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ENGAGE MSU STUDENTS IN RESEARCH OF MODEL-BASED SYSTEMS ENGINEERING WITH APPLICATION TO NASA SOUNDING ROCKET MISSION

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Synopsis:

Large and complex system or systems-of-systems (SoS) design requires efficient collaboration between interdisciplinary teams of engineers. The engineers must communicate effectively with each other and the finished project or system must be reliable and robust. Model-Based Systems Engineering (MBSE) is a useful and effective systems engineering approach, which emphasizes the application of rigorous visual modeling principles and practices the systems engineering activities throughout the System Development Life Cycle (SDLC). Using MBSE methods and tools allows a unified representation of the system in a model that enables a highly related level of details. In this research, we engage Morgan State University (MSU) engineering students in the study of MBSE application to NASA's sounding rocket mission, with the help of the engineers at Goddard Space Flight Center and Wallops Flight Center. Through this effort, the MSU students can significantly enhance their knowledge about systems engineering and the application to a complex system development process.

Engage MSU Students in Research of Model-Based Systems Engineering with Application to NASA Sounding Rocket Mission

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Abstract

Large and complex system or systems-of-systems (SoS) design requires efficient collaboration between interdisciplinary teams of engineers. The engineers must communicate effectively with each other and the finished project or system must be reliable and robust. The common goal of engineers in interdisciplinary teams is to deliver timely and cost-effective products. Model-Based Systems Engineering (MBSE) is a useful approach to achieving this goal. MBSE is a systems engineering (SE) paradigm that emphasizes the application of rigorous visual modeling principles and practices the systems engineering activities throughout the System Development Life Cycle (SDLC). Using MBSE methods and tools allows a unified representation of the system in a model that enables a highly related level of details. When dealing with complex and interdisciplinary SoS, traditional SE methodologies fall short of achieving a project or product objectives. In this research, we engage Morgan State University (MSU) engineering students in the study of MBSE application to NASA's sounding rocket mission, with the help of the engineers at Goddard Space Flight Center and Wallops Flight Center. Through this effort, the MSU students can significantly enhance their knowledge about systems engineering and the application to a complex system development process.

1. Introduction

The responsibilities of a systems engineer as defined by the International Council on Systems Engineering (INCOSE) [1] consist of the following major tasks: state the problem, investigate alternatives, model the system, integrate and launch the system, assess performance, verify and test. INCOSE was established in 1990 and its mission is to address the growing complexity of systems. INCOSE defines Model-Based Systems Engineering (MBSE) as formalized application of modeling to support systems requirements, design, analysis, verification and validation activities beginning in the conceptual design phase and continuing throughout development and later life cycle phases [2].

The Object Management Group (OMG) systems modeling language has provided a solid foundation for MBSE of complex systems. However, the stakeholders are different. System domains are also different. Therefore, the adoption of MBSE in the different domains will depend on the availability of domain-specific MBSE applications, which provide the stakeholders with the tools to architect and analyze in that domain [3]. There are many possible problems that can be identified by industry experts. This is a common issue with large complex systems:

- Projects are becoming so complex. The complexity is growing fast beyond our ability to manage it.
- Insufficient specifications and poor verification process.
- Increased cost and risks.
- Knowledge and investment lost between projects.

As the system's complexity and extent grow, the number of parties involved (i.e., stakeholders, shareholder, *et al*) usually also increases, thereby bringing a considerable amount of view, skills, responsibilities, and interests to the interaction [4]. The field of Systems Engineering (SE) aims to address the complexity and interdisciplinary areas of the system.

The sounding rocket mission at NASA is a complex and interdisciplinary project. Several initiatives have been started, where one is the SE vision. It is imperative that the finished/final systems be robust and reliable. MBSE would then be considered as one of the main approaches to tackle problems of current and future systems development. The NASA Systems Engineering Handbook defines MBSE as a robust approach to the design, creation, and operation of systems[5]. When data about a system to be designed is rigorously captured, this data can be queried, analyzed, validated and transformed into another form for further processing.

