ARTICLE 1
V.11 February, 2011

Title

Tools for Creation of Just-in-Time 3D Procedural Simulations

Author(s)
Abe E. Megahed, 3D[1]; Marty A. Gustafson, 3D[2]; Charles Spencer, 3D[3]

[1] Chief Technology Officer, 3D Interactive Systems & Services, 1212 Fourier Drive, Madison, WI 53717, USA, gustafsonm@ORBITEC.com
[2] Manager, 3D Interactive Systems & Services, 1212 Fourier Drive, Madison, WI 53717, Senior Member, USA.
[3] Lead 3D Programmer, 1212 Fourier Drive, Madison, WI 53717, USA.

Correspondent
Patrick ("Pat") Hogan, CSA, patrick.Hogan@asc-csa.gc.ca

Technical reviewers
 Patrick ("Pat") Hogan, CSA, patrick.hogan@asc-csa.gc.ca
 Mauricio G. V. Ferreira, INPE, mauricio@ccs.inpe.br

Editorial supervisor
Eduardo W. Bergamini, INPE, e.w.bergamini@uol.com.br

Editorial support
Síntique R. dos Santos, INPE, secretaria.rme@inpe.br
Helen Joyce Aparecida, INPE, secretaria.rme@inpe.br

Website editorial support
 Megan Scheidt, AIAA/SpaceOps, MeganS@aiaa.org

Other information

TOOLS FOR CREATION OF JUST-IN-TIME 3D PROCEDURAL SIMULATIONS

ABE E. MEGAHED
MARTY A. GUSTAFSON
gustafsonm@ORBITEC.com
CHARLES SPENCER

Orbital Technologies Corporation, Madison, WI 53717,USA

ABSTRACT

Spaceflight operations, maintenance, and assembly procedures require complex training and sufficient time and access to training hardware prior to flight. In the future, the success of advanced procedures may depend on the support tools available during operations. 3D virtual equipment and task simulations can provide a complete and effective means of training and aiding real-time operations, but development is often cost-prohibitive. Orbital Technologies Corporation (ORBITEC) and Discovery Machine Inc. recently completed an SBIR Phase II project funded through Johnson Space Center titled "Just-in-Time Simulation Platform." The primary objective of the project was to seamlessly integrate decision-support software into a 3D simulation system, and design a user interface for authoring a 3D-based interactive training system without high-level programming to decrease the cost of authoring 3D simulations for training, operations, and in-flight support aids while increasing the complexity of the interactions and decision-making information presented. Internal testing of the tool showed that for creation of linear procedural training simulations, substantial reductions in development time were achieved. The software also made it possible for graphic designers (instead of programmers) to build procedural 3D simulations. To demonstrate the use of 3D simulation-based procedures in operations during the project, ORBITEC also worked with the Wyle Laboratories ISS T2 (COLBERT) Treadmill engineering and training team and NASA to build a 3D simulation of critical portions of the 20hour treadmill in-space assembly and installation procedure.

Nomenclature

3D	= Three-dimensional
BPS	= Biomass Production System
COLBERT	= Combined Operational Load-Bearing External Resistance Treadmill
GUI	= Graphical User Interface
HTML	= Hypertext Markup Language
iPV	= International Procedure Viewer
ISS	= International Space Station
JITS	= Just-in-Time Simulation
MERLIN	= Microgravity Experiment Research Locker Incubator
ORBITEC	= Orbital Technologies Corporation
SBIR	= Small Business Innovation Research
SPDM	= Special Purpose Dexterous Manipulator

1. Introduction

Before its assembly on the International Space Station (ISS), NASA's new Combined Operational Load-Bearing External Resistance Treadmill, or COLBERT, was a 2200 pound pile of 52 subassemblies carrying a $5 million price tag. The 20-hour task of assembling its over 700 pieces into an operational treadmill on the ISS fell to two astronauts, who had just four hours of prior familiarization with the equipment and a 62-page instructional manual. Unfortunately, as space operations and equipment like the COLBERT continue to grow in complexity, it will no longer be manageable or cost effective to send missives of text into space. The demands for astronauts' time preclude them from spending hours of time on the ground memorizing procedures. A shift in training and operational support methodologies therefore needs to be adopted to better suit the electronic tools and Internet connections available onboard and the time constraints of the crew.

