

Applications of Modeling and Simulation for Flight Hardware Processing at Kennedy Space Center

Jessica L. Marshall

Rensselaer Polytechnic Institute, Troy, NY 12180¹

I. Abstract

The Boeing Design Visualization Group (DVG) is responsible for the creation of highly-detailed representations of both on-site facilities and flight hardware using computer-aided design (CAD) software, with a focus on the ground support equipment (GSE) used to process and prepare the hardware for space. Throughout my ten weeks at this center, I have had the opportunity to work on several projects: the modification of the Multi-Payload Processing Facility (MPPF) High Bay, weekly mapping of the Space Station Processing Facility (SSPF) floor layout, kinematics applications for the Orion Command Module (CM) hatches, and the design modification of the Ares I Upper Stage hatch for maintenance purposes. The main goal of each of these projects was to generate an authentic simulation or representation using DELMIA V5 software. This allowed for evaluation of facility layouts, support equipment placement, and greater process understanding once it was used to demonstrate future processes to customers and other partners. As such, I have had the opportunity to contribute to a skilled team working on diverse projects with a central goal of providing essential planning resources for future center operations.

II. Introduction

While traditionally CAD is used to design individual innovations from the ground up, it can also be used to model existing hardware as an important tool in the planning process. Its purpose is still the same: to aid in the visualization of ideas and concepts in order to gain a greater understanding of prospective options for resources. This is the mission of the Boeing DVG. When a facility, or customer, is looking to import new machinery into their current space or modify their existing hardware, they look to DVG to provide an accurate representation of the future operations and setups. This can be accomplished in terms of either stationary models or simulations of whole processes. This modeling helps customers to implement new hardware, enhance the decision-making process, and streamline their processes.

Boeing DVG uses a CAD package created by Dassault Systemes, a French company that combined the modeling program CATIA V5 with the simulation program DELMIA V5. The main benefit of both software elements being produced by the same company is their compatibility with one another. Models can be created in CATIA and imported into DELMIA simulations while retaining all attributes with which they were originally designed. Additionally, the CATIA/DELMIA package is one of few existing CAD packages that can handle the large size of the final simulation files. As such, when DVG receives hardware that was designed in another CAD program, such as ProEngineer (ProE), the file is then translated into CATIA using a custom software package. Consistent use of the software allows for models to remain cohesive with one another given any future design modifications.

Models created in CATIA can be anything from a single five-gallon bucket to an entire high bay. Models of facilities incorporate as many details as possible into the design, so as to provide a truly accurate representation of the actual, or what will be the actual, setup. Models of individual components are often created using photographs of existing machinery, engineering drawings, hand-drawn measurements, or point clouds from a laser scanner. These components are then compiled into full-facility models and used to plan for available space or modify current hardware locations. This practice can be also be used for flight hardware, systems, and vehicles, in order to represent operations for flight hardware processing on site.

¹ NASA USRP Intern, Boeing Design Visualization Group, Kennedy Space Center

Another important element to accurate modeling is kinematics simulation. CATIA utilizes a kinematics package called Digital Mock Up (DMU) Kinematics. This workbench is used to add motion and simulation commands to the model components while still in the CATIA program. An example of this is adding kinematics commands to a model of a flight seat to allow for adjustments that will be made to the heights of the restraints for astronauts of different sizes. DMU Kinematics provides several different joint options that simulate realistic motion with limits set by the user. This allows the user to replicate the motions of both individual components and entire products for use in simulations. It also allows for visualization of the commands and limits of each motion and helps in determining the accessibility and clearances of the components when they are viewed in their respective positions.

These models, combined with their kinematics commands, are used to create simulations of the processes that will be carried out by the customers. They are presented to the customers interactively using either DELMIA V5 or high-definition (HD) video files created using the software. These demonstrations allow customers to see their plans in a three-dimensional context. The DELMIA simulations illustrate the processes and show how the individual hardware components will interact under the assigned scenarios. Meetings in which the simulations are shown allow for customers to give feedback and discuss issues and concerns based on the new representation. Ultimately, DELMIA allows the entire room to see the same "big picture" and thus ensure that everyone is on the same page when discussing the future plans.

