

## Rand Model Designer in Manufacturing Applications

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**Abstract:** Equation based computer modeling is used traditionally for investigation, simulation, and optimization a test subject at the early stage of designing. And with it a computer model may be a real time embedded component of a hardware-software system. Manufacturing models especially for hardware-software system are large-scale models designing by teams usually. Such complex projects demand using special tools for joint operation. Designing large-scale models in business competition at a stated time also needs using special tools for modeling and simulation such as the family of tools developed by MathWorks Inc. for example. In this paper we present a new tool named Rand Model Designer and demonstrate its properties and possibilities using examples of manufacturing models.

**Keywords:** modeling, simulation, virtual reality, simulators, training, real time computer systems, large-scale systems, mathematical models, state charts, hybrid systems, visual modeling languages.

### 1. INTRODUCTION

Rand Model Designer (RMD) is an object-oriented modeling tool (Tiller M. (2001), Fritzson P. (2006), Kolesov Yu. B. (2004)). RMD considers Unified Modeling Language (Rumbaugh J., Jacobson I., Booch G. (2005)) as the standard and accommodates it for modeling multi-component complex dynamical systems with different physical nature components using modeling technologies with «oriented» and «non-oriented» blocks (Kolesov Yu. B., Senichenkov Yu. B. (2006, 2007)). A slightly modified variant of UML state machine is a basis of RMD's visual notation for hybrid systems and planning experiment graphical language (Senichenkov Yu. B. (2004)). Hybrid systems used inside «oriented» and «non-oriented» blocks have no restrictions inherent Modelica language. Simulation in RMD also has its own particularity. Well known numerical methods (Brown P.N., Hindmarsh A.G., Petzold L.R. (1993), Hindmarsh A.C. (1983), Hindmarsh A.C., Peter N. B., Petzold L.R. (1993), Li S., Petzold L. (1999)) were modified taking in account the structure of solved system to increase computation speed and cut down memory expenses.

We will consider two types of manufacturing models for demonstration Rand Model Designer's capabilities and benefits. Rand Model Designer (RMD) may be used for traditional prototyping complex engineering systems at early design stage and for designing embedded real time applications.

### 2. MODELING TECHNOLOGIES OF RAND MODEL DESIGNER

RMD uses hybrid system for modeling event-driven systems with multiple-mode behavior (Fig. 1). Hybrid system is considered as generalization of classical continuous dynamical system (Senichenkov Yu. B. (2004)). RMD's visual notation for hybrid systems is called Behavior-Chart (Fig. 1). Local continuous behaviors (modes) and associated with them discrete actions alternate one-by-one generating a hybrid system trajectory. A hybrid system trajectory in general is a sequence of solutions of systems of algebraic-differential equations (Fig. 2).

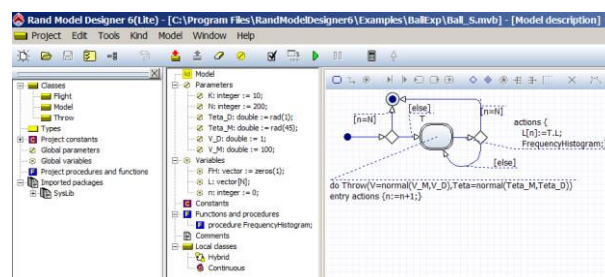


Fig. 1. RMD B-CHART with do-activity in the form of algebraic-differential equations.

