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USING SIMULATION FOR LAUNCH TEAM TRAINING AND EVALUATION

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ABSTRACT

This paper describes some of the history and uses of simulation systems and processes for the National Aeronautics and Space Administration's (NASA's) training and evaluation of launch, mission control, and mission management teams. It documents some of the types of simulations that are used at Kennedy Space Center (KSC) today. It provides an initial baseline and some recommendations for further research into simulation for launch team training and evaluation in the near future. A theme of this paper is that the use of simulation for the training and evaluation of launch teams is very important, and NASA should learn from and expand on these types of simulations especially as it prepares to develop new launch vehicles and processes under the Exploration program.

1 INTRODUCTION

When most people think of NASA simulations, they think of astronaut training simulations, or in-space visualization simulations such as demonstrating how some remote activity will take place in space, or simulations for trade-off-analysis of new processes and architectures in competing designs. These applications are very valuable and interesting areas for NASA to apply simulation. However, one additional area that is just as important, but often under appreciated, is the use of simulations for the training and evaluation of launch, mission control, and mission management teams. (A closely related area is using simulations for the checkout of the systems and processes that those teams use.)

1.1 Simulation for Team Training and Evaluation Is Important

Simulation training of the NASA's teams is critical to the safety of the Space Shuttle Program (SSP). Realistic simulations, evaluations, and feedback within a safe environment provide one of the best methods for ensuring that teams have the experience, knowledge, and capabilities required for correct action during critical operations.

Some very good high fidelity simulation training for launch, mission control, and mission management teams does take place today, and the details in these simulations are improving, but further enhancements are always possible and should be sought. This paper discusses some of what NASA does today, in an attempt to describe a baseline of our current situation, with plans for future work and proposed enhancements in following papers.

1.2 Simulation for Team Training and Evaluation Is Timely and Interesting

After the Columbia accident, every NASA employee was required to read *The Columbia Accident Investigation Board's Report Volume I* (CAIB 2003a). It makes clear the fact that NASA's team decision-making had some problems that needed to be corrected. CAIB Return to Flight (RTF) recommendation R6.3-1 (on page 172 of CAIB 2003a) is very relevant to the topic of this paper. It states that NASA must "Implement an expanded training program in which the Mission Management Team faces potential crew and vehicle safety contingencies beyond launch and ascent. These contingencies should involve potential loss of shuttle or crew, contain numerous uncertainties and unknowns, and require the Mission Management Team to assemble and interact with support organizations across NASA/Contractor lines and in various locations." NASA's response to the above recommendation is *Space Shuttle Program Directive NO 150B-Training Plan for Mission Management Team (MMT) Members* (NASA JSC 2005b). NASA has implemented this plan and complied with this RTF requirement.

The author received additional motivation for writing this paper from briefings by the NASA KSC developers of the Shuttle Ground Operations Simulator (SGOS). The (SGOS Developers 2003) briefings explained how SGOS was developed and how it is used for the checkout of the shuttle Launch Processing System (LPS) and the training of the shuttles' launch teams. The author also attended some shuttle launch team training sessions with the NASA KSC Simulation Team. The work done by these two teams is very important, and NASA should learn from and expand on this type of work to improve its capabilities, especially as it develops new vehicles for new missions under the Exploration Program. More information on these two teams is provided later in this paper.

2 THE LAUNCH PROCESSING PROCESS

Figure 1 shows that the ground processing of a space shuttle is a complex team effort. The figure focuses on processing from landing and delivery through assembly and launch. Many of the operations are complex and potentially hazardous, and there are usually time and resource constraints. Today most of this activity is a responsibility of KSC.

Simulations can be very helpful in the modeling and optimizing of this type of spaceport processing activity, but that is not really the focus of this paper. This paper focuses on using simulation for the training and evaluation of the personnel who control and perform that ground and launch processing.

3 THE PEOPLE

The following sections describe some of the key personnel who are involved in launch team training.

3.1 Personnel Who Require Simulation Training

There are at least four categories of shuttle personnel who require simulation training: the flight crew, mission control, launch, and mission management teams.

3.1.1 Flight Crew

The flight crew is the best known and the most visible group involved in the shuttle program. A flight crew for a space shuttle ranges in size from two to eight. Its member's pilot and care for the shuttle and its payload while in flight, and perform the on-orbit tasks required for the mission. When compared with total NASA time devoted to each mission, time on-orbit is extremely valuable and limited, so a well-trained flight crew is critical to a mission's safety and success.

