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INTEGRATED COMPUTER-BASED SYSTEMS SURVEY AND OUTLOOK

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The objectives of this paper are to discuss trends in integrated computer-based systems used for engineering analysis, identify the principal shortcomings, and provide a few guidelines on needed courses of action.

Design and analysis activities in nuclear reactor technology depend heavily upon a variety of public and private large-scale, general-purpose computer systems. Nearly all of these systems are based upon the Finite Element Method. This paper addresses those Finite Element Method systems which are available in the public domain.

First, the results of an international survey are discussed to show the broad selection of systems offering comprehensive analytic capability and a wide variety of finite element types. Clearly evident are the substantial improvements made over those early systems which solved linear, elastic problems in static and dynamic structural analysis using relatively primitive element types. It is seen that inelastic and non-linear modes of behavior can now be analyzed with suitable efficiency and accuracy. Strides have been made in applying the Finite Element Method to the solution of problems in such areas as heat transfer, aeroelasticity, acoustics, and electromagnetics. The potential application of the Finite Element Method to virtually every type of field problem identifies it as the preferred method upon which to base integrated computer systems.

Inquiries were made into numerous organizations, government-sponsored projects, and individuals to help identify near-term and long-range requirements. These inquiries supported the survey results and helped further identify the shortcomings and opportunities which must be properly managed towards achieving fully integrated systems.

A major shortcoming is the lack of user-oriented interactive graphics and technically-oriented data base management systems which are generally available and portable. The favorable trends in computing and telecommunication hardware represent opportunities to help overcome these shortcomings, but the needed software developments have been hampered by a lack of clearly-stated requirements and standards.

Considering the substantial costs and risks of software development, industry-wide sponsorship and involvement appear to be necessary. The causal factors in the success and failure of other similar joint efforts are useful in helping to formulate guidelines for taking corrective action.

1. Introduction

The growing role of computer-based systems in the design and analysis of nuclear reactors has been enhanced by the measurable achievements made in recent years and is evident from the various contributions at SMIRT Conferences. This dynamic environment will continue both because of the existing shortcomings in meeting user requirements and in the anticipated improvements in computing and related technologies in the forseeable future.

This paper first summarizes the results of an international survey of computer-based systems based on the Finite Element Method. The domination of the Finite Element Method results largely from its potential for, and proven success in, solving problems involving various types of physical systems subjected to arbitrary environmental conditions. Effective and analytic solutions have already been achieved for static and dynamic structural analysis, heat transfer, aeroelasticity, acoustics, and electromagnetics.

The systems surveyed represent a substantial technology base and measurable improvements can be anticipated within the currently-envisioned planning horizon. These improvements will enhance the analyst's ability to cope with increasingly complex geometries, materials, and operating conditions over extended time periods.

These growing complexities, together with existing difficulties in handling large volumes of technical data, call for measurable productivity improvements in the preparation and validation of input data and the evaluation of results. An integrated systems approach, including interactive graphics and a technically-oriented data base management system, is necessary to help achieve these improvements. Progress has been hampered by the lack of crisply-defined user requirements and standards.

Continuing advances in computing and telecommunications hardware and software are then briefly discussed. A myriad of alternative approaches to hardware configuration can now be considered, and increasing interest in the concept of distributed systems is evident. Developments in telecommunications further support the distributed systems approach and offer increasing opportunities in data transmission concepts and modes. Once again, the lack of supportive software is seen as a primary deterrent.

This paper then briefly reviews several privately- and government-sponsored projects aimed at developing and implementing integrated systems. The sponsor's particular interests and requirements have served to prevent any existing integrated system from becoming a standard tool for the nuclear reactor industry, due both to restrictions on availability and capability.

Finally, this paper suggests an evolutionary approach leading to an integrated system having general applicability to the nuclear reactor industry. It is not without its risks and challenges, but it is deemed viable due both to successes already achieved and the lessons learned from relevant endeavors.

