology and has investigated both design and manufacturing needs. Data management requirements for design were derived by investigating the data flow and user requirements identified in studies of design processes for several aerospace vehicles. A limited assessment of design/manufacturing interface requirements was also carried out. IPAD results to date indicate that an engineering data management capability must meet at least the following functional requirements[1]:

1) Accommodate multiple views of data from a variety of users and computing storage devices.
2) Allow multiple levels of data descriptions to support wide varieties of engineering organizations and tasks.
3) Permit easy changes in data definition as work progresses.
4) Allow data to be distributed over networks of computers of various manufacture.
5) Permit data definitions to be readily extended as needs arise.
6) Store and manipulate geometry information.
7) Contain adequate data configuration management features.
8) Provide broad capability to manage information describing the data.

Whether or not engineering data are computerized, the primary responsibility for its storage, retrieval, and protection usually resides with the originator. Access by others to such data typically requires personal contact with the data originator to clarify data definition or a visit to the drawing vault to locate a particular drawing(s). Data handling is also one of the most uninteresting, time-consuming, and error-prone jobs of an analyst. Establishing commonality of data between two users from different disciplines is usually repetitious and occurs each time data are needed. Storage of data in a data base management system provides the opportunity for computerizing the retrieval process through appropriate interface software. The data can then be readily reformatted for use by a specific designer, or his application program, relieving him of mundane data preparation tasks, improving data quality, and substantially reducing design time.

As an example of data management use, the nonlinear stress analysis of tiles for the Space Shuttle Orbiter thermal protection system[8] showed that more than 3000 tiles could be analyzed in a single day when the analysis software was integrated with a data base management system. This productivity rate compares with approximately one tile per day when the input data were prepared by hand. Considerable

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effort was initially required, however, to locate, define, and store the data in the data base because there was no standard characterization of data, and key data were distributed among several organizations and companies. To address these problems, work is currently underway at the National Bureau of Standards, under the sponsorship of the IPAD Project, the ICAM program, and other government organizations, to develop standards for communication of graphics and design/drafting information among organizations and computer hardware. The recently developed Initial Graphics Exchange Specifications (IGES)[9,10] is an example of this work.

A Prototype Integrated Design (PRIDE) System

To assess the use of a relational engineering data management system by integrating various application programs, a Prototype Integrated Design System (PRIDE) is being developed at the NASA Langley Research Center for operation on a DEC VAX 11/780 minicomputer. The PRIDE system (Fig. 1) consists of executive software, a series of application programs, a data base management system, and several pre- and postprocessors. The executive software was adapted from an in-house integrated design system[11]; the application programs are primarily in the public domain; the data management system called RIM (Relational Information Management System, Ref. 12) was developed under the IPAD Project; and the pre- and postprocessors to RIM were developed for this study. A description of relational data base systems, which is the focus of the PRIDE system, is given in Ref. 13. Although the PRIDE system is primarily focused on structural analysis capability, its implementation addresses some issues important to larger integrated design systems to support engineering staffs at all levels of design (conceptual, preliminary, and detail). The application programs represent analysis/design and graphics capabilities for the following areas: structural analysis (SPAR[14]), CAD/CAM (AD-2000[15]), bandwidth minimization (BANDIT[16]), graphics (NCAR[17] and NPLOT, a NASA Goddard Space Flight Center graphics program), aerodynamics (USSAERO[18]), and optimization techniques (PROSSS[19]). Modifications to application programs were primarily limited to input and output; program enhancements were made only when no other alternative was available. The PRIDE system has evolved from previous systems[20,21] as software has been improved or new software incorporated. This section discusses the executive software, use of RIM to manage the data, and the interface of application programs to RIM.

Executive Software

To facilitate use, the PRIDE system is menu-driven through executive software illustrated in Fig. 2. A main menu and various levels of submenus are used to execute application programs in either the interactive or batch mode. The executive is a user-friendly interface which provides access to PRIDE options and returns users to a central set of menus. The executive is written in FORTRAN (and therefore is portable) and has considerable flexibility so that modifications to the sequence of activities is easy to implement. All application programs are completely independent, and the PRIDE system can be entered at any point. BANDIT and NPLOT, for example, were incorporated into the system for use by SPAR although they were originally developed as processors for the NASTRAN finite element program.[22] In use of the menus, however, a specific program must be executed and its output data stored in the data base if that output is required for a subsequent program.