Rigorous SE can be achieved by defining and using:

- Conceptual models
- Languages, standards, and tools
- Methodologies and processes

Conceptual models provide a strong vocabulary for systems engineers to process data with a precise meaning. This will result in creating consistency across modeling artifacts (i.e., specifications, interface requirements, system design, analysis, and test plans).

The use of industry standard (in this project, SysML is used) enables the embedding of the robust vocabulary into a graphical modeling language. Methodologies and processes guide the system engineers to develop a model using SysML and allow the engineer to focus on domain problems.

Systems engineering is one of the key programs being developed in the School of Engineering at Morgan State University (MSU). The Systems Engineering and Management Institute (SEMI) has worked with the systems engineers at GSFC for more than eight years and has engaged more than ten MSU engineering students in NASA-related research. Several doctoral dissertations, master's theses used the topics related to systems engineering. In this MBSE research, we continue engaging MSU engineering students in the NASA-related systems engineering project, which allows MSU students to learn the systems development, life cycle analysis of sounding rockets, collaborate with NASA engineers. This experience can add significant value to student's resumes

and inspire their interests and awareness in STEM study (Science, Technology, Engineering, and Mathematics).

2. Model-Based Systems Engineering Approach and Software

Model-Based Systems Engineering (MBSE) is a system development approach aimed at the creation and collection of system models from different viewpoints and different levels of development using an MBSE approach [6]. There are a number of MBSE methodologies currently used in the systems engineering (SE) community, employing a range of processes and preferred tools, including [7]:

- IBM Rational Harmony for Systems Engineering/Teleological Harmony SE
- IBM Rational Unified Process for Systems Engineering
- INCOSE Object-Oriented Systems Engineering Method (OOSEM)
- Vitech MBSE Methodology
- JPL State Analysis (SA)
- Object-Process Methodology (OPM)
- SYSMOD
- DSTO Whole-of System Analytical Framework

For the NASA Sounding Rocket Program (NSRP), we will use the OOSEM methodology. The OOSEM integrates a top-down model-based approach that uses SysML to support the specifications, analysis, design, and verifications of systems. OOSEM is a hybrid approach leveraging object-oriented technique and traditional SE. Estefan (2008) [8] gives a foundation of OOSEM, for which we can summarize in Figure 1.

Foundation of OOSEM		
OOSEM Unique	Common OOSE	SE Foundation
Causal Analysis Enterprise Model Elaborated Context Requirements Variation Analysis System/Logical Decomposition Partitioning Criteria Node Allocation and many more...	Top down Systems Engineering Approach Recursive SE Approach Use Case/Scenario driven (Reqt's - Test) Black box/ White Box Object Oriented Concepts UML/SysML	Systems Engineering Process Requirements Trades

Figure 1. Object-Oriented Systems Engineering Method (OOSEM)

The term Object Oriented originated from the development of software programming languages. It evolved from work in the 1990's at the Software Productivity Consortium in collaboration with Lockheed Martin. OOSEM is summarized in various papers and its application is available in Lockheed Martin's tutorial. Below are the key objectives of the OOSEM methodology [7]:

- Capture and analysis of requirements
- Design information to specify complex systems
- Integration with object-oriented software, hardware, and other engineering methods
- Support for system-level reuse and design evolution

Estefan (2008) [8] uses a flowchart to describe OOSEM activities, which can be illustrated in Figure 2, you can see that the OOSEM follows a systems engineering process. The OOSEM is a good method to conduct systems engineering process.