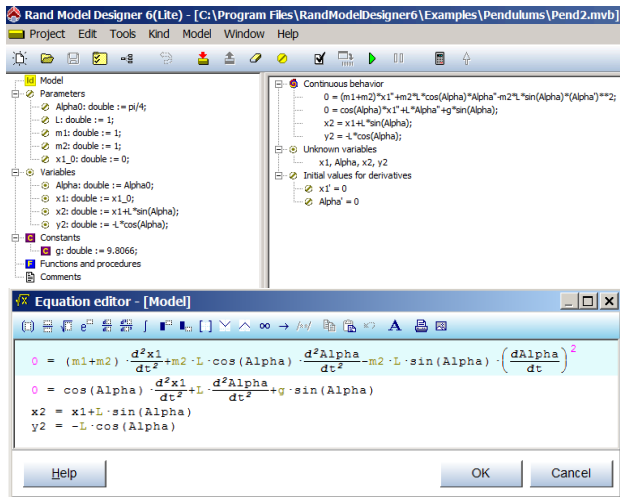


Fig. 2. RMD's Equation Editor

RMD's modeling language called Model Vision Language (MVL) allows modeling with oriented ("causal" modeling, Fig. 3) and non-oriented ("physical" modeling, Fig. 4) components with hybrid behavior (Kolesov Yu. B., Senichenkov Yu. B. (2007)).

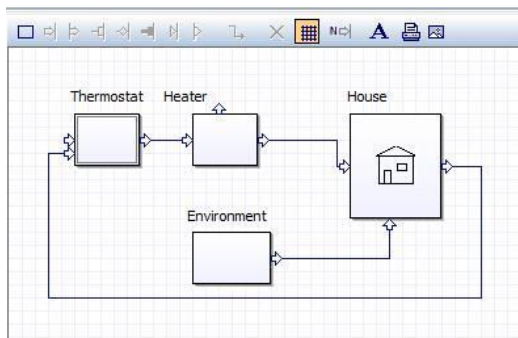


Fig. 3. "Causal" modeling block-diagram

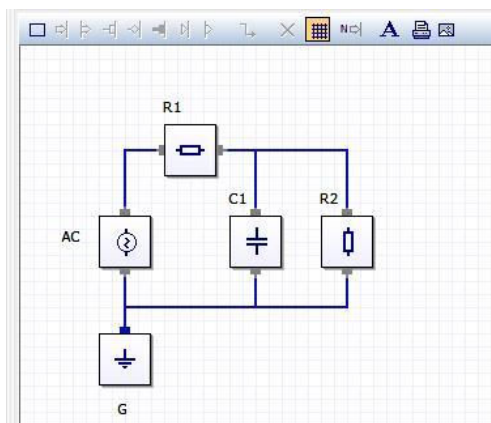


Fig. 4. "Physical" modeling block-diagram

RMD builds two sorts of executable models:

- A visual model that is Windows stand alone application used for testing, visual debugging, carrying out computational experiments, and processing results;

- A "hidden" model which is Windows dynamical linked library (dll) used as an embedded interactive application.

Hereby we can summarize:

1. RMD is oriented on well-defined mathematical models, which are "event-driven set of algebraic-differential equations". A dimension, type, and numerical properties of such systems depend on current model mode.
2. RMD's hierarchical component diagrams and B-Charts allow designing complex large-scale models in intuitive manner.
3. RMD's modelling language maintains technologies for causal and/or non-causal modelling.

RMD is used for scientific research and teamwork computer-aided large-scale systems designing. In both cases object-oriented modelling renders assistance. Working out or classes from existing libraries are used as building material for a complex model.

### 3. MODELING-BASED DESIGN WITH RAND MODEL DESIGNER

Modeling-based design with executable specifications allows step by step modify workable model and compare model behavior with required by specification using computational experiments (MathWorks Inc.). Specifications written in high level graphical modeling language are well-adapted for communication among developers also.

RMD is good for using modeling-based design. It has high level languages for modeling, testing, debugging, planning experiments. There are special visual instruments for parametric optimization (Fig. 5), sensitivity analysis (Fig. 6), and statistical experiments (Fig. 7).

