Thematic Conference

Multibody Dynamics 2013
01-04 July, Zagreb, Croatia

History of Benchmark Problems in Multibody Dynamics

Werner Schiehlen, Professor Emeritus
University of Stuttgart

Institute of Engineering
and Computational Mechanics
University of Stuttgart, Germany
Prof. Dr.-Ing. Prof. E.h. Peter Eberhard

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1. Introduction

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Benchmarking is often associated with assessing performance characteristics of computer hardware, but the technique is also applicable to software.

Software benchmarks include test suites intended to assess the correctness of software.

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In software development, a test suite or validation suite, respectively, is a collection of test cases or benchmark problems that are intended to be used to test a software program to show that it has some specified set of behaviour.

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In software development, a test suite or validation suite, respectively, is a collection of test cases or benchmark problems that are intended to be used to test a software program to show that it has some specified set of behaviour.

A test suite often contains detailed instructions or goals for each collection of test cases and information on the system configuration to be used during testing. Test cases may also contain prerequisite states or steps, and descriptions of the following tests.

1. Introduction

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Ideally, the benchmark problems are solved on the same computer by competitive multibody simulation software. But this is often not possible due to the availability of hardware and software resources.

Nevertheless, the accuracy of the results and the efficiency of the computations provide an important information on performance and correctness for program developers and software users.

2. Classes of Benchmarks

In this historical review a number of benchmark problems is presented from various engineering applications.

There are known four classes of benchmarks, from the origins of multibody dynamics

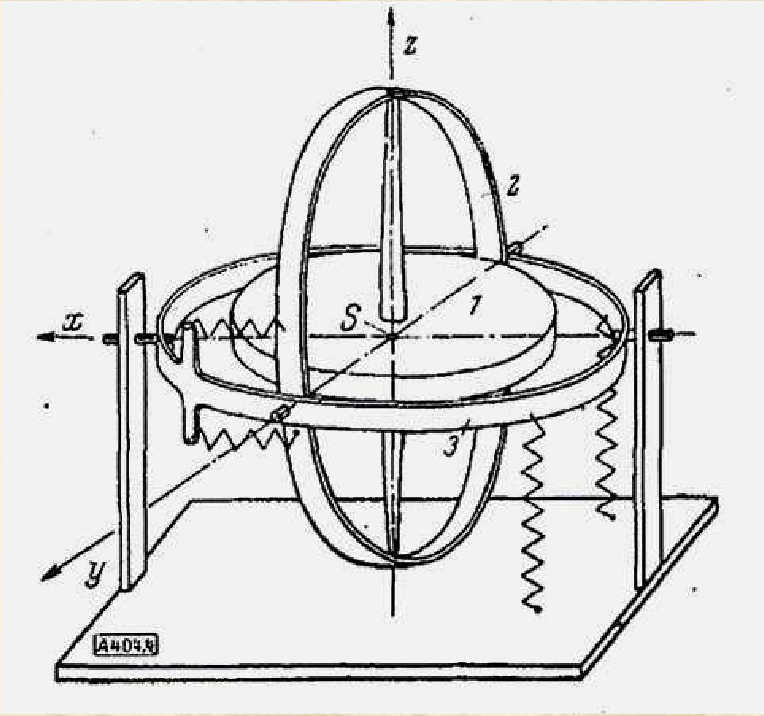
- gyro dynamics, and
- mechanisms,

and more recent applications

- vehicle dynamics, and
- flexible multibody systems.

2.1 Gyro dynamics

A gyroscope in Cardanic suspension represents a three-body system with springs as treated 1942 by Magnus as a benchmark.



2.1 Gyro dynamics

Magnus presented
the completely exact equations of motion

$$(\overset{*}{\mathfrak{J}}_1)_A + (\mathfrak{J}_1)_C\, u'_B - (\mathfrak{J}_1)_B\, u'_C = \{M_{A_3} - (\overset{*}{\mathfrak{J}}_3)_{A_3} - [+(\overset{*}{\mathfrak{J}}_2)_{C_2} + (\mathfrak{J}_2)_{B_2}\, u'_{A_2} - (\mathfrak{J}_2)_{A_2}\, u'_{B_2}]\sin^2\beta\}\frac{\cos\varphi}{\cos\beta}$$
$$+ M_{B_{23}}\sin\varphi - (\overset{*}{\mathfrak{J}}_2)_A - (\mathfrak{J}_2)_{C_2}(\mathfrak{u}'_2)_B + (\mathfrak{J}_2)_B\, u'_{C_2}$$

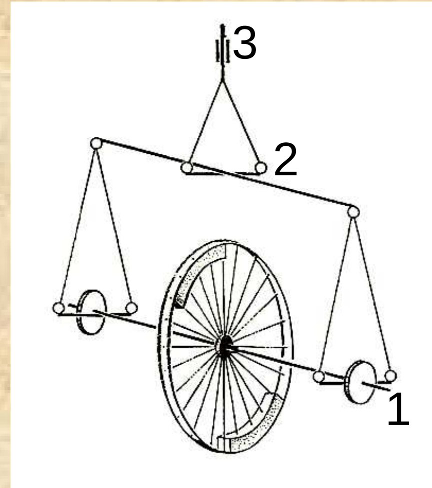
$$(\overset{*}{\mathfrak{J}}_1)_B + (\mathfrak{J}_1)_A\, u'_C - (\mathfrak{J}_1)_C\, u'_A = -\{M_{A_3} - (\overset{*}{\mathfrak{J}}_3)_{A_3} - [(\overset{*}{\mathfrak{J}}_2)_{C_2} + (\mathfrak{J}_2)_{B_2}\, u'_{A_2} - (\mathfrak{J}_2)_{A_2}\, u'_{B_2}]\sin^2\beta\}\frac{\sin\varphi}{\cos\beta}$$
$$+ M_{B_{23}}\cos\varphi - (\overset{*}{\mathfrak{J}}_2)_B - (\mathfrak{J}_2)_{A_2}(\mathfrak{u}'_2)_C + (\mathfrak{J}_2)_C\, u'_{A_2}$$

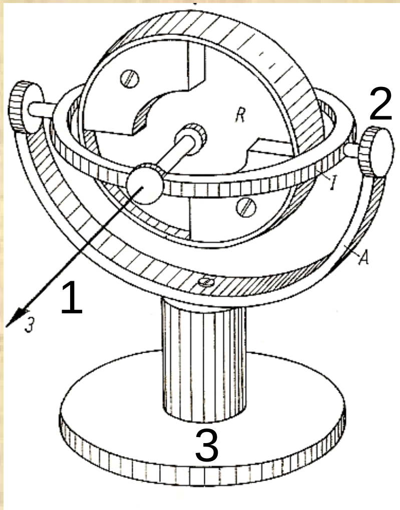
$$(\overset{*}{\mathfrak{J}}_1)_C + (\mathfrak{J}_1)_B\, u'_A - (\mathfrak{J}_1)_A\, u'_B = 0$$

Moment of momentum vector J ,
relative angular velocity vector u' ,
torque vector of the springs M ,
angles β and φ related to the inner ring and the rotor, respectively,
indices 1, 2, 3 for the rotor, inner ring and outer ring.
The indices A, B, C identify the axes of the outer ring, inner ring and rotor, some of them also known as Prandtl rotation axes.
Furthermore, (*) means time derivative in the body fixed frames.

2.1 Gyro dynamics

Later in 1966 Magnus
discussed the stability behavior of
a force-free asymmetric gyroscope
represented by the Prandtl wheel, or Magnus gyro



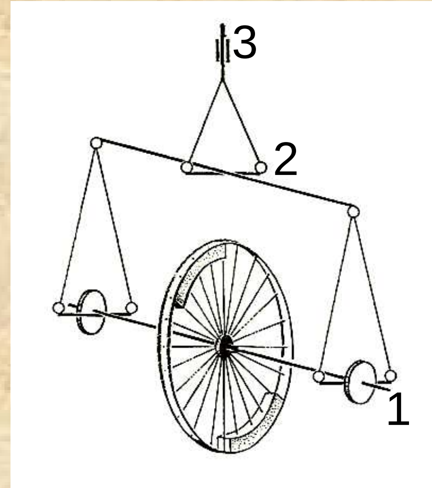


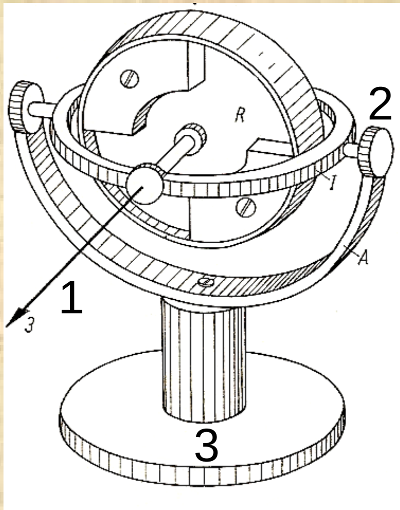
Prandtl rotation	$\theta < \theta_1$	$\theta_1 < \theta < \theta_2$	$\theta_2 < \theta < \theta_3$	$\theta_3 < \theta < \theta_4$	$\theta_4 < \theta$
No. 1	+	–	–	+	+
No. 2	+	+	+	+	–
No. 3	–	–	+	+	+

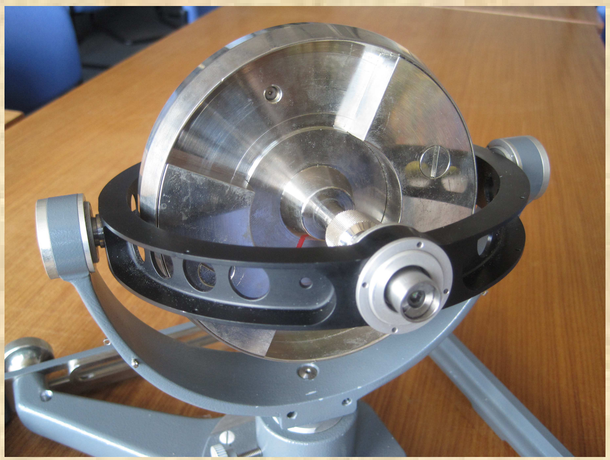
+ stable , – unstable ,

2.1 Gyro dynamics

Later in 1966 Magnus discussed the stability behavior of a force-free asymmetric gyroscope represented by the Prandtl wheel, or Magnus gyro



