The Tools That Help Systems Engineering

Jacob Gamertsfelder
KENNEDY SPACE CENTER
Major: Aerospace Engineering
Program: NIFS , Fall Session
Date: 25 10 2017

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Jacob O. Gamertsfelder[1]
University of Cincinnati, Cincinnati, Ohio, 45219

Abstract

There are many tools that systems engineers use in today's space programs. In my time in the Commercial Crew Program I sought to improve one of the vital tools for the verification and validation team. This was my main project but only a small part of what I have done in the department. I have also had the chance to learn from the best and see actual hardware, this real world experience will help me be a better aerospace engineer when I enter the workforce. I look forward to seeing the Commercial Crew Program progress to launch.

Nomenclature

VE	=	Verification event
CCP	=	Commercial Crew Program
SE&I	=	Systems Engineering and Integration
V&V	=	Verification and Validation
RO	=	Requirement Owner

I.   Introduction

The Commercial Crew Program was created to enable private companies to carry NASA astronauts to the International Space Station. The job of designing, testing, building, operating, and maintaining the hardware, software and ground support falls on the Partner. These Partners are paid when that meet contractual milestones. NASA's primary job in the Program is to provide technical expertise, and to validate that the Partners are meeting the contractual requirements.   NASA functions more as a regulatory agency than the owner of the system. This is a big change from previous programs. There is a strict certification process that the Partner must meet before they are allowed to transport humans, as well as the requirements needed for the ISS Program. These requirements are wrapped up in to the 1100 requirement set. Each Partner has come up with a plan to complete all of the requirements. The SE&I team works with the Partner and the NASA engineers to coordinate the closure of Verification Events, and adherence to the requirements. A VE is a test, demonstration, inspection, or analysis that shows adherence to a requirement or multiple requirements.

In the field of aerospace engineering many projects are very large. Elements are broken into systems and subsystems which are built up from components. The systems must all work together. Issues can arise when one part of the system does not communicate well with the rest of the system. The job of systems engineers are to integrate different teams. The sub-set of the SE&I team that I work in is the Verification and Validation team. We work to

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ensure that the Partner is meeting all of the requirements in 1130, if they meet the requirements that is considered verifications. Verification is defined as "an evaluation of the performance of the as-designed and as-built end-item with respect to defined requirements" (Space Vehicle Test and Evaluation Handbook).

II. Project

The first task that I had when I came on board was to get up to speed. To do this I read the certification plan from the Partner. Then to compare, I read a portion of the Space Vehicle Test and Evaluation Handbook to see how certification was previously done. It became apparent that there are many ways to do it. From there I read up on previous failures in systems engineering. The process that we now go through was heavily shaped by the lessons learned from previous programs. NASA now functions much differently than it did in the shuttle years. Back in the days of the space shuttle all of the data was delivered by hand from the Partner, and all of the requirement work was done by hand. Now there are databases that allow all of the people that need to sign off on a requirement to do so from any NASA center. Being that the Commercial Crew Program is spread out over the country, this is essential. The VE tracker was created to act as a quick and organized way to show everyone in the Program the status of all of the VE's. PowerPoint presentations and excel spreadsheets have come a very long way now we can have an automatically updated spreadsheet that can be put into a PowerPoint that many people can work on at the same time, and then be presented on a large screen to aid the proceedings of the meeting and the explanation of metrics. This is especially true when a complex issue with a lot of data needs to be discussed.

The importance of tools for integration can't be over stated. Without the use of cloud-type databases it would be much harder and much slower to have a large group of people edit and change a document. There are many tools used now that previous NASA programs did not have. Now when data is delivered for the partner many people have access and nothing is stored on a single computer. SharePoint acts the hub for all the activity, allowing the simultaneous editing and updating of complex documents. This amount of simultaneous collaboration allows a much smaller team cross country team to accomplish a review in a short period of time with no travel costs. These new tools are also deigned to show accountability, so nothing can slip through he cracks. This means a safer flight, and more efficient Program.