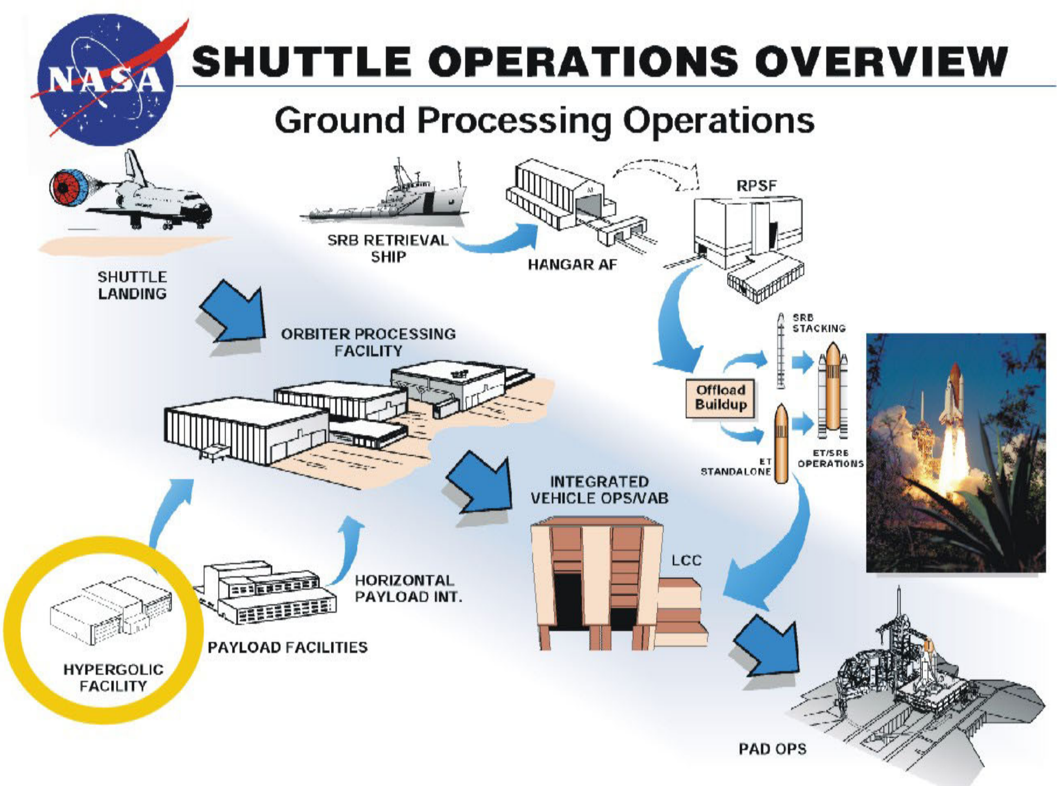

Figure 1: Processing of Space Shuttles Is a Complex Team Effort (from SGOS Developers 2003)

3.1.2 Mission Control

NASA's Mission Control is located at Johnson Space Center (JSC), in Houston, Texas. While the orbiter is in flight, mission controllers sit on station at consoles in flight control rooms (FCRs), monitoring and controlling the space shuttle missions, communicating with the flight crew, and providing their on-orbit ground based support. Mission Control also has many support personnel that don't sit in the FCRs, but who do provide valuable support and analysis to the mission controllers and flight crew.

3.1.3 Launch Processing Team

Most of the focus of this paper is targeted at simulation for launch team training. A launch team is composed of employees from NASA, the Space Flight Operations Contractor (SFOC), and other organizations. They are the people that control most of the activities shown in Figure 1. They are primarily located at KSC, on the East Coast of Central Florida.

Figure 2 provides a hierarchical representation of a space shuttles' launch team. Most of a KSC shuttle launch team sits at consoles in the Launch Control Center's firing rooms (FRs). Figure 3 is a good example of some launch team members sitting at their consoles. A launch team provides control and monitoring of critical activities that occur during shuttle ground processing, launch, and landing. KSC has two firing rooms (FR1 and FR3) that it uses for a prime launch team's operations. KSC also has one backup firing room (FR2) that it uses for additional support and training. Each firing room has twelve to fifteen consoles. During a launch, the prime firing rooms are manned by console operators serving as the Primary System Engineers (PSE), System Specialist Engineers (SSEs) and other supporting systems specialist.