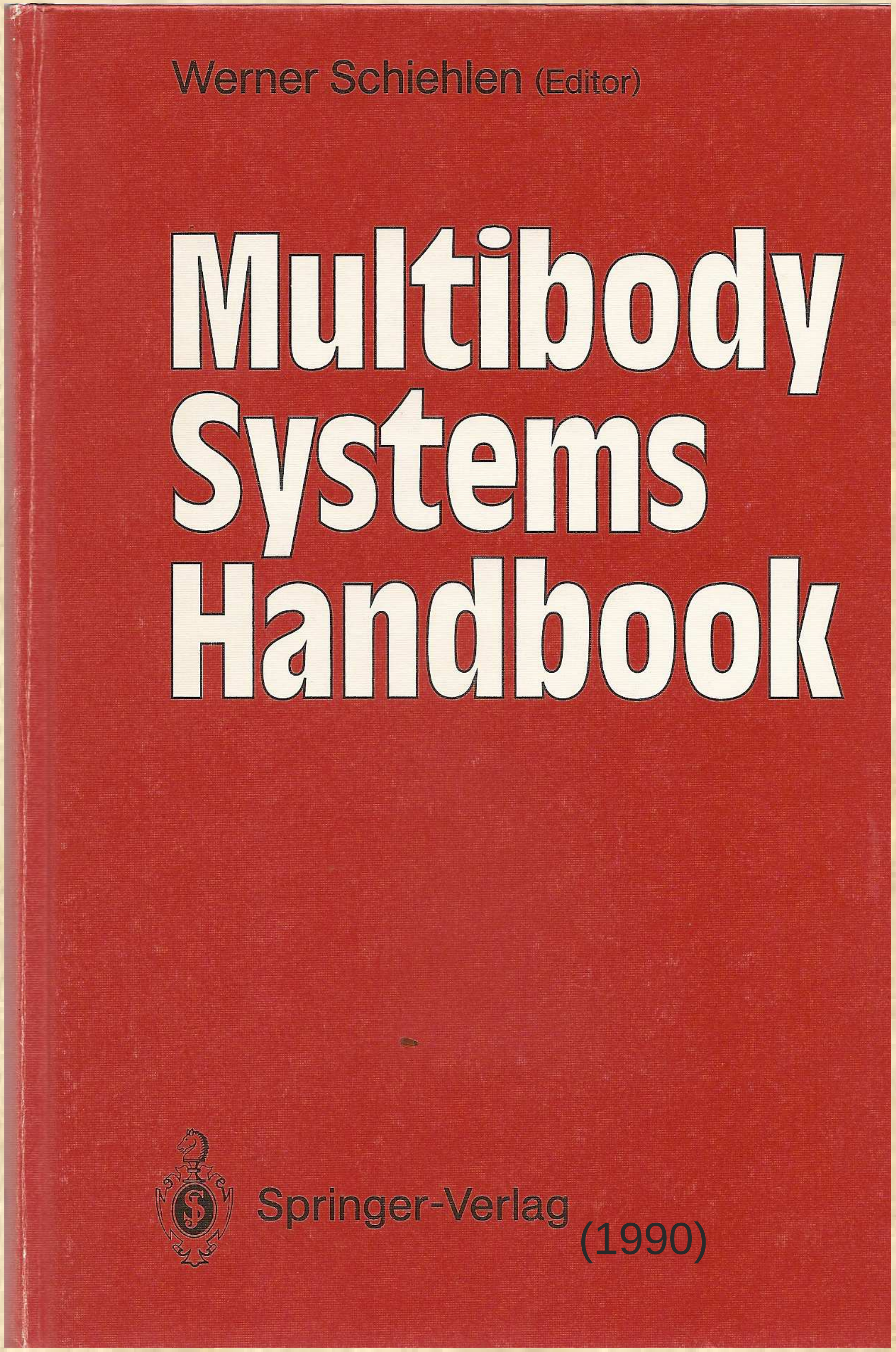




Prandtl rotation	$\theta < \theta_1$	$\theta_1 < \theta < \theta_2$	$\theta_2 < \theta < \theta_3$	$\theta_3 < \theta < \theta_4$	$\theta_4 < \theta$
No. 1	+	–	–	+	+
No. 2	+	+	+	+	–
No. 3	–	–	+	+	+

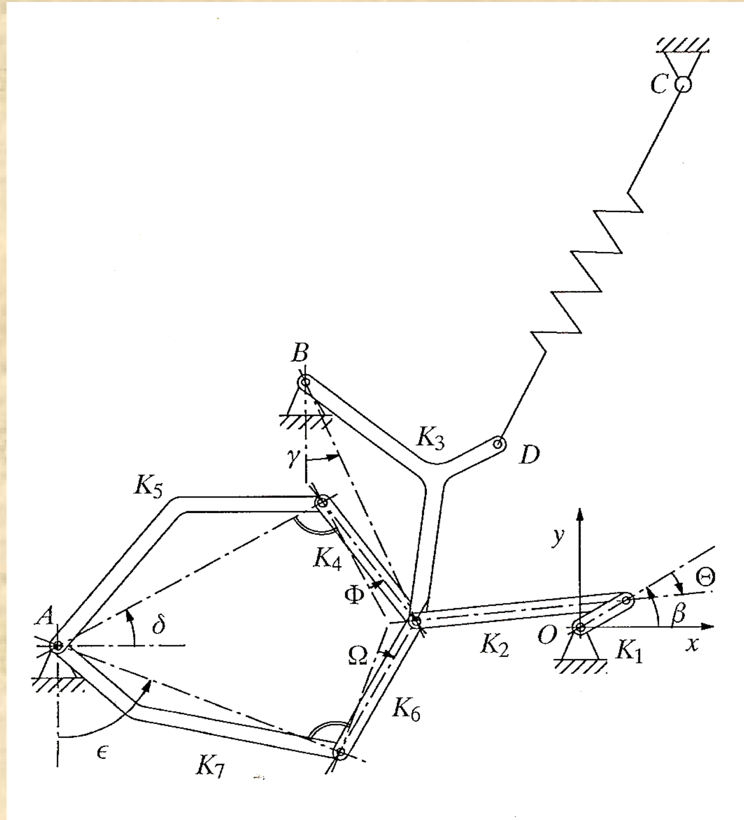
These results have been experimentally confirmed, + stable , – unstable , and can be used as reliable benchmarks in computational multibody dynamics.

2.2 Mechanisms



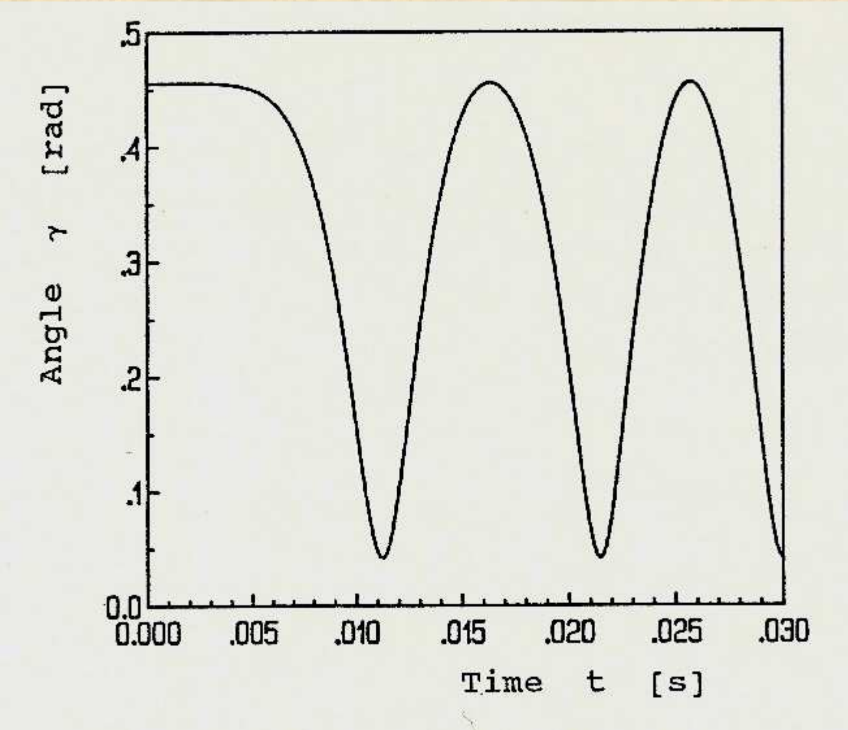
(1990)

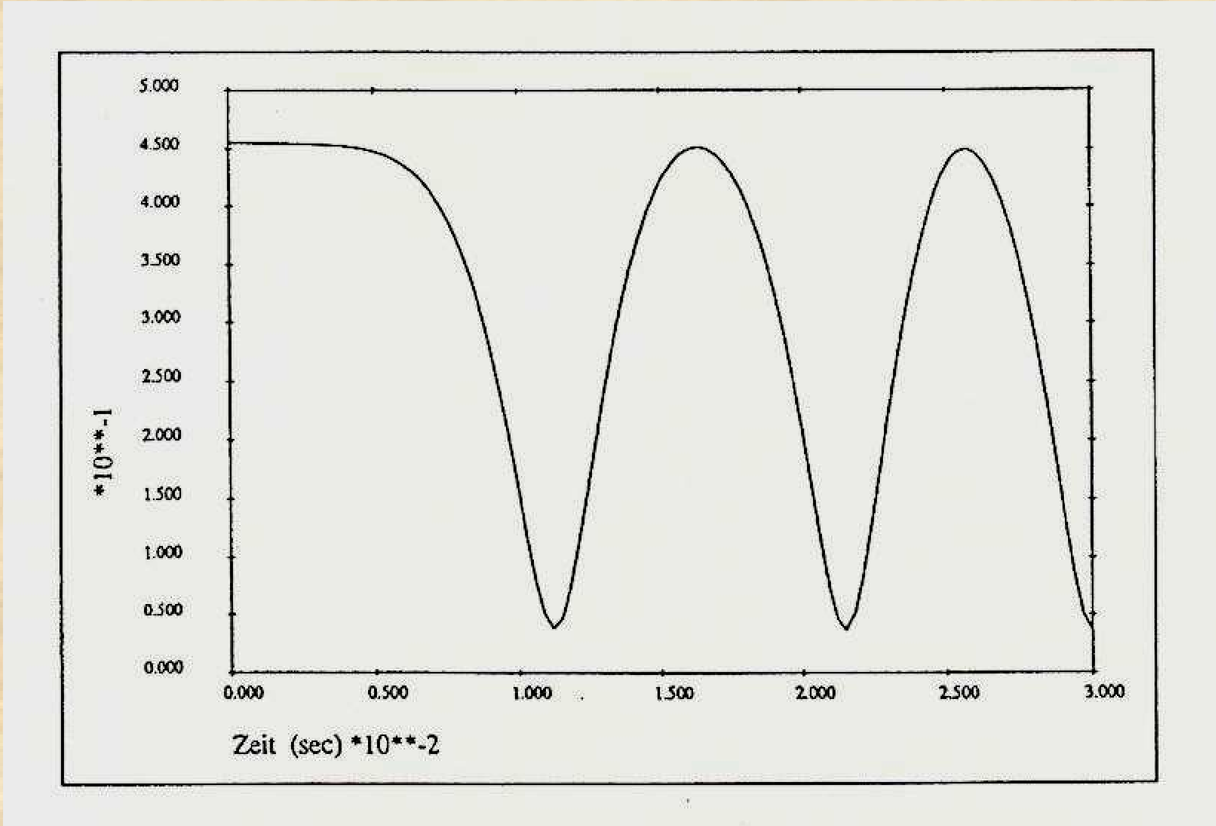
Andrew’s seven-body mechanism also known as Andrew’s squeezer mechanism proposed for early impact printers was used as benchmark for the Handbook.



