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TECHNICAL NOTE

SOME REMARKS ON PROGRESS WITH FINITE ELEMENTS

J. Mackerle

Linköping Institute of Technology, Department of Mechanical Engineering, S-581 83 Linköping, Sweden

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Abstract—Information is the most valuable but least valued tool that professionals have. The amount of data in science and technology grows so rapidly that broad-coverage compilations cannot be maintained but concentrate on the coverage of specialized topics. The volume of finite element literature in the form of books, conference proceedings and journal papers, as well as a number of developed finite element codes, has been growing at a prodigious rate. It is almost impossible to be up to date with all the relevant information. A bibliometric study is presented; the author takes the number of published papers on finite elements as a measure of the research activity in the field of finite element techniques and investigates some engineering fields/topics where these techniques have been/are used.

INTRODUCTION

The volume of scientific/technical literature is growing at a prodigious rate and most professionals are no longer able to keep up to date with all the relevant information. The growth rate of scientific literature appears to be rising by approx. 8% per year; this means that the output of scientific papers tends to double within a period of 10–15 years. Of course, not all areas of scientific activity are growing at the same rate; activity in some areas progresses faster, others slower.

Bibliometric analysis has become a well-established part of information research and a quantitative approach to the description of documents. It offers a type of statistic which can complement more traditional approaches to the study of bibliography and communication. Bibliometrics can be applied to any subject area and to most of the problems concerned with written communication. We can say that bibliometrics is the statistical/quantitative description of a literature.

This note concentrates on the status of information dealing with the finite element method. Two parts are included—finite element literature and finite element software, respectively. The topics of finite element techniques directed to the optimum design process and to fluid mechanics are not included in this paper.

FINITE ELEMENT LITERATURE

The pioneering works on finite element methods started in the early 1960s at the University of California, Berkeley, and at the University of Wales, Swansea. Other important works were carried out at the MIT in Cambridge, MA and at the University of Stuttgart in Germany. The first conference on the topic was held at the Wright–Patterson Air Force Base, Dayton, OH in 1965 (*Matrix Methods in Structural Mechanics*). The first book on the subject was published in 1967. It was written by Zienkiewicz and Cheung. For further reading on the finite element method history see Ref. [1]. Approximately 380 books and more than 400 conference proceedings have since been published. Abstracts for 320 books and 340 conference proceedings are given in Ref. [2].

The status of finite element literature published between 1976 and 1993 is illustrated in Fig. 1. Data presented in this figure include published technical papers in the primary literature. This means papers appearing in the various general and specialized technical and professional journals, as well as papers included in conference proceedings. These sources provide the major channel for communicating results of research to interested readers. The number of respective literature references is taken from the author's database MAKEBASE.

MAKEBASE [3, 4] is a special, menu driven database. It is implemented on Apollo workstations. The database is updated on a daily basis and can be used in both academic and industrial environments. MAKEBASE is an integrated database composed of two distinct parts: literature references and software information. It is directed to support research workers, other professionals and potential buyers of finite element and boundary element software in the use of specialist literature and information on existing software. Sources of information are journals, books, reports, dissertations, theses and conference proceedings. At present the database contains more than 55,000 literature references and information on about 1700 finite element and boundary element programs. About 60 'core' journals and seven abstracting journals are scanned. The choice of subjects is limited to the field of finite elements, boundary elements and design optimization. All fields of engineering activities are included, except fluid mechanics problems.

In the area of finite elements there have been published more than 56,000 papers (excluding papers on fluid mechanics); at present about 3800 papers are published annually. In Fig. 1 it seems that the output of finite element literature has an exponential growth, at least in the period up to 1986. Then it slows, but for the last three years the growth is again increasing. It is shown that between 1976 and 1992 the number of published papers increased from 1250 to 3770 articles per year. This is roughly three times. The individual figures are less important than the implied growth rates.

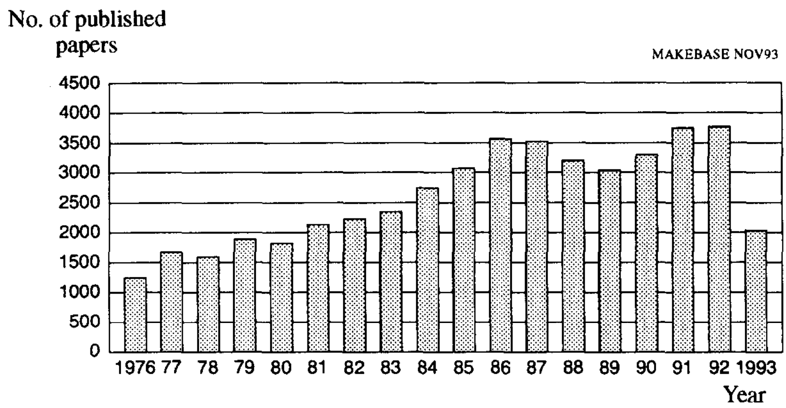

Fig. 1. Chronological distribution of finite element papers.