In many industries, 3D simulation and training methods are becoming the preferred training medium for similarly complex tasks and operations. 3D virtual equipment and scenario-based instruction improve the level of visual understanding for complicated tasks, provide better situational awareness when working with large equipment or multiple users, and can be produced at an equivalent or cheaper cost of training hardware.

Table 1. Benefits of 3D simulation for status and procedure display.

Human Factors Benefits	Technological Benefits
Visually realistic simulations provide a faster understanding of spatial relationships and situational awareness	Electronic real-time distribution is possible due to the small graphic file size relative to other visual approaches (such as video)
Training can take place faster and more often without the need to schedule hardware or travel to simulators	Virtual simulations can replace costly training hardware or risk of training on actual equipment
Visual status displays and procedure materials are more naturally understood by an international crew	3D simulation can repurpose design drawings into working training models
Increased personnel proficiency and confidence due to the availability of effective just-in-time information for emergency conditions	Training can be accelerated by a faster development time than hardware builds, resulting in cost savings in personnel and training staff expenses
	A larger variety of training scenarios can be presented without the risk of damaging hardware

To demonstrate the use of 3D simulation and virtual hardware for space station operations, Orbital Technologies Corporation (ORBITEC), teamed with the ISS Treadmill engineering and training team from Wyle Laboratories of Houston, Texas to build a virtual training system. The goal of the training system, funded under ORBITEC's SBIR Phase II contract titled "Just in Time 3D Simulation Platform," was to provide a 3D simulation for the most complex tasks of the treadmill assembly procedure and upload it to the ISS to assist astronauts in real-time. The simulated tasks would include the procedural text, animations of the steps to be performed, and the ability for the astronauts to manipulate the view of the animation for better situational awareness. The overall goal of the project was to create a software tool that would integrate knowledge management software with 3D simulation in an graphical user interface (GUI) authoring environment.

2. Background of ORBITEC's 3D Simulation Training for NASA

ORBITEC was selected for this simulation tool development due to its past work in 3D training for NASA, begun in 2003 with an evaluation system for ground-based payload operations. Using ORBITEC's Hypercosm™ software, this simulation included virtual hardware for the Microgravity Experiment Research Locker Incubator (MERLIN). The 3D system contained parts familiarization, procedure simulations, and interactive models of the MERLIN payload with sufficient information to perform nominal, malfunction, and contingency operations (Figure 1). When this 3D virtual training system was evaluated by NASA trainers, astronauts and Space Station engineers in August of 2004, Astronaut Peggy Whitson remarked, "I wish I could have had this on all the systems I trained with."
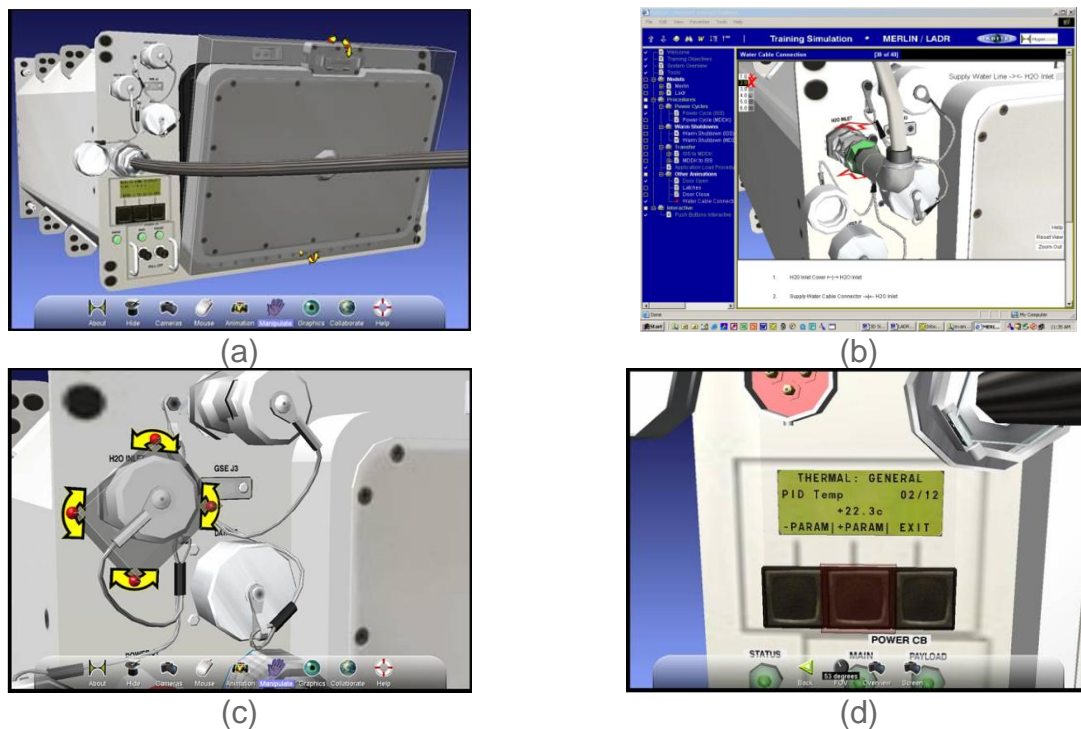