2.2 Mechanisms

Altogether 20 different software codes were used to solve the mechanism benchmark in competition on different computers.



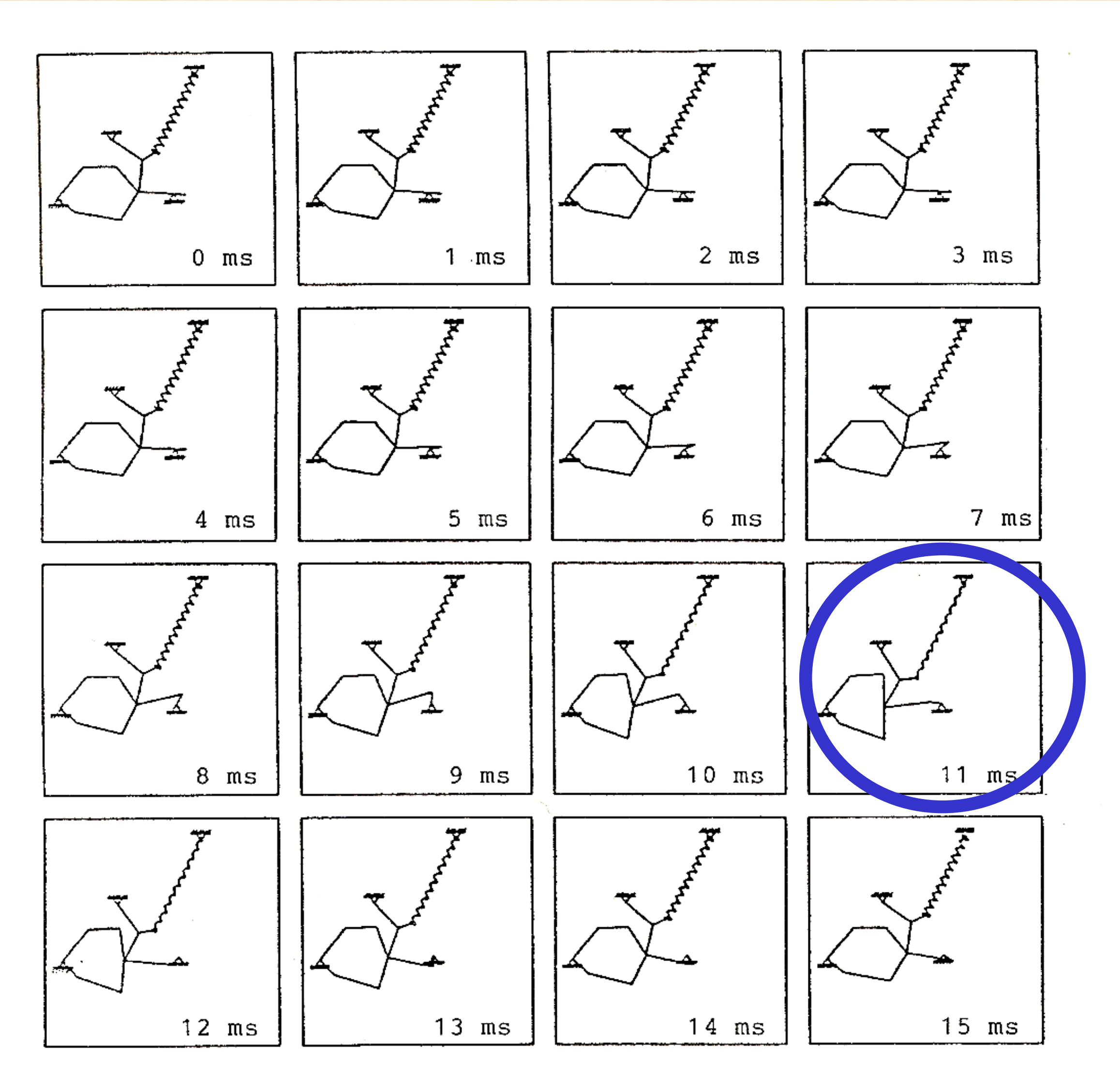


Software NEWEUL

Software SIMPACK

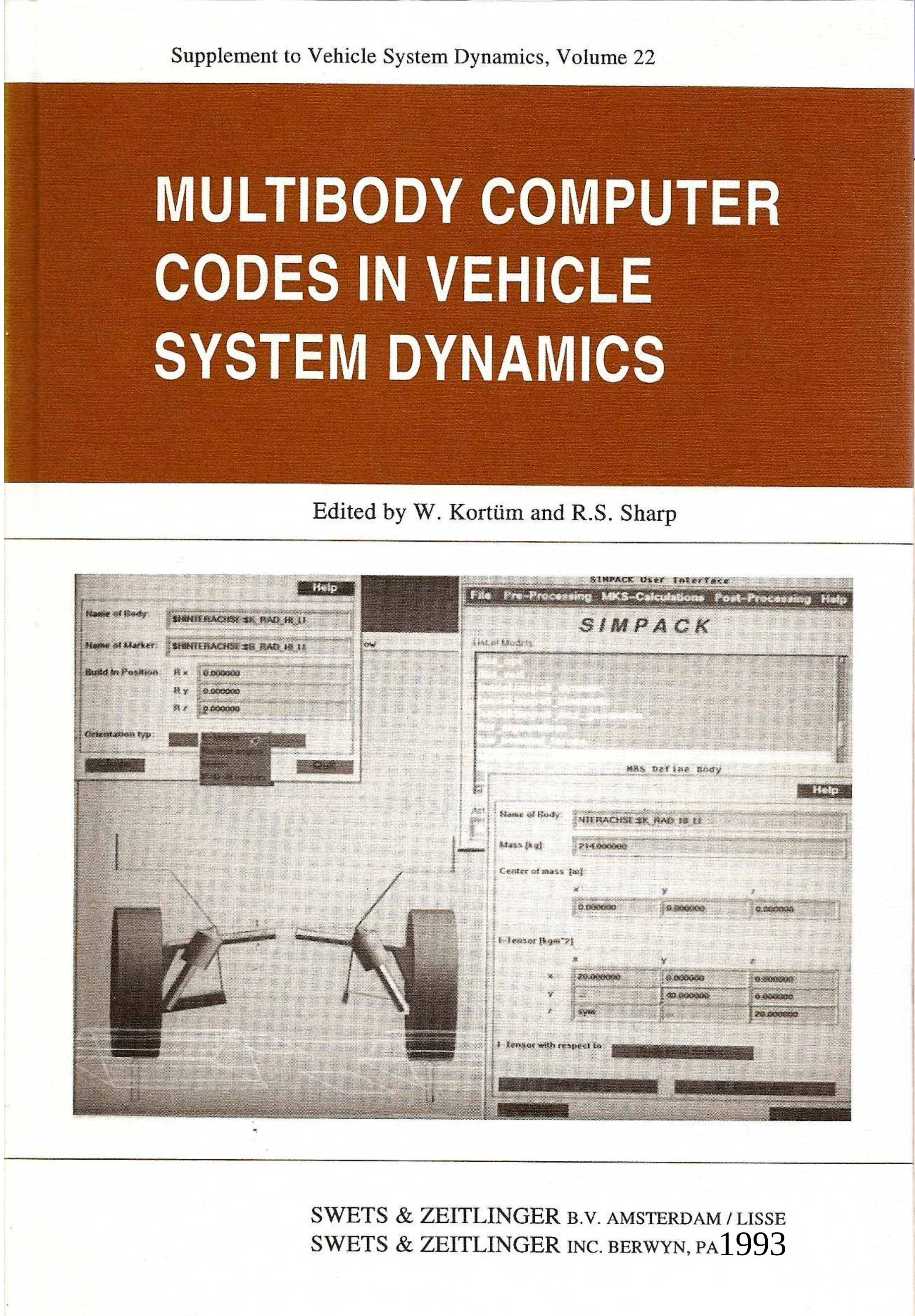
The correctness of the results was easily shown but information on the performance was not available.