The next step in getting me up to speed was to go to a lot of meetings and just listen to the conversation. There were a lot of words and lots of acronyms that I did not understand. But with a lot of questions I was able to understand what they were talking about. Now I was prepared to begin work on my project. The task given to me for the Internship was to improve an excel spreadsheet, this spreadsheet is shared with program management, the working team and in some cases the Partners. This spreadsheet is primarily a status tracker for all of the VEs and the 1130 requirements they are linked to.

The excel spreadsheet that I added to acts as a front page for all of these verification events. There is a lot of things going on behind the scenes. Some tests apply to 15 to 20 requirements, each having multiple people signing off. Some of these requirements need special procedures. Some requirements require coordination with the ISS team. The ISS integration team works to their own requirements documented in SSP 50808. Some tests that the Partner does attempts to fulfill both 1130 requirements and SSP 50808 requirements. As part of my task I had to create a way for the excel spreadsheet to identify what verification events had requirements that needed coordination between Commercial Crew office and the ISS verification team.

This spreadsheet pulls from multiple databases to create a system that tracks the status of the pending and upcoming VEs. Some of the tasks that needed to be complete required the use of visual basic. Visual basic is a programing language that allows manipulation of excel and other Microsoft office products. I did some research of Visual basic on my own. I also talked to the expert on visual Basic and the creator of the original spread sheet to improve my skills. I also had to think outside the box when it came to creating the addition of three columns. This was a very good exercise to learn more of the excel commands and build upon my knowledge. I used these new skills to add two new columns to the VE tracker. These columns gave more information on the event, whether it needs special engineering approval, and/or the VE to be coordinated with the ISS Program.

As part of the systems engineering and integration team we deal with issues that involve many people. Many of the issues are also very complex. With the addition of the three new columns it very clearly lays out if there are special steps that need to be taken to close the verification event. This helps to facilitate the closure of large and complex verification events. There is also an issue of finding a way to quickly update management in the progress, and when progress has stalled. With that in mind, I coordinated with the creator of the excel spread sheet to create a counter to identify those verification events that had disconnects between the Partner and NASA. To quickly show the important information the tracker highlighted the amount of time this VE has been in discussion. Those that have had lots of back and forth require attention of the reader. This highlighting saves time when identifying issues with a verification event. I also added a column that would allow the filtering of verification events to those that required a lot of offices to work together. The filtering of results is also a good way of getting people to focus on the topic and quickly glean the intended purpose. The filtering also identifying the group or groups that may require more integration before the event can be shown as closed.

I was given a list of the requirements, but to integrate them was a difficult task. The first few days on the task it took more of an exploratory approach. It was apparent that a manual input would not be practical as there are over 300 VEs. The first approach used was a VLOOKUP table while it initially worked. It became apparent that the VLOOKUP table failed to identify certain VEs as a shared requirement. After analyzing the failed cases I showed the table was only successful when the requirement listed first was a shared requirement. The solution of a VLOOKUP table was therefore not successful. The next solution tried was using a large table to use a FIND command, this creates its own problems though this command only outputs the number of characters it takes in the cell to find the requirement it matches. Luckily there is a column pulled for one of the databases that lists out all of the requirements. So this command goes through each cell filled with every requirement tied to that verification event. When it finds the exact requirement, it notes the characters. Then another table went through and if the cell contained a number it is replaced requirement ID in the NASA database. These requirement ID's are then concatenated in to the final cell that is display all the requirement ID's. The final step was to add formatting that highlighted all the cells that had at least one requirement that was a shared ISS requirement. This highlighting is very important because it identifies quickly those VE's that are shared

Another column created was to identify the VEs that had requirements tied to them that required special engineering approval. These VEs require a more in-depth review from NASA. It is important to note the tests that require special approval long beforehand so the process is not held up in the short time period that NASA has to review the VE and accept it. The process for creating this column was very similar to the ISS coordination column. I pulled a list, made a FIND table, and then substituted the number with the exact requirement ID and then concatenated them into the final cell for each VE. Then highlighted the cells that had at least one requirement that was as special engineering approval