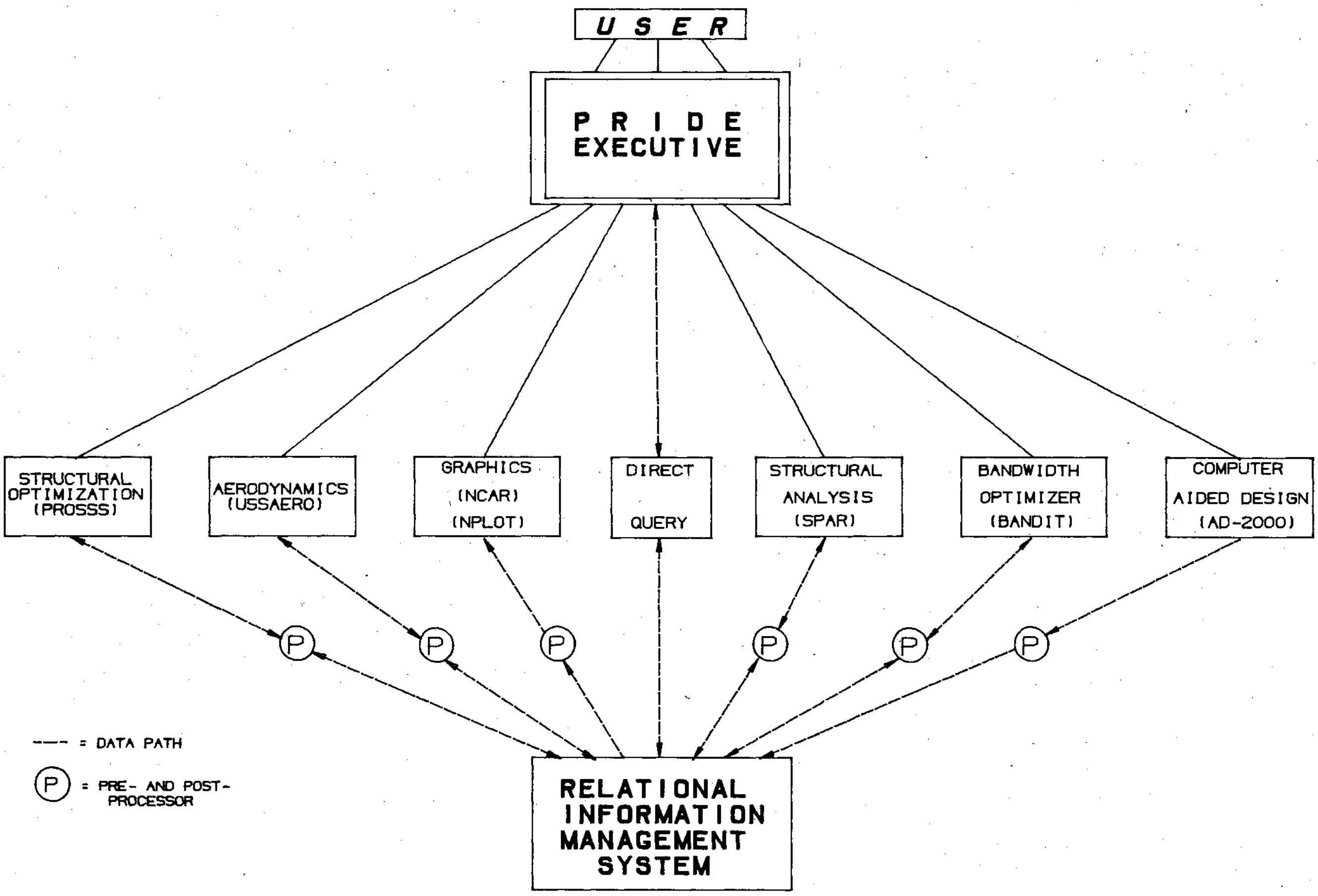

Fig. 1 Flowchart of the PRIDE System.

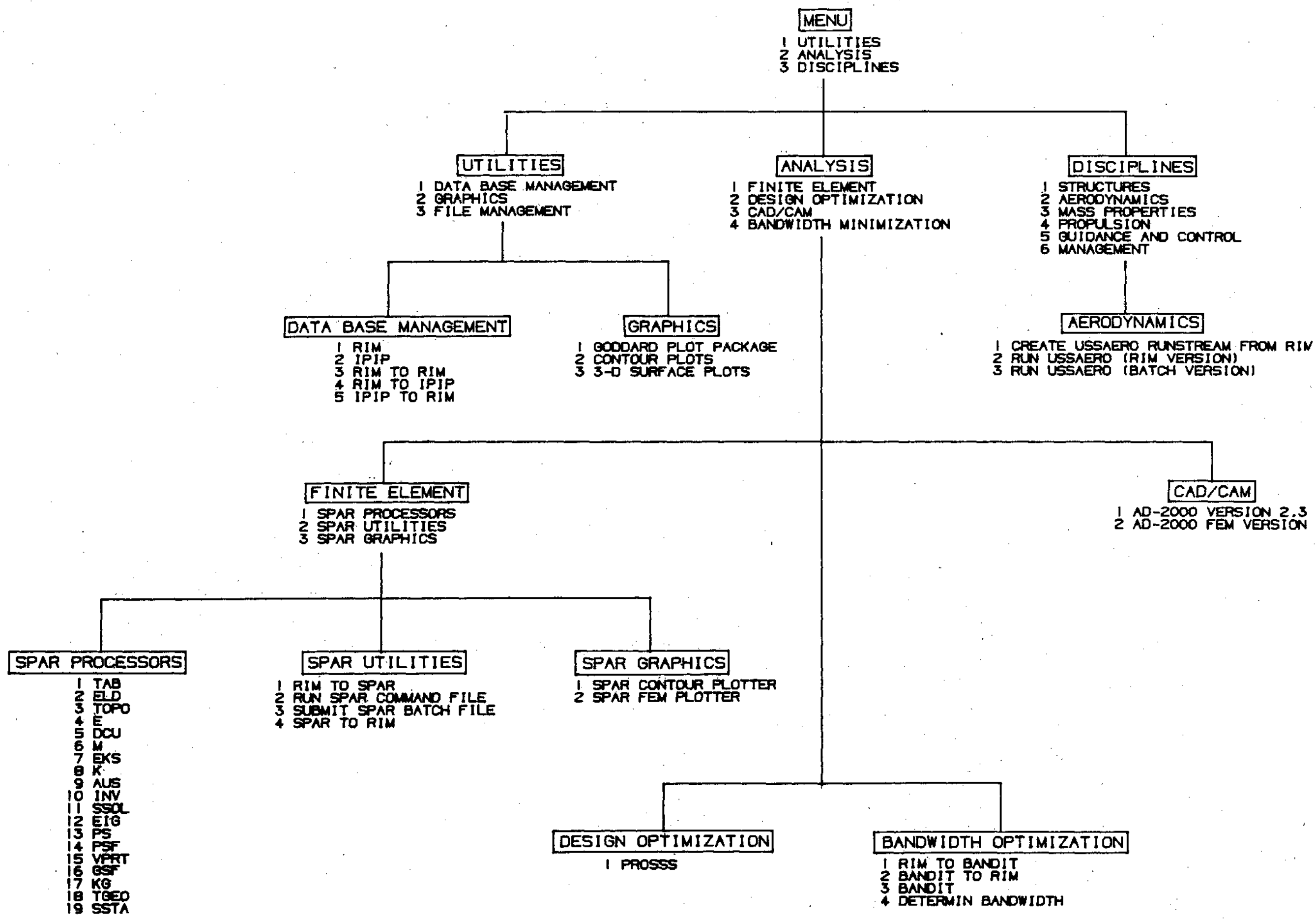

Fig. 2 Menu formatted executor of the PRIDE System.

ORG-MODE	X-DI	V-DI	2-DI	X-RO	V-RO	2-RO
1	YES	NO	NO	NO	NO	NO
2	YES	NO	NO	NO	NO	NO
3	YES	NO	NO	NO	NO	NO
4	YES	NO	NO	NO	NO	NO
5	YES	NO	NO	NO	NO	NO

