# Learning Reverse Engineering and Simulation with Design Visualization

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John F. Kennedy Space Center
Major: Aerospace Engineering
Reverse Engineering and Simulation Spring Session
Date:  13 04 2018

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**Abstract**

**The Design Visualization (DV) group supports work at the Kennedy Space Center by utilizing metrology data with Computer-Aided Design (CAD) models and simulations to provide accurate visual representations that aid in decision-making. The capability to measure and simulate objects in real time helps to predict and avoid potential problems before they become expensive in addition to facilitating the planning of operations. I had the opportunity to work on existing and new models and simulations in support of DV and NASA's Exploration Ground Systems (EGS).**

## I.  Introduction

The world is too complex for any school to teach students everything they need to know before graduating. Therefore, it is beneficial to gain real-world experience through internships and projects. From January to May 2018, I had the opportunity to enhance my learning as an intern with the Design Visualization (DV) group at the John F. Kennedy Space Center. It has been an incredible experience not only for the hands-on learning but for the chance to support Exploration Ground Systems (EGS) as NASA readies the Space Launch System (SLS) and Orion spacecraft to carry human explorers farther than ever before. This report outlines several examples of how my learning has gone outside of the classroom as I completed tasks involving existing models and the creation of new models.

## II.  Working with Existing Models

This internship provided me the opportunity to deal with models far more complex than anything I had previously seen. All the CAD models I dealt with were in a program called CATIA V5, where CATIA is an abbreviation for Computer-Aided Three-Dimensional Interactive Application. The Interim Cryogenic Propulsion Stage (ICPS) and the Mobile Launcher (ML) are two examples of CATIA models that I worked on.

### A. ICPS

One of the first tasks assigned to me was to apply materials to a model of the ICPS.  This model was obtained from United Launch Alliance (ULA) and contained details down to the screws, nuts, and washers holding the ICPS together. These thousands of parts came in all colors of the rainbow and needed to have materials applied to them so that a presentable model could be used for planning in meetings.

While working with the ICPS model, I learned to use the product selection mode to select products and then apply materials from a material library that I was given. One of the challenges was to navigate to select internal parts and parts in tight spaces. To address this, I moved parts to the hidden space after texturing them so that they would not be an obstacle to selecting un-textured parts. Using this approach, I could more easily select parts to apply materials and ensure that all parts were being textured. This work also showed me a problem with CATIA V5 that I had not previously experienced or known about. It takes time to apply materials and when selecting parts by the hundreds or thousands, it took several minutes to complete the operation. For example, applying a material to 300 or more screws, washers and bolts could easily take 10 minutes and when I had over a thousand parts selected, I could expect it to take around 20 minutes or more. I later found that some sets of screws were contained under the same product and that texturing only the highest product level containing those parts could be done in a couple of seconds. Another adjustment I made while working with large CATIA models was using the save management feature. When I learned CATIA at school, the models were simple, and I did not have to worry about accidentally overwriting parts. Due to

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the complexity of the ICPS model and the possibility of overwriting another person's work, I had to use the save management feature to ensure I was only modifying the top-level product.

### B. ML

Updating an existing model of the Mobile Launcher (ML) was easily the most time-consuming project I worked on this spring, but it was interesting learning about the ML systems as I worked. Starting with a class 5 model (A low detail model omitting things like screws and bolts and not as detailed as a class 3 or lower model) containing over 10,000 parts, I was tasked with applying materials and selection sets to the model. This is necessary so that an up-to-date model can easily be used to plan processes or solve problems in the future.

To recreate selection sets, I attempted to use DV's custom CATIA tool to export selection sets from an older model and import them into the current one, but this failed due to the renaming of parts between models. This meant that I had to manually apply materials and selection sets. I found that the search tool helped to some extent after I learned how to use it, but I abandoned this approach after realizing that I was selecting parts and products that I did not want. It was also challenging at times to know what to deactivate when duplicate parts were present because some duplicates had matching part and instance names meaning that both would be deactivated at the same time even if only one was selected. Deactivated parts also caused errors when trying to export selection sets as CGRs (lightweight visual representations of objects). To fix this, the selection sets affected had to be recreated, which was done quickly by isolating parts



**Figure 1.** *The updated class 5 ML with materials and selection sets*

in the visible or hidden space, selecting them, and making a new set. With all modifications done, the final model (figure 1) shows 7,903 parts grouped into 47 selection sets.

