Preprints of the 2013 IFAC Conference on Manufacturing Modelling, Management, and Control, Saint Petersburg State University and Saint Petersburg National Research University of Information Technologies, Mechanics, and Optics, Saint Petersburg, Russia, June 19-21, 2013

Component Modelling of Ship Systems in TRANSAS Liquid Cargo Handling Simulators

Sergey V. Tarasov*. Dmitry V. Lebedev*
Ilya A. Nikolaev*

* *Technological Simulator Department, TRANSAS Technologies (ZAO), 54-4 Maly pr. V.O., St.Petersburg 199178, Russian Federation (Tel: +7-812-325-3131; e-mail: sergey.tarasov@transas.com)*

Abstract: Analysis of requirements of physical realism and computational performance for mathematical models, used in liquid cargo handling simulators is presented. Depth of physical modelling, necessary to satisfy the requirements, is considered. Approaches to composition of mathematical models are outlined. Component-based approach with “RanD Model Designer” visual modelling software is described. Component library, applied for development of mathematical models for Liquid Cargo Handling Simulators of “TRANSAS Technologies” company, is presented. Employed techniques of computation performance enhancement, and result of their application, are presented.

Keywords: simulators, physical models, mathematical models, real-time systems, object modelling techniques.

1. INTRODUCTION

Liquid cargo handling simulators are important part of training qualified personnel of liquid cargo tankers and gas carriers to perform their functions safely and efficiently. Usefulness of training can be ensured when the degree of realism of simulation environment allows conducting training in accordance with requirements of STCW-95 (International Convention on Standards of Training, Certification and Watchkeeping for Seafarers).

Different types of tankers have specific sets of systems, required for modelling by international standards for corresponding types of simulators, such as crude oil tanker (IMO, 2002), chemical carrier (IMO, 2007c), liquefied petroleum gas (IMO, 2007a) and liquefied natural gas (IMO, 2007b). Range of systems, present in most types of liquid cargo handling simulators, includes the following:

- ballast systems,
- cargo systems,
- tank stripping systems,
- tank heating systems,
- tank washing systems,
- inert gas & dry air systems,
- gas detection systems,
- deck wash & fire & spray systems.

In the same time, layout of those systems is different even on the ships of the same type. Ability to perform cargo operations in ship-like manner, requires customization of system layout to produce ship model of every specific prototype ship.

2. PROBLEM DESCRIPTION

Mathematical model, used in the simulator, should satisfy the both the requirements of realism and the computational speed, to enable running the simulator on a typical PC.

Model should be able to maintain real time calculation of all controlled parameters of all components of ship systems, interacting with environment and between each other, with the discrete time step of 0.5-1.0 seconds. Also, as the actual cargo operations take many hours or even days to complete, model should be able to perform calculations up to 25 times faster than real-time, so that training could be completed in reasonable timeframe.

Depth of physical modelling, sufficient for the simulation purpose, can be determined by the analysis of physical processes on all stages of cargo operation technological cycle, described in international standards and model courses (IMO, 2002-2007). Processes in the pipe network of systems may be described as one dimensional quasi-stationary viscous flow of multi-component mixture of different substances in different phase states. The dynamic behavior of the flow depends on heat exchange between flow and pipe walls, phase transition within the pipe, and dynamic processes at the ends of pipe network, such as tanks. Processes in tanks include heat exchange with walls, phase transition between liquid and gas, and vertical stratification of both liquid and gas part of the tank volume, described by differential equations.

3. MODELLING APPROACH

Complex of considered processes, taking place in all modelled systems, can be described by nonlinear differential-algebraic equations system of variable structure, consisting of thousands of equations. Composition of such system may be based on different ways of decomposition of the modelled behaviour.

Component-based modelling methodology uses "vertical" fragmentation. It works with objects, representing separate devices, each of which is described by set of equations, describing its current physical behaviour. The compound system of equations of the system model at every instant is automatically constructed from equations of active states of all the objects and equations of links between objects.

Another approach, which can be also used in the simulators, uses "horizontal" fragmentation. It works with the topological network, which is used as a basis for separate phenomena.

Component-based mathematical models, described present work, are based on object-oriented approach. According to this approach, standard classes and inheritance between them are defined on the basis of the object-oriented analysis of the application domain. Each class is represented as hybrid dynamic objects (Kolesov and Senichenkov, 2006).Definitions of the classes comprise the library of standard components, so that each particular model is constructed from standard components, connected by links. The descriptions of classes and models are presented in terms of UML-like language of the designing software. To incorporate the mathematical model into the simulator software, the source code is automatically generated from the mathematical description of the model by the designing software.