GROUP1	ELEMENT1	MODE1	MODE2	MODE3	MODE4	EL-TYPE	MATERIAL	THICKNESS
1	1	372	377	376	371	OM	AL-6061	.01
1	2	371	376	375	370	OM	AL-6061	.01
1	3	370	375	374	369	OM	AL-6061	.01
1	4	369	374	373	368	OM	AL-6061	.01
1	5	377	382	381	376	OM	AL-6061	.01
1	6	376	381	380	375	OM	AL-6061	.01
1	7	375	380	379	374	OM	AL-6061	.01
1	8	374	379	378	373	OM	AL-6061	.01
1	9	382	387	386	381	OM	AL-6061	.01
1	10	391	386	385	380	OM	AL-6061	.01
1	11	380	385	384	379	OM	AL-6061	.01
1	12	379	384	383	378	OM	AL-6061	.01
1	13	387	392	391	386	OM	AL-6061	.01
1	14	386	391	390	385	OM	AL-6061	.01
1	15	385	390	389	384	OM	AL-6061	.01
1	16	334	389	388	383	OM	AL-6061	.01
1	17	5	10	9	4	OM	AL-6061	.01
1	18	4	9	8	3	OM	AL-6061	.01
1	19	3	8	7	2	OM	AL-6061	.01
1	20	2	7	6	1	OM	AL-6061	.01
1	21	10	15	14	9	OM	AL-6061	.01
1	22	9	14	13	8	OM	AL-6061	.01
1	23	8	13	12	7	OM	AL-6061	.01
1	24	7	12	11	6	OM	AL-6061	.01
1	25	15	20	19	14	OM	AL-6061	.01
1	26	14	19	18	13	OM	AL-6061	.01
1	27	13	18	17	12	OM	AL-6061	.01
1	28	12	17	16	11	OM	AL-6061	.01

JOINTS	X	Y	Z	THETA-X	THETA-Y	THETA-2	LOADSET	CON	CASE
1	0.	0.	0.	0.	0.	0.	1	1	1
2	0.	0.	0.	0.	0.	0.	1	1	1
3	0.	0.	0.	0.	0.	0.	1	1	1
4	0.	0.	0.	0.	0.	0.	1	1	1
5	0.	0.	0.	0.	0.	0.	1	1	1
6	.0014043	.000771	0.	0.	0.	0.	1	1	1
7	.0011433	.0002593	0.	0.	0.	0.	1	1	1
8	.001141	5.7044-9	0.	0.	0.	0.	1	1	1
9	.0011434	-2.595-4	0.	0.	0.	0.	1	1	1
10	.0014049	-2.710-4	0.	0.	0.	0.	1	1	1
11	.0026416	.0009546	0.	0.	0.	0.	1	1	1
12	.0024488	.000457	0.	0.	0.	0.	1	1	1
13	.0023537	-3.209-7	0.	0.	0.	0.	1	1	1
14	.0024488	-4.569-4	0.	0.	0.	0.	1	1	1
15	.0026419	-9.549-4	0.	0.	0.	0.	1	1	1
16	.003919	.0010205	0.	0.	0.	0.	1	1	1
17	.003743	.0004794	0.	0.	0.	0.	1	1	1
18	.0036086	-3.579-7	0.	0.	0.	0.	1	1	1
19	.003742	-4.807-4	0.	0.	0.	0.	1	1	1
20	.0039199	-.001018	0.	0.	0.	0.	1	1	1
21	.005311	.0010567	0.	0.	0.	0.	1	1	1
22	.0050304	.0004817	0.	0.	0.	0.	1	1	1
23	.004788	-3.149-6	0.	0.	0.	0.	1	1	1
24	.0050254	-4.798-4	0.	0.	0.	0.	1	1	1
25	.0053172	-.001061	0.	0.	0.	0.	1	1	1
26	.0057344	.0007558	0.	0.	0.	0.	1	1	1
27	.0054123	.0004174	0.	0.	0.	0.	1	1	1
28	.0051578	-1.526-6	0.	0.	0.	0.	1	1	1

JOINTS	X	Y	Z	THETA-X	THETA-Y	THETA-2	LOADSET	CON	CASE
1	.292.316	-74.3134	0.	0.	0.	0.	1	1	1
2	-475.777	-43.9569	0.	0.	0.	0.	1	1	1
3	-463.762	.005764	0.	0.	0.	0.	1	1	1
4	-475.797	43.9493	0.	0.	0.	0.	1	1	1
5	-292.334	74.32468	0.	0.	0.	0.	1	1	1
6	-1.907-6	1.5259-5	0.	0.	0.	0.	1	1	1
7	1.4735-5	8.3260-7	0.	0.	0.	0.	1	1	1
8	1.5259-5	-7.629-6	0.	0.	0.	0.	1	1	1
9	8.0109-5	-7.629-6	0.	0.	0.	0.	1	1	1
10	-3.009-5	2.2888-5	0.	0.	0.	0.	1	1	1
11	5.5313-5	0.	0.	0.	0.	0.	1	1	1
12	4.6263-5	-4.678-5	0.	0.	0.	0.	1	1	1
13	-1.144-5	-4.196-5	0.	0.	0.	0.	1	1	1
14	.0002059	-2.289-5	0.	0.	0.	0.	1	1	1
15	-3.350-5	-3.719-5	0.	0.	0.	0.	1	1	1
16	-1.526-5	3.8147-6	0.	0.	0.	0.	1	1	1

Fig. 3 Typical data base contents for an integrated design/analysis.

RIM Use

Most current data base management systems originated from business applications and are not well suited to serve as a common data base to integrate engineering applications because they lack an efficient query capability, do not have flexible data structure, or have difficult user interface. In general, engineering data management use requires both the data content and data structure to be dynamic. The IPAD-developed RIM software system avoids the above deficiencies and was developed specifically for engineering use with a relational structure as the data base organization.

The easy access to data in a relational way is an important feature not available in most integrated design systems. This is done in RIM by defining the data organization (schema) by relations (e.g., volume) composed of data attributes (e.g., length, width, height) defined by characteristics (e.g., real, integer, text). Once the data base schema (relations and attributes) is defined, then the actual data items are loaded into the data base and are easily referenced by commands such as SELECT ALL FROM VOLUME WITH LENGTH GT 47. Such queries may be made in both a direct interactive mode and through a program interface mode. Benchmark tests show good performance in both modes.

Ready access to data is provided by the interactive RIM query mode, while program integration and data sharing is accomplished using the RIM program interface mode (for programs written in FORTRAN, PASCAL, or COBOL). Figure 1 shows the RIM direct query mode where users may interactively create, access, add, modify or update, delete, or query their RIM data base. The remaining lines emanating from RIM in Fig. 1 go to applications programs and pre-postprocessors which translate data to and from the RIM format. Thus, through this second mode, RIM provides a common data format and flow between the application programs in accordance with control commands from the executive.

The initial way to gain familiarity with the RIM data base management is typically through the interactive query mode, which provides a convenient tool for engineers to control and retrieve data. For more advanced applications where the quantities of data are large, the RIM interface to an applications program may be needed. Once data have been entered into the RIM data base via the applications program interface mode, the user may then interactively query RIM at any stage in the calculations to review or extract selected data (see, for example, Fig. 3).