In working with DVG, my focus has been centered on four particular projects. The Multi-Payload Processing Facility (MPPF) is used for servicing equipment for space payloads, and is the planned center for future Orion operations. Thus, the facility had to be reworked in order to provide the proper space and connections for Orion servicing operations and ground support. My objective was to modify the panels and additional components of the south wall of the MPPF High Bay according to the planned needs of the Orion program. This involved translating locations of elements from both engineering drawings and ProE, creating new components as needed, and adding the appropriate textures taken from photographs of actual materials.

I was also involved in the weekly updating of the Space Station Processing Facility (SSPF) model. Each week the leads of the facility meet to discuss plans for adding, removing, or relocating hardware. In order to base decisions off the most current data, members of DVG walk the SSPF High Bay and Intermediate (I) Bay and note the location of each component in the facility. We then update the models using Design Vis software (a modeling program that works with CATIA and DELMIA) and produce drawings for the next week. These drawings are then used to assess available space for prospective projects.

In terms of kinematics applications, I had the opportunity to work with the Orion Command Module (CM) and the Launch Abort System (LAS) in order to get the hatches to open and close. Each hatch is designed with a system of complex hinges that must be operated simultaneously to recreate the realistic motion. It is necessary for simulations of Orion servicing to have a modeled hatch capable of several positions in order to determine the accessibility of the hatch from the service stands and design for the optimal locations of all connections and access areas. In order to make this model as accurate as possible, I also added the appropriate textures, or materials, to the components based on existing models.

My last major project was to demonstrate the addition of a maintenance hatch and frame to the structure of the Ares I Upper Stage. When servicing crews operate on the Ares I Upper Stage, they gain access through a main door on the outer structure of the section. There is concern that repeated access through this door would result in increased wear and fatigue on the components of the flight door, thus reducing its life. I was asked to model an additional frame component that would allow for a separate maintenance hatch to be added to the Upper Stage during processing. The hatch could be removed and replaced as often as needed while preserving the flight structure, and the flight door would then be reinstalled once servicing was completed.

Each of these objectives utilized different capabilities of the CATIA/DELMIA package. However, each had interesting applications and demonstrated how CAD modeling can be an essential planning resource.

III. Procedure

A. MPPF High Bay South Wall

For the modification of the MPPF High Bay South Wall (which was my primary focus) I was given both engineering drawings of the 90% updated plans for the wall and a ProE file mapping the prospective locations of all the panels. These drawings were generated using AUTOCAD software (another modeling program) by the contractors that will be completing the work on the High Bay. The original AUTOCAD file was converted to a ProE file, and then finally imported into CATIA later on. The draft of the wall was divided into three drawings: one showing the mechanical components and assemblies (ex. nozzles and doors), one showing the electrical (ex. power supplies and lights), and another showing all of the elements combined. Additionally, I was given a drawing depicting the items from the current arrangement that are to be demolished in order to allow for the new setup. Combined use of the drawings gave me a full view of the wall and a better understanding of the overall plans for the modified layout. Also included in the drawings were details of the individual components, which were crucial to importing and creating the new parts for the assembly. A photograph of the current layout of the south wall is shown in Figure 1.



Fig. 1. Current MPPF High Bay South Wall

The ProE model provided a significant resource for obtaining measurements of the locations and dimensions of each component. Where the printed drawing could at times be difficult to comprehend based on its small print size, the model allowed for zoomed-in views of any section of the model. The outline of the ProE design was overlaid into the CATIA model of the south wall, which allowed me to match the locations of the components and their measurements to the original plans with complete accuracy. Once again, the designs were separated into the three sections: mechanical, electrical, and the total assembly. In the CATIA model these could be turned on or off at will, in order to focus on the component at hand and reduce clutter.

The first step to modifying the wall was to compare the three drawings and note what needed to be added and what needed to be relocated or removed. While the overall drawing that combined the mechanical and electrical components was fairly accurate, it was still necessary to analyze any differences between the drawings to ensure that nothing had been missed in the final printed drawing. As such, there were several components that appeared in either one of the section drawings or the ProE model that did not appear in the overall drawing. These were added along with the other modified components, including several panels and cabinets, nozzles, breathing air units, doors, a cable tray, and other assorted elements. Any existing hardware that did not appear in the modified drawing was either deleted or hidden for future consideration, if it was deemed likely that it could be replaced later on.