2.2 Mechanisms



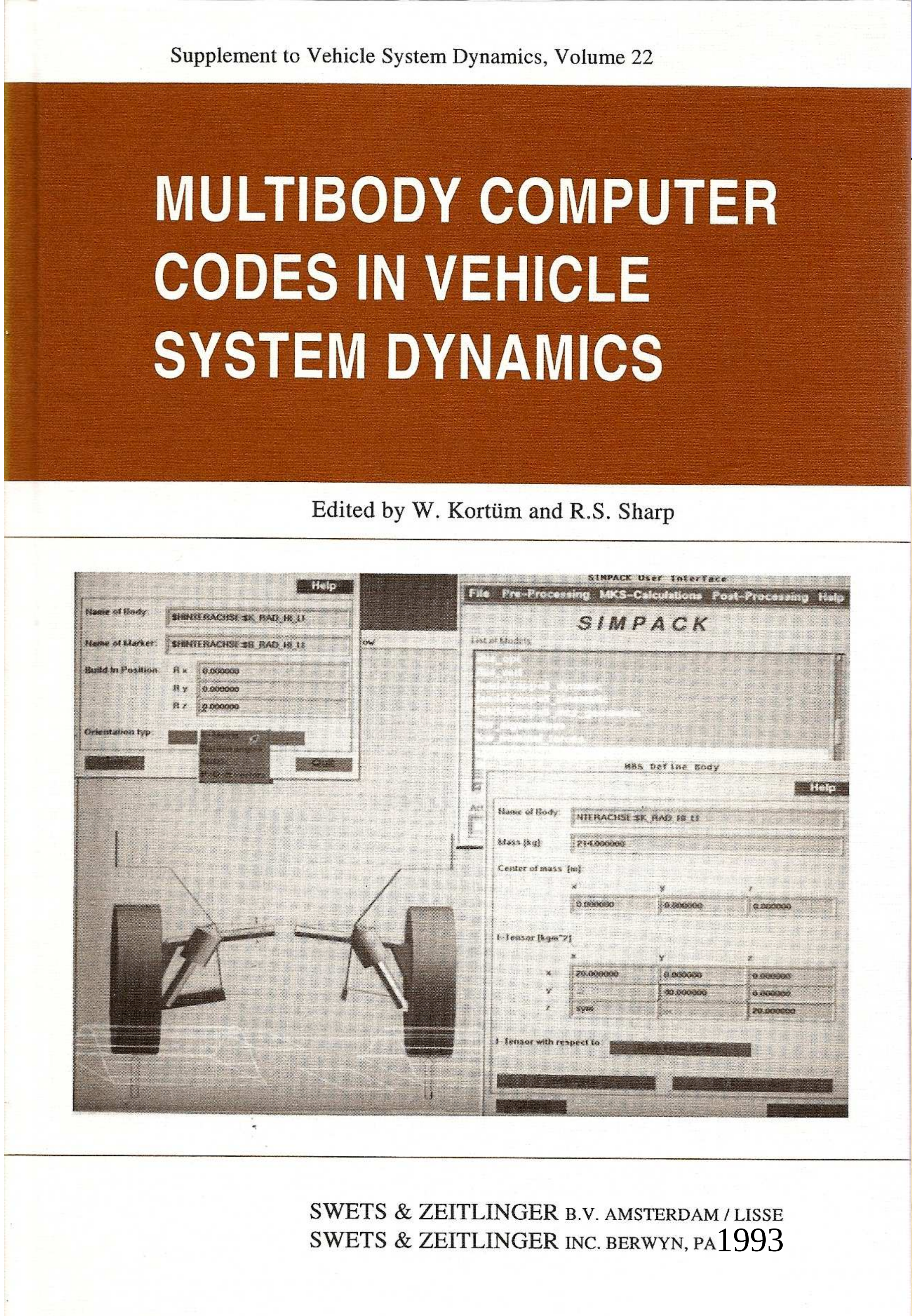
Animation of mechanism motion

Impact position



2.3 Vehicle dynamics

This book compares vehicle dynamic software, and uses the Iltis vehicle as a benchmark problem.



1993

2.3 Vehicle dynamics

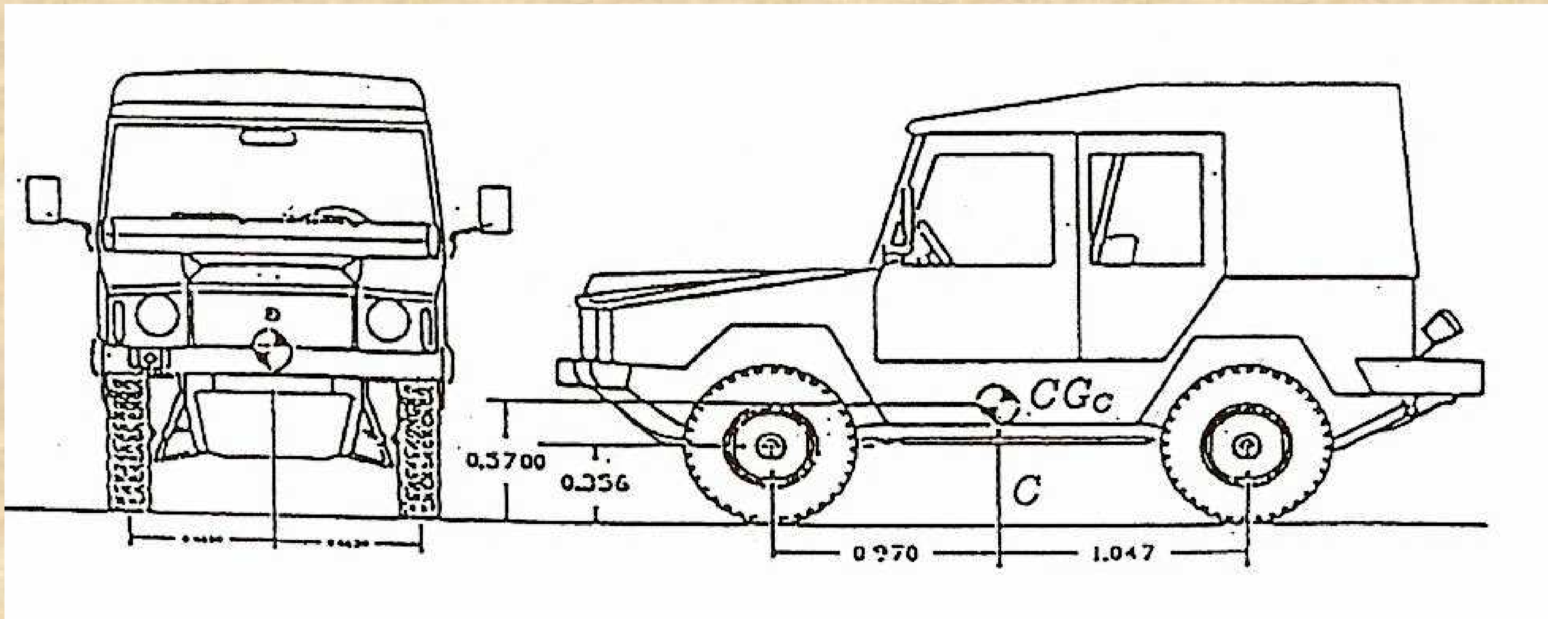
This book compares vehicle dynamic software, and uses the Iltis vehicle as a benchmark problem.

Four test cases are identified:

static equilibrium,
eigenvalues,
response to vertical road profiles,
and handling performance.

2.3 Vehicle dynamics

Bombardier Iltis



The parameters of the Iltis vehicle are described in detail including geometry and masses, force elements and a tire model.

The vehicle has 4 identical suspensions with one degree of freedom each.

Thus, the vehicle has 10 degrees of freedom altogether.

2.3 Vehicle dynamics

Due to four different codes, FASIM, MEDYNA, NEWEUL and SIMPACK many useful results are available.

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The handling is characterized by the lateral acceleration for a 2 mm steering rack displacement resulting in circular cornering.

