Historia del Marc

Un homenaje a Pedro Vicente Marcal

By Dr. Antonio Alonso

"Pedro Marcal opened my eyes to computational mechanics"

James Rice (en su discurso de aceptación de la Medalla Timoshenko en 1994)

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0. Foreword

One day Michelangelo, with his characteristic kindness, told me he would like to know more about the origins of the program Marc. Besides, this coincided with my reflections who was then on the profound changes he was experiencing Ingeciber, particularly about new software that were distributed and more specifically, the distribution agreement and technological partnership with MSC.Software CAE pioneering companies. One of its programs, which will become the tool for engineering analysis and calculation engine or solver for Structural Designer, is as unknown to us as legendary in the history of the finite element software Marc.

That was how I got to dive to great depths to document myself everything and to have (in broad strokes) the history of a program that has seen and test some of the most important achievements in nonlinear mechanics. As we shall see, although it was conceived on the East Coast, virtually all its progress took

place in California, more specifically in the town of Palo Alto, near Stanford University where mythical MARC Analysis Research Corp. had its offices until its acquisition by MSC (current MSC Software Corp.). It is for this reason that in a very genuine classification, this codex (sorry code) what I frame within the "School of California."

As the subtitle, this work is also a tribute to Pedro Vicente Marcal, not only as the creator of Marc and he baptized with his name; also by a long and very fruitful scientific and business career that has made him join the Olympus of the creators of finite element programs: John Swanson (Ansys), John Hallquist (LS-Dyna), Klaus J. Bathe (Adina), David Hibbitt (Abaqus) and Richard MacNeal (MSC / Nastran). But also because despite its "short" but influential career as a professor at Brown, he mentored his most brilliant graduate student David Hibbitt, creator along with Marcal of the first version of Marc, and also creator and "hand iron "until his retirement from mythical Abaqus. Perhaps, and this is a very personal romanticism not without fancy, Marcal's decision to leave his teaching post and moving the company to California, had much to do with the decision to Hibbitt riding his own and therefore the existence of Abaqus (which sometimes I mean, led by my fanaticism, as "work of art"). The question is ... A very personal note, I will say that the figures Bathe Hibbitt and have profoundly influenced my way of understanding the use and implementation of nonlinear finite element methods

Except for very personal opinions and expressed "feelings" in this preface the rest of this brief work there has been no room for opinions or considerations that were not well documented. That I have been inflexible, they make it very clear as the various references used.

Finally, I hope and wish that this work deeply in achieving its objective: to present a wonderful show, and if possible, to welcome him with enthusiasm. For the latter, I acknowledge that other factors beyond my control and scope are necessary. As far as I'm concerned I have greatly enjoyed doing it and I put all my love.

One last thing, this is a story of pioneers and pioneer of CAE in Spain it is this house, let us have this ...

## 1. Introduction

There are numerous documents relating to the history of the MEF, some of them written by its protagonists [1, 2]. However, most of these studies focus on the first stage of the development of the method, which could date from the mid-50s until 1970. There is no systematic study of the evolution of the method in the years after the latter date despite the great advances that have taken place since then and have made the technique is so powerful today. For example, the final form of the Lagrangian incremental formulations in the early 70s, the technology elements to reach the degree of robustness of today, integration algorithms for inelastic behavior or development of formulations and their corresponding algorithms resolution for contacts in the 80s and early 90s.

Any attempt to address the study only taking into account the contributions from academia without considering input from the software industry, would be incomplete. As important theoretical and practical contributions were made by developers (J. Nagtegaal, N. Rebelo, D. Hibbitt, P. Marcal, R. MacNeal, etc.) who were always linked to private companies engaged in the development of finite element codes , even to patent some of their development [3, 4].

Maybe it was Belytschko [5] first described the evolution of nonlinear finite element methods through the history of the programs themselves, both academic (Sap, Nonsap), research centers (Dyna3D,

Pronto) or commercial (Abaqus, Adina, Ansys or Marc). As in the author's opinion and using his own words: "... In This information-computer age, the software Often Represents a better guide to the state of the art than the literature".

This short paper is not intended to be so ambitious, that is, do not rush a study of the development of nonlinear methods in finite element and only focuses on the history of the oldest of its protagonists. Marc Considered as the first non-linear program commercial finite element code in this venerable 40-year history, has been one of the major players in the development and evolution of nonlinear finite element methods. In fact, as we shall see, has been a real laboratory where the Lagrangian formulation to date [7] was first implemented, the simulation of metal forming using contacts [8] or hyperelastic formulations plasticity implemented [9].