It is known that not many processes in the real world have an exponential growth. After some time the growth reaches some limit at which the process has to stop before reaching absurdity. Can we say today that the research progress in the finite elements (if we take the output of published literature as a measure for the research activity) has reached the limit? The author feels that the progress will be very slow in the future, but because the available information on published papers is always delayed we will get the answer to this question in the next 2–3 years.

Finite element techniques are popular not only for the solution of elastostatic problems, as they were in the beginning, but during this time these methods have also been used as analytical tools in other areas, such as elastodynamics, material nonlinear and geometrical nonlinear problems, fracture mechanics, contact problems, etc. Figures 2 and 3 illustrate the total number of published papers on finite elements on various topics and application fields, respectively. The time period is from 1976 to 1993. Types of papers included are journal papers, conference papers and theses/dissertations. The author is of course aware that many papers are missing (hopefully not more than 25%). To find information in a large number of scientific/technical journals as well as conference proceedings is much more difficult than in the case of books. One positive factor in the process of dissemination is that there is always a small number of so called 'core' journals containing a large portion of papers dealing with the subject of interest. The Bradford's Law of Scattering roughly states that of all the papers on a subject, one-third are to be found in journals on that subject, one-third in journals on related subjects and the last third in unexpected journals. Numerous national and international conferences and symposia play an important role in scientific and technological communication by bringing together scientists, researchers and engineers, permitting informal exchange of ideas and information, and building up a network of personal contacts. The main criticism of conferences is that the material presented is often a repetition of what is published elsewhere in the literature. Conference proceedings appear in the form of books, journals or in both forms—they are a source of never-ending bibliographical confusion. The author is particularly aware that many papers from conference proceedings are missing in his database.

Published papers in Fig. 2 are grouped according to the topics into the following categories:

Basic formulation, mathematical and computational aspects (MA)
Adaptive methods (AD)
Thermal sciences (TH)
Dynamics/vibrations (DY)
Stability problems (ST)
Element library (EL)
Material and geometric nonlinear problems (NL)
Fracture mechanics (FR)
Contact problems (CO)
Concrete material/structures (CS)
Composite material/structures (CM)
Fluid–structure interaction (FS)
Acoustics (AC).

Published papers in Fig. 3 are grouped according the application fields into the following categories:

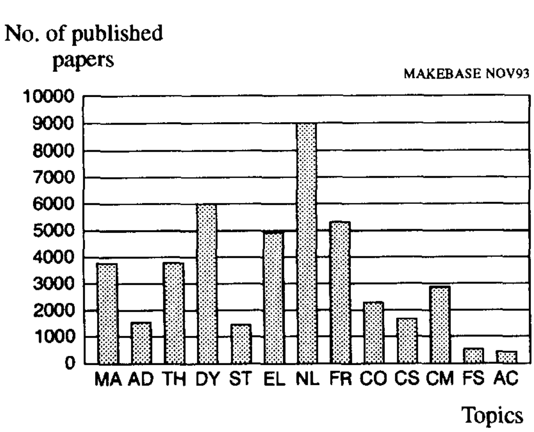

Fig. 2. Finite elements and various topics.

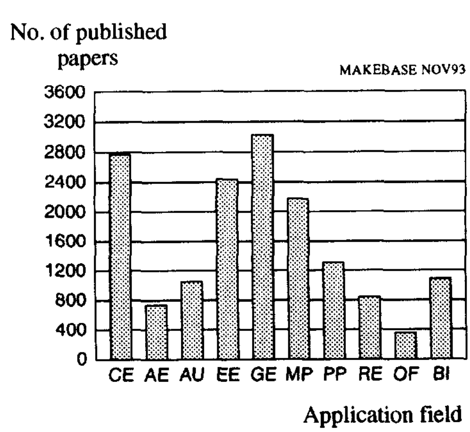

Fig. 3. Finite elements and their applications in engineering.

