SOME RESOURCES FOR MULTIBODY SIMULATION

IN 10 SLIDES

E. Cabrol

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Introduction

Multibody Simulation can be seen as a subset of « systems simulation », which means « simulation of complex systems », usually combining multiple physical domains.

Even restricted to mechanical behaviour, multibody simulation is not an easy task, since the sytems obtained are usually stiff from a numerical point of view.

Main topics are :

- Kinematics
- Stability
- Dynamics
- Linearization / vibration analysis
- Actuation and control
- Motion planning

Caveat : I'm not an expert, and this is not a reference book. Don't trust me !
I'm only a curious guy with some CAE background, both in 3D and in 0D/1D simulation.

Fields of application

- Robotics
- Biomechanics
- Vehicle dynamics (road and railroad)
- Aerospace
- Drivetrain / engine

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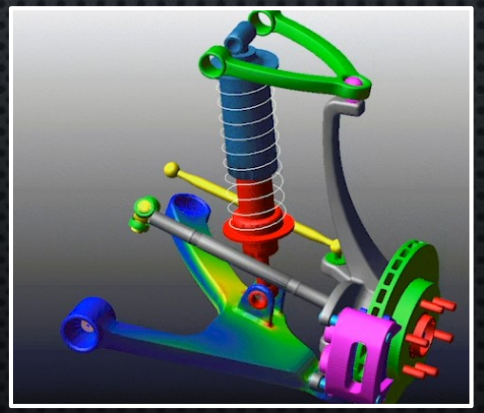

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BEFORE COMPUTERS …

FROM MULTIBODY SYSTEMS HANDBOOK (1990)

For nearly two hundred years after the pioneering technical advancements of Newton and Lagrange, the process of analyzing systems of rigid bodies undergoing overall motions involving large-amplitude rotations remained an intimidating undertaking. First, one had to develop a mathematical model involving idealized components. Then, one was faced with the daunting task of manually formulating equations governing the behavior of the model. This typically involved a substantial amount of tedious algebraic manipulations, was prone to errors, and was virtually impossible to accomplish for any system with more than just a few degrees of freedom. Lastly, if an analyst was skilled enough to complete the first two tasks, the final obstacle of cleverly finding a closed-form solution of the equations using tabulated mathematical functions was difficult enough to restrict the entire process to only the most skilled academicians addressing the very simplest mechanical systems.

A LITTLE HISTORY

One of the first 2D programs was **KAM** (Kinematic Analysis Method) by a team from IBM, based on the PhD of Chace (1964).

A couple of years Later, **DAMN** (Dynamic analysis of mechanical networks) and **DRAM** (Dynamic Response of Articulated Machinery) were developed by Chace (now at Univ. of Michigan), Korybalski, Angel ...

They can be seen as forerunners of **Adams** which was the first general 3-dimensional software for large displacement dynamic analysis, released by MDI (Mechanical Dynamics Inc.) in 1980.

The first textbook was Dynamics of Systems of Rigid Bodies (1977) by J. Wittenburg, who also wrote in 1975 a fortran program for Daimler-Benz, used to simulate the dynamics of a human dummy in a car accident. This software later gave birth to the first symbolic software, ***MesaVerde.***

A BIT OF THEORY

Two approaches co-exist since the equations of motion can be formulated **numerically** or **symbolically**.

The numerical approach generates non-linear differential and algebraic equations (DAEs) that require iterative solution methods which run with variable time steps. This approach is more general, but less computationally efficient. All commercial softwares listed later belong to this family, due to the associated versatility.

The symbolic approach is problem specific, which is particularly interesting when the topology of the system is fixed (often the case for vehicle dynamics). ***Mesaverde*** *(developed by Wittenburg) seems to have been the first of this family, also including* ***Autolev*** *(now called MotionGenesis Kane),* ***Neweul****,* ***Autosim*** *(later integrated in CarSim),* ***DynaFlexPro*** *(now in MapleSim),* ***MBSymba****,* ***Robotran****…*

The symbolic approach has for long been the only one suited for real-time execution, even if recent improvements (both on software and hardware sides) led to real-time versions of general multibody softwares.

