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Guest Editorial

An Important Chapter in the History of Multibody System Dynamics

This note is dedicated to Nicolae Orlandea, John Uicker, and Roger Wehage in recognition of their significant contributions to the field of multibody system dynamics and in appreciation of the value of their innovative work which influenced generations of students, researchers, and practicing engineers

Research activities in the area of multibody system (MBS) dynamics started in the early sixties. Several universities, organizations, and companies in the state of California developed active research and development programs in this area, including Stanford University, University of California-Los Angeles, University of California-San Diego (at a later stage), NASA laboratories, Lockheed Martin, Boeing, etc. European researchers also spent time in California working with the U.S. researchers on MBS dynamics problems, particularly problems related to satellite and other space applications. A large number of technical papers from California institutions on rigid and flexible body dynamics were published in AIAA journals. The contributions of the researchers from California were significant and resulted in a large number of papers and several well-known and highly cited books on the subject of dynamics.

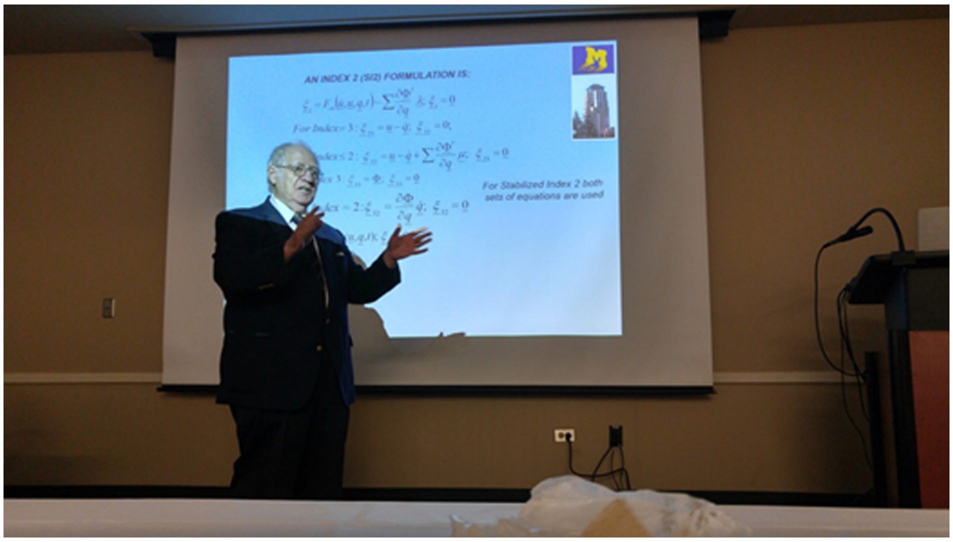
Despite the extensive research efforts and the originality of the approaches developed and used for aerospace applications, no general purpose MBS computer program was developed and successfully commercialized before the seventies. The introduction of these general purpose computer programs, which shaped the field of MBS dynamics as we know it today, happened in the American Midwest. The researchers who introduced the pioneering MBS computer programs were not affiliated with AIAA but were affiliated with the ASME Design Engineering Division (DED), a division with research focus at this time that appeared different from the AIAA research focus in the broader dynamics field.

While there have been many contributors to MBS research and computer program development, this brief note focuses on the contributions of three distinguished researchers at three different universities in the Midwest: University of Michigan, University of Wisconsin-Madison, and University of Iowa. These three researchers, **Nicolae Orlandea**, **John Uicker**, and **Roger Wehage**, made significant contributions that influenced the product design process and the work of generations of students, researchers, and practicing Engineers.

