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Computer simulations in space and planetary exploration systems development

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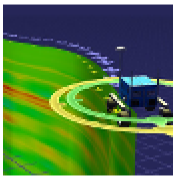

Planetary exploration systems and space probes are always working in very extreme environment. When considering this environment and other conditions which will have significant effect on the functionality and reliability of space probe or planetary rover, then we must focus on very precise design, development and testing of these systems even before their mission starts. For investigation of possible situations in various extreme natural environments we can use various simulation techniques – especially computer simulation. In this paper we will focus on evaluation of possibilities, necessity and place of computer simulation in process of design and development of space and planetary exploration systems.

1. Introduction

Research of technology options of systems for exploring of another planets in Solar system is characterized by several complications and technical constraints. The proposed new systems in this case will often work in conditions vastly different from those on Earth. Validation of new or known technologies and their functionality in the physical conditions of other worlds is therefore possible only by laboratory testing or possibly using of theories and mathematical calculations. In this process, it is highly advisable to use some of the methods of mathematical simulations, as these allow us to accurately simulate the physical conditions and then develop a model on which it is possible to assess the functionality of the proposed system, or to determine a solution of some problem. In this work we will focus on the assessment of the most appropriate methods of simulation and modeling in examining of the proposed system in conditions of the planet Mars.

2. Definitions

Before we will move on to consider the appropriate methods of simulation and modeling in a particular project, we will define the main concepts of the basic procedures for modeling and simulation. Modeling and simulation is a very broad term covering a wide problematics and procedures that are used in almost all areas of professional activity. Therefore, we will focus on basic concepts that will be useable and on those which will cover the problematics of orbital and surface space systems and their functions on other planets.

The fundamental concept is the system itself. The term system defines a collection of entities that interact, and as already outlined above, for each scientific discipline is a different set of entities. Each system is described by state of the system, which represents the variables necessary to describe the system at a given time. In general, the system can be discrete or continuous (continuous). Discrete system is characterized by a step change state variables at the time and continuous system is characterized by continuous changes state variables at the time. At some time point it is necessary to study the behavior of the system, the system changes caused by the changes of components or predict the changes of the state variables. [1]

In the case of the design of new technologies and technological processes which will be working in other planetary conditions, we will consider these systems as discrete as well as continuous systems. The functionality of these systems may be based on interaction with the other systems in their vicinity. For example in terms of orbital telecommunications and data relational systems their activity and performance can be entirely autonomous and independent from other local systems. In many cases it will be a combination of such systems.

Another important term is the experiment. The actual experiment is essentially a simulation model of the situation of the system under specified conditions. During the experiment there will be a verification of this question or problem. The result of the experiment can be positive or negative. Or the result may require the further investigation. An experiment using computer simulation is particularly useful in cases where the verification of the investigational status is not technically possible. For example, review of the performance and operation of space systems on the other planets even in the phase of planning of the mission or the given system. The physical/mathematical model is created before beginning of the simulation by using of the established procedures, and by setting of the required parameters of examined system.

Analytical solution / simulation – once the mathematical model is created, it is necessary to demonstrate the answer to the questions about behavior of the system which we are interested in. If the model is simple enough we can solve the mathematical equation of the mathematical model exactly – we get the analytical solution.

3. Simulation model and simulation

According to Dahl's definition, the simulation is a research method which essence lies in the fact that the studied dynamical system will replace the simulator and with this we will then perform experiments to obtain information about the original investigated system. [2] Transformation model of input parameters to output quantity can be expressed in general functional dependence

$$y = f(p < sub > 1 < /sub >, p < sub > 2 < /sub >, \ldots, p < sub > n < /sub >) \qquad (1)$$

or

$$Y = f(p < sub > 1 < /sub >, p < sub > 2 < /sub >, \ldots, p < sub > n < /sub >) \quad (2)$$

where

$$Y = (y < sub > 1 < /sub >, y < sub > 2 < /sub >, \ldots, y < sub > m < /sub >) \quad (3)$$

while

$$m : P \rightarrow Y \quad (3)$$

where y – outputs, f – function, Y – set of output variables, p – input parameters

The aim of experimenting with the simulation model is mostly the comparison of variants of simulation model in terms of observed output quantity (or more output variables). [2]

4. Simulation in space and planetary exploration technologies development

Use of modeling and simulation methods in examining of functionality of space technologies, events and processes is one of the most important stages of the development of such technologies since it is very difficult faithfully emulate the extra-terrestrial physical conditions in which these devices will work.