The modelling tool, used in present work, is the "RanD Model Designer" design environment, previously named "Model Vision Studium" (RanD Model Designer, 2013).

Standard components library has been created, containing typical devices, present in the systems, modelled in the liquid cargo handling simulators:

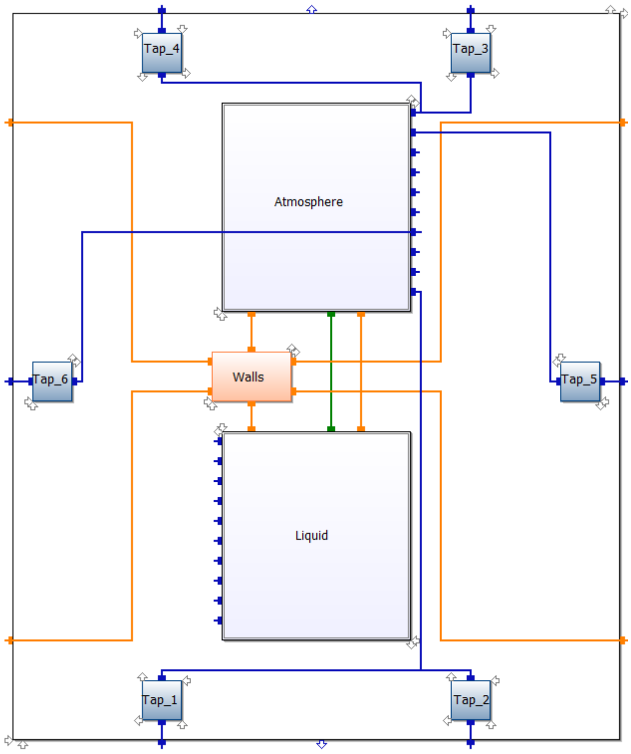
- tanks and reservoirs,
- pipes and ducts,
- valves and retaining valves,
- pumps and compressors,
- heaters and vaporizers.

The component library has hierarchical structure. For example, class "Valve" is inherited from class "Pipe". In addition to inheritance, some library classes can be the combination of other classes, reproducing the construction layout of the device. For example, the structure of the "ValveRemote" class, representing remote controlled valve, contains two local objects: "Valve" and "Controller"

The description of the classes, representing the edges of the hydraulic network (such as pipes, valves and pumps), and principles of combining their equations into the compound system, are presented in the previous work (Tarasov, et al., 2012).

Classes, representing the endings of hydraulic network (tanks) contain differential equations for mass, temperature, phase state and concentrations of the substances in the mixture. The vertical dimension of tank class is modeled with component-based approach.

a)



b)

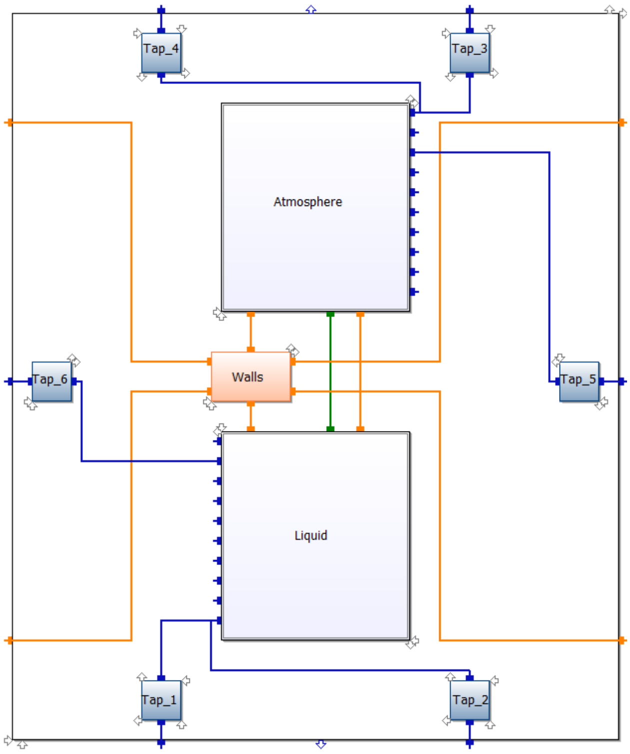


Fig. 1. Internal structure of "Tank" class with dynamic links: (a) empty tank, (b) half-filled tank.

Internal structure of tank includes separate local objects "Liquid" and "Atmosphere", connected with links, which represent mass and heat exchange through the interface (Fig. 1). Pipes can be connected to tank at different heights, so that they may have to be connected to "Liquid" or "Atmosphere" objects, depending on the actual position of interface. Such behavior is modeled with "dynamic links" functionality of "RanD Model Designer". For example, Fig. 1a represents runtime state of empty tank (all openings are connected to "Atmosphere"), and the Fig. 1b represents half-filled tank (bottom openings are connected to "Liquid").