The operations are led by the NASA Test Director (NTD), and the Launch Director (LD), with engineering integration managed by the Shuttle Project Engineer (SPE). The backup firing room is manned by the Chief Engineer and Engineering Team Leads (ETL) and support teams. Other firing room support is provided by representatives from the JSC, Eastern Range, Safety, and Payloads communities.

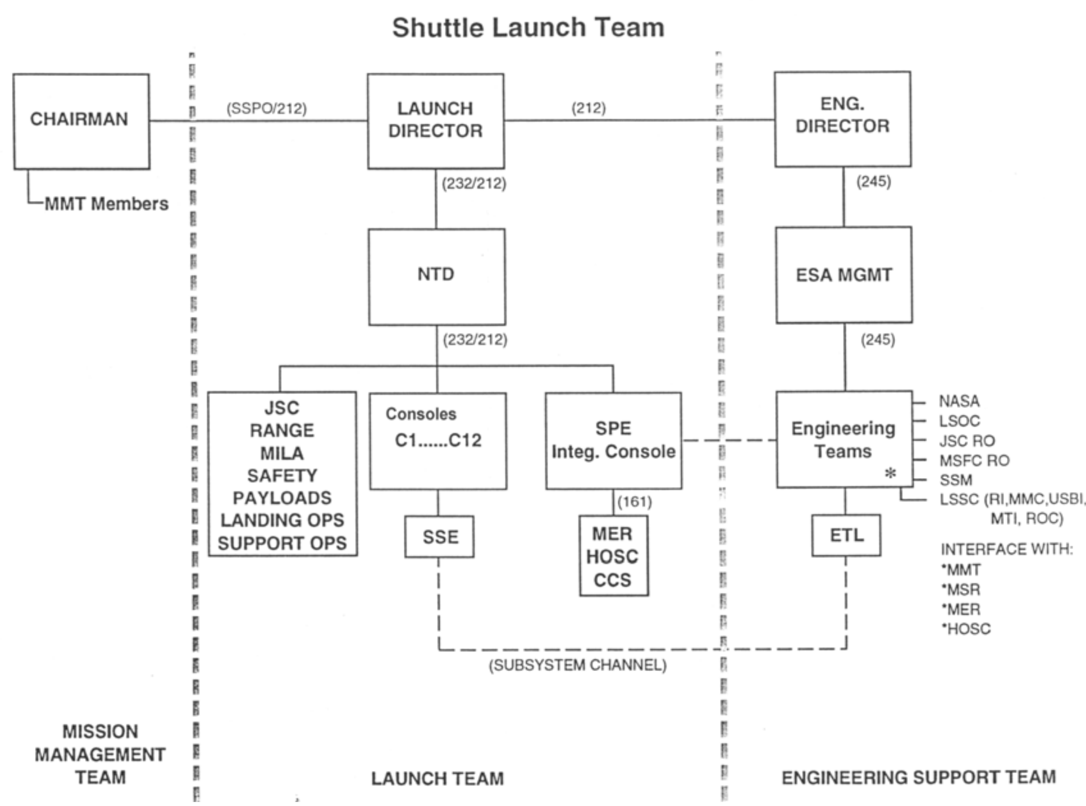

Figure 2: Organization of the Shuttle Launch Team (from NASA KSC PAO 1995)

In addition to the personnel in the firing rooms, there are also a great many support personnel and facilities across KSC, the Space Shuttle Program (SSP), and NASA that participate in the processing and the launch of space shuttles (and who could also potentially benefit from some simulation training).

3.1.4 Mission Management Team

Overall responsibility for the space shuttle missions resides with a mission management team (MMT), which is staffed by senior managers from across the Space Shuttle Program (NASA JSC 2005a). The MMT is activated at the Prelaunch Mission Management Team (PMMT) review two days prior to the scheduled launch (i.e. L-2). The MMT is chaired by the Deputy Manager, Space Shuttle Program (SSP). At T-9 minutes, the Launch MMT is polled for a GO / NO GO launch decision and the Deputy SSP Manager makes the final planned GO / NO GO decision.

After a T-9 minute GO decision, the launch is automated via a Ground Launch Sequencer (GLS) program that runs the remainder of the countdown autonomously. The GLS can abort the launch based on its approximately 1,500 sensor inputs which monitor launch commit criteria (LCC), or based on a command from a human, but if all LCC remain good, and no human intervenes, the space shuttle will be launched. At T-31 seconds, control of the launch switches from the GLS to internal computers within the shuttle.