To tell the story of Marc has seen fit to divide it into several parts to some extent try to follow a chronological order. In the first one speaks of Solid Mechanics Group of the Division of Engineering, Brown University, real hotbed of ideas where the first non-commercial versions of Marc (Marc 2 up?) Were incubated.

Then we talk about the foundation by Pedro Marcal MARC Analysis Research Corp. It emphasizes the feature that made it a genuine company full dedication to research work, perhaps at the price of leaving in the background business objectives, so that its main developers published their papers in international journals.

In a third acquiring MARC Analysis by MacNeal-Schwendler Corp. (now MSC Software Corp.) is described. Abaqus: The following section provides a brief analysis of the similarities with its big competitor is.

Later the period between what is here called the "post-Marcal" stage until today, with a description of the most important advances of the program is analyzed. Finally a review of the most recent lines of research and work of Marcal, who is as we shall see, remains fully active !.

## 2. The beginning of the story: the Solid Mechanics Group of Brown University

In the mid-60s and exploding the MEF were three places where many of the fundamental advances in finite elements were concentrated:

a) the University of Berkeley, with Ed Wilson, Ray Clough and Bob Taylor,

b) the University of Swansea, with Olgierd Zienkiewicz, and

c) University of Stuttgart, with John Argyris.

All these research groups had in common two things:

 consist of civil engineers and

 focus its research on structural applications of the method.

Parallel to Brown University, around solid mechanics department of the engineering division a number of specialists gathered worldwide in theoretical and applied mechanics. Including Daniel Drucker, William Prager, Morton GURTIN [11] Harry Kolsky, Josep Kestin, Alan Pipkin, Ronald Rivlin, Paul Symonds, James Rice [12, 13], and Robert Alan Needleman were Asaro.

This multidisciplinary group was made up of physicists and engineers from various branches whose research topics covered numerous topics, all related to key aspects of the mechanics of deformable solid: constitutive models of continuous media, plasticity, mechanical thermo-mechanical fracture ( J integral comes from "J" ames Rice), fatigue, wave propagation, etc. None of them related to finite elements.

A new line of research in this group opened with the arrival in 1967 of Pedro Vicente Marcal, a young and enthusiastic teacher from the Imperial College of London, very interested in the application of finite element problems of solid mechanics. Marcal, who had already done pioneering work on computational plasticity during his time at Imperial College [14, 15], aroused the interest of Rice at finite elements and together attracted students I created a research team dedicated to the development of techniques of finite elements of the continuum for problems.

One of those first students was David Hibbitt, who from the University of Cambridge went to Brown, quote, "to learn more mechanics", and who years later would create Abaqus.

Figure 1. One of the first works on application of finite elements in plasticity.

Marcal and Hibbitt began implementing Marc as a test of developments in computational mechanics team realized that they were leading. These works were numerous and exerted enormous influence, giving Brown a great reputation in the development of nonlinear finite element methods for the early 70. And so begins the story of Marc: a code of research, designed to solve complex nonlinear problems using this formulation that had been developed at that time at the University of Brown.

Figure 2. One of the magnificent work in the late 60s and early 70s had almost finalized the incremental formulations and finite elements such as used today [6, 16, 17]. In particular, this article is about the here called Lagrangian formulation, from [17] known as Total Lagrangian.

Figure 3. Item in employment shown the problems of sheets Lagrangian formulations developed by the team of Marcal [18] (see Figure 2). Below the reference to Marc shown.

Figure 4. article that first formulation, here called Eulerian, for problems with large deformation plasticity develops. The term Eulerian from [17], corresponding to what is now called Lagrangian updated. Today is the formulation used exclusively for all the programs, problems with non-elastic behavior and large deformations [19]. Below the reference to Marc shown.

Then doctoral dissertation directed Marcal during his professorship at Brown (1967-1974) are shown. Also included which led to Joop Nagtegaal W. Prager, because as we will see later, Nagtegaal years later become director of development of MARC Analysis, and after its march Hibbitt, Karlsson and Sorensen Inc. (HKS) A true guru of Abaqus.