2. Survey of Finite Element Methods

A questionnaire was mailed out to an international audience of system developers, owners and users to obtain their views and plans regarding the commercially-available systems they own and/or use. Table I lists the systems in alphabetical order and identifies the version and release date for the system surveyed. Table I also identifies the system originator, the date the questionnaire was completed, the individual who completed the questionnaire, and his affiliation. Multiple listings of the same system reflect independently-submitted questionnaires. Several submittals listed capabilities available in their internal system which were considered company proprietary and hence not available in the commercial version. These are not reported in this paper. Since the volume of information precludes inclusion in this paper, the detailed survey results can be obtained by contacting the author.

2.1 Types of Analysis

The capabilities common to most systems for structural analysis include linear analysis (mechanical and thermal loads), free vibration analysis, and to a lesser extent, transient and frequency (forced) response. Euler buckling and inertia relief capabilities for static analysis are available on a limited basis. Shock spectra, random response and nonlinear transient response are available in less than half of the systems.

A majority of systems offer capability in steady-state and transient heat transfer analysis.

In nonlinear statics, less than half indicated capability in buckling, and elasticity. A majority indicated the ability to handle large displacements, plasticity, and creep. Viscoelasticity was reported to be available in only a few cases.

As an indication of the advances made in handling large, complex structures, a majority of the systems indicated capability in substructuring and/or superelements both in static and dynamic analysis.

Slightly less than half of the systems showed capability in fracture mechanics and fluids. A limited number offered capability in the analysis of electric circuits, structural optimization, acoustic cavities, and fatigue damage.

It is evident that the analyst has a wide-selection of analysis types at his disposal. The selection of a particular approach is usually influenced by such factors as reliability, accuracy, efficiency, and ease of use. Experienced analysts further prefer the availability of a higher-order language to allow for the modification of predetermined solution sequences or the generation of totally new codes.

2.2 Element Types

The traditional elements are found in most programs, including the rod, beam, offset beam, and pinned end beam. Slightly less than half have a tapered beam and a lesser number offer the curved beam.

The three-node triangular curved shell, the four-node quadrilateral curved shell, the six-node triangular curved shell, and the eight-node quadrilateral curved shell are available in approximately half of the systems. Approximately one-third offer the reduced thick curved shell.

Half of the systems have conical axisymmetric shell elements, while approximately one-third offer curved axisymmetric shell elements.

The three-node and six-node triangular ring axisymmetric elements were indicated to be available in the majority of systems. Nearly the same number reported capability in the four-node and eight-node axisymmetric quadrilateral ring elements.

In the flat membrane and plate elements, the three-node triangle and four-node quadrilateral are generally available. The higher-order six-node triangle and eight-node quadrilateral appear in the majority of programs while the shear panel is available in slightly less than one third of the systems.

Among the solid elements, approximately half of the systems offer the four-node and less than one-third have the ten-node tetrahedron. Most of the systems indicated capability in the six-node wedge, the eight-node hexahedron, and the twenty-node hexahedron, while a lesser number offer the fifteen-node wedge. Approximately half of the systems offer the straight pipe element and the elbow, and only a limited number include the tee element in their library.

Most of the systems offer a spring element, while approximately one-half offer the scalar spring and the input of an element via generalized matrices.

The majority of systems provide for the lumped (diagonal) mass element, and consistent mass matrices.

In the nonstructural mass category, the majority offer the scalar mass, most include the nodal masses, and a lesser number include distributed masses. More than half offer Guyan reduction, while less than half provide for a general mass matrix.

Damping elements, including scalar, dashpot, discrete viscous, modal viscous, and general matrix, are available in a limited number of programs.

Less than half offer the gap, friction, and rigid elements, while only a few offer the rebar solid. Less than half of the systems include capability for elastic foundations, crack tip elements, and laminated shells. The "plot-only" element is available in less than one-fourth of the systems.

It is seen that an impressive array of element types are available in most systems. With the availability of the "dummy" element supplied by the user, the types of structural systems which can be modeled are most extensive. In general, the only limitation is the ingenuity of the analyst.