Once the solid rocket boosters (SRBs) ignite, the control of the space shuttle switches from the firing room in the KSC Launch Control Center, to the flight control rooms in the JSC Mission Control Center.

3.2 KSC Personnel Who Provide Simulation Training

There are at least four categories of KSC personnel who provide some of the components required for simulation training: the NASA SGOS Developers, SFOC Math Modelers, SFOC Test Project Engineering, and the NASA KSC Shuttle Simulation Team. Those four categories are briefly discussed in the following sections.

Note that the author has met with NASA Ames Research Center (ARC) simulation personnel, and would like to meet with JSC simulation personnel, who provide simulation training components. Although their work is valuable and important to NASA, it was unfortunately not possible to cover the ARC and JSC personnel and work along with the KSC personnel and work within the constraints of this first paper. So this paper is mostly focused on KSC.

3.2.1 NASA SGOS Development Team

When the Space Shuttle Program started in the 1970s, KSC developed a Launch Processing System (LPS) for the Launch Team to use. An interesting history of LPS is provided by Tomayko (1988). While developing LPS, KSC had to concurrently build a simulation system to check out the LPS and its application code. That simulation is now called the Shuttle Ground Operations Simulation (SGOS).

Both LPS and SGOS evolved and improved over the next thirty years. Some major SGOS improvements that have been carried out in the past ten years by a team of about ten NASA and contractor software developers include:

- The re-hosting of the SGOS software from a mainframe computer down to a single VME card while increasing the systems performance and capability by an order of magnitude.
- Replacing a video switching interface with a real-time simulation interface.
- Making the new SGOS compatible with other system interfaces including the Kennedy Avionics Test Set (KATS) and the Cargo Integration Test Equipment (CITE).

NASA SGOS Development Team members spent time explaining their architecture to the author, and he believes that NASA should consider employing some of their acquired expertise when developing any future enhanced ground operations simulation for the soon to be developed Exploration vehicles.

3.2.2 SFOC Math Modelers

SFOC provides Math Modelers, who develop simulations of the space shuttle and the ground support equipment (GSE) using the SGOS language. These math modelers work with system engineers and an understanding of physics and ground processing systems to develop models of the physical measurements monitored and the equipment and behaviors controlled using the LPS.

3.2.3 SFOC Test Project Engineering

The SFOC Test Project Engineering (TPE) organization is responsible for staffing the Integration console in support of the SPE for launch engineering integration and problem resolution for launch. It also rotates assignment of these same engineers to the development of large integrated (tier 3) team training simulations.

3.2.4 NASA KSC Shuttle Simulation Team

In 1998, due to shortened launch window time constraints imposed by routine space station missions, NASA KSC decided to increase the simulation training frequency and depth beyond what the SFOC TPE was providing (Saucedo 2003). So, NASA created a simulation team to increase

KSC's simulation capabilities by providing lower tiered (detailed and focused) training simulations, which will be described in more detail later in this paper.

This NASA simulation team is responsible for developing, scheduling, and running tiered training simulations. They and the SFOC Math Modelers use SGOS and the math models to create the simulations. Their challenges include deciding which sub-teams to train, where and how to introduce faults, and preplanning troubleshooting scripts that the simulations should take and against which they can evaluate performance. A short video about the Sim Team is available on line (NASA KSC 2004).

4 THE KSC SYSTEMS

4.1 Shuttle Launch Processing System (LPS)

The Launch Processing System (LPS) is the primary system of hardware and software used to process and launch space shuttles. LPS was originally developed at KSC in the 1970s. It is composed of several major subsystems including the checkout, control, and monitor subsystem (CCMS), central data subsystem (CDS), record and playback subsystem (RPS), front end processors (FEPs), and hardware interface modules (HIMs). The HIMS provide the end item interface for LPS. End items are the monitored or controlled items, specifically the space shuttle and its ground support equipment (GSE). The LPS hardware runs a Ground Operations Aerospace Language (GOAL) for applications software. The primary human interface to LPS is at the CCMS consoles, where the SFOC and NASA Controllers sit in the KSC firing rooms. Figure 3 shows engineers sitting at LPS CCMS consoles in a firing room within KSC's Launch Control Center. One source for additional data on LPS and the shuttle's supporting infrastructure is the *NSTS Shuttle Reference Manual* (1988), some of which is available online.