Application Program Interfaces

The ease of implementing an integrated design system is directly related to the ease of interfacing application programs to the data base. The RIM data base management system provides direct access to the user by entering selected commands and/or pre- or postprocessors through FORTRAN-callable subroutines. For example, an application program can be interfaced with RIM by using the RIMPUT and RIMGET subroutines in place of the conventional FORTRAN WRITE and READ statements. In other cases (see Fig. 1), these statements may be isolated into pre- and postprocessors to avoid any changes to the application programs.

User access allows modifications and/or minor additions to the data base which may be due to data errors or requirements for a particular analysis. However, the data base is created and data are stored, retrieved, modified, and manipulated within the processors utilizing the pertinent FORTRAN-callable subroutines. Representative flowcharts are shown in Figs. 4 and 5 for processors which store the geometrical and design data generated in the modified AD-2000 CAD/CAM into RIM and which retrieve the geometrical, design, and pertinent materials and section properties (e.g., wide flange beam data) from RIM and format these data into a runstream for a SPAR execution. In each of these processors, provisions have been made for cataloging the various files (i.e., data base, command, output, etc.) as they are created. This file catalog is stored on the data base and is meant to be a computerized version of a subject/author library-card index file and is accessible to all users. Such information can provide more effective use of computer resources in a production or research and development environment.

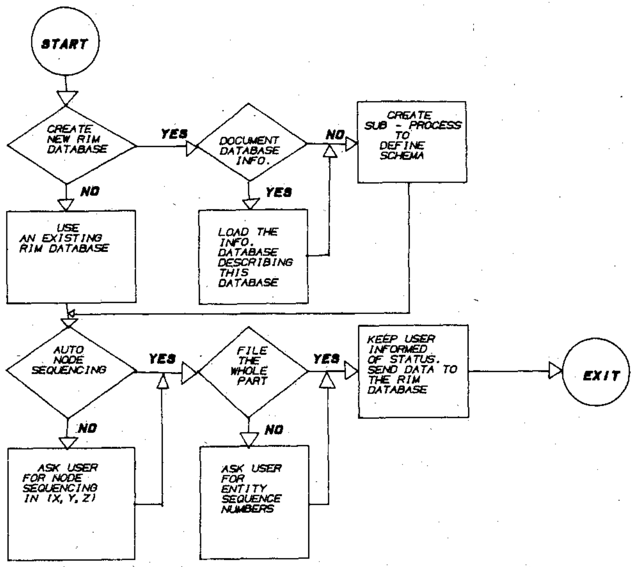

Fig. 4 Flowchart for the AD-2000 to RIM processor.

Engineering Data Management Test Problems

To evaluate the merits of managing engineering data using a relational system, the PRIDE system has been used in the design and analysis of four sample problems including 1) a simple structural panel with a circular hole, 2) a square plate, 3) a conventional wing structure, and 4) a large area space structure. The applications are typical structures considered in the various research activities at the NASA Langley Research Center. A discussion of the problems and data management issues are given below; problem response times for the various

Table 1 Processor response times (in seconds) to store or retrieve, manipulate, and format data

Processor	Panel with hole Coarse	Panel with hole Fine	Square plate 4 nodes	Square plate 64 nodes	Square plate 196 nodes	Swept wing	Space structure
AD-2000 to RIM	297.0	912.0	11.2	79.6	441.7	459.2	N/A
RIM to BANDIT	1.6	3.6	N/A	N/A	N/A	2.9	N/A
BANDIT to RIM	5.7	8.2	N/A	N/A	N/A	2.7	N/A
RIM to SPAR	130.0	227.0	11.9	48.0	168.8	431.1	890.0
SPAR to RIM	180.5	410.2	1.5	72.5	92.3	342.0	509.0
RIM to NCAR	68.4	172.2	N/A	87.1	118.5	N/A	N/A
RIM to NPLOT	25.5	29.5	15.3	25.2	27.5	11.0	56.0
RIM to USSAERO	N/A	N/A	N/A	N/A	N/A	45.0	N/A
USSAERO TO RIM	N/A	N/A	N/A	N/A	N/A	300.0	N/A

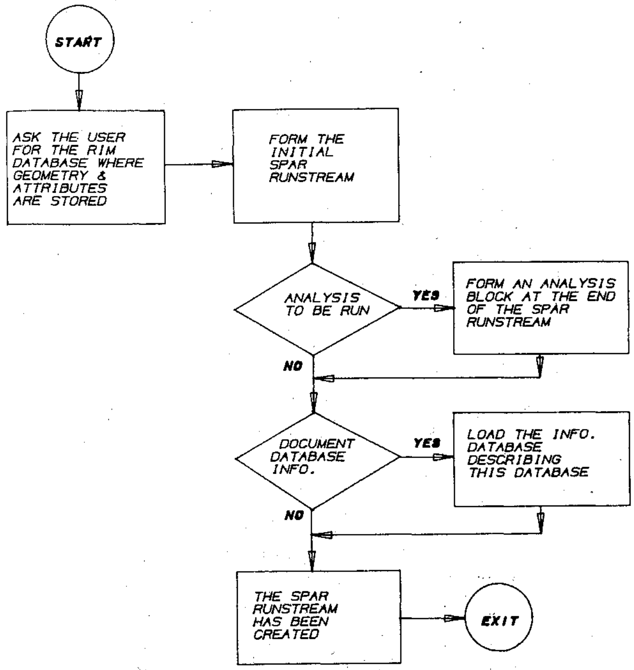

Fig. 5 Flowchart for the RIM to SPAR processor.

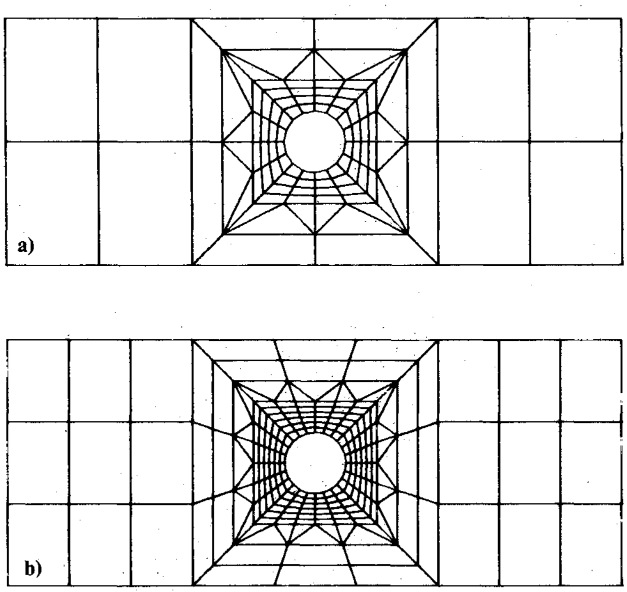

Fig. 6 Finite element models of a panel with a circular hole: a) coarse mesh, and b) fine mesh.

processors are shown in Table 1. These response times are total wall clock times for a lightly loaded computer.