• Hugh David Hibbitt (Ph.D .: Engineering, 1972)

Title: A numerical thermo-mechanical model for the welding and subsequent leading of a fabricated structure

Director: Pedro V. Marcal

• John Francis McNamara (Ph.D .: Engineering, 1972)

Title: Incremental stiffness method for finite element analysis of the nonlinear dynamic problem

Director: Pedro V. Marcal

• Richard H. Messier (Ph.D .: Engineering, 1975)

Title: A finite element algorithm for the determination of dynamic stability

Director: Pedro V. Marcal

• Paul Erik Sorensen, (M.Sc .: Engineering, 1975)

Title: A solid mechanics approach to the solution of fluid-solid vibration problems by finite elements

Director: Pedro V. Marcal

• Johannes Catharinus Nagtegaal (Ph.D .: Engineering, 1973)

Title: Use of optimality conditions in structural design

Director: William Prager

3. Foundation of MARC Analysis Research Corporation

In 1971 Marcal MARC Analysis Research Corp. founded with the idea of marketing the program Marc. The company's headquarters was in Providence, near Brown University, and his first and only employee was his doctoral student Hibbitt [20]. Later another student would join Brown, Paul Sorensen, who was

a short time and left the company to complete his dissertation directed by Marcal own. Finally, this team of the beginning of MARC Analysis were joined in 1976 Bengt Karlssonn, who worked at the headquarters of Control Data Corporation in Sweden (CDC). Karlsson and Sorensen, with Hibbitt, would be that years later would found HKS to develop Abaqus.

Around 1976 and following the halo of Silicon Valley, Marcal decided to move his company to Palo Alto, California. Hibbitt and Karlssonn decide not to continue and chose to start his own company. The new commercial journey of the MARC program posed no detriment to the research of the company. On the contrary, in its development as prestigious people like Robert Melosh (development director) or M. Burke (professor at Stanford) were, whose developments for MARC Analysis were published in international journals.

A very illustrative example of this work was the creation in 1978, in collaboration with Stanford University, the SACON system, one of the first expert systems for structural analysis based on finite elements. This is perhaps interesting to note that this project aroused the interest of Marcal by the use of artificial intelligence in the finite element and accompanied him until today.

Figure 5. An example of the research work of MARC Analysis for Melosh stage [21].

In 1980, after the departure of Melosh, it joins as the new head of development J. Nagtegaal, who previously ran from Holland Analysis MARC offices in Europe. Until his move to HKS in 1987, new developments led Nagtegaal Marc, making important contributions to the implementation of algorithms for problems of plasticity and contact.

Figure 6. Two examples of the contributions of Nagtegaal in computational plasticity [22, 23].

In 1984 he joined the development team Nuno Rebelo, who along with Marc Nagtegaal would first finite element program capable of simulating metal forming problems in 3D. Rebelo developer Marc simultaneously and Abaqus was until 2001, when he joined the team full development of the latter. Here we must draw attention to the fact that in the mid-80 formulations for contact problems, especially for large deformations, were not yet fully developed and were under active investigation.

Figure 7. Work on the system developed by MARC Analysis described to simulate metal forming problems [24].

4. Acquisition of MARC Analysis by MacNeal-Schwendler Corp.

Although he never became a leading company in the market for CAE, Marc Analysis in the period from its founding until 1992 it was characterized by being a highly respected company but with a small market. Perhaps the main explanation of this, was in philosophy itself that had governed the operation of the company from its origins until then: research and development, to the detriment of new capabilities required by users (as opposed to what he did HKS with Abaqus).

In 1992, the company appointed Lou Crain as president and CEO. Crain had been in PDA Engineering from 1975-1989, who as director of the division responsible for the development of Patran is recognized as the principal architect. During his tenure the company seeks to increase its customer base with the development of specific applications such as MARC / Autoforge for rolled steel hot or cold, or by developing their own pre- and post-processor Mentat.

Thus the company reached the figure of 20 million dollars in revenue in 1996, a figure that would remain for the next years. Finally, the shareholders of the company decided that it had touched its commercial roof and Crain left his executive position at the end of 1998. Finally, in May 1999 the company was acquired by MSC worth $ 36 million. Here ends the story of MARC Analysis as an independent company.

In the early 90s MSC had several programs with nonlinear structural capabilities of different amplitude:

• MSC / Nastran, with geometric nonlinearity and a limited number of models of material, both superimposed subsequent to the former linear solver.

• MSC / Dytran for dynamic and explicit solver which was LS-Dyna and

• MSC / FEM Aries with more comprehensive and integrated nonlinear capabilities, which was solver Abaqus / Standard [25].