Nicolae Orlandea: The development of general purpose MBS computer programs in the Midwest started at the University of Michigan (UM), where the first general purpose MBS computer program **DRAM** (Dynamic Response of Articulated Machinery) was introduced. This MBS planar software was marketed, but not successfully because of the lack of appropriate check on the constraint violation. UM researchers Nicolae Orlandea, Milton Chace, and D. Calahan developed the three-dimensional successor **ADAMS** (Automatic Dynamic Analysis of Mechanical Systems). This significant development was the subject of the doctoral research of Nicolae Orlandea [1]. In 1973, Orlandea completed his Ph.D. thesis "Node-analogous, Sparsity-Oriented Methods for Simulation of Mechanical Dynamic Systems." With the completion of this thesis, the ADAMS computer program was born. In 1978, Mechanical Dynamics Inc. (MDI) adopted ADAMS as its main product, and the first commercial version was sold by MDI in 1981. In ADAMS, a sparse matrix approach was used in order to minimize the array storage and enhance the code efficiency. Sparse matrix techniques, which are now widely used in MBS computer algorithms, allow for solving complex MBS models that consist of a large number of bodies and joints. In the early and mid-seventies, the ASME DED community used to meet at the ASME Design Engineering Technical Conferences and used to publish their work in the *ASME Journal of Engineering for Industry*. This gave Nicolae Orlandea and Milton Chace the opportunity to meet, discuss, and eventually influence the work of other groups at other universities in the Midwest including University of Iowa.

John Uicker: ADAMS became and remains until today the most popular MBS computer program. However, prior to the development of ADAMS, there was an important research activity led by John Uicker at the University of Wisconsin-Madison. John Uicker and his Ph.D. student Pradip Sheth introduced an innovative approach for the selection of the independent coordinates. John Uicker arrived to Northwestern University in 1961 as a graduate student. His doctoral research was supervised by Jacques Denavit and Richard S. Hartenberg who received an NSF grant to develop the Denavit-Hartenberg notation widely used in the analysis of robotics systems. During the four years Uicker spent at Northwestern University, he met Milton A. Chace who visited Northwestern for few days; Chace and Uicker met and became friends. Chace pursued parallel research for his graduate degree under the supervision of Professor Joseph Shigley at Michigan. Chace, who later became Orlandea's thesis advisor, completed his Ph.D. degree in 1964. Uicker completed his Ph.D. degree at Northwestern in 1965 and served two years at Frankford Arsenal in Philadelphia before joining the University of Wisconsin-Madison in 1967. Sheth completed his M.S. degree in 1968 under the supervision of another University of Wisconsin professor, Donald F. Livermore. Sheth became Uicker's Ph.D. student in 1968 and finished his doctoral degree in 1972. Sheth and Uicker's work was the foundation of the powerful computational algorithm, known as the *generalized coordinate partitioning*, generalized later at the University of Iowa.

In the Lagrangian approach, the position vector $\mathbf{r}$ of a point on an arbitrary body in a MBS application can be written in terms of a set of coordinates as $\mathbf{r} = \mathbf{r}(q_1, q_2, \ldots, q_n)$, where $q_1, q_2, \ldots, q_n$ are the coordinates used to describe the system configuration. These coordinates for large constrained system or a simple closed loop system can be related by algebraic equations. For complex systems, the identification of independent coordinates (degrees of freedom) can be difficult, and for smaller systems with closed loops, singularities can be also encountered if one set of independent coordinates are used during the entire simulation. For example, in the case of a four-bar linkage, the two loop-closure equations are expressed in terms of three angles while the mechanism has one degree of freedom [3]; a single angle cannot be used



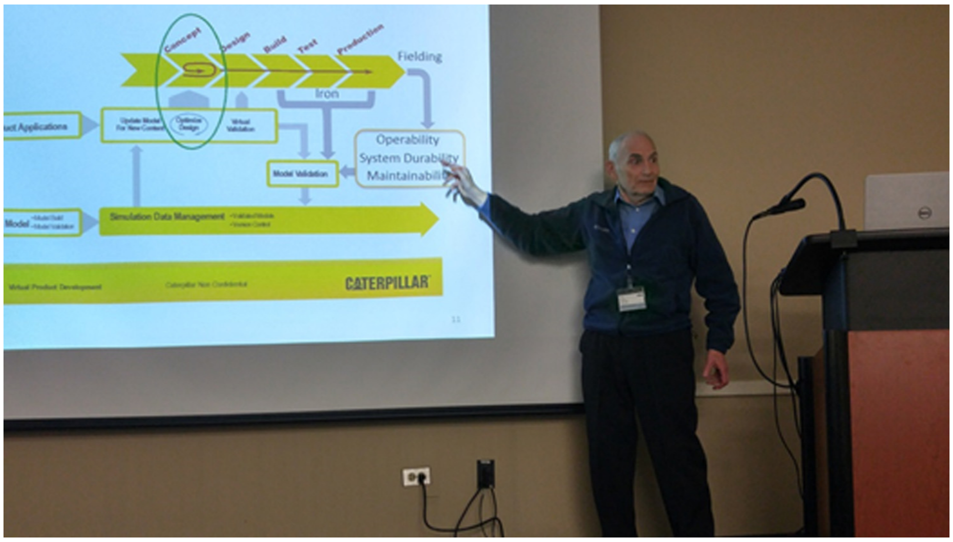
Dr. Nicolae Orlandea speaks at the Workshop on Computational and Nonlinear Dynamics (CNDI) held on the Campus of University of Illinois at Chicago on May 27, 2016