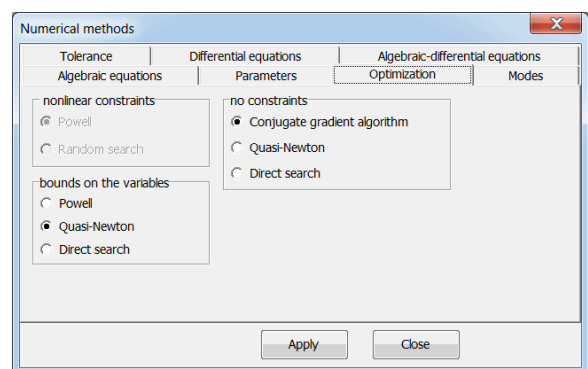


Fig. 5. RMD's numerical methods for optimization

RMD modeling language makes easier developing complex models using "from the simple to the complex" technology. At the first step a set of isolated models is developed. Then these isolated systems may be transformed into a hybrid system. Isolated hybrid systems turn into blocks with external variables ("input", "output", "contact",

“flow”) for using as components of complex hierarchical model.

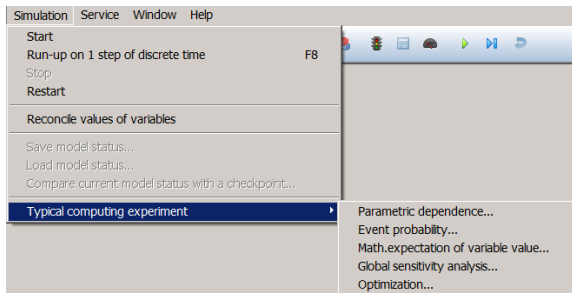


Fig. 6. RMD’s tools for computing experiments

RMD’s B-Charts are used not only as graphical specification of hybrid systems but as visual language for planning computational experiments (Fig. 7). Really a designed model may be automatically transformed into a new class in RMD. A computational experiment is described by hybrid automaton with local behaviors that are instances of this class with concrete values of parameters.

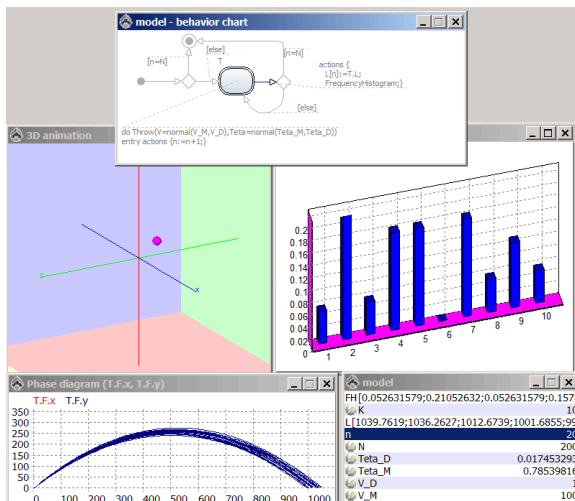


Fig. 7. RMD’s statistical experiments

#### 4. RMD’s NUMERICAL SOFTWARE

RMD’s numerical library contains well known different numerical methods for solving algebraic, ordinary differential and algebraic-differential systems of equations (Senichenkov Yu. B. (2004)). RMD tries to detect and take in account characteristics of model equations (linearity, block structure, sparseness, and so on) decreasing number of unknowns, increasing calculation accuracy, and acceleration of calculating speed. RMD has a set of instruments for analysing numerical properties of solved equations (it is possible to calculate condition numbers, eigenvalues of Jacobi matrix while debugging), experimental data processing, and automatic comparison experimental results. User-friendly mathematical and B-charts Editors facilitate developing models with complex behavior and simultaneously complicate designing numerical library for modeling and simulation component models especially for

