POLITECNICO DI TORINO
Repository ISTITUZIONALE

A powerful tool for automatic validation of a Modelica library for electromechanical actuation systems for primary flight controls

Original
A powerful tool for automatic validation of a Modelica library for electromechanical actuation systems for primary flight controls / Jacazio, Giovanni; Dellacasa, Andrea. - STAMPA. - (2016), pp. 152-157. ((Intervento presentato al convegno 7th International Conference on Recent Advances in Aerospace Actuation Systems and Components tenutosi a Tolosa (Francia) nel 16-18 Marzo 2016.

Availability:
This version is available at: 11583/2639250 since: 2016-04-10T10:46:15Z

Publisher:
Institut National des Sciences Appliquées de Toulouse

Published
DOI:

Terms of use:
openAccess

This article is made available under terms and conditions as specified in the corresponding bibliographic description in the repository

Publisher copyright

(Article begins on next page)

08 November 2022

A powerful tool for automatic validation of a Modelica library for electromechanical actuation systems for aircraft flight controls

DELLACASA Andrea[1] JACAZIO Giovanni[2] SORLI Massimo[3]

[123]Department of Mechanical and Aerospace Engineering
Politecnico di Torino
10129 Turin, Italy
Email: andrea.dellacasa@polito.it
giovanni.jacazio@polito.it
massimo.sorli@polito.it

ABSTRACT

Validation process aims at verifying requirements, specifications and behaviour of the final product. The procedure, outlined in this paper, has been defined to assess the library developed during ACTUATION2015 research project whose components are focused on the simulation of electromechanical actuation systems applied to aeronautic field. Therefore the validation procedure is presented with references to the experience and knowledge acquired during that project. A Modelica based validation tool has been developed to automate the process and manage the components testing independently from their physical domain (e.g. Electrical, Mechanical, etc). The functions composing the validation library are discussed in the paper and significant examples are presented.

KEYWORDS

Actuation2015, Modelica library, validation, verbose testing

I VALIDATION PROCESS

The objective of ACTUATION2015[1] project is to develop and validate a common set of standardised, modular and scalable EMA modules that address cost, reliability and weight requirements from the air framers. In this context the validation activity is essential to demonstrate that ACTUATION2015 library fulfils requirements while checking its features and limitations. The main areas of the validation procedure are listed below and then expanded within following paragraphs:

Numerical stability; each component is tested following a complete permutation of parameters and input (verbose testing) with the purpose of:

1. Highlight parameters values or combination of them for which simulation ends with critical errors
2. Assess the full reversibility of the components

Level consistency; which outlines models features and provides the means for the verification of the components' correct behaviour

Experimental validation; performing a comparison between measured and simulated results paying attention also to multi-level modelling

1.1 Numerical stability

Modelica language allows to not define causality in the equation system, thus full reversibility tests are of great importance to assess components properties and limits. For this reason, all ACTUATION2015 models have been tested following the concept scheme in Figure 1 which represents the whole set of rotational domain input causality (torque, speed and inertia) and source functions (constant, ramp, sine and step) for both connection flanges of the component.

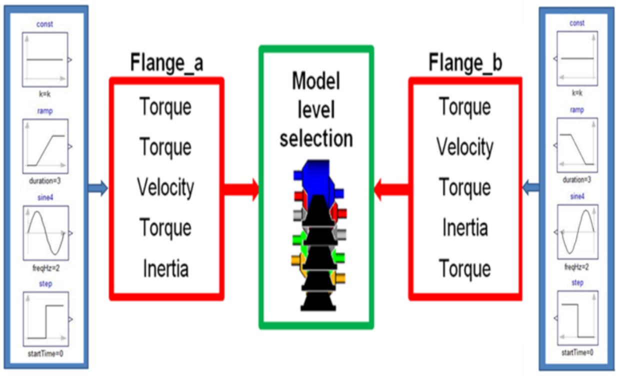


Figure 1. Reversibility test concept

[1]ACTUATION2015 project has received funding from the European Union's Seventh Framework Programme for research, technological development and demonstration under grant agreement N°284915

The outcomes of this test campaign have provided important information concerning full reversibility of the components and how this feature is affected by input causality and source type.
Next phase of the analysis consists in studying the models behaviour to parameters variation. Since computational effort and number of iterations are key aspects of this procedure, it is important to clearly define:

- *Range of the parameters;* unphysical range leads to unnecessary efforts and leads to obvious results
- *Step amplitude;* a wise analysis of both components and previous results leads to fewer iterations while retaining the full characterization of the model
- *Step scale;* it is important to define which between logarithmic or equidistant methods best fits for the selected parameter

For example the validation of ACTUATION2015 library has been conducted looking for the best compromise between quality of the results (i.e. completeness of the tests) and computational time which has led to following assumptions:
Multi-level component approach allows to test the models increasing the level of accuracy (e.g. from ideal to hard-nonlinear). Thus it has been possible to minimise the number of iterations increasing the step amplitude for the parameters already analysed during the tests of the lower accuracy models.
Different components with same mathematical models do not need to be fully investigated. Therefore reducers analysis has been limited to the parallel axis component since all reducers share power loss calculation and friction model.
Logarithmic scale is more appropriate for parameters as inertia and viscous effects resulting in a lower computational effort and in the analysis of more interesting parameters values.
The high amount of results has been managed by means of tables as the one presented in Figure 2 evidencing information like input causality, selected parameters, their variation ranges and final results.

1.2 Level consistency

This section describes the model physical effects coverage addressing the verification of the consistency between mathematical relations and output of the model. In other words it is checked that the model runs as it is expected, without numerical issues.
The above activities require a deep knowledge of the components to attain the goal of a full Level Consistency analysis. Moreover most of the features need a dedicated test procedure to be verified.
For instance more accurate mathematical models of reducers and nutscrew within ACTUATION2015 library consider the transition between power quadrants to simulate the friction. Verification of this feature requires following steps:

- Iteration of input causality to assess full reversibility of the component also in case of discontinuous and nonlinear effects
- Iteration of parameters such as efficiency and tare losses; to verify the correct behaviour of the model varying the parameterisation
- Dedicated input sequence; to check all the possible power quadrants changes

As example Figure 3 evidences the total drag torque behaviour in response to a sinusoidal input torque. The component, after a first phase of stuck, starts moving and switching among the four power quadrants (plotted with dashed lines). Moreover Figure 3 allows a comparison between ACTUATION2015 reducer and Modelica Standard Library Lossygear since the plotted operating quadrants derive from the standard model with same parameterisation

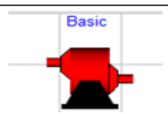
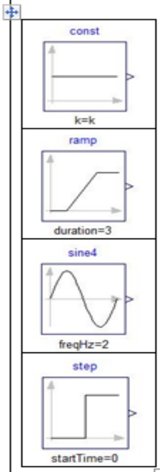
	Model level				
		**Parameter variation**		**Iteration**	
		Speed ratio	**Ext. Inertia**	**N Cases**	**Error cause**
		[-100; 100]	[10^{-4}; 1] kgm^2		
Source	**Input**				
	Torque – Torque [-10; 10] Nm [-10; 10] Nm	OK	OK	3500	1. Ratio = 0
	Torque – Speed, Aid [-10; 10] Nm [-1000; 1000] rad/s	OK	NN	1500	1. Ratio = 0 2. Speed step
	Torque – Speed, Op [-10; 10] Nm [-1000; 1000] rad/s	OK	NN	1500	
	Speed – Torque, Aid [-1000; 1000] rad/s [-10; 10] Nm	OK	NN	1500	
	Speed – Torque, Op [-1000; 1000] rad/s [-10; 10] Nm	OK	NN	1500	
	Torque – Inertia [-10; 10] Nm [10^{-4}; 1] kgm^2	OK	AP	700	1. Ratio = 0
	Inertia – Torque [10^{-4}; 1] kgm^2 [-10; 10] Nm	OK	AP	700	1. Ratio = 0