## III. Creating Models through Reverse Engineering

There are several occasions when a model is needed, but an accurate model does not exist. This is when reverse engineering using laser scanners is useful.

### A. Hydraulic Pressure Cart (HPC)

One such reverse engineering task was to create a model of an HPC that is in High Bay 3 of the Vehicle Assembly Building (VAB). The Surphaser was used to scan the cart. To do this, scan targets were positioned on tripods and magnets around the cart before the scanner could be used to scan the cart from various positions. Scan targets are white spheres of known size that can be identified by software when processing the scan data later. I learned that it is important for each scan to include at least 3 targets from the previous scan so that the scans can be registered later. Another consideration is that a scan should not start facing a target because a slight overlap occurs when the scanner

rotates, and the target data might not be recognizable if the overlap is not clean. The Surphaser, like other scanners, has a setting to determine the scan resolution in scan lines per degree. Resolution affects the time required for a scan, so the user must decide how to trade-off the level of detail in a scan with the time it takes to scan. For the HPC scan, each scan took around 12 minutes. We also took photos of the HPC cart to help with modeling and texturing.

After scanning, the data was processed and given to me in the form of an E57 file. This file stored the point cloud, which I imported into CATIA V5 using one of Design Visualization's custom tools (see figure 2). At first, I was not certain of the level of detail needed, but I learned



**Figure 2.** *Point cloud of HPC scan that has been processed in RealWorks and imported into CATIA*

to focus on overall dimensions of the object in addition to outlets and controls. I also learned to use the compass to move parts (The compass is not a tool I needed when modeling objects for assignments at school.).

After creating the geometry, I learned how to apply image textures to the model from the pictures taken earlier. I learned on my own that CATIA V5's Photo Studio workbench includes a sticker tool that allows images to be mapped to the surface of a model. I thought this was how to apply image textures to models for DV, but I was told that it breaks on large models when I asked about using it. Instead, DV showed me the method they use for adding image textures. It involves creating a thin new part that is snapped to the model surface and given a material with an image texture. The final model is shown in figure 3.



**Figure 3.** *Model of a HPC cart from scan data*

### B. Laser Tracker

Another scanning and modeling task came to me from a customer's need to position a laser tracker on the High Bay 3 platforms. The laser tracker is used to determine the initial coordinates of Space Launch System when it is in the VAB. This information is necessary for an avionics box inside the rocket to calculate the position of the rocket internally, so the rocket can know where it is even if external tracking is lost. A model of the tracker was needed to



**Figure 4.** *The laser tracker is in the middle surrounded by spherical white scan targets. I was standing out of the way as the Surphaser on the right was scanning. Behind the camera is Devin Swanson who helped me with this scan.*

decide on the tracker's positioning so that the laser could shoot through a service hatch in the vehicle.

First, the tracker was scanned by the Surphaser from 3 positions. Figure 4 shows the scan setup. Each scan took around 12 minutes. After scanning, the raw scan data was processed in RealWorks. I relied on documentation and other DV members to process the data as this job was my first time using RealWorks. The process started by importing all the scan files and then registering the targets with the "Auto Extract Targets" tool. This prompted for the type of target used (200mm spherical) and a reference scan station. RealWorks then found the targets in each scan and matched them, which resulted in all 3 point-clouds being aligned and placed in the same coordinate system with the reference scan station serving as the origin. From here, points were extracted from the scans using the "Scan Explorer" window. The easiest way to select the needed points for extraction was with
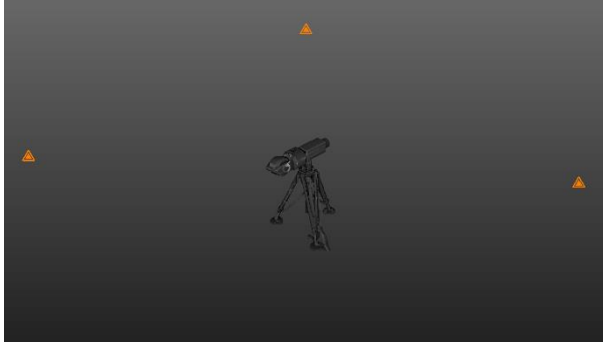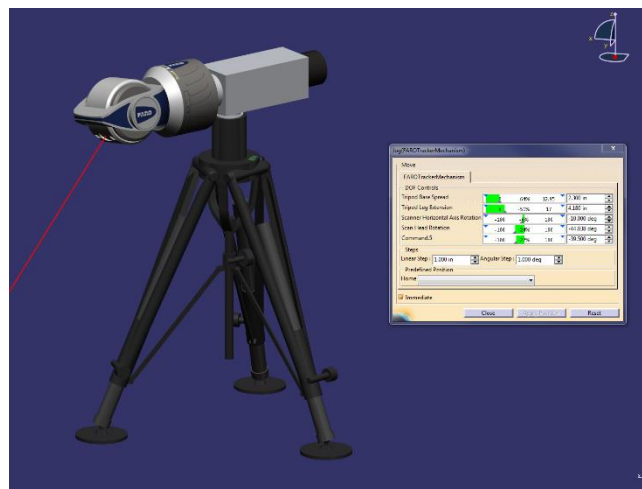
**Figure 5.** *Processed point cloud of the laser tracker in RealWorks. The orange triangles represent the scanner locations.*