“physical” modeling. A B-chart generates a sequence of systems of algebraic-differential equations with different size, structure, and numerical properties for a hybrid system. Algebraic-differential equations in turn may take form of linear and non-linear algebraic equations, differential equations, high index algebraic-differential equations (Ascher U.M., Petzold L.R. (1998), Hindmarsh A.C. (1983), Li S., Petzold L. (1999)). However modern DAE Solvers are oriented on a single problem with known properties. All preliminary work should be crafted individually by specialists beforehand. It is strange but there is no universal numerical software intended for “hybrid” DAE. Hybrid DAE Solver should automatically analyze every new system from job stream generated by B-chart. Usually analysis has two stages that are «symbolic» (a priori) and «numerical» (a posteriori) analysis. Symbolic (structural) analysis allows detecting structural singular systems (they have no solutions for all possible values of parameters), calculating and reducing index (it needs symbolic differentiation) for algebraic-differential equations. Run time analysis implies estimation of numerical solution accuracy for algebraic systems using condition numbers, stiffness for differential equations and so on. It is important to underline that it is necessary to ensure the optimal calculations on whole trajectory for event-driven systems but not for separate problem. Just the same problem we have for computational experiment, testing, and parametric optimization when it is important to minimize total time for whole experiment.

There is special block named Analyzer in RMD for system properties analysis. Symbolic analysis should be done on run time for “physical” models with hybrid behavior with the help of very fast algorithms.

#### 5. BALLISTIC MISSILE FLIGHT

Ballistic missile designing is an example of traditional using computer models for prototyping complex engineering systems at early design stage.

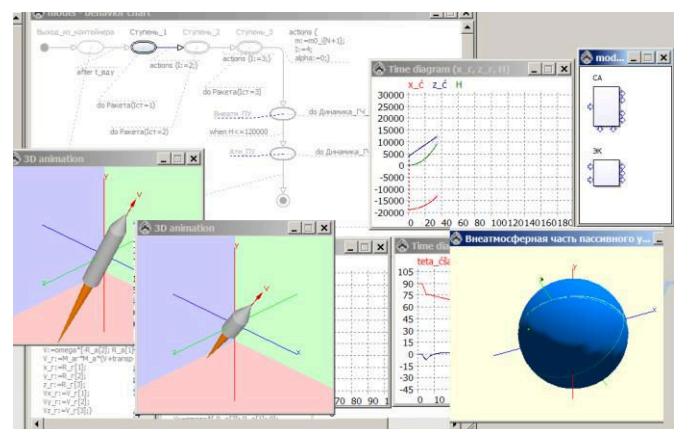


Fig. 8. Three stage ballistic rocket flight: going into orbit

States of the main B-chart (Fig. 8) describe boost phase (1-st, 2-nd, and 3-thd rocket stage running), midcourse stage, and terminal stage (Benevelsky C.B., Kolesov Yu. B. (2009)). Stage changes are associated with changing

parameters values or/and changing of system of equations. The main B-Chart is hierarchical: each of stage states has hybrid behavior and its own B-Chart in turn. Nested B-Charts describes different control modes of stage stop (cutoff of thrust rocket engine command, fuel burn-out). Using Object-Oriented-Modeling (OOM) the complex model behavior is divided on rocket motion, solid-propellant rocket engine dynamics, and control. Each mode is represented by its own class. This decomposition makes model intuitively obvious and simplifies testing and debugging. In addition OOM allows reusing of debugged models. In our case the models of International Standard Atmosphere and Gravitational Field Model for the Earth are imported from previously worked out libraries.

## 6. COMPLEX SIMULATOR DESIGN

Using RMD for complex simulators (Fig. 9,10) design at "Transas Technology" ([www.transas.com](http://www.transas.com)) is a good example of industrial second type modeling (Kiptily D. B., Kolesov Yu. B., Lebedev D. V., Senichenkov Yu. B., Tarasov S. V. (2011)).

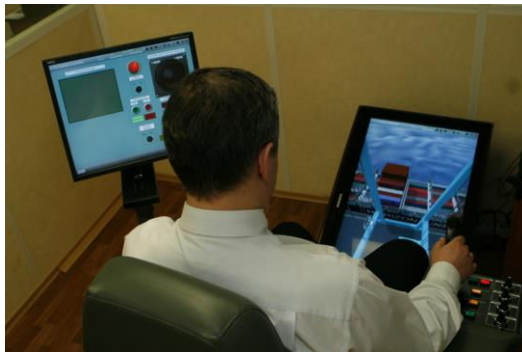


Fig. 9. Simulator operating position.