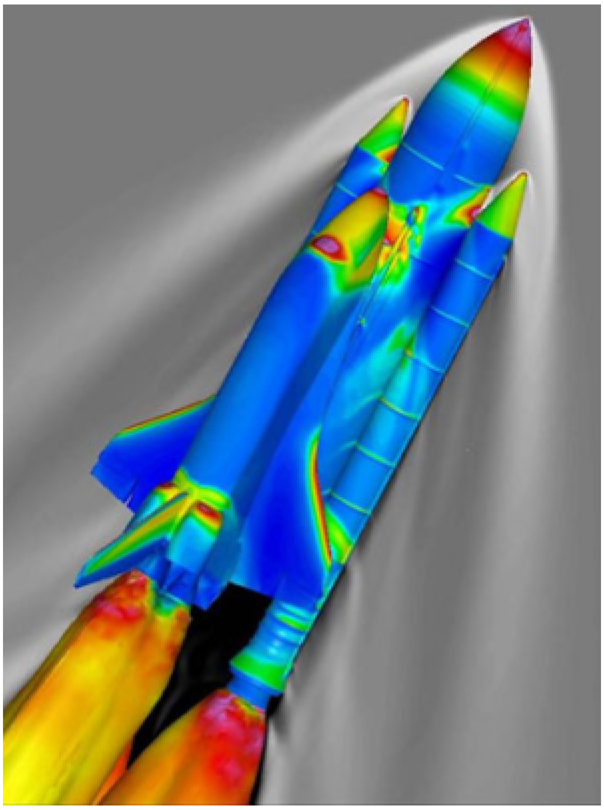

Fig.1 Simulation of SSLV at Mach 2.46 and 20,000 m. The surface of the vehicle is colored by the pressure coefficient, and the gray contours represent the density of the surrounding air. Credit: NASA [7]

Very high demands are placed on the performance and reliability of these systems.

This is understandable since space missions are very expensive and time consuming. For example, just the idea of a technical failure of the probe which traveled to the planet Jupiter for several years, is too frightening. The Mission of space probes consist of several sub-projects, of which the scientific part of of the mission forms mostly one-third of the entire mission and the entire costs. For interplanetary missions within the solar system is the one-third of costs representing the preparation and the second third represents the technical project of the probe and its operation.

The last third represents the operations and support functions of the probe. These include for example the provisioning of relay connections with the other probes in dedicated area. A simple example is the orbital mission of Mars Reconnaissance Orbiter. The primary task of this probe is the examination of the surface of Mars at different levels of the electromagnetic spectrum and the secondary task is to provide a data connectivity of surface probes such as Curiosity and Opportunity rover with a ground control on Earth.

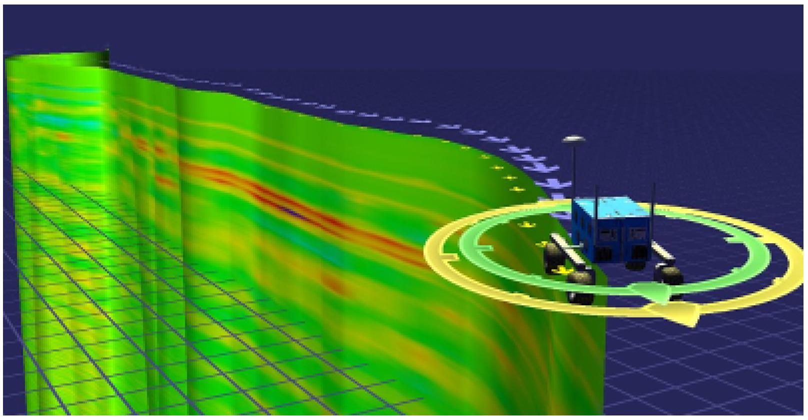

Fig.2 Example of simulation of activity of planetary rover. Computing of precise path and possible faults of rover's traveling around the crater on surface of other planet (Moon). Image credits: NASA Ames Research Center [6]