4.2 Shuttle Ground Operations Simulator (SGOS)

To test, validate, and verify the LPS, the launch team, and their processes, and to insure that they are prepared to control the launch vehicle and GSE, NASA and SFOC use the Shuttle Ground Operations Simulator (SGOS). SGOS allows launch team trainers to introduce faults and abnormal situations into the simulated launch vehicle and GSE, and observe how the launch team handles the situations. It allows individuals and teams to identify, overcome, and learn from weaknesses in a safe environment without damaging the real vehicle and GSE or risking lives.

Figure 3: KSC Firing Room during an Integrated Shuttle Launch Team Simulation (from NASA KSC 1998)

There are both hardware and software components in the SGOS system. The SGOS software includes an SGOS language that is a derivative of the LPS's GOAL. The SGOS system has evolved over many years, and its newer version are sometimes called the "KSC Simulation System", but it still runs the legacy math models written in the SGOS language, so for most of this paper the term SGOS will be used for all versions of the system. SGOS has two modes of operation: real-time mode (RT) and interactive remote terminal mode (IRT). A simulation application programming interface (SimAPI) library has been developed for SGOS and it allows external control and monitoring of the math models.

Figure 4 shows how LPS (the Real-time Processing System block in the figure) interfaces to both the vehicle and GSE, or to the SGOS (the Simulation System block in the figure). Personnel operating the consoles in the firing rooms can't easily tell the difference between the real end items and the simulated end items using the data displayed on their consoles, because the simulations are of high quality. One big difference between the two alternative configurations is that mistakes that happen while in simulation training are safe learning experiences while those made while controlling real end items can potentially be catastrophic.

Figure 5 is a similar diagram where the blocks are represented by pictures of the actual items. (The Real-time Universal Simulation System in the figure is a primary component of the SGOS System).

One of the strengths of recent SGOS development efforts is that the development team selected and used commodity and often free products and tools. During the evolution of SGOS, the math models had to remain in the SGOS language to avoid loss of the large investment in legacy development and training efforts, but the underlying SGOS engine was rewritten in or ported to "C" code. The free tools used include gcc, gdb, and Tcl. The newest versions of SGOS are now very portable and could be valuable for the simulation of future launch vehicles and GSE. One ongoing NASA KSC project includes a soon to be completed work package that is porting the SGOS software to run on a Linux laptop.

Some additional details on the SGOS / KSC Simulation System are available online in a *NASA Tech Brief* (NTB 200a) and a *Technical Support Package* (NTB 200b). There are also internal KSC SGOS user guides and documentation.