Finally MSC in their desire to have a non-linear solver own general purpose acquires MARC Analysis As stated in the previous paragraph.

5. Marc and Abaqus: two programs with very intertwined stories

As already seen, the creators of Abaqus, especially Hibbitt, were closely linked to the beginnings of Marc. Both share the programs being designed from the outset for solving complex nonlinear problems, and this is reflected in its internal structure and how to organize the types of analysis and model information. So for example, they Abaqus organizes data into two clearly differentiated blocks, using their nomenclature are:

A. Model data: It comprises all independent information on the type of analysis (mesh, materials, fixed boundary conditions) and time.

B. History data: types of analysis, control information of various resolution and post-processing, temporary loads, etc.

Furthermore Marc organizes information in the same way in their nomenclature are:

A. Model definition

B. History definition

Here one can suspect the hand of the same (and extraordinary) architect ... Hibbitt?

Another point in common is the fact that developers have shared (Nagtegaal and Rebelo), the same as after Marc implement the system for the analysis of metal forming (Fig. 7) a few years later would do the same in Abaqus.

Figure 8. Work on the system developed is described in Abaqus to simulate metal forming problems [26].

Finally, note the fact that the first programs to be developed based on the Python language to interact with databases and system files results.

6. "post-Marcal was" Marc and present. Current features notables

At the time of this work it has not been able to determine the exact date of the launch of MARC Analysis Marcal. The earliest date that has been able to date is 1990, when it appears as an independent consultant in a meeting of the ASME.

As we have seen Marc had its own graphical interface, Mentat, in 1994, which came to fill an important gap regarding its nearest competitor Abaqus. On the other hand, Marc developers continued to show its high scientific level as shown in [9] (see Fig. 9).

For example, it was the first commercial software to implement a hyperelastic formulation plasticity [10]. It is also the only program that allows the current hyperelasticity Lagrangian formulation, which has also proven to be more robust in large deformation problems numerically although more expensive compared to the total for this type of material behavior.

Finally, as a good example of the pioneering nature of Marc, it is sui generis and somewhat archaic nomenclature that used to dominate the elements mixed formulation: Herrmann elements. These elements are designed to behaviors of incompressible material in complete or near-incomprehensibility as in certain models or hyperelasticity perfect plasticity. Professor LR Herrmann in a series of papers published in the mid-60s developed a variational formulation to address this type of behavior. Marc, based on this formulation, was the first program to have elements soportasen behaviors such materials.

Figure 9. Paper presented at the 4th Congress of the Association for Computational Mechanics USACM United States (1997). Currently Choudhry is part of the management team and Wertheimer's main developer of MSC Software.

Figure 10. In 1995 and MARC Analysis Products Axel created the first course on experimental analysis of elastomers combined with simulation techniques. Daniel Wolf remains part of MSC Software.

Figure 11. Marc most important advances since its inception. There have been those who have boxed more significant estimated [27].

## 7. The last of the "old" Marcal

Since leaving his short but brilliant career as a professor at Brown to start their business careers with MARC Analysis to date, Pedro Marcal has proven to be a person with more than enough enthusiasm and initiative to embark on new projects, always related to computational mechanics.

In 1992 he became president of Phoenics North America, where you have opportunity to introduce and gain experience in the world of CFD, someone like him always moved in the field of deformable solid.

In 1995 he founded PVM Corp. (again your name) in order to develop Feva, program general purpose multiphysics. In 2004 he founded MPACT Corp. (http://www.actact.co.jp/index.php?MPACT%20English), this time to develop MPave (Adaptive Multiphysics Visual Environment), a pre and post-processor written entirely in Python (http://www.actact.co.jp/index.php?Mpave%20English).

Marcal is a Fellow of the ASME since 1975 and was director of the Pressure Vessel and Piping Division where he was awarded in 1989 with the Pressure Vessel Medal Award for his contributions to non-linear finite element methods.

To date he has published over 80 scientific papers related to finite element, fatigue, fracture and artificial intelligence. A tireless worker, he has helped organize numerous scientific congresses. Apart from the finite element codes Marc, Feva, MPave and Sage (Superconvergent Adaptive General Elements), it has also developed the artificial intelligence systems Anlap: capable of generating input data for finite element codes or a statistical analysis based on reports Data and fatigue strength tests written in Japanese or English.

## 8. Acknowledgments

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My friend Paul, who from his position at the Patent Office I got the two patents that have Nagtegaal Hibbitt and finite elements.

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