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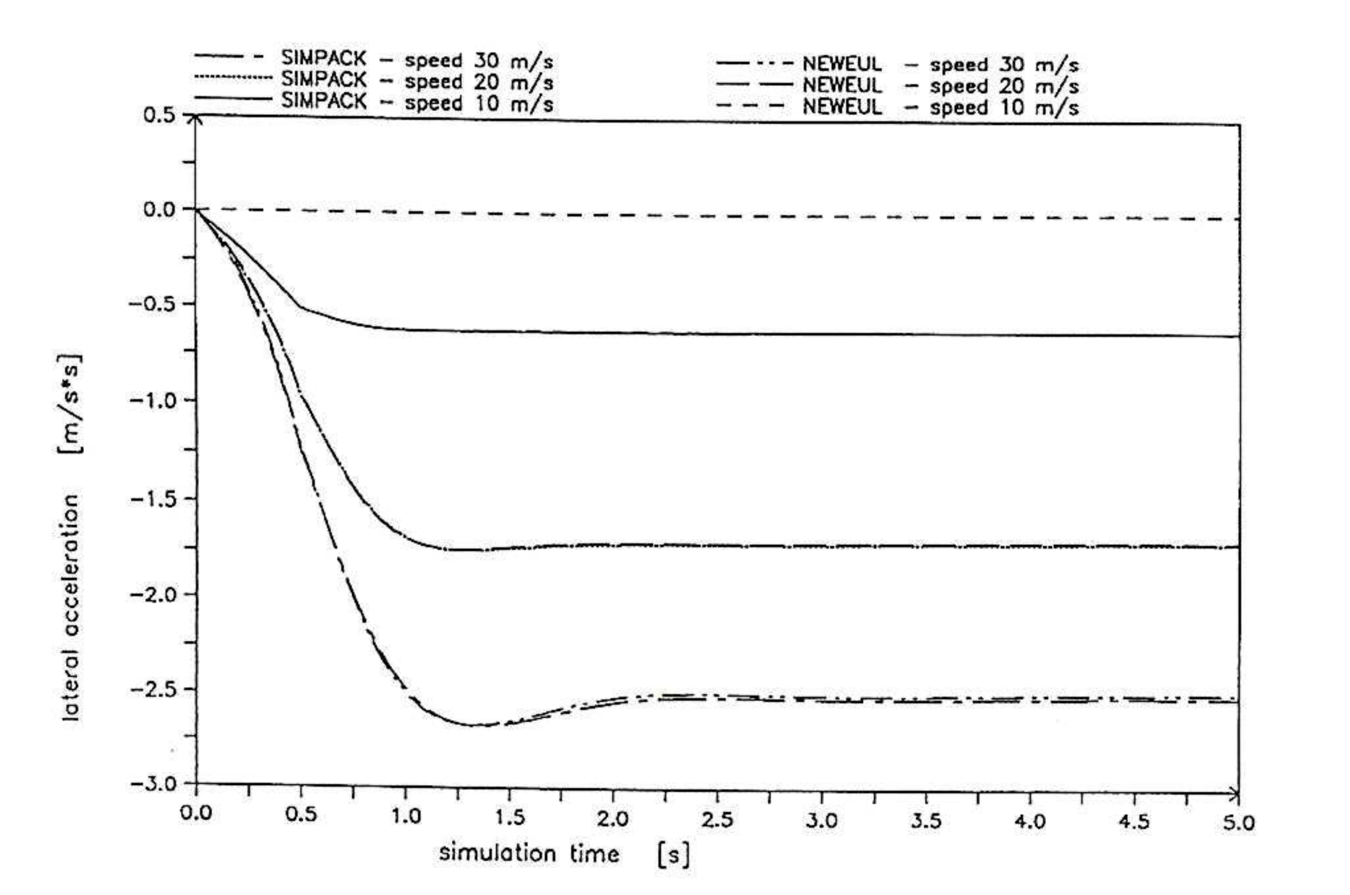
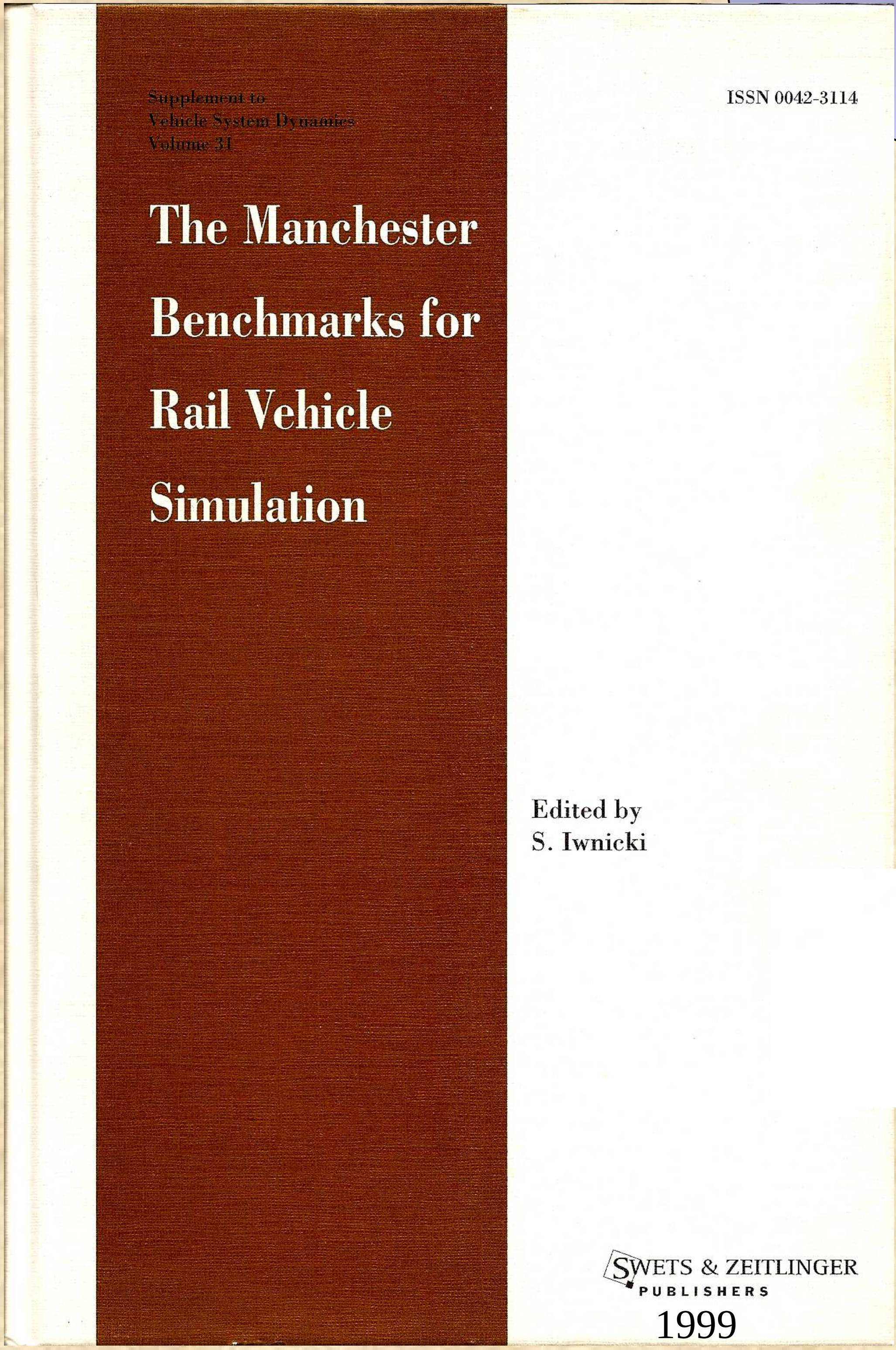
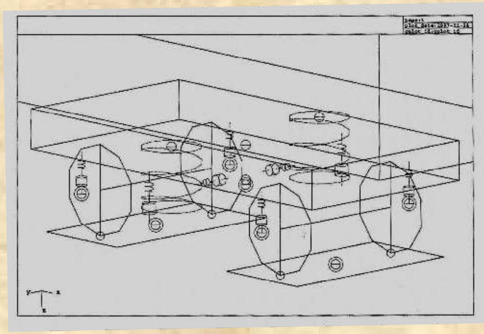
Due to four different codes, FASIM, MEDYNA, NEWEUL and SIMPACK many useful results are available.
The handling is characterized by the lateral acceleration for a 2 mm steering rack displacement resulting in circular cornering.
SIMPACK and NEWEUL simulations coincide very well.

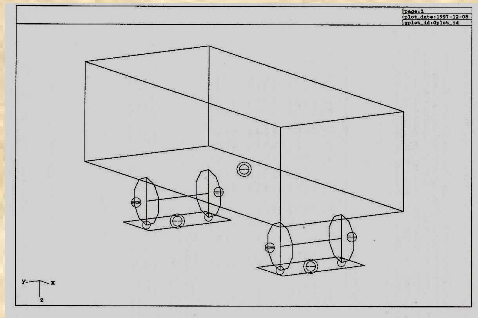




2.3 Vehicle dynamics

Two vehicles and four track cases were designed representing typical modeling and simulation tasks.





	VAMPIRE	GENSYS	SIMPACK	ADAMS	NUCARS
Critical speed /m/s					
Vehicle 1	74	77.05	70	72	79
Vehicle 2	58	70.5	80	75	79

The contact between wheels and rails is part of the software packages.

MULTIBODY DYNAMICS 2009

Performance Assessment of Time Integration Methods for Vehicle Dynamics Simulations

Georg Rill and Werner Schiehlen

Regensburg University of Applied Sciences
Regensburg, Germany

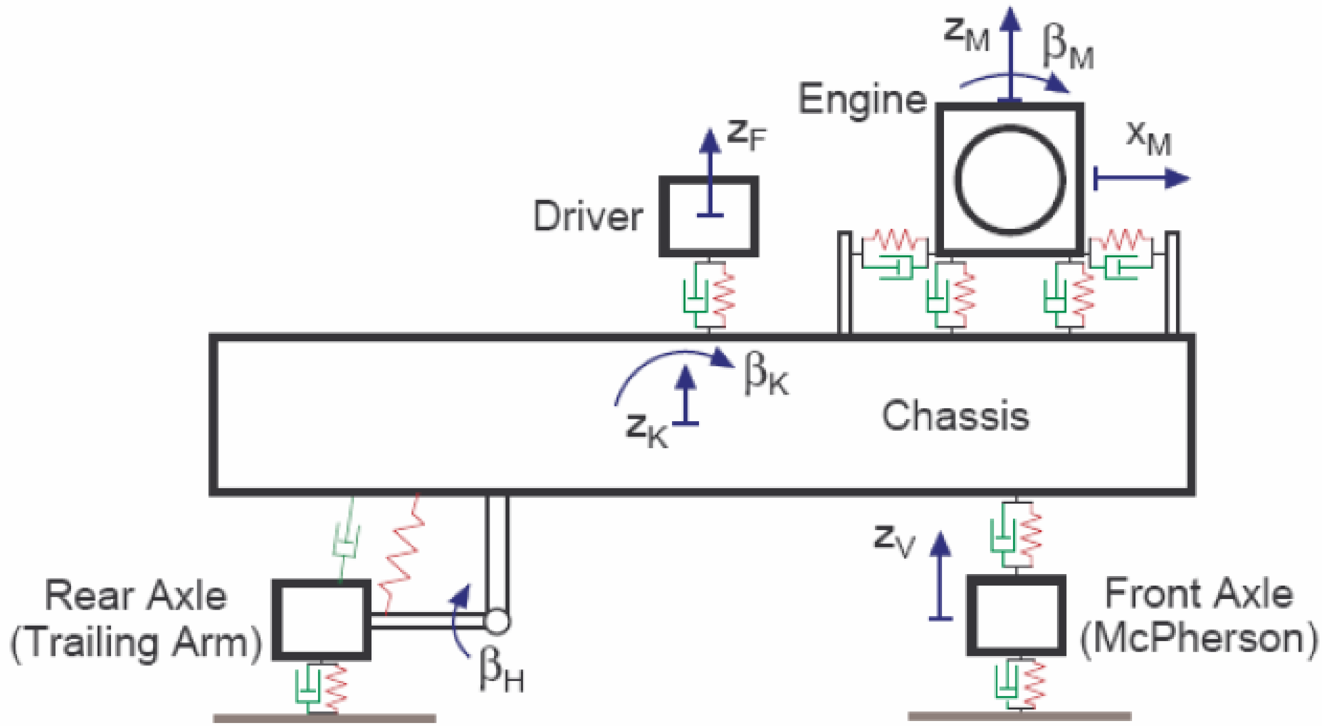
and

Institute of Engineering and Computational Mechanics
Prof. Dr.-Ing. P. Eberhard
University of Stuttgart, Germany

2.3 Vehicle dynamics

Benchmark Problem

Planar vehicle model with 8 degrees of freedom



Integration Codes

Seven Matlab Solvers and One Partially Implicit Euler Solver

ode23 is a one-step Runge-Kutta solver.
ode45 is a one-step Runge-Kutta solver (Dormand-Prince).
ode113 Variable-order Adams-Bashforth-Moulton PECE solver.
ode15s Variable-order solver based on NDFs.
ode23s Based on a modified Rosenbrock formula of order 2.
ode23t An trapezoidal rule using a "free" interpolant.
ode23tb An implementation of TR-BDF2.