A third column was added to make the reading of the spreadsheet easier. The column shows the number of offices that had a responsible owner for a specific VE. The RO is the leader for the requirement, but as noted above some VE's are used to meet lots of requirements. This problem is easily solved if all of the RO's are in the same System offices. That System office can integrate internally without SE&I help. In some VE's there are multiple requirements leading to RO's from more than two system offices. These VE's require pre-coordination and one of those RO's should be the lead for that VE or the SE&I office will acts as the lead integrator. The excel spreadsheet has a search function so the column also acted as a filter to show what VE's need pre-coordination. The process for creating this column was similar to the other columns but with some differences. One being the cell searched is the RO Cell, and the other being that the number was more important than actual office. So instead of replacing FIND return with the requirement it was replaced by the number 1 then at the end they were summed. The resulting summation column was then added to the main sheet. The column then was conditionally formatted so that all the cells with a number greater than two.

To make the spreadsheet more legible in presentations. The Signatories was compacted and the names were organized by their department. This task was done with the help for the excel expert. To accomplish this task visual basic was used. Another column that was added was a counter of status changes. This column also need to be made in visual basic. This column is of particular importance as it shows what VE's have disconnects. These are then brought up at meetings with the Partners.

Updated 28Sep17	# of Status Changes	ID and Title	1130 Reqt #	RO	Signatories	# of Offices Involved	Special Engineering Approval	Shared SSP 50808 Requirement
	0	R.CTS.072 Flight Imagery R.CTS.089 Locate Spacecraft after Landing R.CTS.040 Record and Display Health and Status R.CTS.351 Command and Telemetry Communications R.CTS.380 Communication R.CTS.002 Simultaneous Operation of Spacecraft R.CTS.095 Communications with CVCC after Landing R.CTS.113 Voice Communication with Crew R.CTS.116 Private Audio R.CTS.038 Isolate and Recover from Faults	3.2.4.3 3.2.5.8 3.2.4.2 3.8.1.7 3.8.1.8 3.1.1.2 3.5.1.7 3.8.1.1 3.8.1.4 3.2.3.4	GMO - Hudson, David (SpaceX) SE&I - McKinnie, John; Chan, Steve; Peters, Jim Spacecraft - Quince, Asia	Engr - Dunn, Kevin; Kunkle, John; Butler, Marc; Gaylor, Kent; Peacock, Robert (Mike) FOD - Johns, Ryan; Matthew, Christie; Owens, David; Spencer, Ron (SpaceX); Childress, J. Mark GMO - Hudson, David (SpaceX); Mosteller, Ted (SpaceX); TBD (SpaceX); Snopkowski, Misty (SpaceX) HH&P - Ellenberger, Rich; Haralson, Rhonda ISS - Simon, Tom (SpaceX) Launch Vehicle - Kappes, Ian Safety - Merrill, Richard; Sickler, Leigh; Goebel, Tom SE&I - McKinnie, John; Chan, Steve; Peters, Jim Spacecraft - Randall, David; Quince, Asia	3	R.CTS.002 R.CTS.038 R.CTS.040	R.CTS.002
	0	R.CTS.093 Crew Survival after Emergency Landing R.CTS.364 Spacecraft Ventilation for Emergency Landings R.CTS.094 Crew Survival Kit	3.5.2.4 3.5.2.5 3.5.2.6	Spacecraft - Daniel, Brian; Daniel, Brian (SpaceX); Dub, Mark	Engr - Bue, Grant; Pham, Chau; Moeller, Chad FOD - Moncla, Brandon (SpaceX); Matthew, Christie; Flagan, Adam HH&P - Baitland, Lawrence; Heinbaugh, Randy Safety - Fortson, Russ; Alberts, Seth Spacecraft - Daniel, Brian (SpaceX); Dub, Mark	1		
	0	R.CTS.011 Return Crew R.CTS.373 Sea State Landing Limits for Aborts	3.1.2.2 3.5.2.2	IPerf - Gowan, John Spacecraft - Nguyen, Tri (SpaceX)	Engr - Vega, Kevin (SpaceX); Bernstein, Karen FOD - Spencer, Ron (SpaceX) GMO - Hudson, David (SpaceX) IPerf - Gowan, John ISS - Simon, Tom (SpaceX) Safety - Wilcox, Peter Spacecraft - Nguyen, Tri (SpaceX)	2	R.CTS.011	R.CTS.011
	0	R.CTS.102 NASA Personnel Accompanying Recovery R.CTS.103 Transport NASA Personnel and Cargo from Landing Site R.CTS.104 Contingency Medical Evacuation	3.5.3.6 3.5.3.7 3.5.3.8	GMO - Mosteller, Ted (SpaceX)	FOD - Moncla, Brandon (SpaceX) GMO - Mosteller, Ted (SpaceX) HH&P - Heinbaugh, Randy ISS - Bradshaw, Terri	1		R.CTS.102 R.CTS.103 R.CTS.104
	1	R.CTS.318 Medical Hardware Interfaces	3.6.2	Spacecraft - Daniel, Brian; Daniel, Brian (SpaceX)	Engr - Williams, Dave FOD - Matthew, Christie HH&P - Baitland, Lawrence Spacecraft - Daniel, Brian (SpaceX)	1		R.CTS.318
	0	R.CTS.107 Privacy of Health and Medical Data	3.6.3	GMO - Hudson, David (SpaceX)	FOD - Koch, Will (SpaceX) GMO - Hudson, David (SpaceX) HH&P - Haralson, Rhonda SE&I - Chan, Steve	1		
	0	R.CTS.109 Health Stabilization	3.6.4	GMO - Payne, Steve	FOD - Moncla, Brandon (SpaceX) GMO - Payne, Steve HH&P - Haralson, Rhonda	1		R.CTS.109
	0	R.CTS.112 CVCC/MCC-H Data Integration	3.7.3	GMO - Hudson, David (SpaceX)	FOD - Owens, David; Spencer, Ron (SpaceX) GMO - Hudson, David (SpaceX) HH&P - Haralson, Rhonda ISS - Simon, Tom (SpaceX)	1		R.CTS.112
		R.CTS.351 Command and Telemetry Communications	3.8.1.7 3.8.1.1	GMO - Hudson, David (SpaceX)	Engr - Gaylor, Kent FOD - Owens, David			