Each new assembly (or component) was created in a way that it could be relocated in the future by another user. Every part was based off the same coordinate system and moved from a central point, so that it could be moved in the future without disrupting any other elements of the model. This is important for any potential modifications that will be made, particularly because it should be designed such that anyone working with CATIA should be able to quickly update the model in the future.

Each new part was created as an extruded solid so that it could be saved for use in any model made through CATIA or DELMIA. Even inset panels and the wall itself were converted to solid parts so that they would act as three dimensional components. When possible, preexisting assemblies were imported into the design to retain consistency between the servicing hardware used in the facilities. The measurements were obtained from the

outlines of the ProE design using either the measurement tools or constraints that were later converted into isolated dimensions. Any additional measurements, such as the diameter of a particular nozzle, came from real data of existing hardware. It was necessary to include not only the locations of the panels (for use in determining the connection points of the service stands) but the protrusions of certain aspects of the wall (such as the nozzles or the cable trays). This, when combined with the rest of the MPPF High Bay assembly, allows for analysis of any interactions that should be noted or any interferences that may occur. This model is a tool in determining the optimal placement of the ground support equipment (GSE) and helps streamline the servicing process.

The final step was to add the materials, or textures, to the parts to create a realistic view of the wall. The majority of the textures, such as panel covers and doors, were taken from a facility material library containing textures specific to the MPPF High Bay. This library was created by taking photographs of the desired materials and converting them to CATIA material files using Adobe Creative Studio (CS). These textures were applied to each component and individually sized to match the dimensions of the part. Textures can be anything from a flat, black panel door to the lettering on an exit sign. Several of the panels, however, required specific labeling of their contents. In this case the lettering had to be created separately in Adobe CS and converted into a CATIA material file. They were then added to their respective parts and sized accordingly. The textures help the viewer to fully visualize the different elements of the wall.

B. SSPF Mapping

In order to support members of DVG and the SSPF facility operators in their weekly Monday planning meetings, I would walk down the High Bay (shown in Figure 2) and the Intermediate (I) Bay of the SSPF every Thursday morning. The area is separated into eleven footprints: eight in the High Bay (numbered from 1-8) and three in the I-Bay (labeled east, center, and west). These were divided among four members of the DVG team (myself included). We would walk the area before the bulk of the SSPF workers reported to work, so as to limit the congestion of the area and gain a clear, stationary view of the updated space before any hardware was moved for use during the day.

Each footprint contains a combination of large hardware (ex. servicing structures), small hardware (ex. equipment racks and cones), and flight hardware (International Space Station modules and components). While the servicing stands are fairly permanent and the flight hardware does not move often (in eight weeks only once was a module relocated), the smaller items are moved around quite often, either in daily use or to make room for new equipment. Most areas are contained by a series of ropes that can be moved around to redefine the confined section. The drawings take into account the locations of these ropes and show how the facility is making use of each of these spaces.

I was generally given three footprints to focus on during our walk down. I noted the locations of each item on a printed drawing. We would try to complete our work as quickly as possible, so as to not obstruct any work that needed to be performed in the facility and to maximize our own productivity. This being said, we would try to use consistent notation, checking off each item as it had appeared the week before and sketching in new items. Each member developed their own notation for use in updating the drawings later that day.

We used Design Vis software to update the facility drawings. This program is of an older design and is thus rather difficult to navigate, however a member of the DVG team designed an interface for the program to enhance the user compatibility. A seed file is used which contains the overall layout of the SSPF. Into that model a work cell is loaded, being one of the eleven footprints. The loaded work cell shows all of the existing items and locations based on the previously saved model from the week before. Because of the design of the program, it is generally necessary to follow a disciplined process in updating the footprint. For example, the program's version of



Fig. 2. SSPF High Bay

the "Undo" command only allows for one return step. Therefore it is important to be careful in updating the facility, particularly when deleting components.