Panel with Circular Hole

Two finite element models of a panel with a circular hole are shown in Fig. 6. The two models were not selected for structural accuracy but to provide a simple data management test problem. The physical and geometric properties of the panel were modeled using finite element modeling enhancements included in the AD-2000 CAD/CAM program. Also, several constraint sets and load sets were specified during this modeling phase. Approximately one man-hour was required to set up the geometrical and physical properties for these models using PRIDE. The computer times required by each of the processors to format the data are shown in Table 1.

These models, consisting of 108 nodes and 104 triangular and quadrilateral finite elements and 228 nodes and 222 triangular and quadrilateral finite elements, were stored on separate data bases whose schemata (data organization and relationships) were automatically defined by the processor. At this point, the name of the data base file, owner description, and identification of subject matter are requested in order that this file can be listed on the file management data base. This information, as stored in the data base, is shown in Fig. 7. Partial listings of the data stored in the data base by this processor are shown in Fig. 3.

To obtain an efficient finite element solution within limited memory space, the bandwidth of the stiffness matrix should be as narrow as possible. For these two panel models, the nodal and element data were extracted from RIM and formatted into an input runstream for BANDIT. The program BANDIT was then executed, reducing the bandwidth of the coarse-mesh model from 53 to 22 and the fine-mesh model from 120 to 33. These two new sets of node numbers were then loaded into RIM, replacing the old node sets, and all nodal data were changed accordingly, using the BANDIT to RIM processor. Alternatively, this could have been accomplished by putting a new relationship in RIM between the old and new sets of node numbers.

Having revised the model in the data base to reflect the minimized bandwidth, the RIM to SPAR processor is selected from the menu to create a SPAR runstream. Relations in the predefined data base schema are able to interpret the various names for identifying element types and section properties. For example, the "QM" designation used by AD-2000 to identify a quadrilateral membrane element would be recognized as an "E41" in SPAR; as a "CQDMEM" in NPLOT. In addition to retrieving and formatting the nodal, element, loads, and constraint data from the data base(s), this processor allows the specification of the problem-oriented constraints (e.g., planar analysis), solution type (i.e., static, vibration, etc.), and load and constraint sets. Since these created command files were to be saved, they were documented and stored on a RIM data base. For the coarse- and fine-mesh models, the following solutions were obtained: 1) static or stress solutions with three different configurations of constraints and applied loads 2) vibration analyses with simply supported and fixed edges; and 3) buckling analyses with simply supported and fixed edges. The data, consisting of 29,104 and 61,444 pieces of data for the coarse- and fine-mesh models, respectively, were stored in the data base. Approximately 90% of the time used to store the SPAR data in RIM was for the stress data. This was due to a mismatch of element numbers in the RIM and SPAR data bases. In the RIM data base, elements are grouped according to their number of nodes and numbered consecutively. In the SPAR data base, there is a subgrouping of the elements by type (i.e., quadrilateral membrane, bending, membrane-bending, or shear), in addition to the grouping by number of nodes, and the elements are numbered consecutively in the subgroups. Therefore, in order to make the element numbers consistent, the node numbers of each element were used to identify the element stress data, which required a time-consuming RIM search routine. These times will be reduced significantly in future work by including a RIM relation which maps the element numbers in the RIM data base to those in the SPAR data base.

Graphical representations of the data stored on the data base are accomplished by exercising the graphics software which is interfaced with the data base through a processor. Figure 8 is a contour plot of the maximum principal stress, which was calculated in the processor from available stress data in the data base for a uniaxial tensile load and simply supported opposite edge. The fundamental mode shapes for the vibration and buckling analyses with simply supported edges are shown in Figs. 9 and 10, respectively. The times indicated in Table 1 for the RIM to NCAR processor include the times to extract data, create an input file, and draw the contour plots. The entire analysis of a panel with a circular hole required approximately 10 man-hours from initial concept to final results.

SUBJECT	OWNER	PROJECT	FILETYPE	FILEMANE	DIR	DATE
BIGPAM SPARRUN FILE	TRS	SDM PAPER	SPAR RUNST	RIM2SPAR.COM	[TRS.BIGPAM]	5-MAR-82
BIGPAM SPARRUN FILE	TRS	SDM PAPER	RIM-DB	BIGPAM	[TRS.BIGPAM]	5-MAR-82
IPAD VAX FILE INFO	TINA	FILE MGMT.	RIM-DB	INFO	DBAO:[INFO]	5-MAR-82
PANEL WITH HOLE	CLB	IPAD	AD-2000-UR	SDM	DBAO:[CLB]	8-MAR-82
PANEL WITH HOLE	CLB	IPAD	RIM-DB	PANEL1	DBAO:[CLB]	8-MAR-82
PANEL WITH HOLE	CLB	IPAD	SPAR-COM	STAT11	DBAO:[CLB]	8-MAR-82
PANEL WITH HOLE	CLB	IPAD	SPAR-COM	PANEL1	DBAO:[CLB]	8-MAR-82

SUBJECT	OWNER	TITLE	ABSTRACT
BIGPAM SPARRUN FILE	TRS	COMPL. ANAL. DATA BUCK STAT	COMPLETE SPAR RESULTS FOR BIGPAM-CLAMPED INCLUDES: 1) STATIC DISPLACEMENTS 2) VIBRATION VECTOR 3) BUCK VECTORS FOR: 1) FIXED-FIXED 2) FIXED-SIMPLE 3) SIMPLE-SIMPLE 4) FIXED-FREE BOUNDARY CONDITIONS.
IPAD/VAX FILE INFO	TINA	IPAD/VAX FILE CONTENTS AND OWNERSHIP	RIM DATABASE NAME: INFO RELATIONS: DATABASE, IDENT, OWNER REL. DATABASE ATTRIBUTES ARE: SUBJECT; OWNER, PROJECT, FILE-TYPE, FILENAME, DIR(ECTORY), DATE. REL. IDENT ATTRIBUTES ARE: SUBJECT, OWNER, TITLE, ABSTRACT. REL. OWNER ATTRIBUTES ARE: OWNER, NAME, ORG, MAILSTOP, PHONE. INFORMATION IS LOADED IN THE DATABASE VIA PROGRAM DBLOAD RESIDING IN DIRECTORY [INFO].
PANEL WITH HOLE	CLB	COARSE MESH FINITE ELEMENT MODEL	FOR THE AD-2000 MODEL, THE PART NAME IS PANEL1, SHEET NO. 1. IT IS A 4X10 PANEL 108 MODES, 24 TRIANGULAR AND 80 QUADRILATERAL MEMBRANE ELEMENTS. AN AXIAL INPLANE LOAD AND VARIOUS CONSTRAINTS HAVE BEEN SPECIFIED. THE RIM-DB CONTAINS THE GEOMETRICAL AND PHYSICAL PROPERTIES OF THE MODEL AND CORRESPONDING STRESS, DISPLACE-MENT, AND EIGENVALUE RESULTS. STAT11 IS FOR THE INPLANE AXIALLY LOADEDPANEL. PANEL1 IS FOR THE STATIC SOLUTION OF A UNIFORMLY LOADED PANEL AND THE VIB-RAION AND BUCKLING ANALYSES WITH SIMPLE AND FIXED EDGES.