Figure 2. Example of test matrix used for the parameters variation

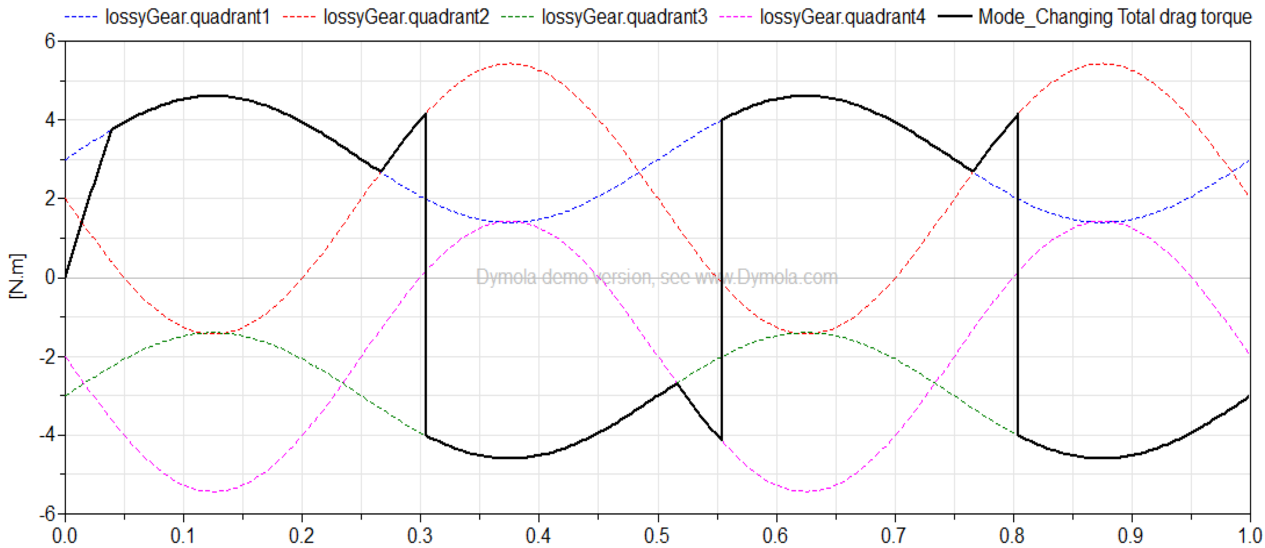


Figure 3. Example of total drag torque switching between the four power quadrants

1.3 Experimental validation

The experimental validation consists in studying the components capability to represent the real equipment behaviour.
Outcomes of this activity can be evaluated in terms of:

- *Overall process*; it must be focused on project aims (e.g. validation at component or system level). Moreover it have to be as clear and complete as possible in order to fulfil partners needs and positively affect customers judgment.
- *Tests Completeness;* depending on the simulated physical effects, a certain number of experimental acquisition, covering operating conditions in terms of temperature and input commands, are required to assess the mathematical model behaviour.
- *Results confidence;* which can be maximised by means of regression results algorithms.

The above criteria must be satisfied to ensure project results and maximise its exploitation.
Availability of experimental data is a common issue during the validation activity.
Therefore it is required a wise optimisation process between needed experimental measures and accessible ones.
The experimental validation procedure, applied to ACTUATION2015 case study, has led to following considerations:
One of the goals of ACTUATION2015 library is to attain a well-integrated library of reusable physical components. Thus the overall process has been focused at component level retaining the requirement of modular validated elements.
Availability of experimental results suitable for this kind of validation represents a critical issue since it requires dedicated test rigs with provision of sensors placed upward and downward each component in analysis. Consequently the validation activity has been pursued taking advantage from outcomes and knowledge of other research projects.
Reaching a good level of *tests completeness* in the field of electromechanical actuation systems involves availability of results in different environmental (e.g. operative temperature) and working (e.g. full power, hard stops) conditions. Therefore tests allowing benchmark at different temperatures have been considered suitable for this activity.
Modeling of components with multi-level approach is a key feature of ACTUATION2015 library. Thus outcomes of lower accuracy models have been studied to provide a complete analysis also in terms of *results confidence*.
For example Figure 4 presents a Dymola block diagram reproducing a text rig taken as reference for worm gear reducer validation.
The real test bench is equipped with sensors upward and downward the mechanical drive which allowed to limit the virtual prototype to the transmission line. Moreover existing data provided a comparison of the component varying both environmental conditions and input commands.
In the same figure it is also reported a comparison between accuracy friction models and experimental data. The graph shows angular velocities trends in response to a torque increase followed by an hard stop due to torque limiter activation.
Tests as the above one are useful to get information about confidence of accuracy levels with experimental data. From Figure 4 it is possible to argue that:

- More accurate models (hardNonlinear and Nonlinear) have a good degree of confidence with experimental data
- Linear friction model is not well fitted for simulation where angular velocity has low effect on drag torque. In other words linear model is not able to faithfully reproduce real behaviour in which the increase of drag torque is a consequence of the load acting on the system. Anyway single phases of the test as initial/final plateau and hard stop can be simulated quite well also with this kind of model.