Figure 1. The MERLIN interactive 3D training model (a), training interface (b), moveable connectors (c) and display screen (d).

This format was also used to develop maintenance and operations training on ORBITEC's own Biomass Production System (BPS) payload (Figure 2). This training system was developed to show how NASA could maximize the use of crew training time. It featured linked voice annotations that make it easy to integrate multiple languages for international users. The file size of the completed system is also compatible for distance learning, with a complete set of animated interactive 3D simulations.
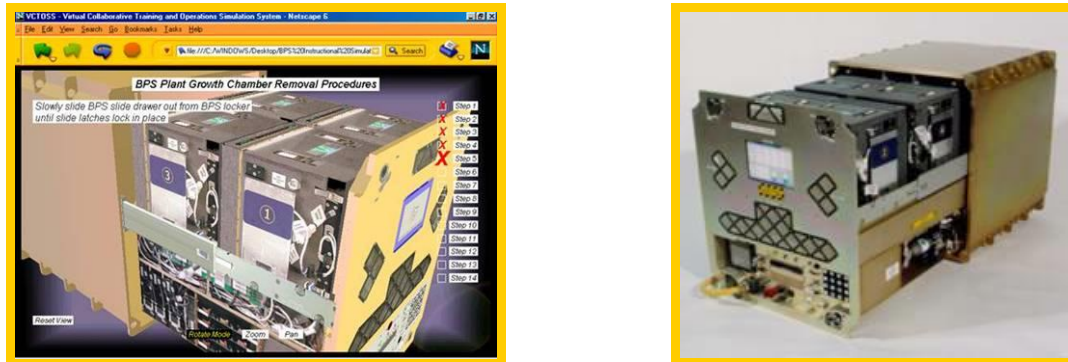

Figure 2. NASA training prototype of BPS payload (left) and actual payload (right).