Figure 1. Verification Event tracker showing the columns that were added, all sensitive partner data had been scrubbed

In my time here at KSC the excel spreadsheet has only taken up a portion of my time the rest has been spent being a member of the Verification and Validation team, I have helped with various projects. I have attended many of the meetings that the team has had. This exposure to an actual systems engineering and integration process has taught me a lot. I took a systems engineering class at my university. While this class showed me a broad overview of the process, my experience here has given me an up close view of a program. I have learned that it is never simple, and the larger the project the harder it is. I was given the opportunity to see hardware of the Partner. This has given me a great appreciation for the pace of the Program, the building of the hardware is extremely meticulous as is necessary when a small flaw can lead to catastrophic results. I also have experienced how a large project is managed (timetable, risk, and cost). This is interesting and something that is not normally taught to engineers.

Software is often overlooked in the construction of a spacecraft. It may appear as though one can simply construct the craft and then develop the software as an afterthought. Many of those in the SE&I team understand that this is

simply not the case. Hardware and software must be designed in tandem and both must be integrated into the spacecraft to ensure a timely and safe launch. To make sure software was integrated properly I went through all of the requirements to identify all those tests and demonstration that use flight-like or flight software. First I narrowed down the list by removing those that have a primary stakeholder who is software focused person. Next I scoured the list of secondary stakeholders to remove those that have a secondary stakeholder that is software focused. With the list narrowed down significantly, I moved on to looking at what VEs these requirements are ties to. The nature of how these VEs are signed off means that as long as one requirement in a VE has a software stakeholder on one of the requirements that would be ok. This is because someone that signs of signs off for the total VE, not for a specific requirement. So I filtered out all of the requirements that were always tied to VEs that have requirements that have a software stakeholder.