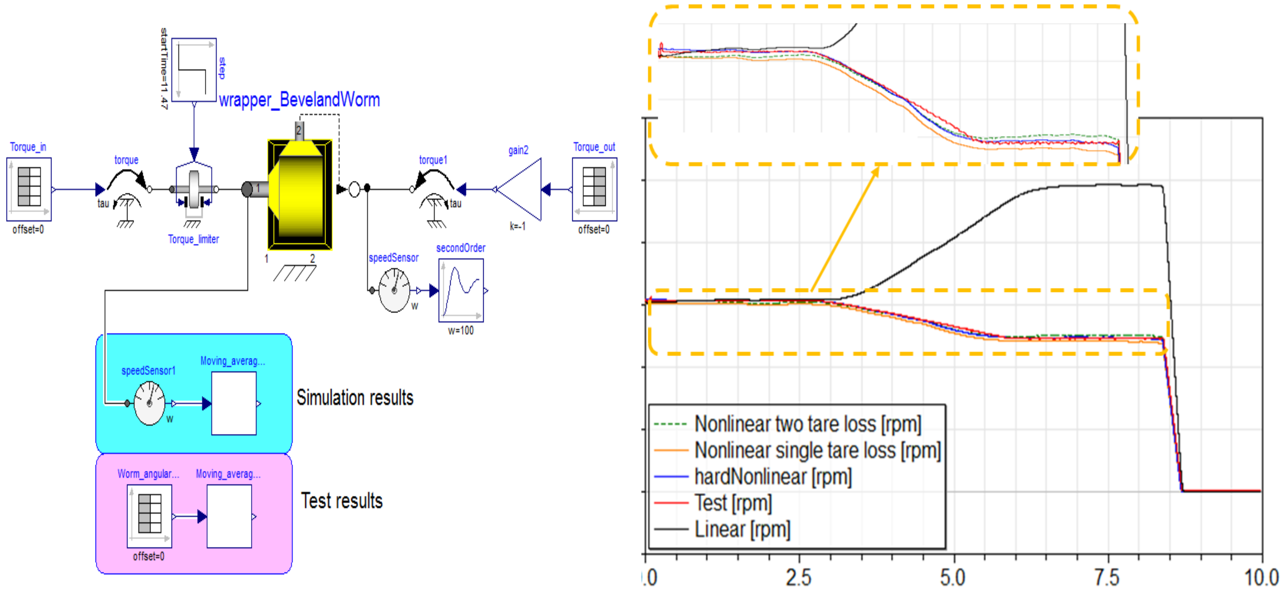


Figure 4. Test model structure and example of different accuracy level comparison

II VALIDATION LIBRARY

As previously outlined the validation process need a strong effort in terms of iteration to prove components stability and consistency, in the meanwhile this task will provide a debug of the models underlining possible errors and wrong implementation of mathematical relations.

A Modelica based validation tool has been developed to automate the overall process and to manage tests on the components independently from their physical domain (e.g. Electrical, Mechanical, etc).

There are three main functions composing the library (presented in Figure 6):

1 *Verbose testing*; which executes the permutation of the selected parameters values among the imposed ranges of variation;
2 *Catalogue;* developed to import tables of parameters (such as the ones provided from manufacturer) and simulate the defined combination of input values
3 *Compare*; it executes the same verbose testing of the first function but allowing the comparison between accuracy levels (e.g. with different inputs and same parameters and vice-versa) or between different modeling approaches of the same component (e.g. comparison of MSL Lossygear and POLITO reducer)

The listed functions share an user-friendly GUI allowing the selection of:

- The model to be tested
- The parameters and the range of values to be considered in the permutation tests
- The variables to be stored and plotted
- The simulation setting options and the path of the stored results

Another common part of the code is the one dedicated to the results storage. Simulations outcomes are saved in a log file with following structure:

- Iteration number
- Parameters values in input for that simulation
- The plot of the selected variables (if required)
- The simulation result (i.e. true if the solver reached successfully the end of the simulation)

The post-processing is partially automated by means of a reasoning system which will be discussed in section 2.4.
Features of each function are outlined in next chapters
.

2.1 Verbose testing

The preprocessing consists in a matrix generator whose output is equivalent to the following nested loops structure and to the concept diagram of Figure 5:

$$for\ Param[1]\ in\ [\min[1], \cdots, \max[1]\ loop$$

$$\dots\dots\dots$$

$$for\ Param[n]\ in\ [\min[n], \cdots, [\max[n]\ loop$$

$$\boldsymbol{SimulateModel}\ \{\mathrm{Paman}[1], \cdots, \mathrm{Param}[n]\}$$

$$end\ for;$$

$$\dots\dots\dots$$

$$end\ for;$$

The matrix is instantiated with columns and rows respectively equals to the number of the selected parameters and to the possible permutations of the parameters values.