Dr. John Uicker speaks at the Workshop on Computational and Nonlinear Dynamics (CNDI) held on the Campus of University of Illinois at Chicago on May 27, 2016

as the degree of freedom during the entire simulation of the mechanism. Sheth and Uicker pioneered the use of numerical methods in identifying the independent coordinates [2]. The Jacobian matrix of the algebraic constraint equations was used to identify the dependent and independent coordinates of the system. Sheth and Uicker implemented this approach in one of the first general purpose mechanism program called **IMP** (Integrated Mechanism Program). There were attempts to commercialize IMP, but these attempts were not very successful. It is worth mentioning also that Sheth, after completing his Ph.D., joined University of Michigan as a postdoc, where he taught a course that was attended by Nicolae Orlandea. Sheth later joined the faculty of the University of Virginia. Sadly, he passed away in 2009.

Roger Wehage: The pioneering work at the University of Michigan and University of Wisconsin was the foundation for the MBS research program established at the University of Iowa. After receiving his Ph.D. from the University of Michigan, Nicolae Orlandea joined the faculty of Iowa State University as a visiting professor for one year before joining John Deere where he spent the rest of his career. In the mid-seventies, an electrical engineer, Roger Wehage, decided to make a career change. While working in industry and later in the Air Force, Wehage had developed an interest in structural vibration and failure problems. After leaving the Air Force in 1973, he pursued an M.S. degree in mechanical engineering at Iowa State University, where he met Orlandea who introduced the subject of MBS dynamics. Wehage worked with Orlandea on developing a planar version of the Adams computer program. He also collaborated with the late Paul W. Claar, exploring the intricacies of ADAMS and IMP.

After completing his M.S. degree at Iowa State University, Wehage had not anticipated pursuing a Ph.D. degree because of family obligations. However, unknown to Wehage, Orlandea had recommended him as a Ph.D. student to Edward Haug, a professor at the University of Iowa, whose research was partially funded by



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the U.S. Army Tank-Automotive Research, Development, and Engineering Center (TARDEC). Wehage initially declined offers to join the University of Iowa Ph.D. program, but because of a poor job market he accepted and continued the MBS research he had started under the supervision of Orlandea at Iowa State University.

Influenced by Sheth and Uicker's work, Wehage extended their generalized coordinate partitioning method to arbitrary open and closed loop MBS systems whose configuration is defined using the absolute Cartesian coordinates [4,5]. He also used an efficient sparse matrix implementation to ensure that the constraint equations are satisfied at the position, velocity, and acceleration levels. The sparse matrix implementation of the generalized coordinate partitioning method, which does not require finding the inverse of the Jacobian matrix associated with the dependent coordinates, was the foundation of a new general purpose multibody computer program called **DADS** (Dynamic Analysis and Design System). Wehage worked as an assistant professor at the University of Iowa and later joined TARDEC. In 1995 he left TARDEC and joined Caterpillar, where he spent the rest of his career before retiring in 2007. Following the development of DADS in 1979, he directed development of the NUSTAR MBD program at IABG, Ottobrunn, Germany in 1985, the SOVAS MBD program at TARDEC in 1991, and the TomSim MBD program at Caterpillar in 1997.

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