Another NASA application completed by ORBITEC was for robotic maintenance operations of spaceflight equipment (Figure 3). The Special Purpose Dexterous Manipulator (SPDM) trainer demonstrated how Hypercosm simulations could be combined with different navigation and control options to train astronauts on the operation of a robotic arm. Using simple voice commands, users could navigate through step-by-step procedure training, while utilizing a joystick to manipulate the model of the robot arm to test the procedure's requirements.
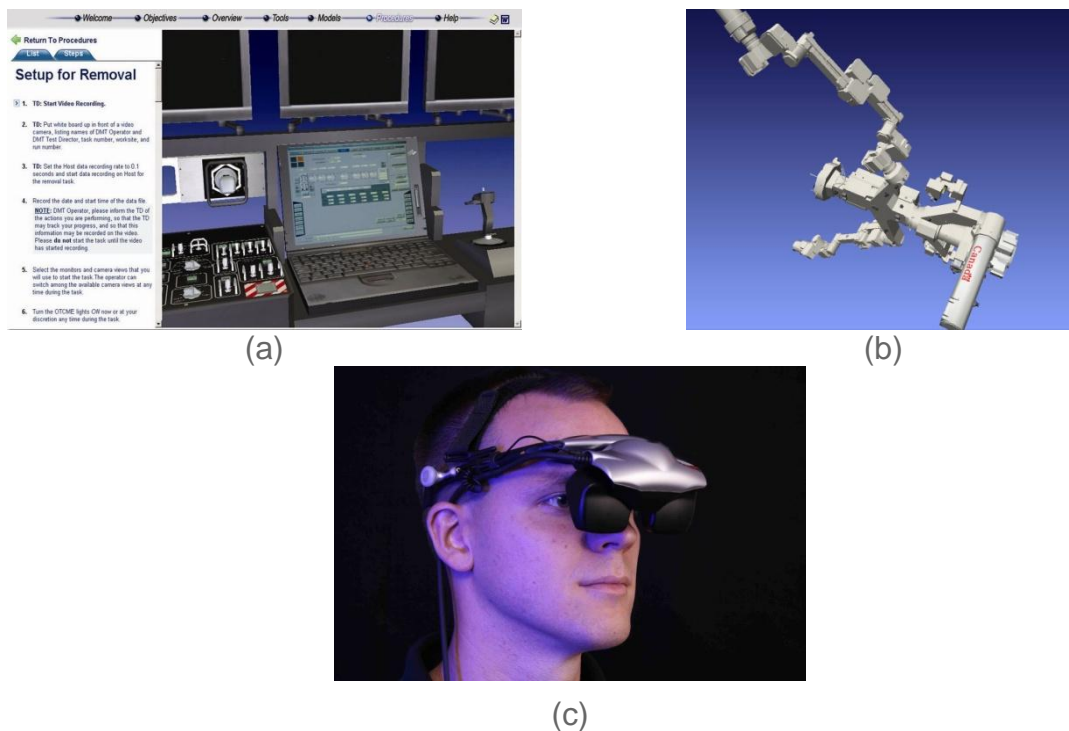

(a)

(b)

(c)

Figure 3. SPDM control station procedure (a), robotic arm (b), and stereo goggle display (c).

ORBITEC's work developing this NASA content led to a need to research techniques to simplify the authoring process for 3D simulations to improve their cost effectiveness and increase their ability to handle complex simulation content. The company received a contract from NASA for this work in 2008.

3. Project Scope

When traditional programming methods are used for authoring complex training simulations, specifying logic can be difficult. Subject matter experts, instructional designers, and game developers may know what logic should be encoded, but they usually cannot specify it directly. Instead, they must describe the desired logic to programmers who then encode the logic in software. This multi-step approach is expensive, time-consuming, and error-prone. As a result, few scenario-based simulators are written for PC-based training systems within NASA. Although NASA has begun to use more 3D step-by-step simulations (like the treadmill assembly), they can be less instructional for mission operations, emergency training, or just-in-time training, which could all benefit from PC-simulation.

The Phase I project, completed in 2008, determined the feasibility of authoring more complex simulations by prototyping a software tool that combined a method for intelligent tutoring with a Hypercosm interactive 3D simulation of a critical task required by astronauts during extra-vehicular activity (Figure 4). Figure 5 highlights the prototype authoring system. Subject matter experts were able to complete flowcharts of possible user interactions, events or problems, which in turn trigger changes in the animations or user options of a simulation.