a "Key Plan," which is a top-down view of the scan. After extracting the area that included the tracker, more points were removed by selection until only the tracker's point cloud remained. A new coordinate system centered on the tracker was made by fitting shapes to the point cloud. This simplified modeling later. The processed point cloud is depicted in figure 5.

The tracker was modeled from the point cloud like the HPC, but this time kinematics were applied. I learned how to use kinematics from a book during week 2 of this internship. This provided me with an understanding of joint types, degrees of freedom and how to constrain parts so they can only move in desirable ways. Even with this working knowledge, a couple of problems were encountered. After applying geometry-based joints to the

tracker, I realized I could not move parts in the product tree without breaking joints and needing to re-create them. This is when I was told to use axis-based joints, which I had not encountered in the textbook I read earlier. Also, the handles that are created to jog a mechanism were reversed so that clicking and dragging the arrows to move a joint one way only made it move the opposite direction. After experimenting with joint creation for a while, I found that the order of geometry or axis systems selection affects the handle direction. For example, the tracker needed to rotate horizontally on the tripod. From the frame of reference of the tripod, the tracker should rotate and so the tripod's reference geometry or axis system should be selected first in the creation of a revolute joint. When these problems were solved, the final model (figure 6) was used to help the customer determine where to place the tracker on the VAB High Bay 3 platforms.



**Figure 6.** *Completed laser tracker model with image textures and kinematics*
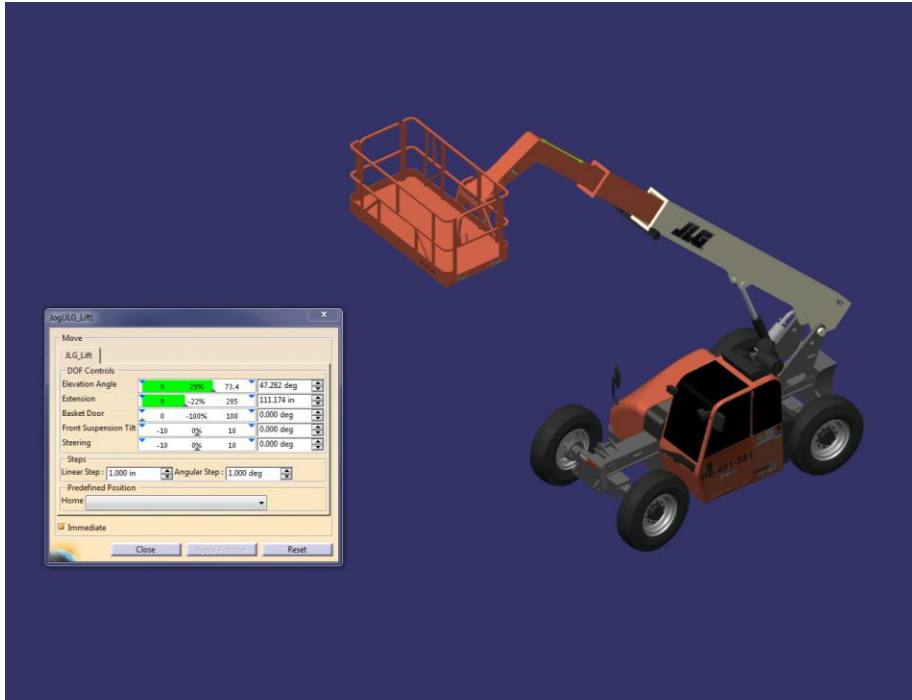
### C. Man Lift