Another task given to me was to help setup a PowerPoint presentation for the CCP manager to present to a board of all the center directors and the NASA director at headquarters. This meeting is a yearly update to show the progress to the Program. For my task I started with the presentation from the previous year. So I first scrubbed the data from the previous year leaving only the template. I then went through the previous years and put together a draft for the slides from the previous 4 quarter progress reports. The draft was then brought up to the manager of CCP to get her thoughts and amendments. A lot of my time was spent finding relevant pictures for the tests and hardware updates for each Partner. I also spent time meeting with the certification leads for each Partner to ensure that the main highlights from tests and hardware milestones were presented in the meeting. I also met with those in charge of the metrics. The purpose of these meetings were to fact check the numbers presented in the slides. Another objective for the meetings were to determine the most important uncompleted items from the past year. This activity really helped me get a feel for the progress the Program has made over the past year. Below are some of the pictures that I pulled together. These show various verification and qualification tests.
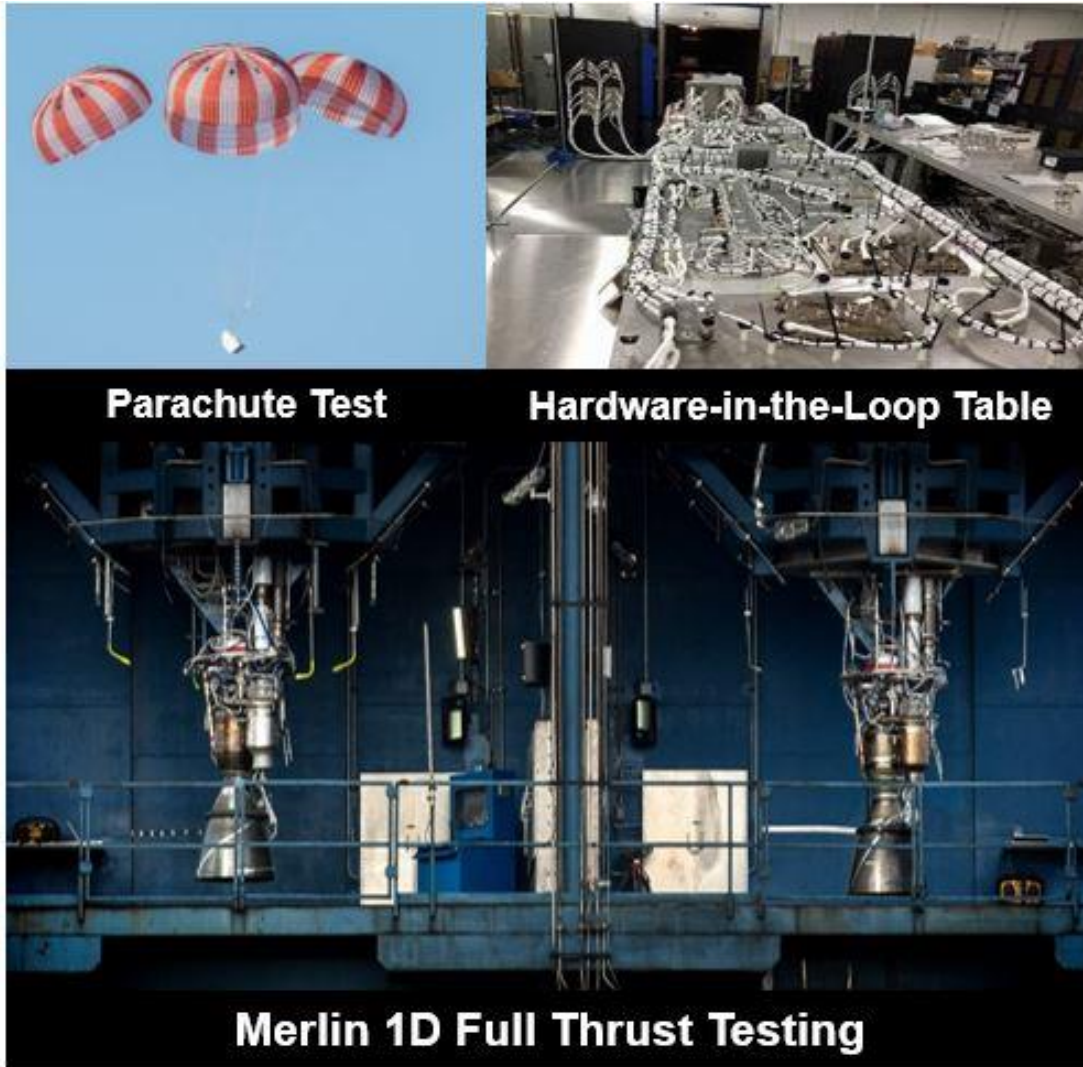
Figure 2. An excerpt from the annual review charts put together, also showing actual verification events.

