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A Pilot Study to Determine MBSE Utility for Modeling Complex Interfaces

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Abstract. Modeling a full system or a complete interface between systems in a MBSE environment is a very large task and not all organizations will benefit enough from using MBSE to offset the effort that is required to do this. Completely modeling a system or interface is not necessary to evaluate the utility of MBSE for a specific application or organization. A small pilot can be executed over a short period of time that only models small portions of a system or interface and, if structured properly, this pilot can successfully demonstrate the utility of MBSE for an organization before having to invest a larger amount of resources to fully implement and deploy MBSE. This paper documents one such pilot that was conducted for NASA's Launch Services Pr

MBSE Pilot Objective

The NASA Launch Services Program (LSP) MBSE pilot had a very specific objective, but unlike most pilot programs, this objective was not to start using Model-Based Systems Engineering (MBSE), but rather to answer this simple question... "Do the benefits of MBSE outweigh the modeling efforts (cost) required to sustain the use of MBSE for the L

Right from the start, it was not known whether this pilot would result in the LSP adoption of MBSE, result in deciding to not adopt the use of MBSE, or if we would simply decide to wait to adopt its use until a later date when our launch vehicle contractors and spacecraft customers had adopted its use more widely within their programs and projects. Since the objective of our pilot was to determine both the utility of MBSE for the LSP and the effort required to achieve that utility, we needed to identify potential uses of MBSE that were specific to the LSP. Choosing what to model during the pilot involved taking into consideration both the overall scope of what our specific group, the Integration Engineering (IE) group, does within the LSP but also the limited duration we had to execute the pilot program. Due to the very challenging workload of our Integration Engineering group we needed to acquire additional resources in order to have a successful pilot program. The additional resource we decided to use was that of a student intern. NASA has a very robust internship program that allows current students to come work at NASA for a Fall, Summer or Spring semester. The LSP MBSE pilot was run during the Summer of 2017, which was only 10-weeks in duration. The student chosen for the internship was Alexandra Dukes, who is currently attending Purdue University pursuing a master's degree in Aeronautical and Astronautical Engineering with a focus in Aerospace Systems, is also a co-author on this paper.

The limited duration of the pilot led to the decision to only model small portions of the system/interface, rather than attempting to model the entire scope of the system interface for which we are responsible. There are a couple of benefits to this approach. Modeling, when done correctly, takes a considerable amount of time and effort. Not only is the modeling effort itself very time consuming, but the initial task of fully understanding the system before modeling it also takes a significant amount of work. If a large and complex item is chosen, then there is little time left over in the schedule to allow the team to change the modeling approach or decide that modeling that aspect of the system interface is not value added and then move on to the next modeling task. The ability to iterate and change direction based on lessons learned during the pilot was the main strategy for our pilot. Having a student intern performing the modeling also had to be taken into consideration when scoping the pilot. A student intern was a good analog for the systems engineers in our Integration Engineering group that were not already using MBSE, but it also meant that the summer intern needed to both learn the specifics of our MBSE tool and learn about the role of the Integration Engineering group within the LSP.

An Overview of LSP Integration Engineering

To assist our intern in expediting the familiarization process within our organization, we started simply by moving between physical groups and stopping to interview and explore examples of common interactions between team members within LSP. Further exposure to ou regarding our external customers was accomplished through attendance at mission level meetings. This initial work sought to explain the role of Integration Engineering (IE) as the end-to-end systems engineering lead between launch vehicle and spacecraft who are seeking access to space. During the familiarization phase, we examined previous mission requirements, requirement verifications, and familiarized through the use of shadowing. Shadowing was necessary beyond book level examples because IEs provide technical leadership and direction to the Mission Integration Team (MIT) across varied engineering disciplines internally within NASA and interact externally with both launch vehicle providers and spacecraft developers.

This early work was followed up through mentee to mentor questions on a daily basis, weekly progress meetings, and further supported by the use of interviews with discipline experts within the LSP, so our intern began to understand why the NASA Launch Services Program is known as "Earth's Bridge to Space." It became evident that MBSE, if utilized within our organization, would not be for hardware development as many others currently use MBSE for their projects, but we instead look to model the processes our team uses regularly. These regular operations and product development occur between when spacecraft development is authorized to proceed (Phase C see figure below), when LSP has procured the launch services from a commercial offeror, and through integrated operations up to operations on orbit (Phase E see figure below).