The model is often best viewed from the top of the work cell, and commands are provided in the interface to quickly jump to a convenient view for each footprint. Commands for selecting, translating, and rotating an item allow for existing elements to be moved about the drawing and placed in their new positions. Removed items can also be deleted using the respective command key. A component library can be accessed through the software, containing hundreds of hardware elements that were created using the CATIA modeling software. These components include anything from a badge board to ladders of several sizes to entire module servicing stations. Each component can be imported into the work cell and positioned appropriately using the command icons.

Finally, a saving process is followed to ensure that no parts have been accidentally placed outside of the footprint boundaries and that the file tree is organized. Once the files is saved it can be printed out to be evaluated at the next planning meeting and used for the next week's walk down.

C. Orion Hatch Kinematics

The Orion Command Module (CM) is composed of several elements, including the interior, the pressurized shell, the unpressurized equipment, and the exterior. Attached to the CM is the Launch Abort System (LAS), which allows for the crew to escape should anything go wrong within the first moments of their launch. The LAS is also divided into an interior and exterior model. Both the LAS (shown in Figure 3) and the CM are accessed through hatch doors that align with one another for entry on the launch pad. To demonstrate the launch process and test any limits on the swing degree of the hatch door, it was necessary to apply kinematics to the model.

Each hatch is designed with a system of complex hinges composed of eight major links. The hinges function simultaneously and are mounted to the inner frame of their respective modules. The CM incorporates a piston assembly into the function, allowing for added support to the hinges upon opening the hatch. The LAS uses a ball joint, operating upon the same principle. Both hatches are set to open to a predetermined limit so as to not interfere with any servicing equipment, or even one another.

The first step was to analyze the individual components and restructure the product tree in the CATIA file. Each product is composed of several parts, and each component in the hinge is generally isolated to its own product. To apply kinematics to a model, each product must be at the top level of the assembly (i.e. it cannot be a sublevel of any other product). To do this I separated the components of the hinge from the rest of the hatch assembly and created new products from them. I then examined each element to determine how it would function in the hinge command. The DMU Kinematics workbench allows the user to either convert existing constraints to joints or create joints manually. For this particular assembly I chose to create the joints manually, so as to limit any undesired constraints that could be generated by the automatic function.

The hinge is primarily composed of revolute joints. Any parts that were set to move together, or that were meant to remain fixed either to the frame of the CM or the hatch door itself were assigned a rigid command. The motions of the piston assembly and its associated constraints and joints were also incorporated into the hinge mechanism. After adding the joint constraints to each part interaction the mechanism is left with one degree of

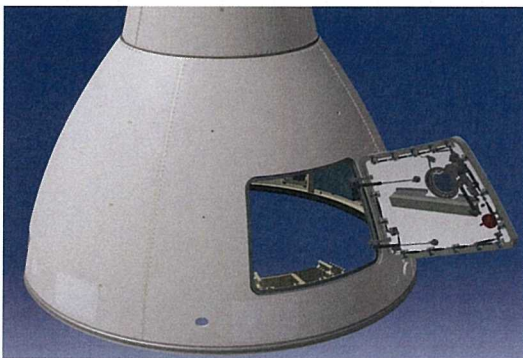


Fig. 3. Orion LAS Exterior with Open Hatch

freedom (or direction of movement), which in this case was its ability to rotate. Because this was the desired motion, a command was added to the rotation of the part attached to the fixed portion of the hinge to make it angle driven. This angle was set to an arbitrary value in order to simulate the hinge, but was later changed based on observations of the interactions between the hatch door and surrounding equipment. When the mechanism was reduced to zero degrees of freedom, it was able to be simulated, and the motion of the door could be produced on command. Finally, the mechanism application was imported into the top level of the assembly (i.e. the entire CM exterior file).

The same process was also followed for the LAS exterior hatch, which operates under the same function. The main difference between the two was the replacement of the piston assembly by a ball joint, which utilized a spherical joint in the kinematics of the assembly.