The spatial discretization of tank equations in vertical dimension, required for modelling vertical stratification and convection within liquid and gas parts of tank volume, is also component-based. "Atmosphere" class consists of multiple local objects "Layer" (Fig. 2), connected by links. Each "Layer" represents horizontal layer within the gas part of the tank volume and contains ordinary differential equations, describing mean values of gas properties within that layer.

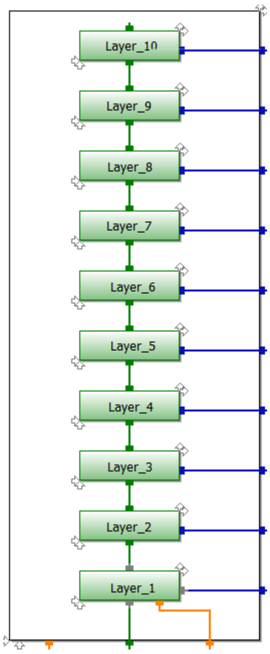


Fig. 2. Internal structure of "Atmosphere" class.

4. COMPUTATIONAL PERFORMANCE

As the experience has shown, the real time operation of the models was one of the most challenging requirements for the modelling.

To reach the sufficient calculation speed of numerical methods, "RanD Model Designer" automatically modifies the compound system of equations, to minimize the computational load on numerical methods:

- variables, connected by links of types "contact" and "flow", are considered as the same ("equivalent") variable, instead of forming algebraic equation, thus reducing number of algebraic equations,
- number of algebraic equations is reduced by excluding formulas,
- linear equations are marked out from the compound system of equations into the separate subsystems and solved by direct inversion of the system matrices, thus the Newton method has to be applied only to the nonlinear part of the system.

The usage of nondirectional links lead to the necessity to rebuild of the system of equations in runtime, and therefore to the limited time for the equation system analysis. System analysis time is reduced by the following means:

- unknown variable for the equation can be assigned explicitly by the user,
- variables, which cannot be unknowns, can be explicitly marked as "known" by the user.

Example results of applying described modification to compound system of equations of real mathematical models from the simulator of "LNG Membrane Tanker" ship are presented in Table 1. Columns of the table correspond to typical cargo operations of ship systems.

A. Cargo system, operation "Cooling down cargo tanks".

B. Cargo system, operation "Liquid cargo loading".

C. Nitrogen insulation barriers system, operation "Purging".

Table 1. Results of system modification

	A	*B*	*C*
Total number of objects in the system	264	264	174
Number of valves, opened during operation	34	43	35
"Equivalent" equations	14512	14790	4873
Formulas	652	840	758
Linear equations	981	1504	613
Nonlinear equations	309	318	124
Computation time of 0.5 seconds of model time	0.125 s	0.144 s	0.124 s

5. CONCLUSION

Presented component library is applied in the development of mathematical models for TRANSAS Liquid Cargo Handling Simulators of different ship types, some of which are already released (Chemical Tanker, Product Tanker, LNG Membrane Tanker, LNG Regasification Terminal) and other are under development (LCC Tanker, LPG Tanker).

REFERENCES

IMO Model Course 2.06: Oil Tanker Cargo and Ballast Handling Simulator (2002). IMO, Portsmouth.

IMO Model Course 1.35: Liquefied Petroleum Gas (LPG) Tanker Cargo and Ballast Handling Simulator (2007). IMO, London.

IMO Model Course 1.36: Liquefied Natural Gas (LNG) Tanker Cargo and Ballast Handling Simulator (2007). IMO, London.

IMO Model Course 1.37: Chemical Tanker Cargo and Ballast Handling Simulator (2007). IMO, London.

Kolesov Y.B., Senichenkov Y.B. (2006). *Modeling of systems. Object-oriented approach.* BHV, St. Petersburg, Russia, (in Russian).

Kolesov Y.B., Senichenkov Y.B. (2006). *Modeling of systems. Dynamic and hybrid systems.* BHV, St. Petersburg, Russia, (in Russian).

RanD Model Designer – high-performance visual environment for the modelling and simulation of multy-domain component models, [Online], Available: http://www.randservice.com [1 Apr 2013].

Tarasov S.V., Kiptily D.V, Lebedev D.V. (2012). An Object-Oriented Approach to the Development of Liquid Cargo Handling Simulators in TRANSAS. In Troch I., Breitenecker F. (es). *Preprints MATHMOD 2012 Vienna. ARGESIM Report no. S38.* ARGESIM, Vienna, Austria.