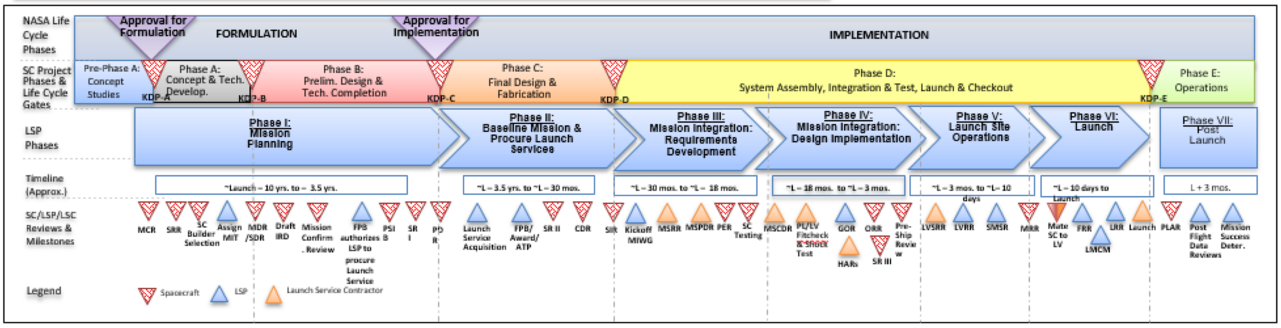

Figure 1. LSP Mission Support Phases

The primary focus of a LSP IE is to manage the interfaces between the launch vehicle and the spacecraft, ensuring requirements are developed and verified all while considering the safety of all teams and ensuring timely integration of the spacecraft with the launch vehicle for delivery on orbit. LSP IEs start this process early in the mission planning and development stage of the spacecraft project. This early involvement helps establish the spacecraft environmental test levels. The LSP IEôs involvement continues through the spacecraft build, verification of integrated requirements, major spacecraft and launch vehicle design reviews, integrated operations, launch, and early orbit operations.

Integration Engineering is responsible for working with our spacecraft customer on the development of the spacecraft Interface Requirements Document (IRD) and later with our launch vehicle contractor to develop the Interface Control Document (ICD). The ICD is where all of the spacecraft to launch vehicle interface requirements are defined and verified. NASA LSP IEôs have, over time, developed a set of best practices (lessons learned) we share with our spacecraft customers which has been proven to be helpful to both new and returning spacecraft development teams. Within our own internal team though, there are often areas which have a high level of input from different disciplines in a short timespan approaching the launch date. These points of debate are what we sought to first consider when modeling in MBSE. As we noted, there were interconnections we could see at the system level between disciplines that our disciplines were not themselves realizing existed. Identifying these and other common processes became a manageable subset of activities we could examine in the short pilot timespan. By exploring these areas, we believed we could share the pilot with our internal teams to improve our interactions and develop better communication for both in times when teams are working linear and parallel verification closures and in the service to our customers.

MBSE Modeling During the Pilot

The Mars 2020 mission was chosen as the basis for the LSP MBSE Pilot for several reasons. The primary reason for selecting Mars 2020 for our pilot was that there is a significant amount of similarity between the Mars 2020 mission and that of the Mars Curiosity Rover (also known as Mars Science Laboratory (MSL)), which has been operating on Mars since August of 2012. Mars 2020 is using the same basic rover, cruise stage, and Entry Descent and Landing (EDL) designs as MSL. Even more importantly, the Mars 2020 mission has nearly identical interfaces and operational requirements with respect to the launch vehicle. Therefore, for the purposes of our MBSE pilot, we were able to use the large amount of historical engineering data products and verification closure data from the MSL mission as a starting point for our Mars 2020 MBSE pilot. This is a significant advantage compared to other MBSE pilot efforts that are attempted on active projects because we do not run into the issue of not having engineering closure data to complete the modeling process since the full life cycle of engineering products is available right at the start of the pilot.

The other advantage to using Mars 2020 as the basis for the LSP MBSE pilot is that the Jet Propulsion Laboratory (JPL) is the NASA organization in charge of the spacecraft. JPL has played a major role within the NASA community with respect to piloting the use the MBSE within the agency. If LSP were to eventually adopt the use of MBSE, JPL would be one of our first spacecraft customers who would be interested in engaging within that environment.