The last step was to apply textures to each of the files. Because this was one particular revision of the Orion design, textures could be copied from previous versions of the capsule in order to retain consistency between the models. The way products are established in CATIA, any materials assigned in the top level of the assembly will only show up in that level. Thus, if you were to open the hatch door outside of the central model, it would not appear to have any materials assigned. Instead, it was necessary to open each product of the top level assembly individually, apply the appropriate materials, and then import the links to the textures back into the main file. While the hatch door kinematics only needed to be applied to the CM and LAS exterior, the textures needed to be applied to all sections of the Orion design (with the exception of the Service Module (SM), of which I did not work with as part of this project). Textures for the Orion assembly are stored in their own CATIA material library, along with materials for the Ares program.

I tiled the windows of CATIA so I could view both versions (the textured and the non) alongside one another. I then matched the material files at each level they appeared for each individual element. When completed, I then imported these textures back into the top level product, producing a model with significantly more realistic appearances.

D. Ares I Upper Stage Hatch

For the hatch on the Upper Stage (US) exterior, it was desired to add an extra frame component to the existing structure so as to place a maintenance door in the place of the flight door. The flight door is attached to the frame of the US exterior with a series of bolts. Every time the ground servicing crew wants to access the US interior they must remove the flight door and replace it at the end of their work. These bolts take a considerable amount of time to service, causing the removal or installation of the flight door to take a lot of effort. Additionally, repeated accessing of the bolts applies additional wear and fatigue, thus reducing their life. The idea is to remove the flight door when the structure first arrives at Kennedy Space Center, install the maintenance frame and door for access throughout the duration of the ground servicing operations, and reinstall the flight door just before the rocket is taken out to the launch pad. A soft cover was also designed with simple snaps for short term maintenance use. Thus, the servicing operations would take less time and the quality of the US exterior could be preserved.

Several options were considered for the representation of the frame. A previous concept had been to add a large, rectangular frame to the outside of the US, installing new bolts into the exterior. It was determined that this idea resulted in unnecessary drilling and could be better optimized. The new frame was designed to be mounted to the existing bolt pattern with an inner row of bolts for the new hatch. This allowed for no impact to be made to the existing structure. In order to reduce the servicing time the number of bolts on the inner segment was greatly reduced, because the door and frame would only be used while on the ground. The model frame was created using 1/4" steel and was aligned to the outer structure and curvature of the US exterior. The texture for the steel came from the CATIA default library, which is composed of an array of metals, ceramics, and other assorted construction elements. The frame assembly was modeled as a series of individual sections that were joined together, in order to best fit the design of the structure. Care was taken to avoid any interference between the existing frame and bolts and the added elements. The inner row of holes for the new bolts was designed in a pattern that would reduce the number of bolts and not greatly affect the outer row that connected the door to the main structure.

The maintenance door (shown in Figure 4) was created to mirror the design of the flight door with the decreased bolt design. The number of bolts on the door was reduced by approximately 50%. The model was created from a single extruded part and was textured to match the orange of the US exterior. Handles were added based on the measurements of the flight door handles, which

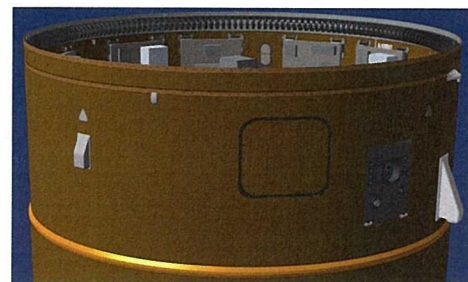


Fig. 4. Modified Hatch on Ares I US Exterior

were designed to be accessible on the servicing platforms. A soft cover was also modeled, as a solid piece using the same inner section of the new frame. This cover would likely be applied using snaps attached to the maintenance frame and would eventually be made of a flexible material.

This same design was also used for a similar hatch on the Ares I Inter-Stage (IS) model, with the only notable difference being that this particular hatch was set to match the white exterior of the IS. Each of these components can be hidden or shown at will, allowing the user to view different scenarios of the hatch assembly, which is then used in simulations of the various servicing processes. When completed, the products were saved to the file for use in future demonstrations.

IV. Results and Discussion

A. MPPF High Bay South Wall

When completed, 106 additions were made to the south wall. The majority of these items were service panels that will house power supplies and other operational equipment. Each panel was individually detailed and dimensioned according to its description in the AutoCAD drawings and the ProE file. Additionally, several items were removed from the wall, such as valves and other connections that will not be necessary for the new program. Many of these items that were deemed possible to be used again in the future were simply hidden in the model, so that they could be called back without the need of generating a new part.