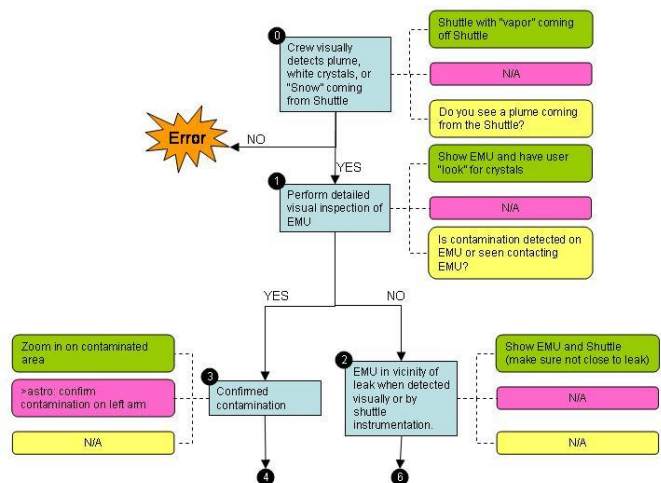Figure 4. Phase I JITS prototype.

Figure 5. Authoring flowchart tool from Phase I JITS project.

When completing the final tool in the Phase II in 2010, ORBITEC required the system to avoid reliance on expensive proprietary tools, or tools with an inability to work with industry standards for Internet design (such as JavaScript or Flash), database communication (such as XML), or graphics development (such as 3ds Max™), which would result in a work flow too difficult to use commercially. The final system also

needed to provide a cost-effective authoring mechanism suitable for use by a subject matter expert without the aid of a computer programmer. The completed tool is known as the "Just In Time Authoring Tool" (Figure 6). In designing this tool, ORBITEC leveraged its extensive experience creating procedural content to identify a relatively small number of functions needed to create procedural and reference content. While procedure trainers may seem complex at first glance, in the end the interactions almost always consist of playing animations, hiding and showing shapes or graphics, moving cameras, changing material properties, and showing labels and markers.

ORBITEC focused on this subset of functionality, and the simplicity of the design lent itself to a tool in which each function's use is apparent and intuitive, and the functions can be combined easily into cohesive content. The content generated with this tool in a few hours is indistinguishable from content created over a period of days by experienced programmers.
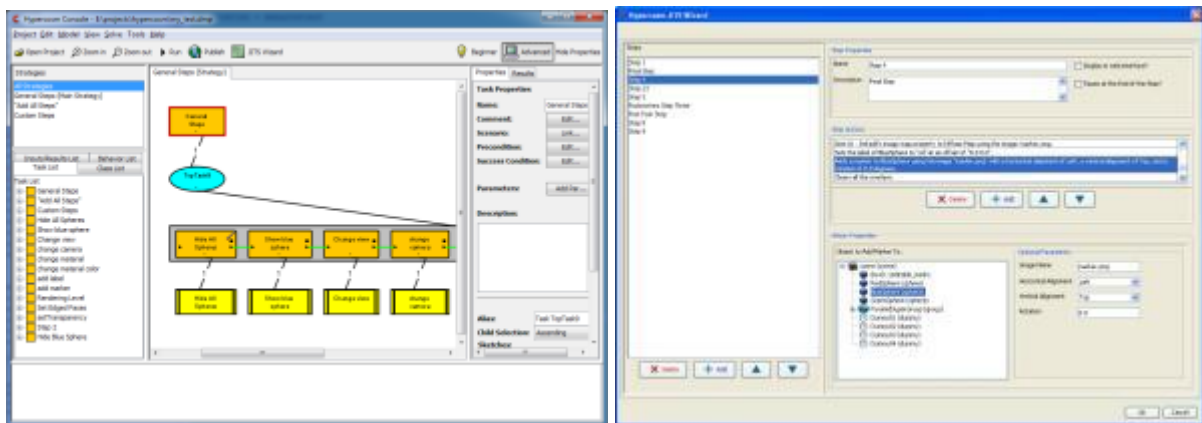

Figure 6. The Hypercosm Just-In-Time Simulation Wizard User Interface, showing flowchart authoring (left) and adding controls to procedure steps (right)

The JITS Authoring Tool consists of a two separate tools that work together to create a complete web-based or standalone procedural training system. The work flow begins by exporting 3D models of the equipment or environment required for training from Autodesk's 3ds Max using the Hypercosm XML Teleporter. The XML format allows training developers to create libraries of elements (graphics, 3D models, text databases) and easily integrate these different elements into the web-based JITS tool in far less programming time than other methods. Since XML is also a standard web format, it can communicate with other web-based software packages in a standard format, expanding the applications for 3D simulation and training on the web.