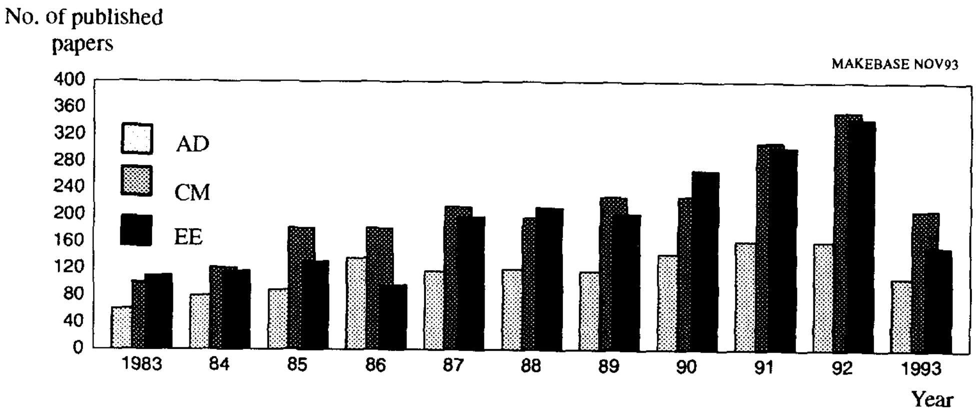

Fig. 4. Chronological distribution of finite element papers on adaptive methods, composite materials and applications in electrical engineering.

Civil engineering (CE)
Aerospace, aircraft engineering (AE)
Automobile, automotive engineering (AU)
Electrical engineering (EE)
Geotechnics (GE)
Material processing (MP)
Pipes and pressure vessel technology (PP)
Nuclear/reactor technology (RE)
Offshore engineering (OF)
Biomechanics (BI).

Figure 2 shows that most published papers on finite elements deal with nonlinear problems, followed by the analysis of dynamic problems, fracture mechanics applications and developments of new elements. Figure 3 illustrates that most applications of finite elements are in the fields of geomechanics, following by civil and electrical engineering.

If we are looking on the number of published papers in each specific category and considering the time, no conclusions can be made about the trends. The number of papers varies and no visible growth can be seen, with some exceptions such as the adaptive methods, thermal sciences, contact problems, composite materials/structures, applications in electrical engineering and material processing technology. For the limited space of this paper the trend is illustrated for three categories only (Fig. 4), namely:

Adaptive methods (AD)
Composite materials/structures (CM), and
Electrical engineering (EE).

The time period is the last 10 years, from 1983 to 1993.

FINITE ELEMENT SOFTWARE

First finite element codes were developed for mainframe computers because at that time no other computers were available. Then, at the end of 1970s two new trends started. At one end the trend was towards microprocessing, and at the other end it was towards supercomputing and parallel processing. At present much more activity is directed to supercomputing, perhaps as the power of supercomputers becomes more affordable. Figure 5 shows the number of published papers dealing with finite elements on microcomputing and supercomputing, respectively, for the period 1980–1993.

The range of applications of the finite element method is continually growing. New programs based on this method have been/are under development in many countries. Programs developed could roughly be classified into two main groups—general purpose programs and special purpose programs.

General purpose programs are large programs/systems that are oriented towards general use in different application fields. Special purpose programs are relatively small specific programs with enhanced features for certain analysis capabilities. Their use is limited to a specific application area.

Two program categories according to the user's point of view can be distinguished:

- academic programs serving primarily as an educational/ research tool, often available for a nominal fee for other users for non-commercial applications (documentation of these programs is often limited);
- programs commercially available, tested and fully documented.

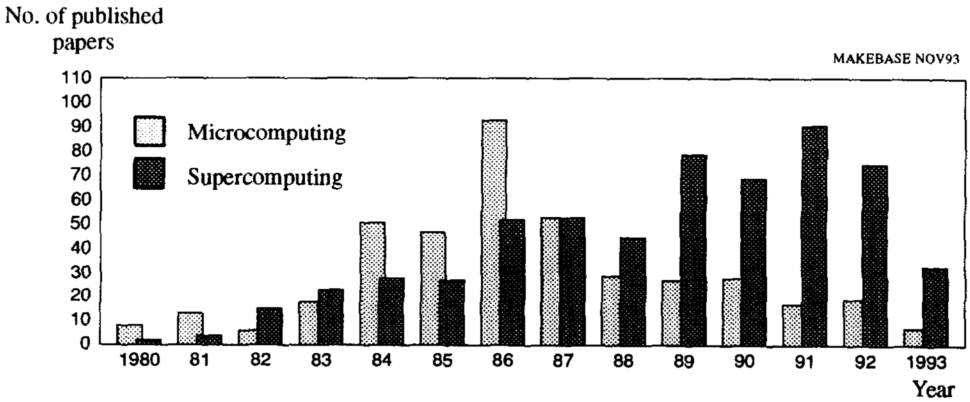

Fig. 5. Chronological distribution of finite element papers on microcomputing and supercomputing.