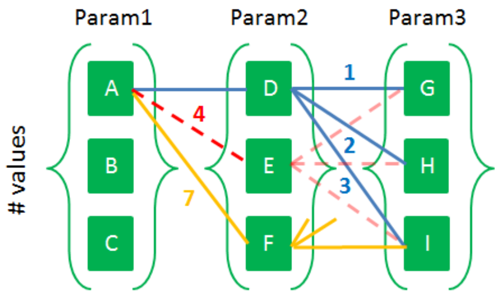


Figure 5. Block diagram of the permutation process

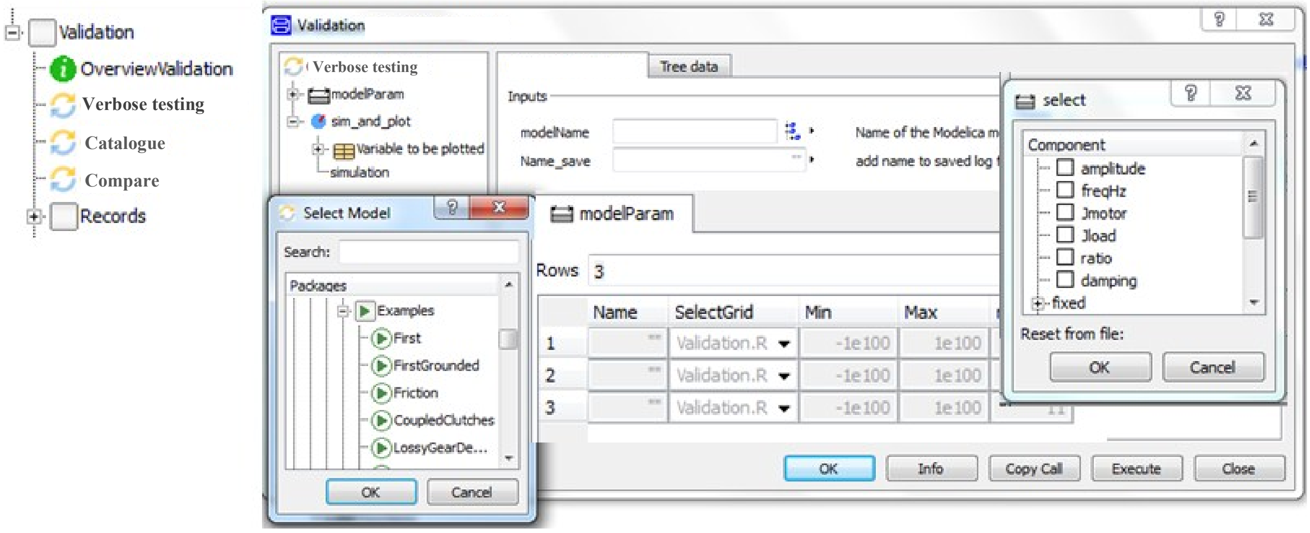


Figure 6. Validation library structure and Graphic User Interface

The filling process is then performed column by column, as shown in figure 7, through a movable index which selects the cell value on the basis of the remaining parameters possible combinations.
Though the matrix is built to enhance the verbose testing of the model, it can also be exploited for the calibration of the virtual prototype, in fact the grid represents a multidimensional interpolation of the parameters and enables the tuning to minimize the error between simulation results and measurements (e.g. same process has been adopted to find optimal solution shown in figure 4)
Thus the proposed approach is well suited for verbose testing and validation purpose since it results in a lighter function with decreased simulation time, avoids the use of external script and allows parallel computing.

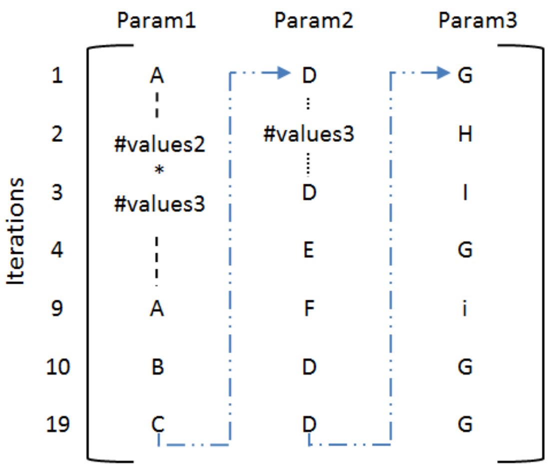


Figure7. Filling process of the matrix

2.2 Catalogue

This function has been developed to test components importing tables of parameters as the ones available from catalogue. The GUI eases this process assisting the user in the selection of the parameters to be varied and in the processing of different format tables.