OWNER	NAME	ORG	MAILSTOP	PHONE
TRS	TOM SUTTER	IPAD	246	827-3195
TINA	C.G. BROWN	IPO	246	827-3195
CLB	C.L. BLACKBURN	KENTRON	246	(804)827-3975

Fig. 7 Typical data stored in the file management data base.

Square Plate

To evaluate the performance of the AD-2000 to RIM, RIM to SPAR, and SPAR to RIM processors, a simple square plate, as indicated in Fig. 11, was subjected to a static finite element analysis for varying mesh sizes. A data base containing 35 relations with 283 attributes was created by the processors in approximately 1.5 min. The times to store, retrieve, manipulate, and/or format the data in each of the processors are shown in Fig. 12. For the AD-2000 to RIM processor, 7 relations with 33 attributes were loaded with data varying between 123 and 3207 pieces. For the SPAR to RIM processor, 3 relations with 28 attributes were loaded with between 88 and 5272 pieces of data. The larger times required for the AD-2000 to RIM processor are due to the deletion of duplicate nodes that usually occurs in the modeling phase, sorting the nodes in a user-prescribed order, and assigning node numbers to the corner coordinates of the finite elements, coordinates of applied load points, and coordinates of the constraint points. Most of this time is in the processors and could be improved substantially. For the RIM to SPAR processor, the material properties data base was incorporated into the geometry/design data base such that one data base only had to be accessed. When two data bases were accessed by the RIM to SPAR processor (material properties and geometry/design), there was an additional 9.3 s required to open the data base, retrieve the data, and close the data base. Substantial time increases are expected for models composed of many materials and varying structural elements if the various data bases are not combined into a single data base. This would suggest that when performing a particular analysis, one may wish to formulate a problem-oriented data base.

Swept Wing Structures

Figure 13a shows a hidden line drawing of a swept wing, and Fig. 13b is a finite element model of the wing box structure. These drawings were based on geometry generated in AD-2000, stored in RIM, and then retrieved and formatted

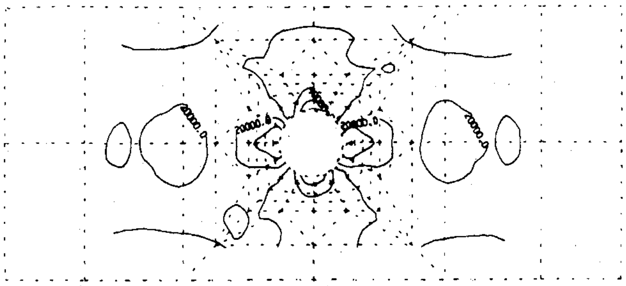

Fig. 8 Maximum principal stress distribution.

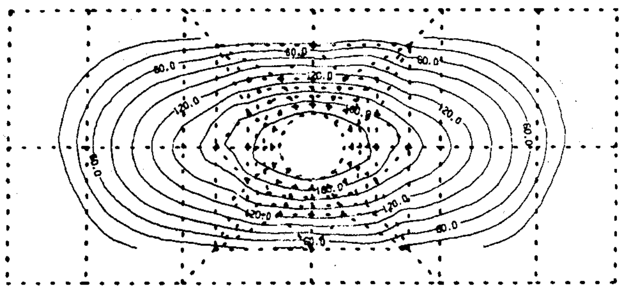

Fig. 9 Contour plot of the fundamental vibration mode.

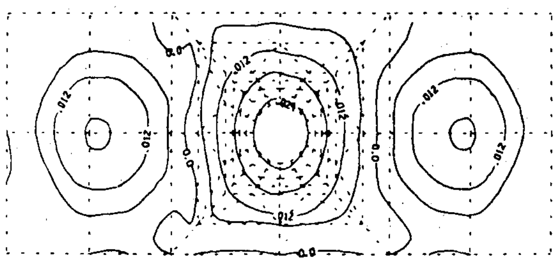

Fig. 10 Contour plot of the fundamental buckling mode.

into "NASTRAN-like" input data for the NPLOT graphics program. The cross section of this wing is composed of standard NACA airfoil sections. More current versions of AD-2000 now have a bulk data input capability which would allow input of the airfoil data directly from a RIM data base. In any case, this finite element model, which represents a built-up structure composed of rib and spar caps, rib and spar shear webs, rib and spar shear web stiffeners, and external cover panels, required about 4 h to generate, including keying in the airfoil ordinates and other geometric and physical data.

To incorporate a second discipline in the PRIDE system, an aerodynamics program denoted Unified Subsonic Supersonic Aerodynamics (USSAERO), has been interfaced with the RIM data base through pre- and postprocessors. The preprocessor creates an input runstream primarily based on the standard NACA airfoil data stored in the data base and secondarily on user-supplied data (i.e., Mach number, altitude, and angle of attack). The postprocessor creates a data base schema and automatically stores the resulting aerodynamics data. A contour plot of the pressure coefficients for the subject wing is shown in Fig. 14, as generated by the NCAR graphics program.

Plots of the deformed wing due to the generated pressure or aerodynamic loading and the mode shape of the fundamental frequency are shown in Figs. 15a and 15b. For this study, the response times of the processors were similar to those for the panel with a hole.

Large Area Space Structure

The repetitive nature of the geometry for a large area space structure, as shown in Fig. 16a, makes it particularly adapt-

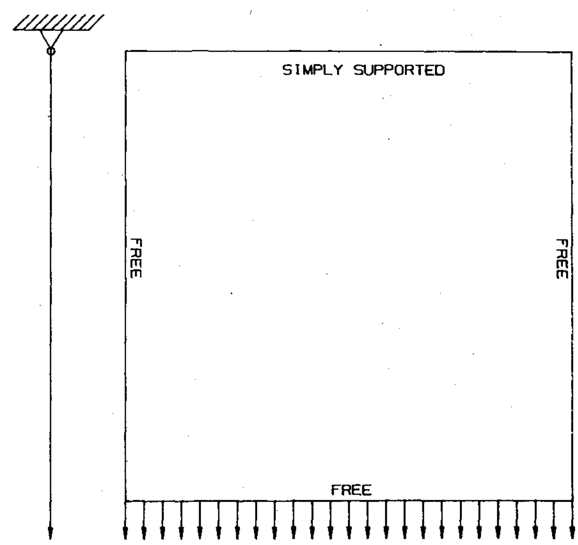

Fig. 11 Schema of the square panel used in the processor response study.