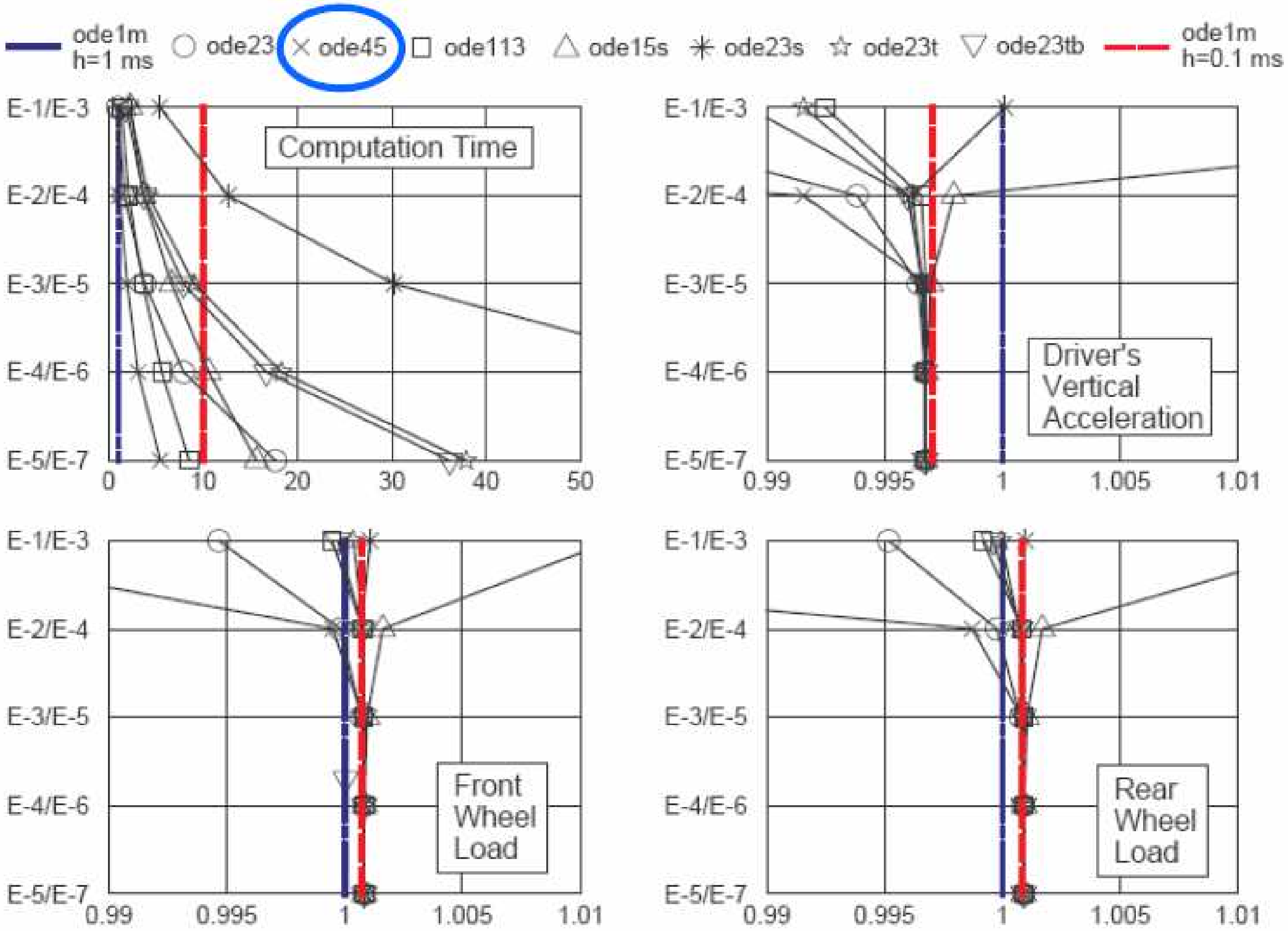
The partial implicit Euler code is denoted as **ode1m**.
The results for step-sizes of h = 1 ms and h = 0.1 ms
are used for the comparison with the Matlab.

2.3 Vehicle dynamics

ECCOMAS

Comparison of Time Integration Results

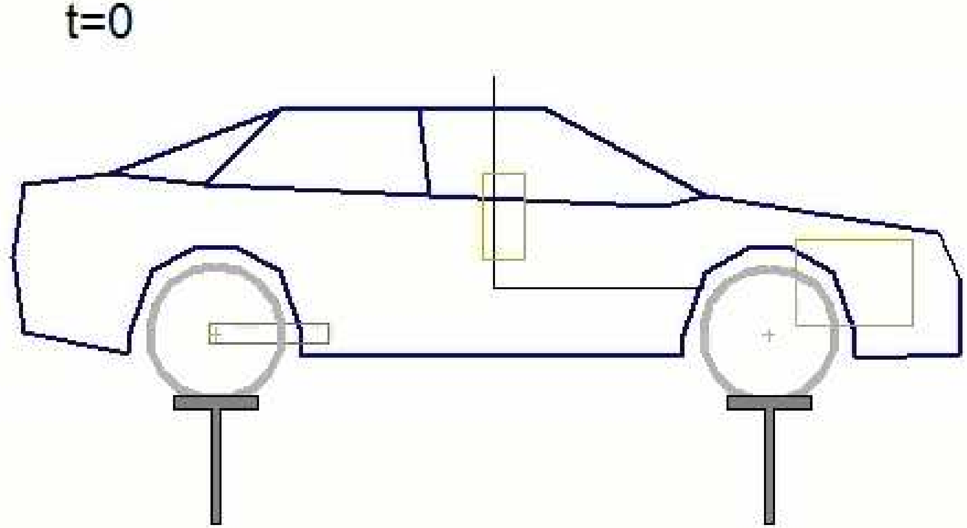
Uneven Road Excitation



2.3 Vehicle dynamics

Simulation Results

Uneven Road Excitation



2.3 Vehicle dynamics

Simulation Results

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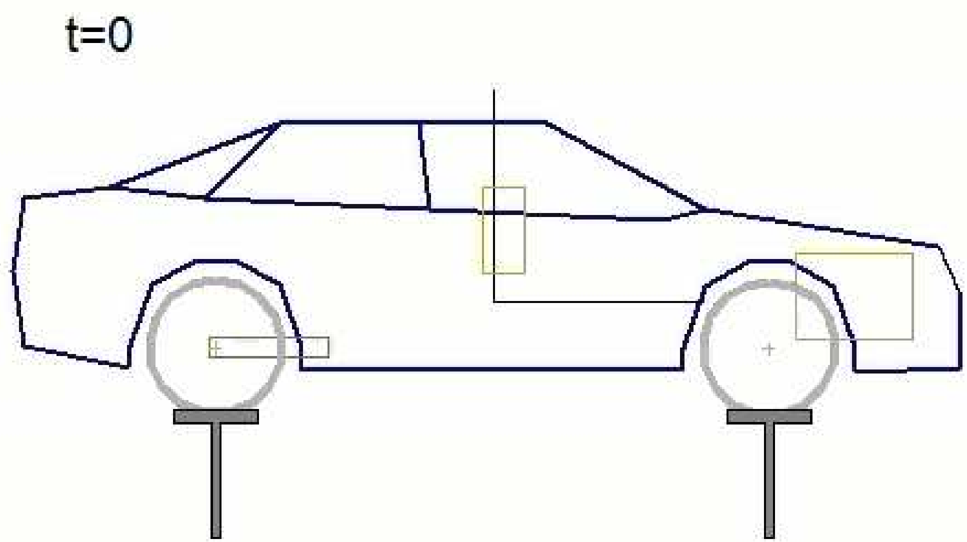


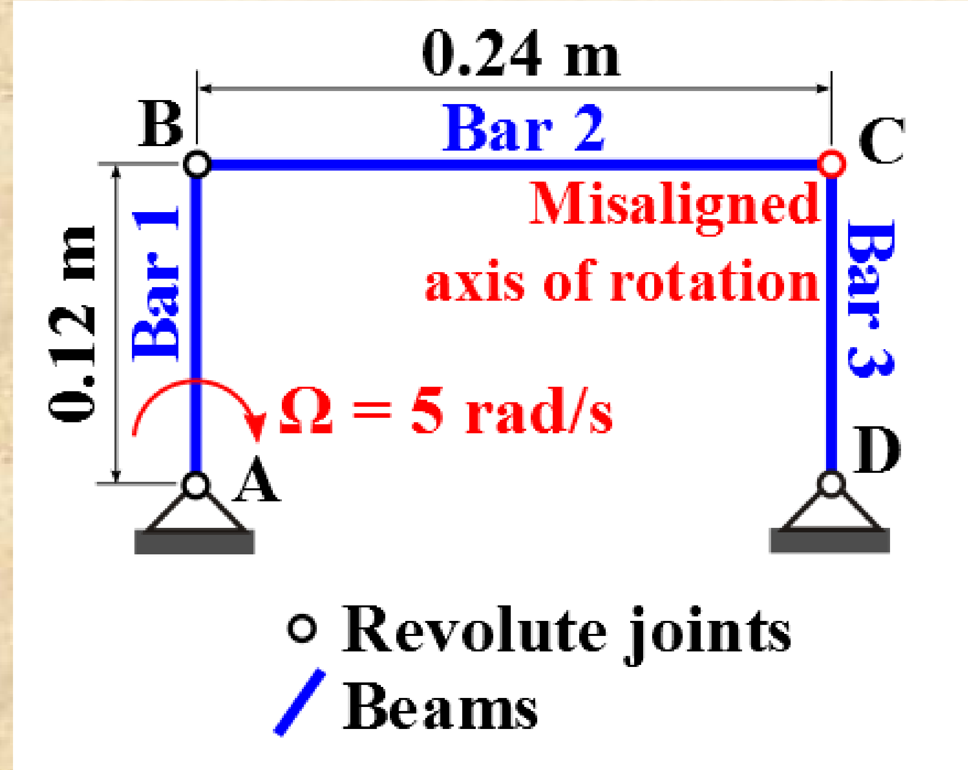
2.4 Flexible multibody systems

Dymore Solutions
Simulation Tools for Flexible Multibody Systems
Benchmark test case: four-bar mechanism