The next stage in the authoring process is to build the logic or procedural flow in the JITS Authoring Tool Console. The JITS Console contains two modes of operation: TMK modeling and the Hypercosm JITS Wizard. The TMK modeler is used for creating complex multi-tiered logic models, and the Wizard provides a fast and easy way to create straightforward linear procedure trainers. The training author uses the console to create the logic and flow of the simulation by selecting and assigning step-by-step function calls within the simulation for actions such as:

- Events (cause an action based on a message, such as a mouse click): activate camera, switch materials, hide a model, show a model
- Animations: play all, play a range
- Scene markup: add labels, add markers
- Material properties: change colors, change textures
- Rendering: add wireframe, add transparency
- Movement: send a model to a new position
- Scene handling: load a new scene, display a scene, add new groups or shapes

The console uses a JavaScript API to handle the function calls based on user actions in the simulation. The author also uses the console to link these function calls to a selected model from the 3D model library. For example, the author could select a model of an indicator switch and assign a color change event to occur if the user clicked on the switch with the mouse. A new model showing the indicator switch in a different color would then be displayed.

With a small amount of training on the system, non-3D programmers, subject matter experts, or graphic designers can assign potential actions to standard 3D models, and have those actions triggered by users in the simulation. The authoring interface wizard also allows the content developer to include procedural text or tutoring feedback for each action path taken by the user. When these elements are complete, the system can export the content into a web-based or standalone training simulation.

4. The COLBERT Simulation

To demonstrate 3D-based procedural training in NASA operations, a training content demonstration was chosen by ORBITEC's NASA Technical Monitor for the Phase II, James C. Maida. Mr. Maida identified the new ISS Treadmill as a sufficiently difficult operations procedure on which to test the system. Wyle Laboratories (the providers of the treadmill) identified three possible candidate procedures for 3D simulation: daily operation, periodic regular maintenance, and in-space assembly and installation. Since the astronauts must first complete the 20–hour in-space assembly and installation procedure, Wyle selected 33 of the most highly complex tasks in this procedure for the initial simulation demonstration.

ORBITEC began by converting the existing 3D CAD models of over 700 individual components of the treadmill into its low-file size interactive 3D format. To reduce creation time, geometry such as screws, bolts, brackets, and fasteners were reused, and other pieces made into clones to be mirrored across a Cartesian axis in the final simulation.
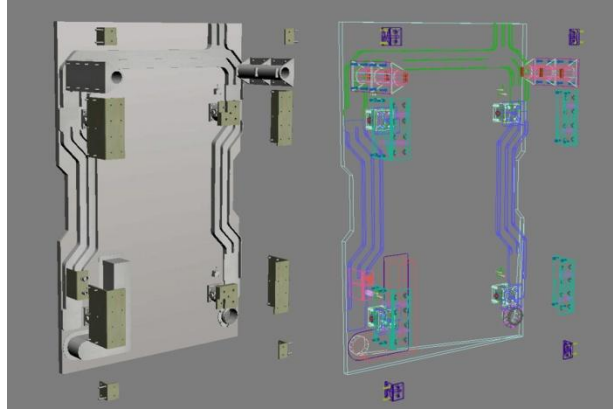
Figure 7. Textured and wireframe views of the middle support plate assembly