Therefore the test matrix is externally defined and the script consists in the processing of the required simulations.
Catalogue script has been employed for consistency studies in which specific sets of parameters have to be tested for assessing the correct behaviour of the model.

2.3 Compare

The script executes the same analysis of the first function, however the matrix generator is modified to address input causality tests and to support the comparison of different modeling approaches of the same component.
This is typically done by creating a single test environment, as the one in figure 8, characterized by parallel branches simulated at once.

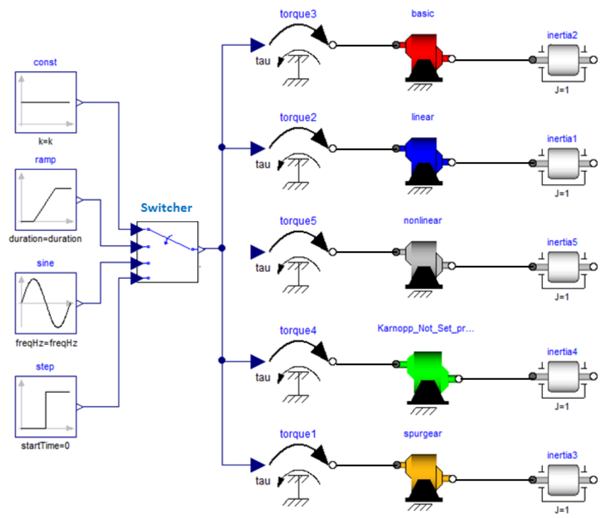


Figure 8. Example of test environment

The GUI allows to identify relationships between parameters so that the ones defined as dependent will not be considered in the permutation process and will be added to the final matrix.
In other words dependent parameters do not increase the number of nested loop but are processed within the for cycle of the independent parameter to which they are linked.

The function with this feature is well suited for different kind of tests since it not require further work for adapting the model to the type of analysis and can avoid unnecessary iterations such as the permutation of the parameters between parallel branches.

2.4 System for automated post processing

The post processing consists in the analysis of the failed simulations and in the identification of the root causes responsible of the critical error.
Since the functions discussed in paragraph 2.1 and 2.3 entail a large amount of simulation to be checked and verified, a code has been developed to ease the final assessment of the model.
The script is able to identify and discern between failures due to single or combination of parameter values. This is done exploiting the input matrix structure, the dimension of the error cluster (i.e. sequence of consecutive errors) and its recurrence.
Moreover the analysis is enhanced by statistical approach looking at the modal repetition of the parameters value into error log respect to the possible iteration of that particular parameter.

CONCLUSION

The reported methodology has led to the verification and validation of the mathematical model developed within ACTUATION2015 research project and provides a positive answer to the issue of consistent processes for assessing the effectiveness of commercial software and library.
The developed tool has proved able to automate the process independently from the physical domain and to handle the burden of numerical stability studies.
Moreover the features of each function make the tool suitable for analysis beyond the validation purpose such as the optimization of the actuation system design and the recognition of the components health status.

REFERENCES

ASME, (2006), *Guide for Verification and Validation in Computational Solid Mechanics*, The American Society of Mechanical Engineers, ASME V&V 10-2006

Mayes, R. L., (2009a), *Developing Adequacy Criteria of Model Validation Based on Requirements*, Proceedings of the 27th International Modal Analysis Conference, SEM, Orlando, FL.

Paez, T. L., Swiler, L. P., (2009), *Probabilistic Methods in Model Validation*, Proceedings of the 27th International Modal Analysis Conference, SEM, Orlando, FL.

Pfeiffer A. (2012), *Optimization Library for Interactive Multi-Criteria Optimization Tasks,* Proceedings of the 9th International Modelica Conference

Roache, P. J., (1998), *Verification and Validation in Computational Science and Engineering*, Hermosa Publishers, Albuquerque, New Mexico.

Schamai W., Buffoni L., Albarello N, Fontes De Miranda P, and Fritzson P. (2015), *An aeronautic case study for requirement formalization and automated model composition in modelica*, Proceedings of the 11th International Modelica Conference