It should be noted that the existence of a given type of element by itself is an incomplete measure. The quality of the elements listed may vary substantially from one system to the next depending on such factors as the assumptions made, the algorithms used, and the programming skills applied.

2.3 Heat Transfer Element Types

A majority of systems offer heat transfer analysis. The linear, three-node triangle and four-node and eight-node quadrilateral elements are available in approximately half of the systems, while the transverse conducting shell is available in approximately one-fifth of the systems. Of the axisymmetric elements, the triangular ring, four-node quadrilateral ring, and eight-node quadrilateral ring are generally available. The solid elements generally available include the tetrahedron, the wedge, the eight-node brick, and the twenty-node brick. The twelve-node tetrahedron is available in only a limited number of systems and only a few systems offer general matrix input for heat transfer elements.

2.4 Coordinate Systems and Material Properties

Cartesian and cylindrical coordinate systems are generally available, while spherical coordinates are available in a lesser number of systems, with a few systems offering general coordinate systems.

In material properties, most systems offered isotropic, two-dimensional orthotropic, three-dimensional orthotropic, and temperature dependent properties. A lesser number showed capability in stress dependent, time dependent, and nonlinear elastic properties.

A majority of systems showed capability in isotropic, and kinematic properties for work hardening, while a limited number offered combined and general properties for work hardening.

2.5 Loading and Boundary Conditions

Static loading conditions are generally available for such load types as concentrated loads, distributed (beam) loads, pressure loads on plates, shells, and solids, thermal loads, acceleration loads, and, to a lesser extent, rotational velocity, and axisymmetric loads on axisymmetric shells and rings. Most systems offer time-dependent dynamic loading conditions, while frequency response, PSD random response, and shock spectra capabilities are available in no more than half of the systems.

All systems offer single point displacement constraints, and most offer multipoint constraints and specified nonzero displacements.

Heat transfer is available on the majority of systems, including heat source/sink, convection, radiation, and specified temperature capability.

2.6 Pre- and Postprocessors

The survey inputs on pre- and postprocessors were somewhat cloudy since many systems have not had these features incorporated. This is partly due to the availability of quasi-independent subsystems which provide input data generation, including mesh generators.

Substantial capability was reported in the ability to plot such input data as undeformed geometry, node labels, element labels, and two-dimensional sections. A lesser capability was identified in plotting property labels, while only a few systems can display three-dimensional systems with the hidden lines removed.

Similarly, a substantial amount of capability is available in plotting the results of computation, especially in areas such as deformed geometry, contours for two-dimensional and three-dimensional structures, and time histories. Limited capability is reported in displaying frequency response and power spectral density, while less than half can display arbitrary X-Y plots.

In the data generation area, virtually all systems indicate capability for nodes, elements, restraints, and loads.

Output sorting capability is generally available, especially in comparing multiple load cases. Approximately half of the systems offer sorting on an element-by-element basis, present summaries of maximum/minimum values, and present results for selected nodes and/or elements.

The majority of systems surveyed offer some form of technique for minimizing the bandwidth or wavefront of the matrix to be solved.

Much effort is still required in pre- and postprocessors. No single product has distinguished itself, largely due to the lack of cogent, uniform requirements.

2.7 Additional Criteria

In addition to the specific issues covered by the survey, other somewhat subjective criteria are relevant in helping to evaluate the role of a given system in an integrated environment. These are discussed below.

The actual and potential growth of a system is evidenced in part by observing the frequency of new releases which incorporate new features.

The ease of data entry and validation is reflected somewhat in the availability of preprocessors but, in addition, many systems include extensive editing. Flexibility in output data mode and format is essential in facilitating the reading of the computation results. Other features to look for include: the availability of a higher-order language for generating/modifying unique solution sequences; restart/recovery, especially for large, complex problems; and an effective Quality Assurance program in which system reliability is emphasized and existing errors are systematically tracked and eliminated.

Operational efficiency is difficult to quantify because of the mutual influence of problem type and computing hardware and software configurations. Benchmark studies may help evaluate the efficiency and accuracy of a given system for a user's specific type of problems and operational environment.