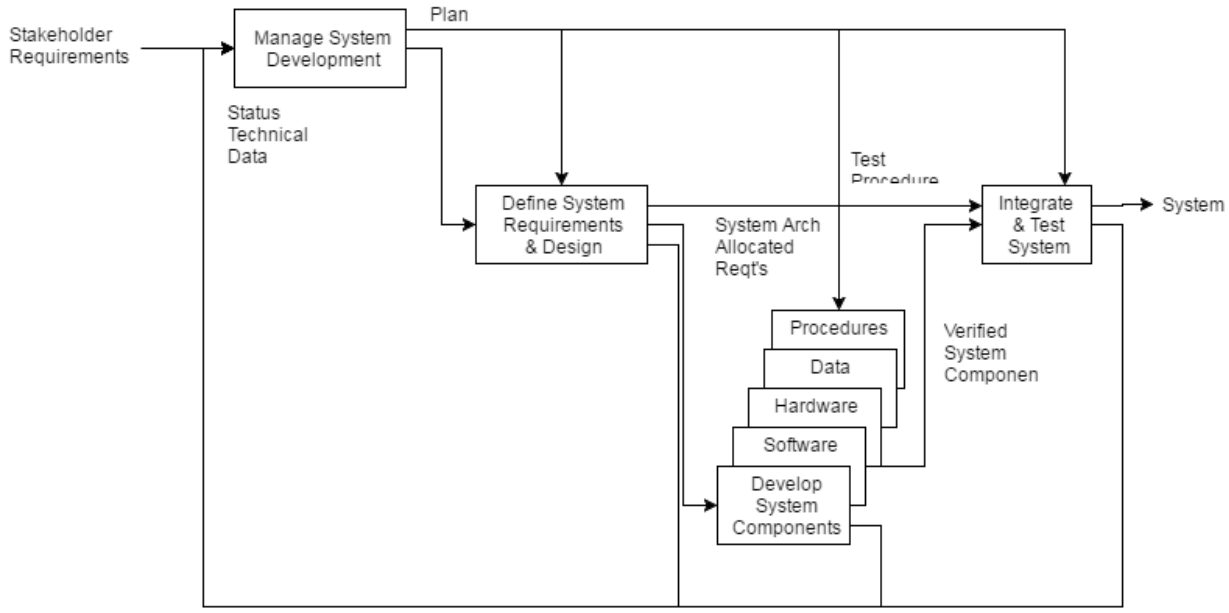

Figure 2. The OOSEM Process

The model-based approach has been a standard practice in electrical and mechanical design and other disciplines for many years. As defined by INCOSE, "MBSE is the formalized application of modeling to support systems requirements, design, analysis, verification and validation activities beginning in the conceptual design phase and continuing throughout development and later life cycle phases"[1]. MBSE takes a document-intensive system and moves the information into a single model. The advantages of this method are given below:

- Enhanced specifications and design quality
- Reuse of system specifications and design artifacts
- Improved communications among development team
- Increased ability to manage system complexity by enabling a system model to be viewed from multiple perspectives, and to analyze the impact of changes
- Improved ability to teach and learn systems engineering fundamentals by providing a clear and unambiguous representation of the concepts

MBSE supports the analysis, specifications, design, verification and validation of complex systems. These complex systems include hardware, software, personnel, procedures, and facilities. A system model is created using a modeling tool and stored in a model repository [9]. The system

model includes system specifications, design, analysis, verification information. MBSE uses the system modeling language (SysML) to display the system information. The importance of using models is to gain insight into large and complex systems. According to Rumbaugh *et al*[10], the models are important to do the following:

- Capture and state the requirements so that all stakeholders may understand them
- Think about the design of a system
- Produce usable work products
- Organize, find, examine, filter, manipulate, and edit information about large systems
- Explore several solutions
- Master complex systems

Rigorous and formal modeling has evolved in the last decade and many software tools are used to model complex systems. MagicDraw is the software tool used by the students in this research, as suggested by NASA systems engineers.

MagicDraw is a business process, architecture, software, and systems modeling tool. It is considered as one of the most popular UML and SysML tools in the market [11]. It is also used by NASA MBSE teams. According to the www.nomagic.com website, there are over 500,000 MagicDraw installations. More and more books, papers and even OMG specifications are prepared using MagicDraw, its plugins, and other No Magic Inc. modeling products [12].

MagicDraw is essential for the application and completion of this project. Below is the list of key important factors supporting the fact that MagicDraw is important and widely used software in the market and MBSE applications [11].