5. Software simulation tools

Modeling of the processes and following mathematical and computer simulation must be based on a validated algorithm that meets all the necessary requirements. This algorithm must also contain the previously mentioned conditions of the physical environment where the probe will be operating. It is essential that the algorithm involves all the technical capabilities of the probe and also any situation which may occur in the operation of the probe. When taking in mind that the most of the current space probes are autonomous and that these do not require any direct human intervention, in some cases it is necessary to mention also this option.

Direct control or input commands to the probe is complicated because for example only the time needed for travelling of the command signal from Earth to space probe may last from a few tens of minutes to several hours. Sending command is not the only thing what is necessary to count. Also it is necessary to count with the travel time needed for confirmation signal sent by probe as a response back to Earth's ground control – in order to verify the correct continuation of the whole process. Therefore it is necessary to count with the least number of possible human interference from ground control.

In the process of modeling and simulation of these systems is therefore necessary to compile the correct algorithm and its subsequent transcription into the mathematical form. Although the mathematical form is fine, for simulation of all possible situations and events it is necessary to rewrite the mathematical model into a simulation language. In the case of research activities of space probes is thus the best to use a computer environment which allows this procedure. Currently one of the most used programming environments is Matlab. This environment is suitable for scientific and numerical computing, modeling, design of algorithms, computer simulations, analysis and presentation of data, measurement and signal processing, design management and communication systems. Matlab has a separate extension called Simulink – a program for simulation and modeling of dynamic systems. This program uses Matlab algorithms for the numerical solution of nonlinear differential equations. [4]

Alongside the commercial products there are also some simulation environments available for free. One of these platforms is Scilab. Scilab is an extensive, powerful, free software for the use of numerical mathematics, which originated in the Institut national de recherche en informatique et en automatique (INRIA) in France in 1990 as an alternative to Matlab. Functionality and Scilab syntax is in many respects identical with Matlab and there is a conversion option from Matlab into Scilab. Scilab is being used for technical, scientific purposes, in teaching, or research and industry. [3]

Between these two programming environments there is some kind of mutual compatibility, because the Scilab environment contains the script compiler written for Matlab. So it is possible to translate the simulation model from one environment to the other one that way, so the result will be executable in the target environment. The difference between these two worlds is more or less that while Matlab is a commercial product developed and supported by Mathworks, Scilab is programming environment based on freely available and distributable free licenses and is supported by wide community of users. However Scilab has a wide variety of developers and users it is more or less the same quality as its sophisticated commercial variant Matlab. For the purposes of modeling and simulation of space technologies and related processes is the appropriate to use any of these environments.

There is also wide range of many other simulation environment. One of these known alternatives is GNU Octave. This programming environment is freely available just like above mentioned Scilab and is very similar to Matlab, but it lacks such a wide range of different accessories. However, it is partly compatible with both programming environments (Matlab and Scilab). Most other programming environments designed for simulation are less frequent in the area of research and development of space technologies and related processes. The use of these other environments is more or less isolated and mostly not focused on the development and testing of individual components of larger projects. The development and testing of integrated projects such as space probes, there is usually an international cooperation of various scientific and technical teams. So the mutual compatibility and interoperability is one of the highest requirements for simulation software environment. This is also one of the main reasons why there is dominant usege of Matlab or Scilab.

6. Conclusion

Simulation and research of very specific kinds of events, systems and activities requires very complex software environment, which allow us to determine conditions and function of designed system in the development process. Especially in area of development and design of space systems and technologies must be the simulation process very precise, because there is no way how to fix or calibrate any system which is in the space, travelling millions of kilometer from Earth. In this case it is very important to use complex simulation environment which will allow to compute and simulate any possible conditions and situations which may occur in the space probe's future life.

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