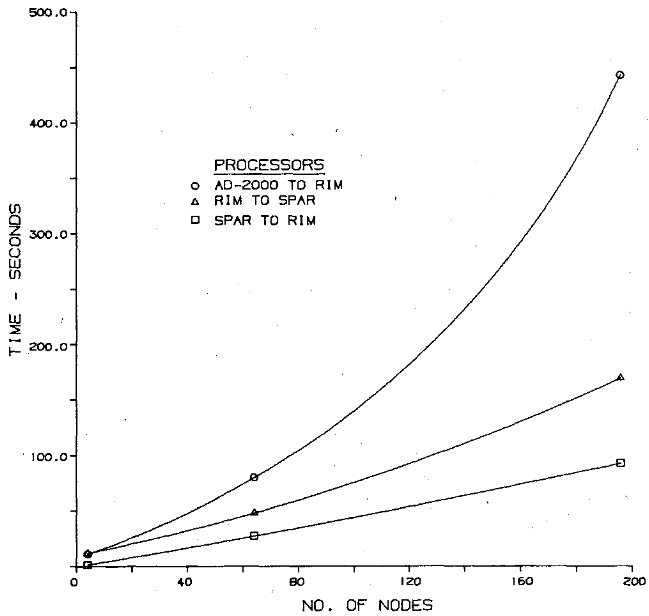

Fig. 12 Processor response times for a finite element model of a square panel with a varying mesh size.

able to the automated finite element modeling routines that were incorporated into the AD-2000 CAD/CAM program. However, this particular structure had been modeled earlier and subjected to a NASTRAN finite element analysis. The input nodal and element data, as given on a disk file, were edited into a format suitable for loading onto a RIM data base whose schema had been defined previously in the AD-2000 postprocessor.

Since provisions have not been incorporated into the present finite element modeling modification of AD-2000 for applying temperature to the structure, it was decided to edit the SPAR input file as created in the RIM to SPAR processor. Nodal temperatures were defined which represent a thermal gradient resulting from the application of heat to one side. This editing operation also incorporated the materials, section properties, and constraint data into the runstream. Of course, these data could have been stored in the RIM data base and then automatically formatted into the input file.

A SPAR thermal stress analysis of the structure was performed and the resulting displacement and stress data were stored in the RIM data base. A vibration analysis was sub-

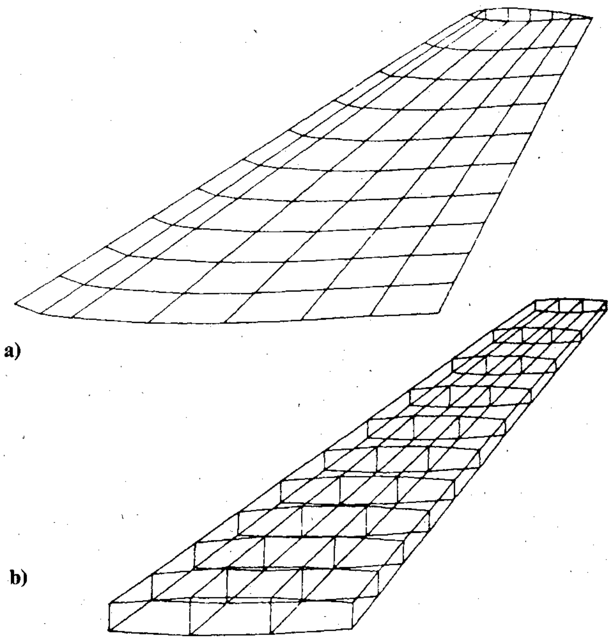

Fig. 13 External shape and finite element model of the wing box of a swept wing: a) external shape, and b) finite element model.

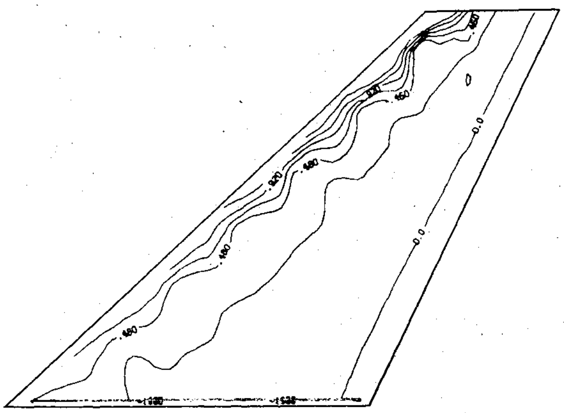

Fig. 14 Variation of the pressure coefficient over the upper surface of the swept wing.

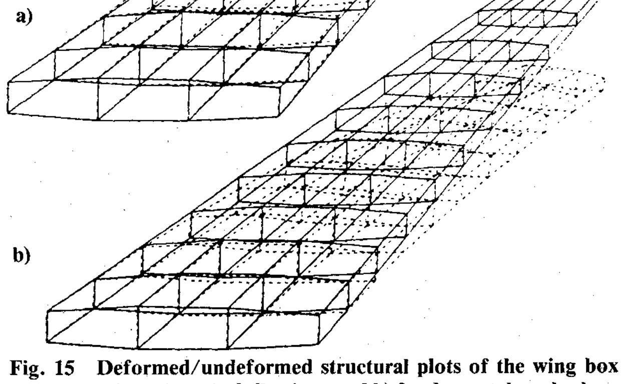

Fig. 15 Deformed/undeformed structural plots of the wing box of the swept wing: a) static deflection, and b) fundamental mode shape.