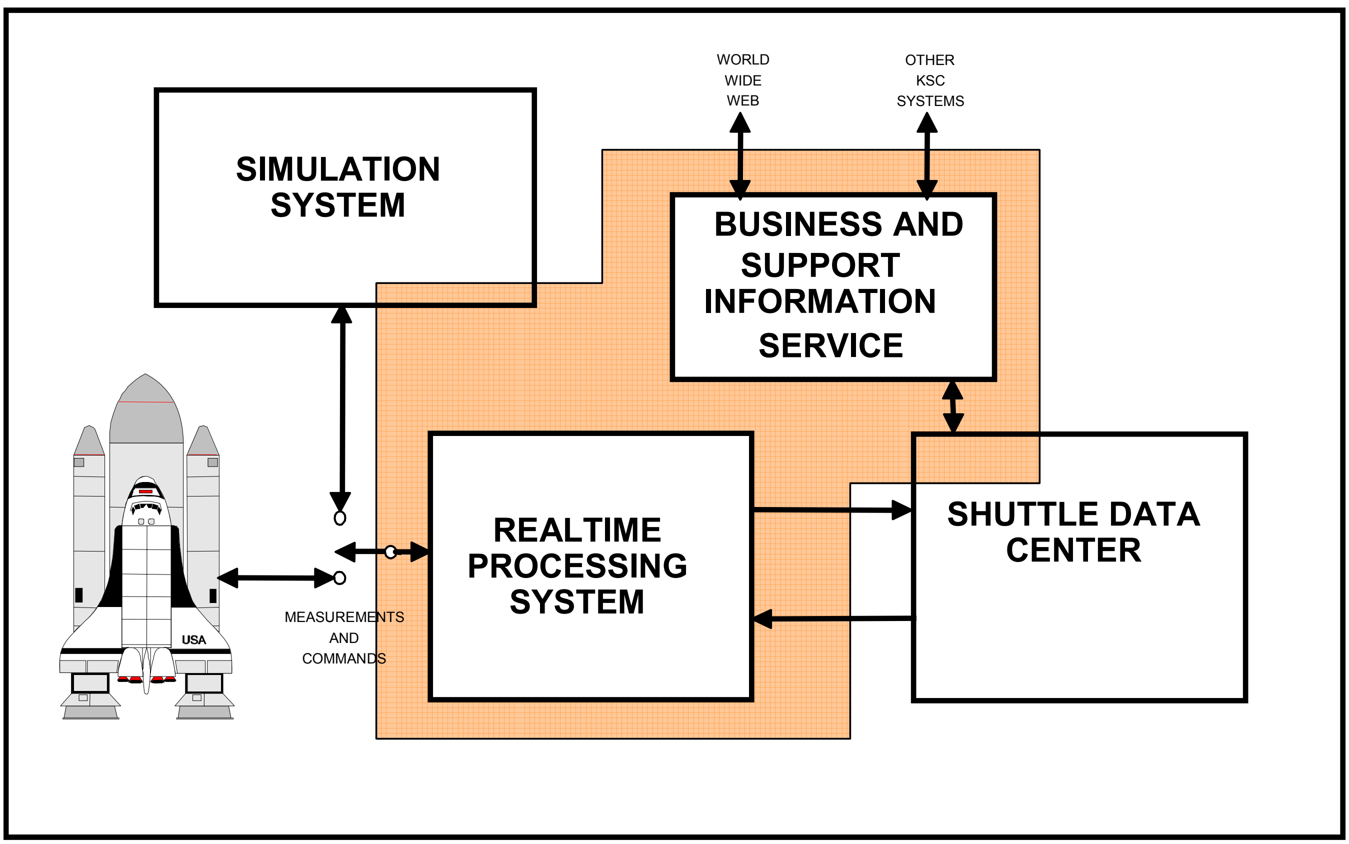

Figure 4: Launch and Simulation System Architecture (from SGOS Developers 2003)