The MBSE Modeling Approach

The approach taken for the pilot study was performed in three steps: determine the needs of the LSP, develop an understanding of the system and that w then create a model to determine that ability. This process was repeated often throughout the 10 weeks to refine both the needs and model as the capabilities of MBSE and the software were identified.

The main objective in answering the question outweigh the modeling efforts (cost) required to sustain the use of were asked at the start of each modeling effort within the pilot study, including:

- What is the need that is being addressed by the pilot study?
- How can MBSE make a productive addition to the LSP?
- What should be modeled and what should not be modeled?

Due to the time constraint, these questions were crucial to the success of the pilot study as they created a direction to properly evaluate the utility of MBSE for the LSP. The pilot study began by addressing three key needs within the LSP. The group wanted a more efficient way of performing their verification peer reviews, a visual representation of their integrated operations, and a better understanding of the relationships between internal discipline teams and contractor parties throughout the requirement verification processes.

One strategy for addressing these needs was to start modeling by creating small test cases and expand the model with time permitting. The goal of the pilot study was to determine whether MBSE would be a useful tool for the LSP, not to deliver a complete model. Starting small allowed us to evaluate the usefulness of the model artifacts as well as change the direction of the model based on lessons learned as the model was developed. Another strategy utilized during the study was to treat MBSE as a supplement to current document-based processes and not as a replacement of the current processes. This allowed us to focus on what MBSE could provide that current processes cannot. This strategy, in turn, created an interesting inquiry into how MBSE could be integrated as a supplemental model application to an existing process. In order to shorten the learning curve required to properly use MBSE, Lenny Delligattiôs book óSysML Distill services of the author through his company, Delligatti Associates, was utilized throughout the duration of the pilot study. His insights were invaluable in creating a greater understanding of the SysML language and MagicDraw, the software chosen for the study, as well as grounding our needs and efforts with known MBSE applications and examples. His consultation sessions allowed for the time it would have taken to understand MBSE as a modeling application to be focused on evaluating the benefits of MBSE for the LSP.

Choosing Test Cases for the Pilot

Specific modeling, or test cases, were needed for the purposes of our pilot. Before the pilot started, we created a list of potential modeling activities and goals to consider for the purposes of the pilot.

Figure 2. Potential Goals & Modeling Tasks

We knew we couldnôt possibly tackle every pot duration pilot, so we chose the modeling cases we thought represented the greatest potential benefit but were small enough in scope to be modeled in a short amount of time. The test cases specifically chosen to address the objective of our pilot were the verification of the In-Flight Disconnect (IFD) system and the Mass Properties of the system. The verification of the IFD provided a hardware focused perspective in the MBSE artifacts meaning the focus of the model was on the hardware of the system itself and the verification processes carried out on that hardware. The verification of the Mass Properties provided a process focused perspective in that the verification of the mass properties does not focus on a specific system but is a process involving the entire system and several groups both within and outside of the launch. These two test case studies, and their varied perspectives, provided a platform to address the identified needs of the LSP and the objective question. These two test cases also addressed the three key needs identified in the previous section of the paper (more efficient verification peer reviews, visual representation of integrated operations, and a better understanding of the relationships between internal discipline teams).

After identifying the needs and test cases, the second step of the modeling process is developing an understanding of the systems chosen for the test cases . This ste- [illegible] or defining the model elements and their relationships to other identified elements before modeling

Figure 6. Example Package Diagram: Shock Test Operations Summary

While views similar to the package diagram in Figure 6 can be created in a set PowerPoint charts, the consistency of the elements and their relationships within the various diagrams, the ability to easily replicate previously made diagrams into different models, and the amount of time it takes to construct these diagrams within MagicDraw versus other flowchart software, make a MBSE approach a highly-desirable option for meeting the need to visually and dynamically depict integrated operations.

Conclusions, Next Steps, and Lessons Learned

The LSP MBSE pilot was executed with a single modeler, who had previous MBSE experience but was new to both Magic Draw and to the type of work done within the Integration Engineering organization within the LSP. Despite the learning curve with a new MBSE tool and a new organization, a single MBSE modeler was able to learn enough about the LSP processes and functions to create multiple sample MBSE products and demonstrate the utility of these products with respect to LSP needs.