While the outward facade of the modified wall appears cluttered, it will provide the appropriate interfaces and servicing supplies for the operations of the Orion program. Because of the large number of additions to the wall, many of the panels are within a marginal degree of one another. One of the purposes of modeling the wall in this way is to analyze the positioning of these panels and ensure that once construction occurs none of the connections will interfere with one another. The additions are detailed in Table 1 below. Listed are the quantities of each component that were added to the south wall of the High Bay. This includes the modification of the lower access door to a double door capable of the transfer of larger hardware. However, it does not take into account the specific items that were removed from the wall - these components were minimal as compared to the components that remained in the new model of the High Bay. Instead, the table highlights the large array of components that will be necessary for Orion ground support operations.

Table 1. MPPF High Bay South Wall Modifications.²

3	Doors (including modified double door)	4	Power Cabinets
1	Cable Tray	3	Potable Water (PW) Supplies
1	Fire Alarm (FA)	2	Control Electronics System (CES) Panels
4	Phone Outlets	7	Gaseous Nitrogen (GN ₂) Supplies
2	Graphics Processing Units (GPU)	3	Ground Cooling System (GCS) Panels
3	Test and Operations (TO) Panels	3	Ground Special Power (GSP) Supplies
3	Communications (COMM) Panels	3	Operational Television (OTV) Cameras
2	Kennedy Ground Control System (KGCS) Racks	4	Switches
3	KGCS Panels	3	Hypergol Vent Interface Panels (HVIP)
3	Exit Signs	14	Power Supplies
2	Power Conduits	7	Ground Operations Processing (GOP) Panels
5	Environmental Control Systems (ECS) Ducts	5	OTV Panels
1	Hose Reel	3	Breathing Air (BA) Units
2	Ground Plates	5	Timing and Countdown (TCD) Interfaces

Many of the connection points are intended for use by the Orion Crew Exploration Vehicle (CEV) service stands that will be constructed in the High Bay. The CEV is composed of the Command Module (CM) and the Service Module (SM). The service stands are designed with a platform for each level of access to the CEV. The upper doors on the wall of the High Bay reflect the egress points from the platforms. Egress stairs will be built from

² Acronyms: NASA Scientific and Technical Information (STI)

those doors to the outside of the building in the case of any emergency procedures. The panels and interfaces are designed to accommodate the needs of the service stands.

When the south wall (shown before and after modification in Figure 5) is combined with its five associated walls (ceiling and floor included), a model is produced of the entire MPPF High Bay. This is a crucial element in planning the operations of this facility, as any equipment that will be brought in can be analyzed in either CATIA or DELMIA so as to determine the optimal positioning of the components and connection points. Any clearances can also be tested ahead of time, so that there are no surprises when the actual components are placed in the High Bay. Even the ceiling with its lighting construct has been modeled in CATIA, allowing for a realistic view of the work space and accurate renderings of the room to be produced.

DELMIA allows the user to show the customer each step of a process via simulations and HD video files. For example, a simulation can demonstrate the transport of the Orion CEV into the MPPF, its installation into the service stands, and any procedures that will be followed in the servicing of the capsule (i.e. a hatch being opened for access by technicians). The simulation often includes modeled technicians that are created using the CATIA Ergonomics Design & Analysis Human Builder, which allows the user to place the body into any position necessary (ex. a kneeling technician vs. one reaching for an object). These modeled technicians are a valuable resource in determining the accessibility of the design, and thus affect the overall structure of both the process and the model itself. The tools in CATIA allow the user to explore a variety of options, testing clearances and measurements along with analyzing the general efficiency of the process, long before any of the steps are put into action. During meetings with the customers, the simulation is shown and directed by the people who model them, while the customers have the opportunity to express any concerns or changes based on the new data. This instantaneous feedback allows for open discussion of the best practices for the facility and a forum for determining new analyses that will aid in the design of the new operations.