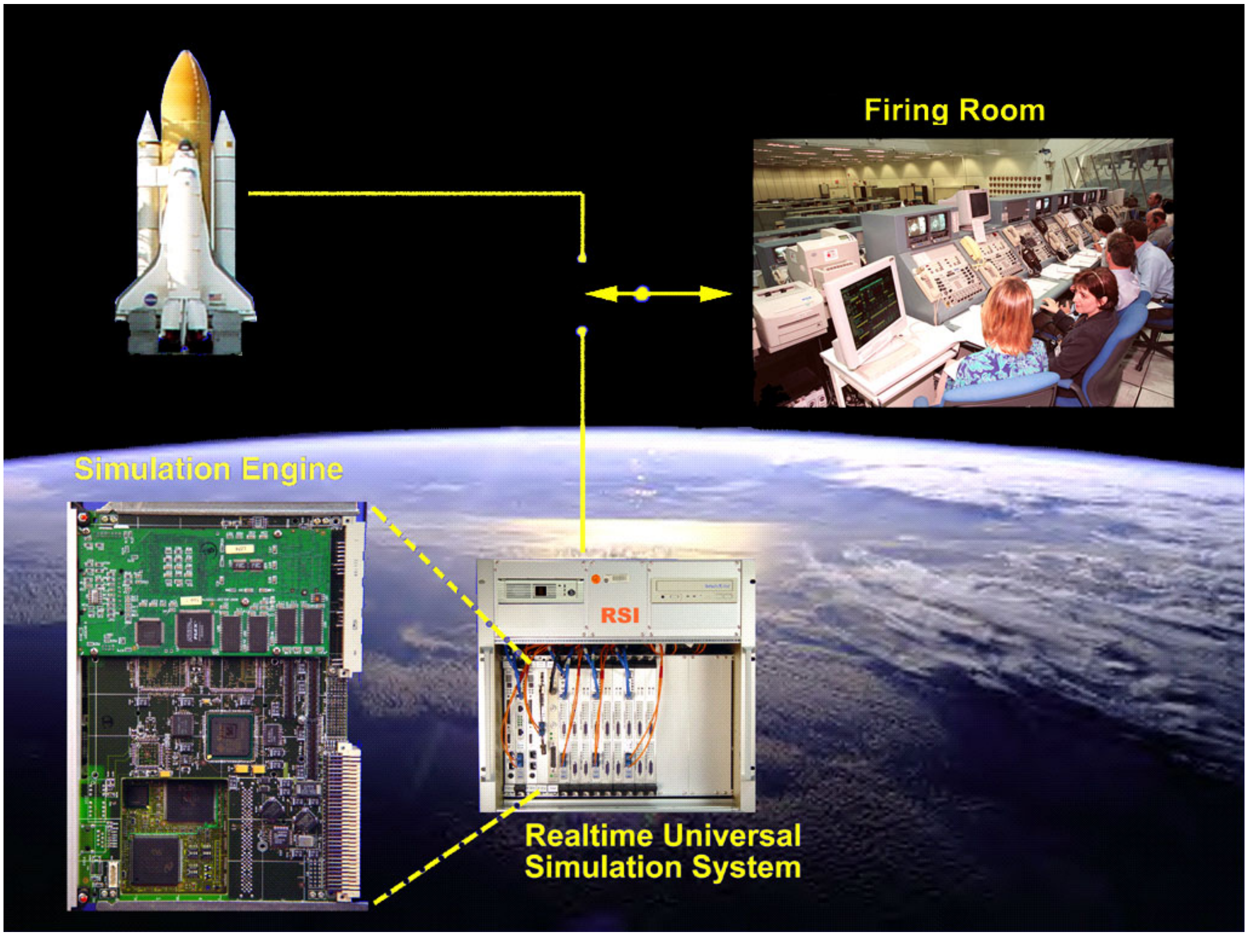

Figure 5: Real-time Universal Simulation System Simulates the Vehicle and GSE (modified from SGOS Developers 2003)

5 TYPES OF SIMULATION FOR TEAM TRAINING AND EVALUATION

There are several types of simulation for training and evaluation that are relevant.

5.1 Tiered Simulation Training of Launch Team

Tiered training at KSC is a little over six years old. Prior to 1998, KSC just ran large integrated simulations, which are now classified as tier 3 simulations. Tighter launch windows imposed by missions that must rendezvous with Space Station in orbit reduced NASA's tolerance for troubleshooting delays (Saucedo 2003). NASA and SFOC's solution to that decreased tolerance for delays included increasing the details in and frequency of simulation training at lower organizational levels.

Tier 3 training simulations are used to test out large integrated shuttle launch processing steps. The primary tier 3 simulation is *Operations and Maintenance Instruction (OMI) S0044 – Shuttle Final Countdown Simulation* which starts at T-20 minutes and runs to launch. Tier 3 simulations are all day events that involve the complete launch team, and typically include the Flight Control Team at JSC and the Huntsville Operations Support Center at Marshall Space Flight Center. This level of training is very valuable, but it requires a large investment of everyone's time, and many individuals play only a very minor role. NASA and SFOC are typically only able to conduct this type of training once or twice prior to each launch. The author observed a tier 3 S0044 training simulation on August 4, 2004.

Tier 2 training simulations are used to test out interactions and required troubleshooting across two or more partially integrated systems. One example of a tier 2 training simulation is a power simulation that involves three systems: Electrical Power Distribution and Control (EPDC), Environmental Control and Life Support (ECLSS), and Fuel Cell Powerplant / Power Reactant Storage and Distribution (FCP/PRSD). This particular tier 2 simulation was created as a result of a weakness that was identified during one S0044 simulation. Other tier 2 simulations include the *OMI S0066 – Simulated Hypergolics Loading of the Or-*

bital Maneuvering System (OMS) Pods, and *OMI S0056 - Simulated Shuttle Tanking* (Liquid Loading) which runs from T-6 Hrs to T-3 Hrs. Usually tier 2 simulations are half-day events, but occasionally they are full day exercises. Since these simulations involve fewer trainees, their involvement, challenges, and value to the average trainees are significantly increased. The quality of the training per trainee is higher, but the number of people trained per session is of course lower.

Tier 1 training simulations are used to test out individual systems and system engineers. For example, on July 29, 2004, the author observed a tier 1 simulation that was developed for the Environmental Control and Life Support Systems (ECLSS) and engineers. Tier 1 simulations usually take a half-day. Since these simulations are focused on a particular system and a small group of engineers, the thoroughness of the individual training for the average trainee can be significantly higher than either of the higher tier simulations. Of course there is great value in working with the larger teams, and the higher-level simulations provide that larger cross team value.

One reference for additional information on simulated launch team training is provided by Wells (1998).