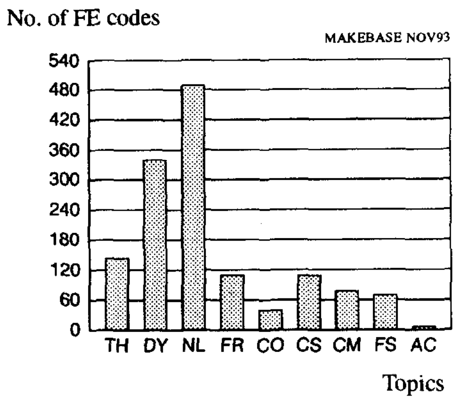

Fig. 6. Finite element codes and various topics.

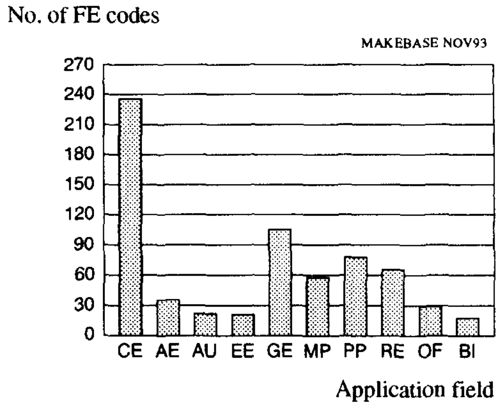

Fig. 7. Finite element codes and engineering fields.

Programs developed at industrial companies are usually not for outside users.

The first problem the potential user is faced with is how to find information about existing programs, and, when the sources of information are known, how to sort out the programs of interest. To evaluate the finite element codes is no easy task because too many parameters of objective and subjective characters are involved. Each program has a relative strength or weakness when used for the analysis of a certain problem. There are two steps in program evaluation. The first one is to evaluate programs from the view of functional description and the program architecture. The second step is an advanced program evaluation which can include element tests, convergence tests, efficiency measures, etc.

It is impossible to estimate how many finite element codes are in existence. Most finite element programs have been developed in an academic environment. In the MAKEBASE there is information about 1490 finite element codes. Of them, 310 codes are general purpose, others are special purpose, used in various fields of engineering activities. The information on these codes stored in MAKEBASE has been received directly from program developers who are filling in the author's questionnaires (the frequency of responses is about 25%). Figures 6 and 7 illustrate the total number of special purpose finite element codes, retrieved from the MAKEBASE, which have been developed for various topics and application fields. The notation in these figures is the same as in Figs 2 and 3.

Increasing demands in finite element analysis led to the development of various pre- and postprocessors reducing the efforts for modelling and result evaluation/presentation. This area is still in progress.

The development of expert systems as an aid for non-experienced users of finite element analysis started at the end of 1980s. It seems that this area of code-development is not so successful as was believed a couple of years ago. Approximately 170 papers have been published on the subject in the period 1986–1993. To the author's knowledge no commercial expert system for finite element analysis is available and it is questionable if any will appear in the near future. The last figure, Fig. 8, illustrates the number of published papers on pre- and postprocessing in the period 1976–1993.

CONCLUSIONS

It is not the author's intention to draw any conclusions. To give a view of the future of finite elements and the unresolved problems associated with them is an extremely difficult task. These notes should be considered as an example of a different usage of a database. There are many papers written by experts on trends in finite elements; readers interested in this subject can find some of them in Refs [5–49].

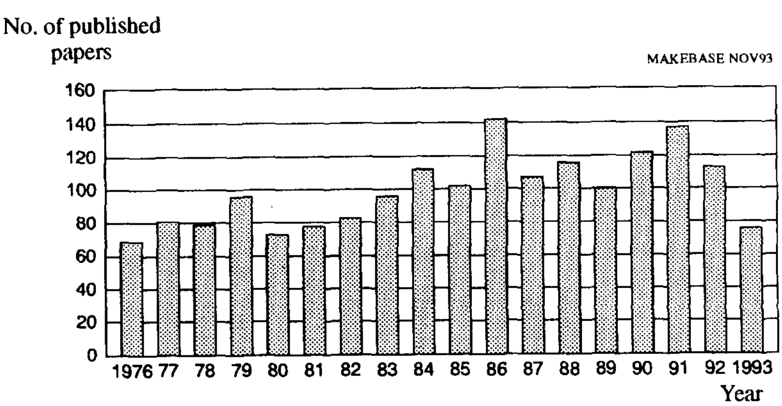

Fig. 8. Chronological distribution of papers on pre- and postprocessing.

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