B. SSPF Mapping

The model of the SSPF is similar to the model of the MPPF in that each piece of hardware in the facility is accounted for in the digital representation. Its purpose, along with that of the MPPF model, is to optimize the facility's utilization of space. The drawings produced by the Design Vis software are used, as well, as a tool for interactively presenting the layout for discussion. The difference is that while the particular MPPF model described previously is focused on future modifications, the model of the SSPF is based off of current properties and equipment. Additionally, the model of the SSPF is not entirely three-dimensional as the MPPF was, in that only the floor of the room is modeled, although the components placed there are in 3D.

The model (and the associated drawings) indicate the most up-to-date locations of all the equipment present in both the SSPF High Bay and the I-Bay. When the drawings of each individual footprint are produced they are shown at a weekly meeting in which the facility owners discuss plans for the building. The drawings allow the owners to note open spaces for any potential equipment or operations. They also provide a view of the space requirements for each existing operation. While in the past the hardware moved considerably more often due to the height of the assembly of the International Space Station (ISS), the current day-to-day operations are still motive enough to continue mapping the facility for process and usage optimization, as well as future facility use.

The Design Vis software that is used to generate these drawings is considerably outdated by traditional standards of display and user compatibility, yet it serves its function with simplicity and an interface tailored to the specific needs of the facility updating process. The component library is a valuable resource for retaining consistency, both within the models and between different facilities on site. For example, a ground plate that is used

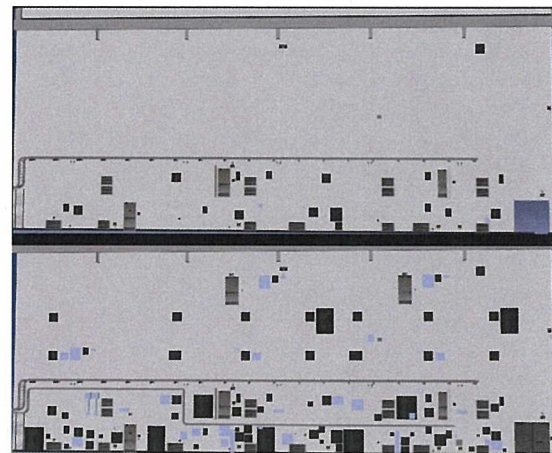


Fig. 5. MPPF High Bay South Wall Before Modification (Top) and After (Bottom)

in the SSPF is the same as the plate used on the wall of the MPPF. The library function helps to keep track of the parts that have been modeled, which increases the site efficiency in terms of time and effort. The Design Vis user interface is composed of simple commands that allow the components in each footprint to be moved, added, or deleted quickly and easily. This maintains the process as a productive means of equating equipment locations from week to week.

It is important, in any facility, to know how the available space is being used, and furthermore, to determine how that space can be best used going forward. The drawings produced of each footprint detail how much space is being employed by each individual operation. This is a resource for deciding the optimal locations for equipment and analyzing the means by which the facility can become more efficient. Week-to-week updates demonstrate the hardware housed in the SSPF over time, and can represent practices that either worked or needed to be improved, either of which are lessons for the future. The drawings are also tools for determining the positioning of flight hardware, most notably the large ISS modules. Because this program is an international partnership, drawings such as these can help other space agencies to determine how their hardware will assimilate into the SSPF construct, before it even arrives on center.

C. Orion Hatch Kinematics

The Orion CEV will be housed in the MPPF, as described previously. The service stands for ground processing of the capsule are established in the models, and are incorporated into the facility model of the MPPF High Bay. In order to perform analyses on the intended servicing procedures for the CEV, it is crucial to demonstrate any moving parts that must be considered before the actual construction occurs. The doors of the hatch must not interfere with any of the service stands and must also be accessible by the technicians responsible for the ground support. Simulations of the transport of the CEV into the MPPF, and out of it, require a CM hatch that can open and close, thus demonstrating the operations that will be performed on the vehicle prior to launch.