- Standard conformance and enforcement – MagicDraw supports the latest UML (Unified Modeling Language), SysML standards
- Visually pleasing diagram
- High degree of usability - MagicDraw provides intuitive controls within a very well designed, graphical user interface (GUI) that allows users to model without having to spend time learning about the controls
- High definition and scalability of image export
- Wide range of supported domains
- Attractive and competitive pricing

3. General Sounding Rocket Mission

For over five decades, NASA's Sounding Rocket program has provided an essential component of the agency's exploration and education initiatives, provided quick and convenient access to space. A sounding rocket is an instrument-carrying rocket designed to take measurements and perform scientific experiments during its sub-orbital flight. A sounding rocket is divided into two parts, a payload, and a solid-fueled rocket motor (Figure 3) [13].

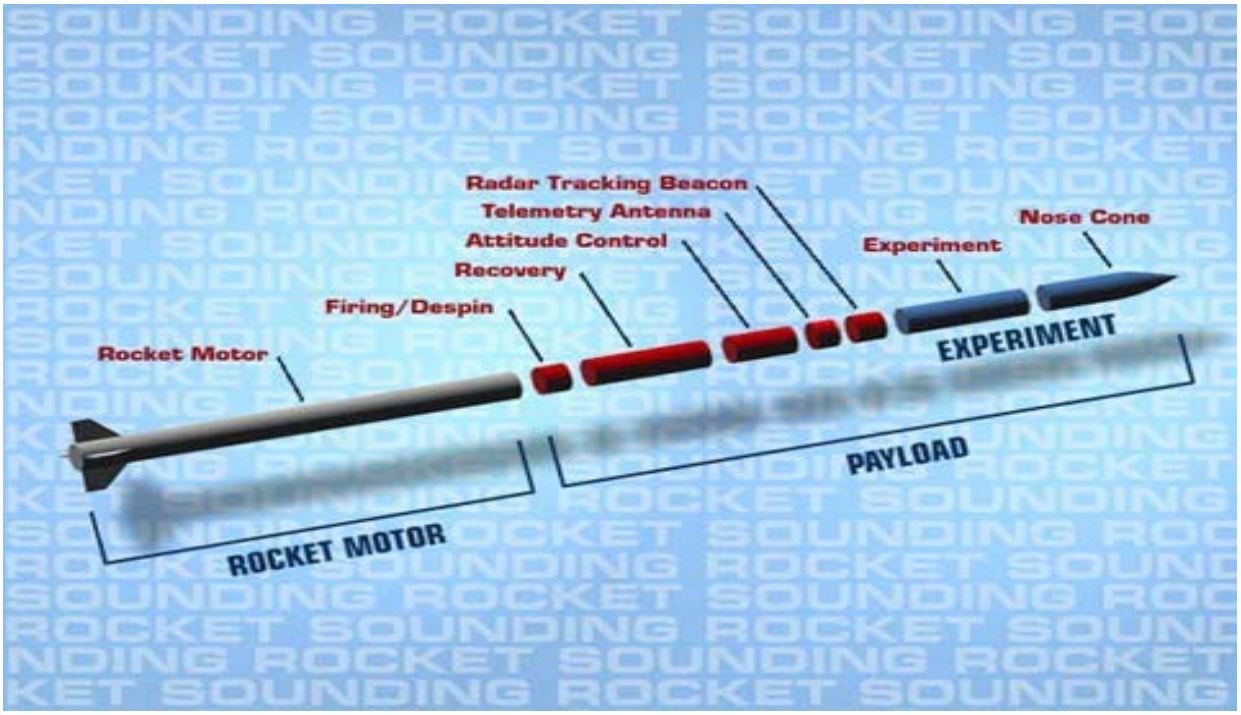

Figure 3. NASA's Sounding Rocket.

Sounding Rocket Program rests solidly on 4 key elements:

- Unique opportunity for scientific research
  - Scientific instruments are carried into space
  - Overall time in space is brief, 5 – 20 minutes
- Low-cost access to space
  - Rocket does not go into orbit. Therefore, no need for expensive boosters
  - There is an acceptance of a higher degree of risk compared to other missions
  - Low-cost missions
- Rapid, quick turn around
  - The payload can be developed in a very short time frame – sometimes as quickly as three months
  - Scientists are quick to react to new phenomena because of the rapid, quick turn around
- Education
  - Sounding rockets provide invaluable tools for training, research, and education
  - Collaboration between students, young researchers, and engineers
  - More than 350's Ph.D.'s have been awarded as part of NASA's sounding rocket program

MBSE application to NASA's Sounding Rocket program is a critical opportunity to expose MSU engineering students to NASA-related research and state of the art technology, and engage them in applied research in collaboration with other students and world's class engineers and scientists. This would be a great opportunity for them and will prepare them for a rewarding, fulfilling, and challenging career.