By Olivier A. Bauchau

http://www.dymoresolutions.com/Benchmarks/Benchmarks.html

1. Overall description of the problem



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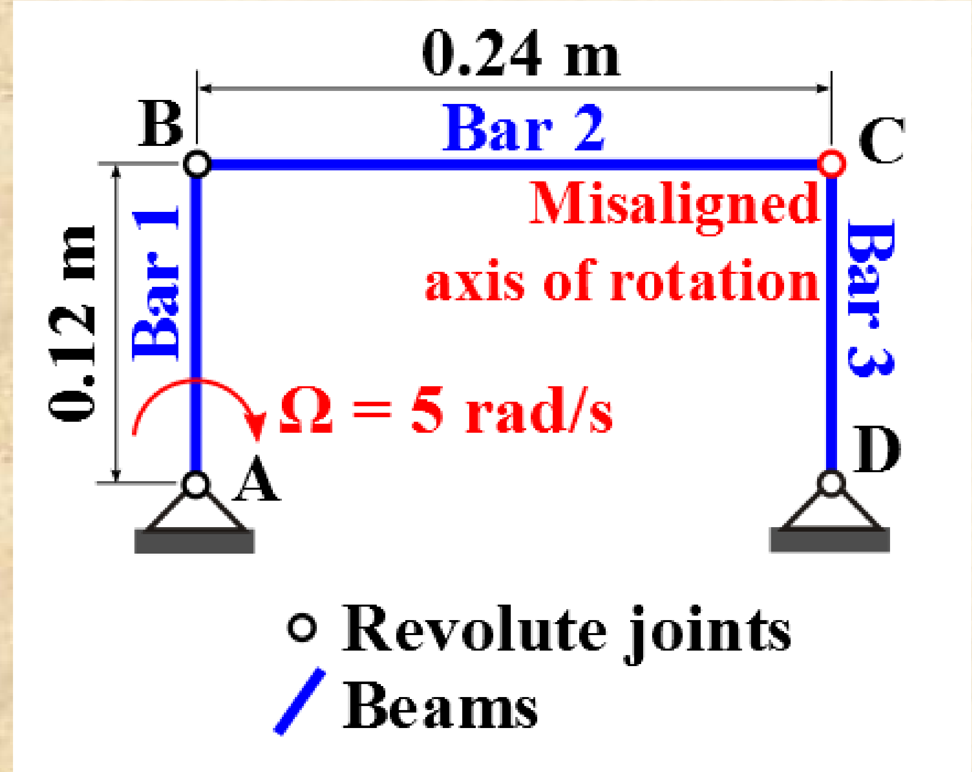

If the bars were infinitely rigid, no motion would be possible because the mechanism locks.

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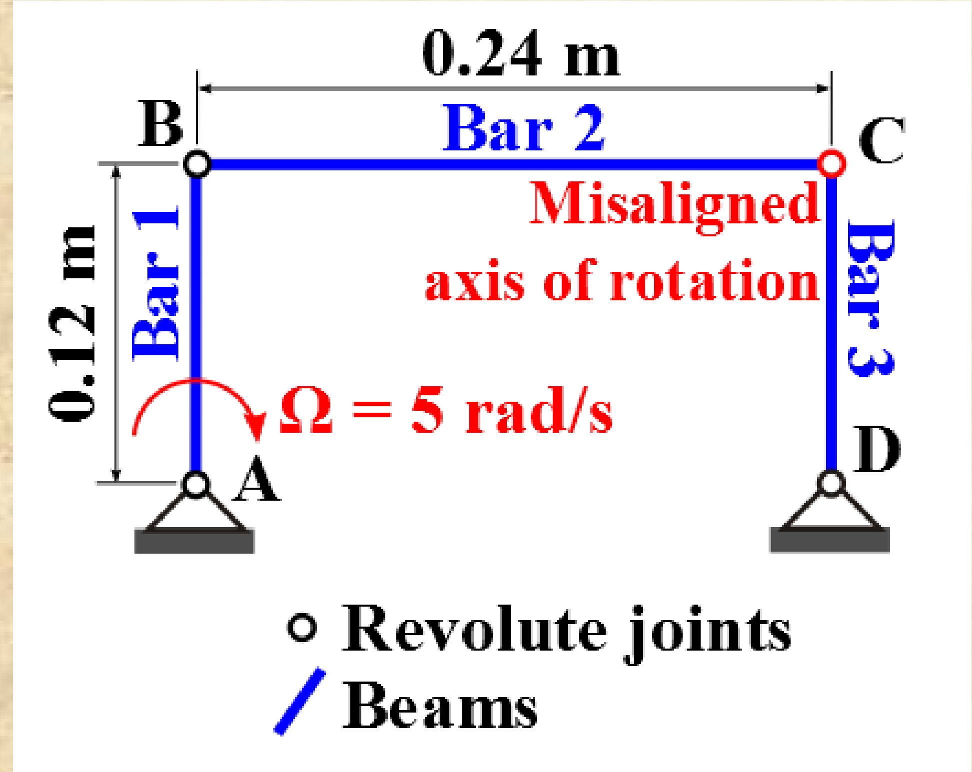

If the bars were infinitely rigid, no motion would be possible because the mechanism locks.
For elastic bars, motion becomes possible, but generates large, rapidly varying internal forces and moments.

2.4 Flexible multibody systems

2. Detailed input file in html format

A web version of the input file is available.

3. Input file

A plain test version of the input file is also available.

4. Detailed numerical results

Numerical results obtained from Dymore 4.0 are available as a zip archive. Instructions on how to interpret this zip archive are also available.

5. Movies

Visualize the movie in you browser (Be patient 1.9Mb file).

Competitive results are not available on this benchmark website.

3. Future Developments

IFToMM Technical Committee for Multibody Dynamics

In 2012 the IFToMM Technical Committee for Multibody Dynamics started a project on multibody benchmarks.

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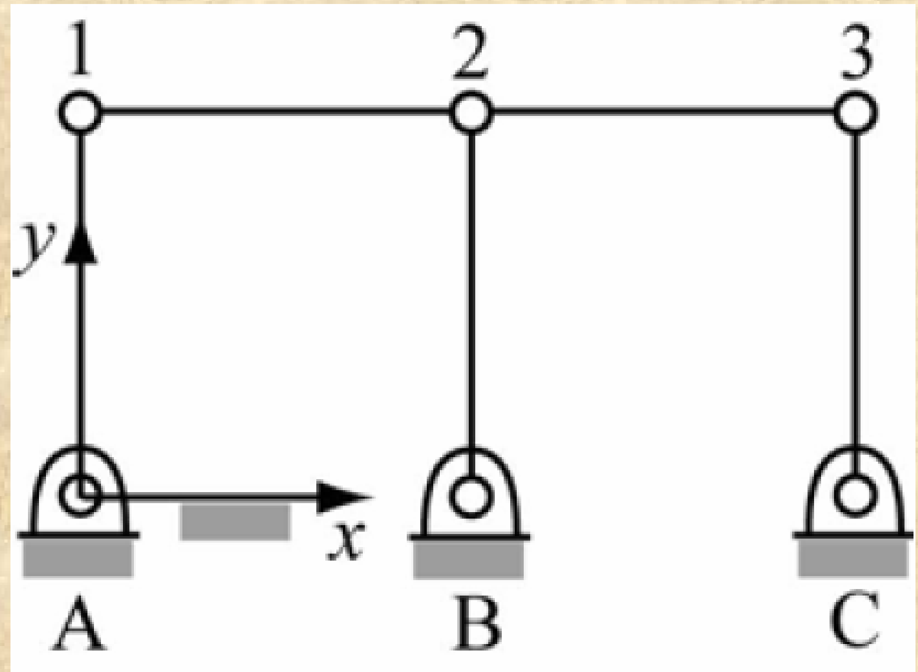
IFToMM Technical Committee for Multibody Dynamics

In 2012 the IFToMM Technical Committee for Multibody Dynamics started a project on multibody benchmarks.

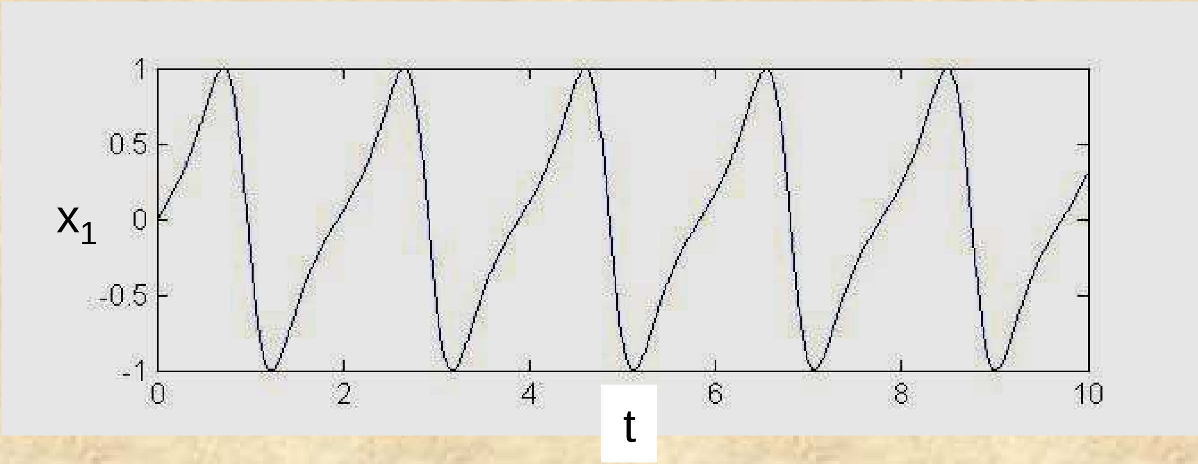
In a first step, a double four-bar mechanism was considered by the research groups of John McPhee and Javier Cuadrado.