The same requirements are true for simulations of the Orion capsule on the launch pad, when it is combined with both the Ares rocket and the Launch Abort System (LAS). Because of the design of the CM hatch residing within the LAS, both hatches must open in a way in which neither interfere. Modeling, such as this, is used to check clearances on all aspects of the ground servicing process, from its initial transport in the MPPF to its assembly in the Vehicle Assembly Building (VAB) to access on the launch pad. These clearance checks ensure that the CM and LAS hatches will neither obstruct one another or interfere with any section of the mobile launcher. The same goes for processing within the VAB, in terms of stacking the components. Models and simulations demonstrate the complete launch process, step-by-step, and can help to cite any potential issues before they occur in practice.

The design of the hatch itself is also analyzed in this way. The motion of the hinges can be clearly seen through the CATIA commands and DELMIA simulations, and can thus be optimized. For example, when the CM is combined with the LAS and is presented on the launch pad, a clear determination can be made of the optimal degree of opening of the hatch. This angle can then be tested throughout all of the venues in which the CM will be accessed.

Texturing the CM and LAS, along with the rest of the flight components, allows both the user and the customer to have a clear understanding and vision of the process at hand. This is shown in Figure 6. Simulations in which the elements appear as close to accurate reality as possible limit confusion and produce more effective meetings and presentations.

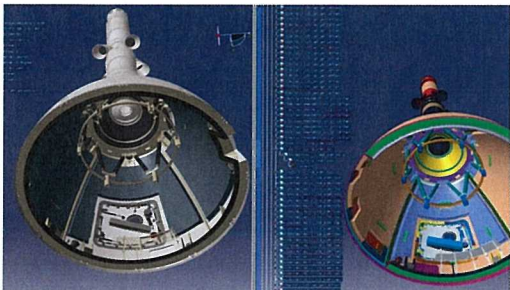


Fig. 6. Texturing of the Orion LAS Exterior (Left) as Compared to Original Model

D. Ares I Upper Stage Hatch

The design of the maintenance hatch and frame are central to the process of servicing the Ares I launch vehicle. The goal was to demonstrate a means by which a process could reduce wear on the structure and the servicing time. This is an example of a case in which customers are looking to streamline a process and make ground servicing more

efficient. Both hatches, one located on the Upper Stage and one located on the Inter-Stage, are designed to be accessible by technicians while the vehicle is being supported in the VAB. This determination was made based on the access measurements of the modeled technicians using the respective CATIA workbench. As with the hatch doors of the Orion capsule, the design of the modified frame and door assembly was monitored for any interferences between the existing structure and the addition.

Simulations in DELMIA will show the step-by-step process, in which the initial transport with the original flight door will be shown as the vehicle is brought into the VAB. The flight door will then be removed, or hidden in the model, and replaced by the installation of the maintenance frame and door. Throughout the servicing processes represented by DELMIA the maintenance hatch and the soft cover can be interchanged depending on the needs of the operation. In order to show the vehicle as flight-ready, the maintenance section can be hidden in all depictions and the flight door can be reinstated.

As with the other models, the textures applied to the model create a realistic view of the structure. The clear vision of the process allows for an open forum for discussion, in which everyone is on the same page in terms of the presentation based on the given data. In this way the customer can determine the next step in the design process and evaluate whether or not the model demonstrates a component that satisfies all assigned needs.

V. Conclusions

The key to future operations on site is to optimize the resources we have now and design processes that will be efficient and productive. It is essential to the design process to have a means of presenting and representing the customers' ideas in a way that can be quickly modified and incorporated into the overall model. In the case of the MPPF High Bay, this is reflective of the preparations being made for the next generation of space vehicle and associated ground operations. The design of the Orion CEV will affect how the facilities which with it operates will be designed, along with the access requirements of the Ares vehicle. For the SSPF, this is an example of optimizing the current operations and preparing for both the immediate and long-term future needs. Modeling and simulating these facilities and hardware will help Kennedy Space Center to streamline their ground support processes and prepare for new programs in the future.

Acknowledgments

J.L. Marshall would like to thank her mentor, Kristin Lucas, along with Robert Edwards, Bob Humeniuk, and the rest of the Boeing DVG team.

References

²Heimerl, Lynn. *Acronym Listing*. NASA Scientific and Technical Information (STI). NASA Center for AeroSpace Information (CASI). <http://www.sti.nasa.gov/nasaonly/acronym/main.html>. [cited 28 July 2010].