4. Objectives of MBSE Application to Sounding Rocket Mission

This project is a research project still in progress. MSU students are learning sounding rocket systems development, payload requirement and life cycle analysis. The main objectives include but are not limited to:

1) To develop a reliable system model using MBSE methodologies that will ensure the design of a robust sounding rocket. We also want to help with system understanding among team members. We would also like to make a repository about the system. We also intend to establish the model-based engineering methodology. The scope of our model must support its intended use within resources constraints.
2) To use MBSE to streamline the development of complex systems like the sounding rocket. This method would use a model – based systems engineering workflow (see below).
3) To enhance and inspire engineering students in systems engineering study and research through application to real NASA projects.

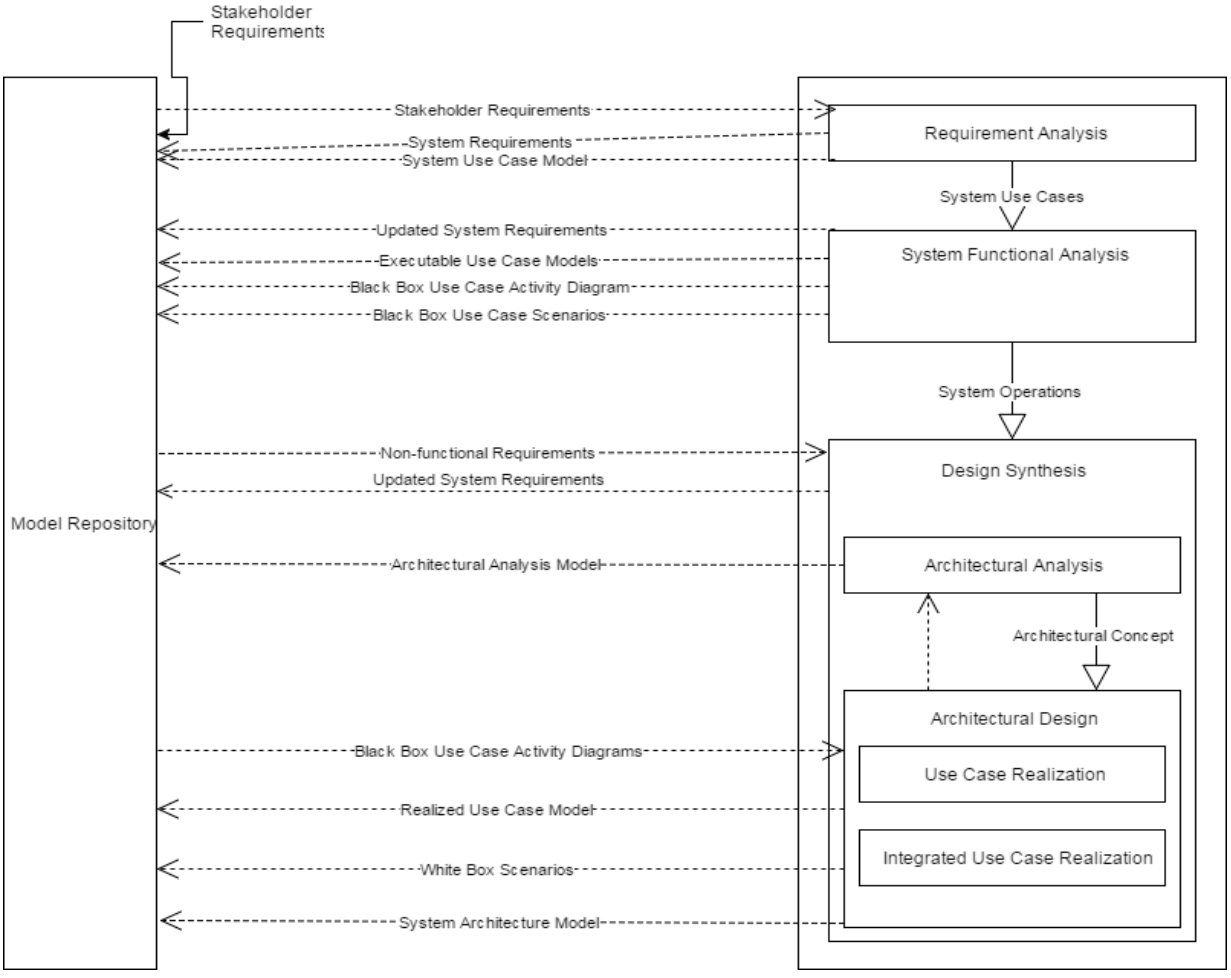

Figure 4. Model-Based Systems Engineering (MBSE) Work Flow

Figure 4 represents a workflow illustration of Model-Based Systems Engineering (MBSE). In the past over ten years, we have collaborated with the systems engineers at Goddard Space Flight Center working on the application of systems engineering to complex projects. In September 2013, SEMI (Systems Engineering and Management Institute) at MSU completed a 257-page systems engineering report "System Description Document for Software Defined Radio (SDR) Technology", as one of the major reports for a NASA Center grant [14]. In this MBSE project, MSU engineering students, including graduate and undergraduate, are involved and guided by Dr. Chen and NASA engineers on MBSE application to sounding rocket development. Specifically, the MSU students will work on the following tasks:

1) MSU students will use Magicdraw to develop the system model. Although MSU students can get a permit to use the software at GSFC, it will be more efficient to have the software available at MSU. Magicdraw is installed on the computers in the systems engineering laboratory at MSU.
2) MSU students will also study NASA sounding rocket development process and life cycle analysis so that they can better understand the systems architecture and process. MSU students will also collect the necessary data and systems information and enter the information into Magicdraw for systems modeling.
3) MSU students will also test and refine their MBSE model in Magicdraw and develop a document or manual about how to use Magicdraw for MBSE procedure and team collaboration. MBSE for NASA sounding rockets will be a direct case study for this project.