$g = 9{,}81\ m/s^2$



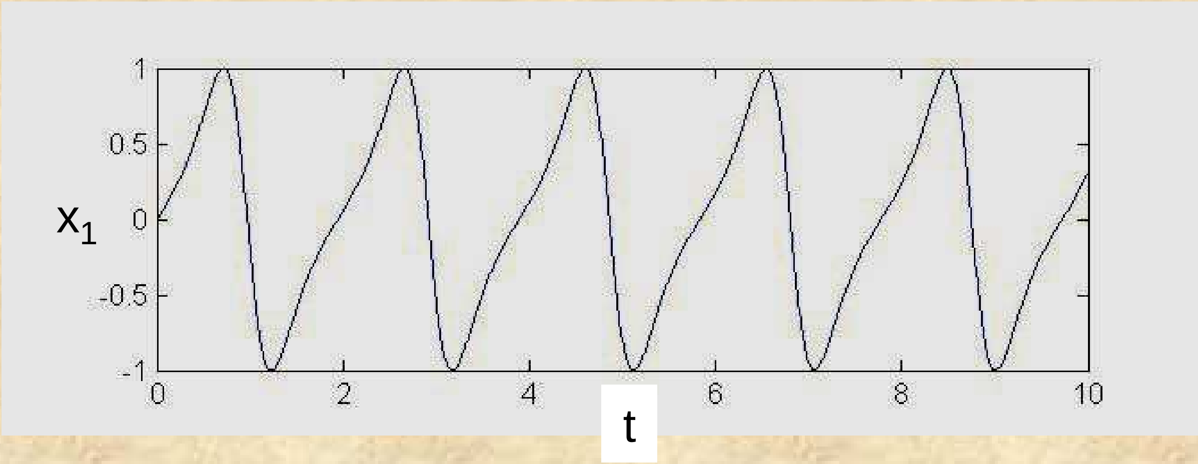
$v_0 = 1\ m/s$

3. Future Developments



Time history of x-coordinate of point 1

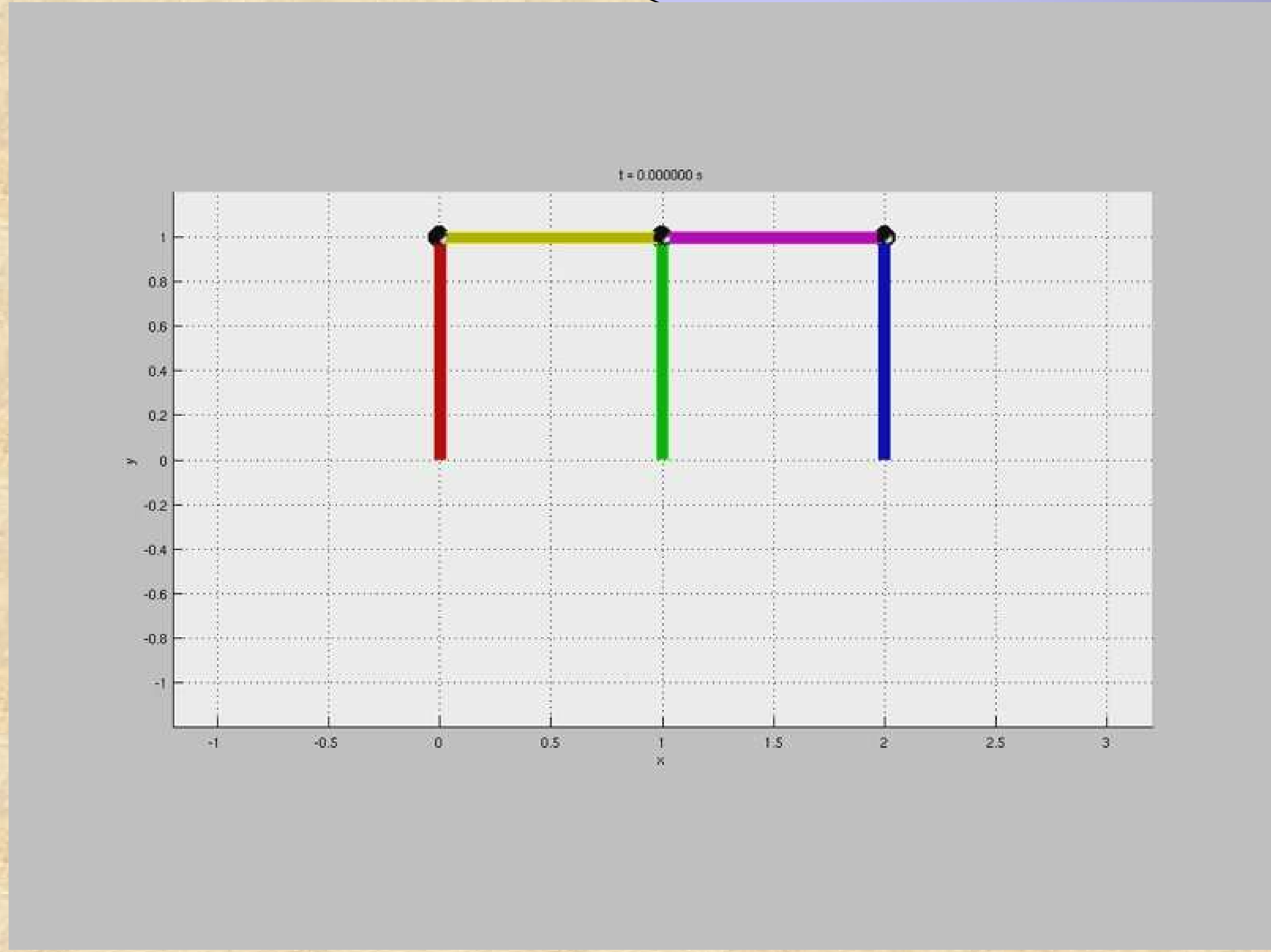
3. Future Developments



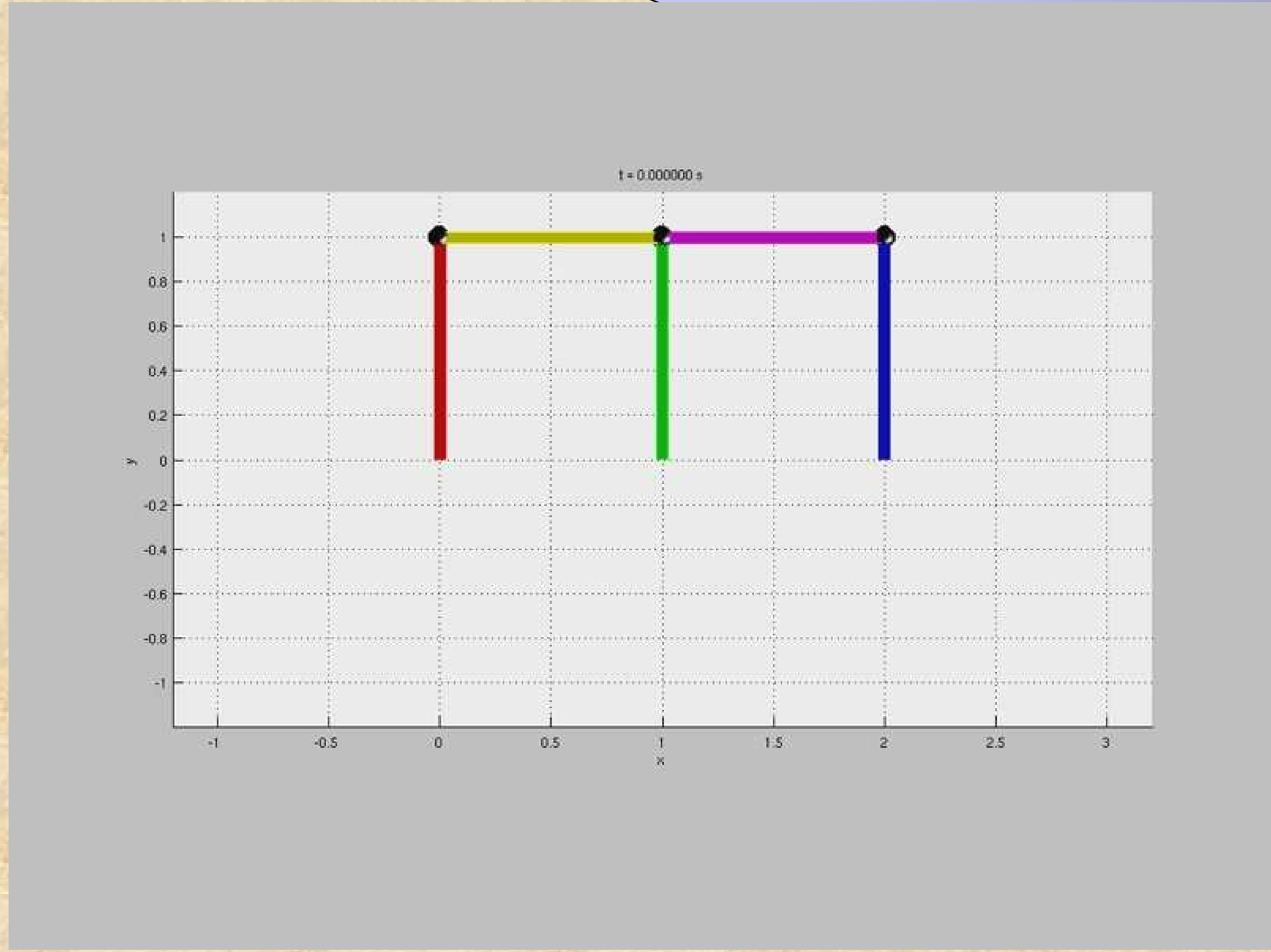
Time history of x-coordinate of point 1

Periodic motion of conservative mechanism
with more than 5 turns in 10 seconds

3. Future Developments



3. Future Developments



3. Future Developments

Submitter	Accuracy (Energy drift)	Results	Efficiency (Performance)	Coordinates
Javier Cuadrado (javicuad@cdf.udc.es)	0.0917		0.6	Natural
Alberto Luaces (aluaces@udc.es)	0.0137		1.7	Relative
Markus Burkhardt (markus.burkhardt @itm.uni-stuttgart.de)	0.0014		0.05	Minimal

3. Future Developments

Details

CPU time (s)	0.6
CPU / GPU	Intel Core 2 DUO E6550 @ 2.33 GHz
Operative System	Windows XP SP3
Method description	Coordinates: natural
	Equations of motion: index-3 augmented Lagrangian formulation with projections of velocities and accelerations
	Integrator: trapezoidal rule
	Solution: Newton-Raphson iteration
	Time step: 0.01 s (fixed)
	Penalty factor: 1.E9
	Programming language: Matlab

Research group
Javier Cuadrado

3. Future Developments

A second step is this special session on benchmark problems.

In the IFToMM Library of Computational Benchmark Problems
for Multibody Dynamics only problems should be published
for which at least one group has submitted the following information:

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In the IFToMM Library of Computational Benchmark Problems
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for which at least one group has submitted the following information:

- ❖ Description of the benchmark
- ❖ Definition of system parameters for all elements
- ❖ Initial conditions, force and position actuation
- ❖ Time integration methods and eigenfrequency analysis

It is most preferable to have two or more submissions for each problem.

4. Conclusion

The benchmark problems in multibody dynamics are mainly motivated by the many applications in engineering and science.

Due to the great variety of problems the establishment of a committee is recommended to initiate the submission of benchmarks and to review the results prior to the publication on a website.

Such a committee could meet annually on the occasion of one of the major conferences on multibody dynamics.