Several respondees volunteered information pertaining to their extensive documentation and their policy of documentation maintenance. References [1] through [9] list some of the documentation available for MSC/NASTRAN, and are listed here to exemplify the substantial documentation required for a large-scale, general-purpose system. Reference [10] is one of the user documents for ANSYS. MSC/NASTRAN and ANSYS are singled out because they made the strongest showing in the survey.

Of specific interest in achieving effective system integration is the nature of a system's architecture and its data base management system. References [11] through [13] show that a modular design concept is essential both to facilitate growth and user accessibility.

3. Integrated Systems Assessment

Integrated systems are generally considered as a subset or as comprising the totality of Computer-Aided Design (CAD) and Computer-Aided Manufacturing (CAM). CAD and CAM are receiving much attention from various government and private organizations. Reference [14] describes IPAD, Integrated Programs for Aerospace vehicle Design, which is sponsored by NASA. IPAD is not expected to produce a production system. The Grumman Aerospace Corporation has been developing an integrated system for their internal use as described in Reference [15].

The IPAD studies discussed in Reference [14] indicated the strong need for improved capability in such areas as technically-oriented data base management systems and interactive graphics. In addition, the need for measurable advances in computer main frames, peripheral devices, data communications, and overall networking concepts were identified.

The general requirements for technically-oriented data base management systems are identified in Reference [16] which notes that hierarchical data base management systems are generally available for business systems which have well-structured and well-defined needs. A hierarchical-only system is inadequate for technically-oriented organizations because of the complexities of data relationships, large data volumes and archiving requirements. Reference [17] describes a technically-oriented Information Model which was developed in support of the U.S. Department of Defense's ICAM (Integrated Computer-Aided Manufacturing) project. Although it has not yet been fully refined, this Information Model merits serious consideration as the basis for future developments.

The effective use of interactive graphic devices offers to enhance the relationships between the engineering user and the computer system. The development of portable, general-purpose interactive graphics software and devices has been measurably hampered by a lack of standards (Reference [18]). Because of the investment already made in interactive graphics systems and devices, the realization of such standards will be most difficult to achieve. User influence on existing standing committees must be strengthened or else it will be necessary to start new initiatives.

In order to fulfill its potential as the core of a totally integrated system, the Finite Element Method must continue to effectively analyze a broader range of problem types beyond traditional structural mechanics, aeroelasticity, heat transfer, and fluid mechanics problems. Reference [19] discusses the analysis of electrical currents using MSC/NASTRAN. Additional developments are required to formulate effective analogies and procedures covering the spectrum of field problems. Pre- and postprocessors may fulfill most of these needs.

Requirements are now surfacing for "microscopic" analyses to perform crash simulations and to analyze the "neutron swelling" of structural components in fusion reactors. This will call for substantially increased capability in computing hardware. References [20] and [21] discuss the potential role of supercomputers in this regard and give cause for a certain amount of optimism in coping with number crunching challenges. However, data storage devices must also be improved. Bubble memories should provide at least partial relief.

The extensive software developments needed to develop a fully-integrated system will be most expensive as indicated in References [22] and [23]. Developments are continuing in such areas as interactive graphics (References [24] and [25]) but it is believed that coordinated efforts are necessary to assure that system interfaces are effectively implemented. A viable alternative is the evolutionary approach of building an integrated system around an existing major finite element system such as MSC/NASTRAN.

4. Concluding Remarks

The integration of computer-based engineering analysis systems should substantially improve the design and analysis of nuclear reactors. An integrated system can be envisioned as a cohesive set of building blocks consisting of hardware and software entities such as computer mainframes, data storage devices, telecommunication networks, applications programs, preprocessors, postprocessors, executive (steering) routines, terminal devices, interactive graphics systems and technically-oriented data base management systems. In general, the competitive pressures affecting these entities are conducive to achieving a fully-integrated system. The last three entities listed are particular exceptions to this general rule where such factors as vested interests seem to be working contrary to the goals of integration.