I have received a lot of exposure to the manufacturing of spacecraft. I have been in many meetings where this hardware is being discussed. I was able to tour the building where one of the Partner's is building their spacecraft. Another opportunity I received was to tour the launch pad of another Partner. The launch pad was the historic LC-39A. There have been over 100 launches from this pad including all of the moon landings, the first and last shuttle launches, and is now being utilized by a private company to launch cargo to the ISS. It was very interesting to see an active Launchpad and all of the hardware that is there. Seeing all of the actual hardware puts all of the integration work, and all of the lessons that I have learned in school into a real world perspective.

I was also tasked to an in-depth look at the VEs that will be closed in the coming months. This was a rather tedious task that involved going into the NASA database and pulling out all of the data that relates to these VEs. The data that was pulled out was placed in a table. The table was broken down by system office. Each requirement needing to be closed for this VE is listed under what office owns that requirement. This table was displayed in PowerPoint charts for easy explanation of complex VEs. The RO for each requirement was listed as well as the signatories for each individual requirement. In addition to all of the 1130 requirements, I also added the ISS requirements that are also being accomplished for the VE. The picture this expanded view gives really helps the systems offices coordinate these complex VEs.

My experience here in CCP has taught me why systems engineering and the work of integration is vital. Because space travel is inherently risky, there is no way that the risk can be zero, but the question that this Program deals with is how much risk can be accepted. The loss of crew risk is a balancing act between being too stringent and making the mission overly cumbersome, and putting the crew at unnecessary risk. . The end goal of the systems engineering and integration it to lower the risk by ensuring that all of the parts are communicating and that one knows what the other is doing. In our smaller group the V&V team works with the System offices to make sure the contract requirements are met team. The V&V team also creates tools to help them get a quick and easy visual to help the teams in the integration process.

The Commercial Crew Program is the first of its kind. NASA is acting more like a regulatory agency than the builder. While in the past it was not uncommon for NASA to subcontract out parts of the mission, in this program NASA has given the task of designing, testing, operating, and maintaining entirely to a company and not the government. This has led to some interesting issues. NASA is still learning how to take a backseat. While other NASA programs have successfully taken cargo to the ISS, manned missions are significantly more complicated and require more safety and oversite.

III. Conclusion

In conclusion I have taken on and completed many tasks for the CCP office. I have also learned many things about the systems engineering process. These lessons that I have learned and the actual hardware that I have seen are invaluable to my education. The main project that I had for the internship was the excel spreadsheet. This serves as a vital tool for the personnel in the SE&I team. I have helped improve a tool to allow the V&V team to quickly communicate with the rest of the team and show more information about certain VEs. This is especially true for those VEs that have a large amount of data or have many requirements and system offices and therefor require a large amount of integration. I have also taken on tasks ranging from verifying that all VEs calling out software have a software stakeholder to helping build a PowerPoint for the CCP manager to give to the NASA director. This internship has given me to see the production of spacecraft, active launch-pad, and multiple commercial launches from the spaceport. All of these activities have helped further my education as an aerospace engineer. The actual integration of space systems is something not easily taught in classes. I also learned a great deal from the exposure I had to some of the philosophical discussions that accompany working in a manned space program. I have had a great time in Florida and when I complete my studies I look forward to working in the space industry.

References

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