5.2 Simulation Training For Flight Crew and Mission Control

From research it appears that the simulation training provided and required for the flight crew at JSC appears to be very thorough and of high quality. JSC's Mission Control is also known for a high level of training. The author would like to visit JSC sometime during this upcoming year to learn specifics of their simulation for training of the flight crew and mission controllers.

5.3 Simulation Training For Mission Management Team

The Mission Management Team (MMT) is one of the most important real time decision making bodies for the space shuttle, yet it seems to be historically one of the least well trained from a team perspective. A document that supports this theory is Appendix D.1 STS-107 Training Investigation of the *Columbia Accident Investigation Board Report Volume II* (CAIB 2003b). It notes that only six MMT simulations were held prior to the Columbia accident.

In the CAIB (2003a), it is clear that the MMT made several critical mistakes during the Columbia flight which contributed to the accident. From research into the Challenger accident, it is apparent that several high level mistakes were also made then, including the decision to waive the booster constraints on minimum launch temperatures.

Fortunately, NASA is addressing this problem. During the recent Return-to-Flight period, the MMT participated in numerous simulations with the launch and mission control teams (Banke 2004). A NASA JSC (2005b) document details the current mandatory MMT training needs and certification requirements. The author was able to observe some MMT training during the recent return to flight period.

5.4 Simulation Training For NASA Expendable Launch Vehicle (ELV) Team

NASA's Expendable Launch Vehicle (ELV) organization forms rehearsal anomaly teams (RAT) to practice launch operations, but they don't have a simulation engine and math models like those provided by the SGOS system that actually emulates the launch vehicle and the ground support equipment, and the ELV simulations are less elaborate than those used for shuttle.

That is probably fine for the role that NASA is currently playing in that unmanned space program. However, NASA is considering putting a manned capsule on top of one of the ELVs (or a shuttle derived vehicle) to meet some Exploration Program needs. If NASA decides to do that, the agency will obviously have to reexamine testing, training, and evaluation programs for the new vehicles. Something like SGOS, perhaps an enhanced ground operations simulation (EGOS), will be one of the many new capabilities required. NASA should consider the requirement for launch system checkout and launch team training while developing next generation vehicles and launch processing system concepts and alternatives.

6 SIMULATION RECOMMENDATIONS FOR FUTURE VEHICLES

From readings and discussions with experts in the simulation and training fields, the following preliminary recommendations were identified:

- Learn from past experiences and the current baseline.
- Develop distributed tiered simulation capabilities.
- Utilize standards.
- Develop and integrate simulations of the vehicle and the launch systems while you develop the vehicle and launch systems. Don't wait until after the vehicle is developed to begin developing the simulation infrastructure.
- Prepare to certify the launch team for a whole new vehicle.
- Train NASA system engineers to the same or better standards as those used for the contractor's system engineers. According to one of the NASA Sim Team members, there are certification training requirements for the SFOC system engineers (SFOC 2001), but training requirements for the NASA system engineers are less stringent.

- Study how our military, other government organizations, and industry are using simulations for training and evaluation of their workforce and consider applying some of their technologies and lessons learned in improving NASA's simulation training and evaluation.
- Recent reports indicate that NASA's Exploration vehicles may be developed on an aggressive scheduled and may include shuttle derived components. Therefore NASA may benefit from the reuse of some elements of LPS and SGOS. Consider adding High Level Architecture (HLA) support to the SGOS Architecture so that it can communicate with other simulations using that DOD and IEEE simulation interface standard.
- Consider whether it might be possible and beneficial to add some low fidelity software simulated humans to certain training curriculums. Today NASA KSC simulates the vehicle and ground support equipment using software (SGOS), but NASA KSC doesn't simulate the humans with software. Research into simulated humans might eventually allow on-demand simulations of absent teammates and improve the availability of some training while reducing costs.

7 FINAL THOUGHTS

Because of budget, resource, and time constraints, NASA must prioritize. With respect to training and evaluation simulations, NASA's historical priorities seem to have been the flight crew, mission control, launch control, the mission management team, and then the supporting ground based team. It appears that NASA may not have given enough attention to all of the priorities. Increasing resources spent in the lower priority training areas is prudent.

In the future, simulation is going to become even more important to NASA, and to our country, if we want to operate safely and remain competitive with other space programs. NASA must continue to invest in these applied types of simulation technologies and training sessions and to research related new technologies. NASA needs to build from what it has learned.

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