MBSE is traditionally used as an application of modeling from conceptual design through development of a system; whereas, the system is 90% designed and developed by the time it reaches LSP. Additionally, this pilot study was unique in its application of MBSE as it focused on the verification of requirements and the processes within those verifications. We found that MBSE has enough potential to become a productive modeling application to LSP that it is worth pursuing future, larger scale, pilot studies which would work towards transitioning from asking the question ñ
MBSE is useful to LSP, given its costs, to demonstrating ñhowò MBSE is useful to LSP.

In order to reach this conclusion, the pilot
than current processes?ò LSP asked: ñWhat is MBSEôs The answers to these questions arise out of the pros we found of using MBSE for LSP. The key pros contributing to its potential productive addition to LSP are MBSEôs ability to:

- Utilize MBSE artifacts without being an MBSE expert
- Provide a single snap shot of the interrelations during LSP IE processes
- Provide process models of verification activities

The ability of the MBSE tools to create publishable model products without requiring everyone to know MBSE, or its tools, allow for those who wish to use the model, interact with it, and benefit from it without needing to understand the software. This was essential for LSP as it would not add to the burden LSP personnel already have in managing documents through multiple systems and software suites. This feature allows those who were interested in using MBSE to develop the models, and those who did not want to, or do not have the time to, use MBSE to still benefit from the models. Additionally, a developed MBSE model answers the question V ³:KR LV DWWHQGLQJ W activity "´ ³ idK is responsible for bringing what hardware "´ DQG ³:KDW LV HYHU\RQH a verification activity "´ ZLWK D FOLFN RI WKH PRXVH UDWKHU WKD document-based process. This allows for a single, easy to read, view of the interrelationships between /63¶V LQWHUQDO JURXSV DV ZHOO DV WKRVH RXWVLGH RI multiple sources to be synthesized into one format, allowing for easier access to information pertinent to the successful execution of verification processes. Currently, verification processes are regarded DV ³WULEDO NQRZOHGJH´ DQG RQO\ H[LVW DV WH[W ZKLF involved in the verification. MBSE allows for a pictorial view of the verification process that can be better communicated across attending actors and verifies everyone begins a verification on the same page. These three pros of MBSE provide a utility that LSP does not have in the current document-based process, and provides enough evidence to move forward with a larger scale pilot study on 0%6(¶V SRWHQWLDO UROH ZLWKLQ /63

MBSE, while providing several benefits to LSP, has one major drawback: Time. Currently there is a large discrepancy between the time it takes to properly build a functional model that provides the benefits listed above versus the time LSP IEs have available to create the model. With the short 10-week duration of this pilot study, we have only scratched the surface of providing the right motivations for LSP to invest in building MBSE based models. With additional time and a larger scale study, LSP would have the ability to further determine if the benefits to integrated operations and verifications processes is feasible for current personnel, if a MBSE focused position within LSP is appropriate, or if the effort would not be worth its benefit. The initial results from this small pilot study show that the value produced from the models, especially when considering their potential for re-use, outweigh the costs/time it took to produce them.

The example activity diagram shown in Figure 3 ZDV DEOH WR FRQYH\ D ³ELJ SLF a timeline for a spacecraft shock test, all in a single diagram. Before creating this diagram in MBSE the only way we have been able to achieve getting multiple teams on the same page before a major operation was to have everyone read all of the applicable procedures for the operation and conduct a review of the operation in a conference room setting. While an activity diagram would not replace the existing practice of reviewing procedures and walking through the operation in a conference room setting, it would make a very valuable addition to our current process.

The example verification matrix showing mass properties verifications in Figure 4 immediately provided value. Within a few seconds of an IE reviewing this diagram, the IE was able to identify a few verifications that were missing. This was not so much an error in how the MSL mission verified mass properties but was an artifact of a process change that occurred between the time we processed the MSL mission and the present. The ability to quickly spot a missing or incorrect verification like we were able to do using this mass properties verification matrix was exactly the type of enhancement we were hoping for to our verification plan peer review process.

And finally, the block definition diagram showing hardware responsibilities in Figure 5 demonstrated the ability to quickly display in a single graphic the hardware responsibilities for a single operation.

References

Delligatti, Lenny. SysML distilled: a brief guide to the systems modeling language. Addison-Wesley, 2014.