More experience in reverse engineering was made by modeling a man lift that will be used in the processing of the SLS core stage. I used a TX-8 to scan the man lift in an extended and then retracted position. Four targets were placed on tripods around the lift and several others were magnetically attached to the lift itself. The lift was retracted for 6 scans after conducting 6 scans with the lift fully extended. A small problem resulted from retracting the lift because the vehicle and the spheres attached to it shook violently in the process leading to higher fitting errors in RealWorks when registering the scan later. For this reason, I unmatched the targets on the vehicle and used only the 4 tripod-mounted ones. I performed a station-based extraction of points so that the resulting point clouds could be merged into two separate ones for the retracted and extended lift positions as shown in figure 7.

I encountered difficulty when creating kinematics for the man lift because a piston-arm mechanism that raises the basket caused a build error when jogging the mechanism. To solve this, I tried to check the alignment of the axis systems, experiment with joint combinations and create a simple model in another CATIA session to show that the joint combinations worked. None of this solved the problem. Kinematic relationships were used to drive other joints in the model and so I decided that the same might need to be done for the piston and arm. A discussion about the problem with DV revealed that CATIA's chain link solver function stopped working as soon as kinematic



**Figure 7.** *Man lift scan data in RealWorks with both the extended and retracted lift point clouds. The green plane was fitted to the lift arm and used to create a user-defined coordinate system.*

relationships were made to keep the lift's basket level. This was the cause of the build error and the solution was to add kinematic relationships to all joints without commands. Defining the kinematic relationships for the piston and arm was not difficult because the parts make a triangle. That said, I had some confusion involving angle units for kinematic relationships because CATIA's documentation does not clearly state that radians are used regardless of the user setting all angle units to degrees. All these issues were solved after a while and the completed model is seen in figure 8. The lessons I learned while creating this model will help me in the future, and I hope they help others as well.



**Figure 8**. *Completed CATIA model of the man lift with the piston-arm mechanism defined using kinematic relationships*

**D. SRB Aft Skirt**

The ROMER Absolute Arm is another metrology instrument that I learned to use during my internship. To begin, there is a mock-up solid rocket booster (SRB) based on those of the Space Shuttle in the VAB. Although similar to the Space Shuttle SRBs, the SRBs that will power SLS have modifications. For this reason, a group requested a 3D-scan of the mock-up aft skirt so that an umbilical attachment could be printed and attached to more accurately reflect what SLS will have. The ROMER arm was chosen for its ability to scan corners and create a mesh that can be exported as a 3D-printable Stereo Lithography (STL) file.

Scanning with the ROMER arm differs from scanning with the TX-8 and Surphaser because of the proximity to the object being scanned and ability to move the scan head. We set up the ROMER arm beneath the section of the aft skirt that needed to be scanned and completed the scan. Since the ROMER arm scanner operates at a short distance from the object and the part to be scanned was above our heads (see



**Figure 9.** *The author using the ROMER arm under the SRB aft skirt. On the left is Rich Overleese and behind the camera is Devin Swanson, who both helped me tremendously during the internship.*

figure 9), it was tiring and awkward at times to move the arm. Nevertheless, we produced what the customer needed, and I enjoyed learning to use the ROMER arm while standing beneath a SRB.

## IV.  Conclusion

This internship experience has been an interesting and unique learning opportunity that is unlike anything a student can find at school. I encountered and overcame challenges in the work done this spring, which has made me more effective at CAD modeling and simulations. The methods I learned for making kinematics and texturing in CATIA have unique advantages that I would probably never learn at school. I received an introduction to RealWorks, which I was unaware of before this internship and I now understand the usefulness of 3D scanners and trackers in engineering. In the remaining three weeks of the internship, I hope to learn more about metrology and CAD modeling in addition to 3D printing, the wiring harness assembly in CATIA and inverse kinematics. I hope to use the skills gained from this experience in the future to contribute to solving the world's engineering challenges and specifically America's space exploration goals.

### Acknowledgments

Thanks to Adam Luchner, Alden Pitard, Devin Swanson, Jeffrey Bonggren, Rich Overleese, Robert Edwards and Robert Humeniuk of the Design Visualization team.

Additional thanks to David Macon for mentoring me.