An MSU doctoral student had completed a doctoral dissertation two year ago with Dr. Chen as his advisor, on systems engineering approach for software defined radio technology development [15]. He proposes a specific approach for implementation of systems engineering in the academic environment. The MSU students in this project will develop a similar SE procedure and study for the sounding rocket by using MBSE approach.

5. Anticipated Outcome Assessment by Engaging MSU Students in This Research

This is a research project still in progress. It is anticipated that an MBSE model will be developed by using MagicDraw software and the implementation procedure will be illustrated, which should be useful to NASA project teams. Through conducting this project, MSU students can significantly enhance their systems engineering skill and knowledge. Some of them may work as systems engineers after their graduation in the future. Specifically, the following evaluation measures can serve as the outcome assessment on the effectiveness of the project:

1) A technical report with illustration of MBSE implementation and application can be completed;
2) Through a survey, students will demonstrate the improvement of their systems engineering skills and knowledge, as well as enhanced capability of SE application;
3) At least one student will be graduating using this project as his master's thesis;
4) The students will be tracked down after their graduation and some of them should be eligible to serve in a systems engineer role.

6. Concluding Remarks

Systems engineering (SE) is a multidisciplinary approach that is intended to transform a set of stakeholder needs into a balanced system solution that meets those needs. SE is a key practice to address complex and often technologically challenging problems. The practice of systems engineering is transitioning from a document-based approach to a model-based approach. MBSE offers significant benefits that enhance design quality. Various kinds of software can be used to model complex and challenging projects. However, by using SysML as a language with MagicDraw, we can develop the modeling and procedure of MBSE for the best practice of sounding rockets, which may enable the project team more efficiently to develop, verify and validate system architecture through model execution and simulation. Students engaged in this research will demonstrate significant improvement of their systems engineering skills and knowledge, as well as the capability of MBSE application to industrial projects, and eligible to serve on a systems engineer role. In addition, at least one student will use this project as his master's thesis.

Acknowledgement

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