Components of prototype system with complex switching logic (mechanical, electrical, hydraulic, and pneumatic, etc.) are described by variable structure systems of nonlinear differential-algebraic equations with a dimension of up to ten thousands. Obviously, building such model manually is almost impossible. The only way is using Object Oriented Modeling for designing applied class libraries. Typical mechanical, electrical, hydraulic, and pneumatic active dynamic object is described as a class or a hierarchy of classes. RMD's Object Oriented Modeling allows inheritance and redefinition of classes, independent design and import of packages by users. Complex model is assembled out instances of classes and used as built-in modules in simulators. Built-in modules should work in real time. Supporting real time environment needs fast numerical methods and fast algorithms for analyzing, transformation and building current system on run-time. Symbolic transformations and simplifications of equations before numerical solution may decrease total run time if and only if they are fast enough. As a result, an acceptable compromise was found.



Fig. 10. Visual presentation of wharf crane.

Designing complex simulators reveals a few undecided problems. Sometimes assembling new device using standard components leads to structural singular equations for whole device or causes difficulties during numerical solution. Detect such kind of errors is very difficult. The only practical way is run time debugging. RMD's debugger visualize structural matrix, calculates Jacoby matrix, its eigenvalues for the current system of equations. This information helps to detect errors. Additionally it is available interactive step by step discrete actions debugging for validation switching logic.

## 7. STRATEGIC AUDIT

Let us consider another hardware-software system named «Strategy - Chamber of Accounts» developed by St. Petersburg Institute for Informatics and Automation of Russian Academy of Science. The system is intended for strategic audit of socio-economic development of Russian Federation. Complex selection of development strategy for the county or a region is based on results of simulation. Stochastic experiment with a model of stock of projects and estimated measures is carried out during simulation for macroeconomic goals achievement. On the one hand it is impossible to build a model of stock of projects and estimated measures by hands because all needed information for concrete project is stored in huge project management database («Spider Project») and users are non-specialist neither in programming nor in modeling. Meanwhile a macroeconomic model may be developed a priori by hand and customized with the help of parameters for concrete region. The solution of this problem was found with the help of OOM. A macroeconomic model is considered as a class of «Macroeconomic» Package. Special classes that are "Job", "Computer experiment" and so on was developed for modeling a stock of projects and estimated measures. It was designed special tool which is able transform data base specification of model of a stock of projects and measures to build corresponding model into RMD modeling language automatically using special applied library classes for the integration software complex «UPE&PlanDesigner» (developed by «SoftProm»).

Fig. 11 illustrates this technology. The shown model is the object of “Macroeconomic” class. Class “Macroeconomic” uses inner classes RMD specification generated automatically using data base specification. RMD builds embedded executable model, runs it, and exports results for visualizing in «UPE&PlanDesigner».

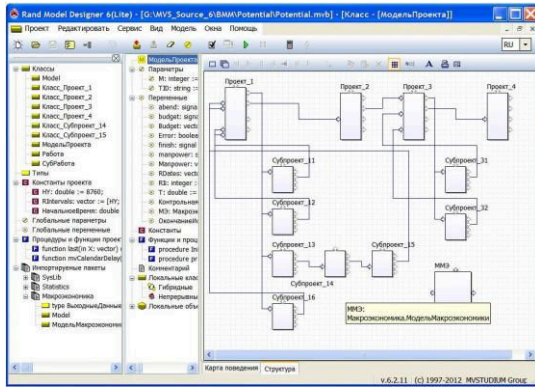


Fig. 11. RMD’s macroeconomic model.

## 7. USING RMD IN EDUCATION

Virtual laboratories for schools and university are special type of simulators (Fig. 12).

In the article (Biryukov S.V., Guskov D.N., Fedyanin V.V., (2005)) prof. Biryukov S.V wrote: “One of the most difficult problems in teaching physics is real-world experimental skills training. Real world experiments are often used, but it is too expensive. Computer simulations can be helpful in many cases instead. Computer model must be cheap, variable, and must present initial example to make pupil’s own model. Menu, Help, Tutorial, and Teaching materials must be in student’s native language. All these requirements are satisfied by Model Vision Studium (Former name for RMD).”