The next step was to add the procedural animations using standard 3D modeling software. Most of the procedural steps typically required the manipulation of only a few pieces at a time (Figure **9**); however review of the system by Wyle training personnel resulted in a number of human factors improvements.   For example, some of the procedures required the use of tools. These tools were originally missing from the simulations, so they were added for more complete comprehension. Second, due to the large size of the treadmill, small parts assembly (such as screws or pins) was difficult to view in the animation. We therefore added highlighting to these difficult-to-see parts to improve the ability to quickly and accurately see where the next assembly step took place.
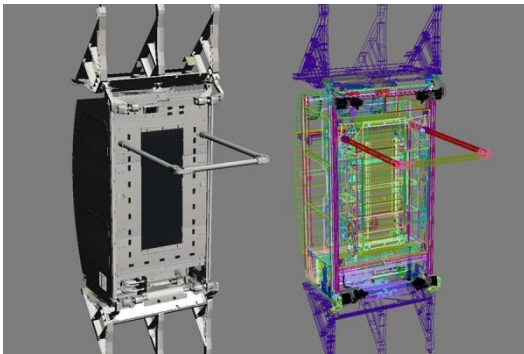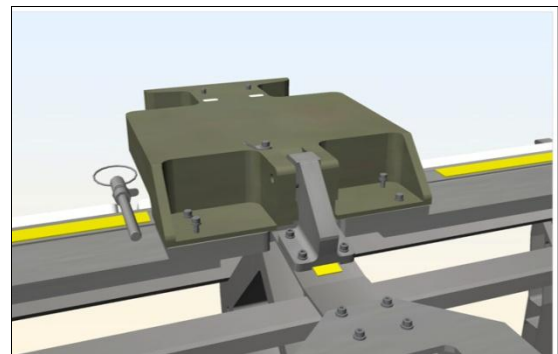

Figure 8. The completed treadmill model
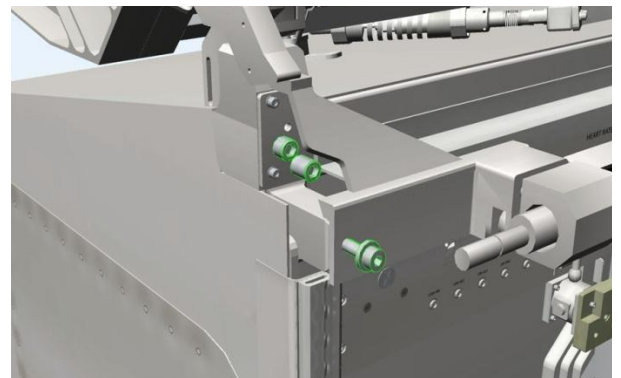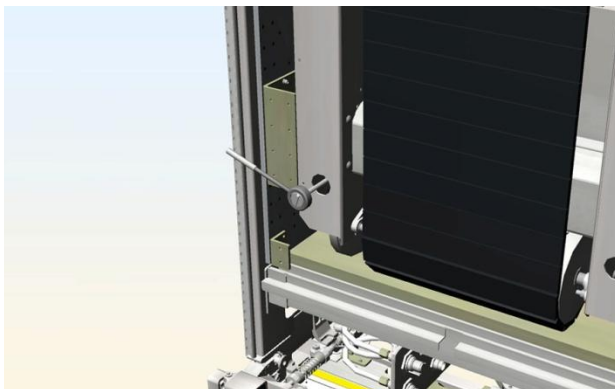

Figure 9. An assembly animation

Figure 10. A tool used in treadmill assembly (left) and green highlighting on the moving parts (right).