COMMERCIAL SOFTWARES

ADAMS (BY MSC SOFTWARE) IS CLEARLY THE HEAVYWEIGHT, STRONG OF 40 YEARS OF DEVELOPMENT.

ALL THE MAJOR ACTORS OF THE « 3D CAE » WORLD PROVIDE A COMPETITIVE SOLUTION :

- **MOTION SOLVE** (ALTAIR)
- **SIMPACK** (DASSAULT SYSTEMS)
- **SIMCENTER MOTION** (SIEMENS)
- **ANSYS MOTION** (ANSYS)

MOST OF 0D/1D SOFTWARES ALSO HAVE A PRODUCT FOR MULTIBODY SIMULATION NOW :

- **SIMULATIONX** (ESI)
- **SYSTEM MODELER** (WOLFRAM)
- **MAPLESIM** (MAPLESOFT)
- **SIMSCAPE MULTIBODY** (MATHWORKS)

OTHER ALTERNATIVES : RECURDYN, 20-SIM, COMSOL, AVL EXCITE, PTC CREO MDO

FREE OR OPEN SOURCE

MBSymba developed by Roberto Lot (Univ. Padova) and **Neweul-M²** (Univ. Frankfurt) are not really free since based respectively on Maple and on Matlab Symbolic toolbox, but they are worth a look for the good reason that they use a symbolic approach.

So is **Robotran**, from the University of Louvain (provides a GUI, and a Python API !)

Last for the symbolic team, a still nascent project, developed in Julia by Bruce Minaker : **EoM**

Now for the "numerical team" :

- Project Chrono, open source, with a strong contribution from the univ. of Madison. The project received a funding from the US Army, hence the animations with Humvees ☺
- Drake, open source project started at the MIT and now developed by the Toyota Research Institute
- Bullett, collaborative development with an active community
- DART, cross-platform, open source, initiated by Georgia Tech
- ODE (Open Dynamics Engine), developed since 2001 (!) by Russell Smith. ODE is the default engine of the well known Gazebo used by many roboticists.

See also Simbody, FreeDyn, MBDyn, Hotint, and of course the multibody library of the **Modelica** family.

« MULTI-NON-RIGID-BODY »

The first programs were handling rigid bodies only. The need to take the flexibility of some components into account led to different techniques that enhanced existing codes.

Dynamic substructuring is often used (in particular Craig-Bampton method), with some hypotheses : the component behavior is supposed to be linear, and no contact is allowed.

The workflow complexity is increased, since a superelement of the component must be prepared in advance, resulting from a modal analysis.

Latest software evolutions gradually removed some of the restrictions :

- Contact can now be modelled
- non-linearities can be included (see Adams MaxFlex for example)
- integration of flexible bodies from FE analyses becomes more and more seamless

But simulation of complex multibody systems still requires a solid expertise, with many pitfalls.

RESOURCES

Memories

- History of Multibody Dynamics in the U.S. (link)
- An extensive list of "historical" softwares can be found in chapter 3 of *Control System Analysis and Design*

Conferences

- ECCOMAS Multibody Dynamics Conference (*)
- *Joint International Conference on Multibody System Dynamics*

Books

- *The Multibody Systems Approach to Vehicle Dynamics* (*M. Blundell, D. Harty*)
- *Dynamics of Multibody Systems, 2nd ed.* (*J. Wittenburg*)
- *Modern Robotics* (*K. Lynch*), and the associated *Youtube channel*
- *Multibody Systems Handbook*, *W. Schielen*

PHDs

- *Symbolic Computer Methods to Automatically Formulate Vehicle Simulation Codes* (*M. Sayers*), and other technical papers on CarSim *Website*

(*) the ebook of the 2015 edition is online, if you fancy a 1600 page pdf