If large volumes of technical data are to be properly managed, breakthroughs are needed to produce portable interactive graphics systems, and technically-oriented data base management systems which offer a blended balance of user accessibility and system management in a multi-vendor environment. A viable approach is to effect the development of these systems around an existing analysis system such as MSC/NASTRAN.

Various study teams and committees have been formed but have not as yet shown a clear sense of direction in clearly identifying industry requirements and the specifications for acceptable software systems designs. Continuing user involvement should provide hardware and software developers with approximate guidance and influence. Credible cost/benefits studies must be prepared to give involved management sufficient confidence that the payoffs justify the investments.

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Table I

SYSTEMS EVALUATED IN SURVEY

NO.	System, Version, Release Date	Owner/Developer	Survey Date	Evaluator	Evaluator's Organization
1.	ADINA, V78 (12/78)	MIT	12/18/78	Bathe	MIT
2.	ADINA, (1977)	MIT	1/5/79	Shoppee	SIA
3.	ADINA/ADINAT, (5/77)	MIT	1/5/79	Pfaffinger	Fides Trust
4.	ANSYS, R3-UP37 (11/77)	Swanson Analysis Systems	1/5/79	Pfaffinger	Fides Trust
5.	ANSYS	Swanson Analysis Systems	12/21/78	Cornett	CDC
6.	ANSYS, R3-UP37 (6/78)	Swanson Analysis Systems	11/27/78	Swanson	Swanson Analysis
7.	ANSYS, R3 (1977)	Swanson Analysis Systems	1/5/79	Shoppee	SIA
8.	ASAS, G08 (1/79)	Atkins R&D	1/3/79	Henrywood	Atkins R&D
9.	ASAS, G104 (1/78)	Atkins R&D	1/5/79	Shoppee	SIA
10.	ASKA, 7.8 (6/30/78)	ISD, Stuttgart	1/18/79	Argyris	ISD, Stuttgart
11.	ASKA, 7.01 (7/24/77)	ISD, Stuttgart	1/5/79	Shoppee	SIA
12.	ATLAS, 4 (3/77)	Boeing	1/18/79	Dreisbach	Boeing
13.	CASTEM, 1.0 (4/78)	CISI, France	1/5/79	Shoppee	SIA
14.	E3 SAP, 1.1.0 (7/78)	U. of Cal., Berkeley	1/9/79	Herness	BCS (Boeing)
15.	GT STRUDL, V1 M5 (10/78)	CDC Strudl, Georgia Tech	1/5/79	Shoppee	SIA
16.	LARSTRAN, 80 (12/31/79)	ISD, Stuttgart	1/18/79	Argyris	ISD, Stuttgart
17.	MARC, H.3 (3/78)	Marc Analysis	1/10/79	Marcal	Marc Analysis
18.	MARC	Marc Analysis	12/21/78	Cornett	CDC
19.	MCAUTO STRUDL, 4.0 (1978)	MCAUTO Multisystems, Inc.	1/4/79	Kuhne	MCAUTO
20.	MSC/NASTRAN, 56 (7/79)	MacNeal-Schwendler Corp.	11/20/78	MacNeal	MacNeal-Schwendler
21.	NASTRAN, CDC	MacNeal-Schwendler Corp.	12/21/78	Cornett	CDC
22.	SAP, IV (4/74)	U. of Cal., Berkeley	1/5/79	Shoppee	SIA
23.	SAP6, 2 (1/30/79)	USC	12/19/78	Weingarten	USC
24.	SMART, 2 (3/31/79)	ISD, Stuttgart	1/18/79	Argyris	ISD, Stuttgart
25.	STARDYNE	CDC	12/21/78	Cornett	CDC
26.	SUPERB, 5.1 (6/78)	SDRC	12/31/78	Tolani	SDRC
27.	SUPERB	SDRC	12/21/78	Cornett	CDC
28.	WECAN, (9/12/78)	Westinghouse	1/5/78	Bogden	Westinghouse