Experiments with computer models and designing computer models help students to understand real world phenomena better. Simulation is active method of learning and teaching not only physics.

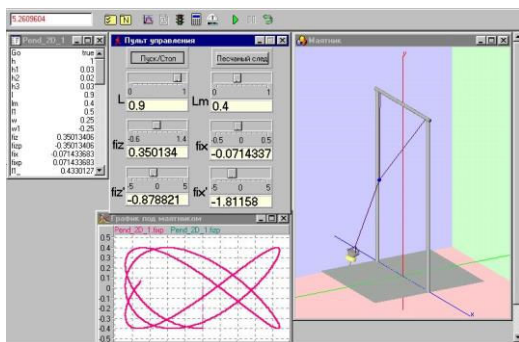


Fig. 12. Professor Biryukov’s S.V. model – test bench for schools.

Several virtual workshops for the course of General Physics (Mechanics) developed in Model Vision Studium are

presented in (Biryukov S.V., Guskov D.N., Fedyanin V.V., (2005)): “Motion investigation using Atwood’s machine”, “Bullet velocity determination by kinematic and dynamic methods”, “Measuring moment of inertia of a bicycle’s wheel using dynamic and oscillation methods”, etc.

Prof. Biryukov S.V consider: “These workshops are very similar to real world workshops in the General Physics Labs of the Moscow Pedagogical State University and they are used as an additional home study for campus students. Furthermore it can be used in Physics distance learning as initially it was developed for open education portal. “Physical pendulum oscillations” is a workshop with real-time simulation and at the same time simple real world experiment with hand-made physical pendulum – modified additional computer mouse. Modification is so simple that it can be done by many students and thus it can be recommended as real-world and real-time computer experiment in distance learning or just for fun. “

## 8. MODEL CONVERTING

There are a lot of tools for modeling and simulation of complex dynamical systems (Breitenecker F., Proper N. (2009)). Modern tools based on Object Oriented Modeling approach more advanced that old ones but have no extensive and infallible applied libraries. To overcome this typical encumbrance is possible using model converters (preprocessors) from one modeling language to another.

RMD has special library (SysLib) with Simulink-like components (Fig. 13-14). They were written by hand and intended for Simulink’s users doing their first steps in RMD.

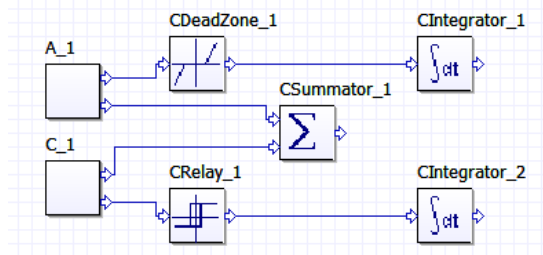


Fig. 13. RMD’s Simulink simulator.

Practice shows that convertor from Simulink to RMD models (and vise-versa) is required not only for reusing applied libraries but for comparative study of separate models developed with the help of different technologies. Model converting takes advantage of using both tools for modeling simultaneously.

RMD convertor transforms Simulink specification of a model to MVL language using extended SysLib library for Simulink blocks.

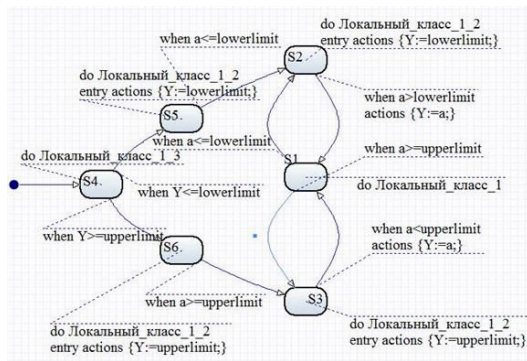


Fig. 14. RMD's "Integrator" simulator.

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