The simulation was then dropped into an interface that was created following NASA guidelines for International Space Station laptop displays. The display was designed and programmed in HTML (HyperText Markup Language) and JavaScript used to communicate from the user-interface to the simulations. Visual clarity and simplicity were the focus for framing the Hypercosm 3D applet used for the visual demonstration of the assembly. A simple clickable text interface activates the corresponding 3D simulation of that particular assembly step while simultaneously displaying the text instructions. Plus (+) and minus (-) symbols were used to expand and contract the menu, allowing the user to see or hide portions of the assembly instructions as needed. By clicking on the "view" link inside each sub-step, the corresponding 3D animation was triggered, demonstrating that particular portion of the assembly. Instructions were also displayed at all times for manipulation of the 3D simulation, including controls for "rotate," "pan," and "zoom" as well as an option to reset the camera view.
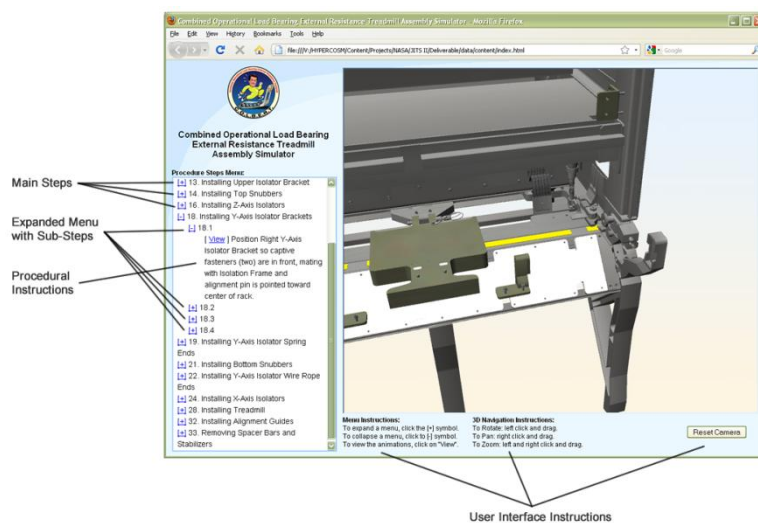

Figure 11. The COLBERT assembly applet with its user interface

5. Project Deliverables

Prior to its use in training, the simulation and its required viewing program (the Hypercosm Player) required review and acceptance by a number of NASA departments. The complete simulation and the program required to run the content were packaged into an 84 MB file. This file size, though reasonable, was larger than the majority of simulations created by ORBITEC due to the sheer number of pieces in the treadmill assembly that were individually modeled.

Since the training system was ultimately destined to reside on the ISS flight computer, the initial testing was completed by the Flight Laptops and Network Integration group at Johnson Space Center. This testing was only for the underlying software code, however, and was not a validation of the content presented in the simulation. The content itself had to undergo acceptance testing by Wyle Laboratories and ultimately by the Astronaut Crew Office.

Though the software Player was able to pass testing, there was not enough time prior to flight to get the system approved by the Astronaut Crew Office and installed on the ISS. Unbeknownst to the ORBITEC and Wyle personnel working the project, the Astronaut Office requires that all instructional training text to be pulled in xml format from the International Procedure Viewing system, or iPV, instead of coming in as text from html, pdf, or MS Word formats. By limiting all training information to a single upload point, procedures can rapidly be updated so the crew on board has the most current information possible. The iPV system is not, however, very supportive of interactive technologies such as hyperlinks to graphics or video. The crew office is currently committed to updating the system to provide astronauts with more visual information for future missions.

The Hypercosm system is XML-based and has the ability to upload from the iPV; however the accelerated schedule of this deployment did not give ORBITEC enough time to pass the iPV's monthly review board procedure required to get a copy of the iPV system for integration testing. We were also restricted from simply deleting the text in our simulation, as that would have been construed as a "change to the software" and would have required the approval process to begin again. As a result, the text was removed from ORBITEC's treadmill assembly, and a video of the simulations was created and sent to the ISS.

6. Conclusions

Although ORBITEC was not able to see its complete simulation system uploaded to the International Space Station, feedback from the Wyle Engineering and Training team and NASA was overwhelmingly positive. The steps being taken by the iPV group to expand the visual information that accompanies training materials will also provide simulation a greater chance of entering into the standard NASA training repertoire.

We also successfully demonstrated the commercial feasibility of a 3D simulation authoring tool for training systems without requiring the user to program. The JITS Authoring Tool does a particularly good job of establishing a balance between power and flexibility and of providing multiple tiers of functionality for different users and applications. At its simplest, the JITS Wizard Console can be used by someone with minimal training to create the kind of linear training procedures that account for the majority of training content.

As for the feasibility of the tool's resulting content for current NASA workflow, the ability to use these simulations easily in NASA operations proved to be less technically feasible than expected. Until NASA selects a standard format for visualization and graphics in operations materials for the ISS (and future missions), each new simulation project will need to forge its way through the certification process on its own, and continue to push for its use over the current text-based manual training methods. For ground-based training, however, this tool could immediately be used to create excellent, low cost procedural training materials.