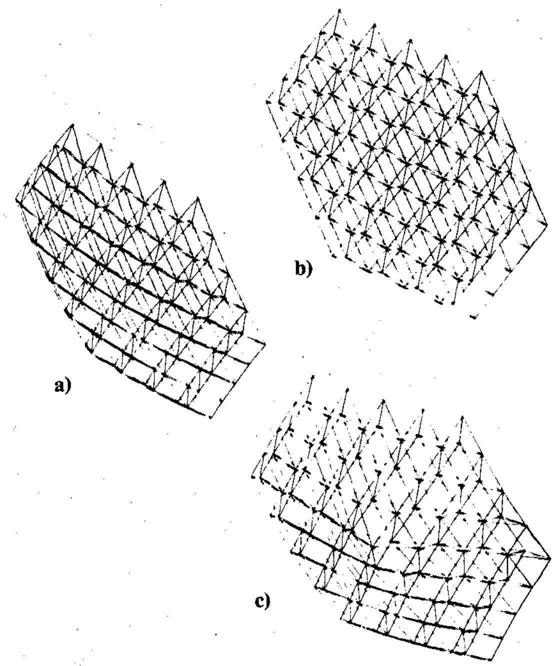

Fig. 16 Large area space structure: a) undeformed, b) thermal deflections, and c) fundamental mode shape.

sequently performed and the resulting frequencies and mode shapes stored on the same data base. Figures 16b and 16c show the deformed shape of the structure for the thermal loading and the fundamental frequency, respectively, as generated by the NPLOT graphics package using data extracted from the data base and prepared in the proper input format by the preprocessor. Once the NASTRAN input file was available, less than two man-hours were required to obtain these SPAR solutions.

Concluding Remarks

Several investigations have been conducted to evaluate the role and performance of a relational data base management system in an integrated computer-aided design environment. Results from these investigations have yielded the following conclusions:

1) The relational data manager RIM was found to have excellent functionality, user interface, and performance to meet a broad spectrum of integrated design system requirements. It performed well during the present study and user evaluations were very favorable. There were significant time savings in the conduct of computer-aided analysis tasks due to use of relational data manager to locate and retrieve specified data and correctly format them into an input runstream for a particular analysis.

2) In most cases, the response time of the pre- and post-processors to RIM was not objectionable to the analyst. However, the response time was not trivial and increased as the amount of data increased. For example, the largest portion of the response time for the SPAR to RIM processor involved the storage of stress data which had to be sorted to make the element identification consistent with previously stored element data.

3) Because of the FORTRAN CALL statements available in the RIM software, it was possible to develop processors which integrate the various analysis/design/graphics programs through a data base with minimum effort after a short learning cycle of less than one man-week for an engineer with applications programming experience.

4) As opposed to a system in which the output of a program directly feeds another program, the data generated in a data base oriented integrated design system is available to many users and/or programs. However, the capability to find the desired data is not a well-defined process. An attempt at data

identification has been made in this prototype system using a RIM data base. Probably, only user experience in this type of environment will yield an adequate solution.

5) The modular organization of PRIDE around a relational data management system driven by an executive provides great flexibility to add and/or replace application programs with minimum programming effort and impact on other existing application programs.

6) In a product development atmosphere, the design process usually is highly specialized and repetitive and the benefits discussed here would be further amplified as the number of design cycles increases.

References

[1] "IPAD: Integrated Programs for Aerospace-Vehicle Design," NASA CR 2143, Sept. 1980.

[2] Fulton, R.E., "Overview of Integrated Programs for Aerospace-Vehicle Design," NASA TM 81874, Sept. 1980.

[3] Heyer, D.D., "Development of Integrated Programs for Aerospace-Vehicle Design (IPAD)—Reference Design Process," NASA CR 2981, March 1979.

[4] Crowell, H.A., "Development of Integrated Programs for Aerospace-Vehicle Design (IPAD)—Product Manufacture Interactions with the Design Process," NASA CR 2982, March 1979.

[5] Isenberg, J.M. and Southall, J.W., "Development of Integrated Programs for Aerospace-Vehicle Design (IPAD)—Product Program Management Systems," NASA CR 2983, March 1979.

[6] Southall, J.W., "Development of Integrated Programs for Aerospace-Vehicle Design (IPAD)—Integrated Information Processing Requirements," NASA CR 2984, March 1979.

[7] Anderton, G.L., "Development of Integrated Programs for Aerospace-Vehicle Design (IPAD)—IPAD User Requirements," NASA CR 2985, March 1979.

[8] Giles, G.L. and Vallas, M., "Use of an Engineering Data Management System in the Analysis of Space Shuttle Orbiter Tiles," AIAA Paper 81-2192, San Diego, Calif., Oct. 1981.

[9] Nagel, R.N., Braithwaite, W.W., and Kennicott, P.R., "Initial Graphics Exchange Specifications IGES Version 1.0," U.S. Dept. of Commerce, National Bureau of Standards, Washington, D.C., NBSIR 80-1978(R), Jan. 1980.

[10] Fulton, R.E., "CAD/CAM Approach to Improving Industry Productivity Gathers Momentum," *Astronautics & Aeronautics,* Vol. 20, Feb. 1982, pp. 64-70.

[11] Wilhite, A.W., "The Aerospace Vehicle Interactive Design System," AIAA Paper 81-0233, St. Louis, Mo., Jan. 1981.

[12] "RIM User's Guide," Academic Computer Center, University of Washington, Seattle, Wash., W33, Jan. 1980.

[13] Knuth, D.E., *The Art of Computer Programming; Volume 1, Fundamental Algorithms,* Addison-Wesley, Reading, Mass., 1968.

[14] Whetstone, W.D., "SPAR Structural System Reference Manual," NASA CR 145098, 1977.

[15] Hanratty, P.J., "AD-2000—A System Built Today to Grow for Tomorrow," *Proceedings of the Interactive Design Systems Conference,* Stratford-upon-Avon, United Kingdom, April 1977, pp. 70-87.

[16] Everstine, G.C., "Recent Improvements to Bandit," NASA TM X-3278, Sept. 1975, pp. 511-521.

[17] McArthur, G.R., "An Introduction to the SCD Graphics System," National Center for Atmospheric Research (NCAR), Boulder, Colo., NCDR/TN-16141A, Jan. 1981.

[18] Woodward, F.A., "An Improved Method for Aerodynamic Analysis of Wing-Body-Tail Configurations in Subsonic and Supersonic Flow," NASA CR 2228, Part II, May 1973.

[19] Sobieski, J. and Rogers, J.L., "A Programming System for Research and Applications in Structural Optimization," *Proceedings of the International Symposium on Optimum Structural Design,* Univ. of Arizona, Tuscon, Ariz., Oct. 1981, pp. 11-9–11-21.

[20] Storaasli, O.O., "Integrated Computer-Aided Design Using Minicomputers," ASCE Preprint 80-671, Miami Beach, Fla., Oct. 1980.

[21] Blackburn, C.L., Dovi, A.R., Kurtze, W.L., and Storaasli, O.O., "IPAD Applications to the Design, Analysis, and/or Machining of Aerospace Structures," AIAA Paper 81-0512, and Materials Conference, Atlanta, Ga., April 1981.

[22] McCormick, C.W., ed., "The NASTRAN User's Manual (Level 15.0)," NASA SP-222(01), May 1973.