Human Performance Modeling and Simulation for Launch Team Applications

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ABSTRACT

This paper describes ongoing research into modeling and simulation of humans for launch team analysis, training, and evaluation. The initial research is sponsored by the National Aeronautics and Space Administration's (NASA)'s Office of Safety and Mission Assurance (OSMA) and NASA's Exploration Program and is focused on current and future launch team operations at Kennedy Space Center (KSC). The paper begins with a description of existing KSC launch team environments and procedures. It then describes the goals of new Simulation and Analysis of Launch Teams (SALT) research. The majority of this paper describes products from the SALT team's initial proof-of-concept effort. These products include a nominal case task analysis and a discrete event model and simulation of launch team performance during the final phase of a shuttle countdown; and a first proof-of-concept training demonstration of launch team communications in which the computer plays most roles, and the trainee plays a role of the trainee's choice. This paper then describes possible next steps for the research team and provides conclusions. This research is expected to have significant value to NASA's Exploration Program.

ABOUT THE AUTHORS

Cary J. Peaden is the Principal Investigator for SALT. He has managed many NASA KSC software and simulation projects, has a B.S.E. in Elec. Engr., an M.S. in both Comp. Sci. and Engr. Man., and is a P.E.

Stephen J. Payne provided much of the shuttle launch team operations expertise required for the SALT effort. He is a NASA Test Director in the NASA KSC Shuttle Launch and Landing Division.

Richard M. Hoblitzell Jr. focused on SALT's OpenGL and SAPI prototype training application. He is a NASA KSC coop team from the University of Louisville Speed School of Engineering, Louisville, KY.

Faith T. Chandler is a NASA OSMA sponsor of the SALT effort. She provided direction and insight for the team, especially in human factors and human performance modeling. She is based at NASA HQ in Washington, D.C.

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Timothy M. Bagnall is an Associate Systems Engineer with Alion Science and Technology's MA&D Operation in Boulder, CO. He performed systems engineering including data collection, task analysis, and human performance modeling on SALT. He has a B.S. in Systems Engineering from the University of Virginia.

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INTRODUCTION

Sending humans into space is a complex, high energy, high profile, and high risk endeavor. Teams of humans are and will continue to be key components in that endeavor. This paper discusses an effort to introduce new human performance and behavior modeling and simulation technologies for analysis, training, and evaluation of NASA's current and future launch processing operations at Kennedy Space Center (KSC).

Existing KSC Launch Team Environment

The existing KSC launch team environment was described by Peaden (2005), but important summary and update information is provided in this section. Figure 1 shows the Space Shuttle Program's (SSP's) launch team interfaces - the people and organizations that make up and support a shuttle launch team.

Figure 1. Launch Team Interfaces (Mosteller 2005)

The Mission Management Team (MTT) has overall responsibility for the total mission from ground processing through launch, flight, and landing. The prime launch team (located mostly at KSC) has responsibility for the shuttle's ground processing and launch. The launch team includes several hundred people in a hierarchical organization. During a launch, approximately one hundred of the launch team sit at consoles in the prime firing room. After the shuttle's solid rocket boosters fire, control of the shuttle passes to mission control at Johnson Space Center (JSC). On landing, control passes back to KSC. Both the KSC launch team and the JSC mission control team benefit from engineering support and safety teams distributed across multiple NASA and contractor locations.

Currently, KSC trains the launch team and checks out the applications software using a Shuttle Ground Operations Simulation (SGOS). SGOS simulates the vehicle and ground support equipment (hardware, software, and systems) involved with the launch, however it does not simulate any humans. Consequently, the whole team must be present for training or trainers must play the role of absent teammates.

For training, KSC uses a tiered approach: Tier 1 focuses on the operators at a single console, Tier 2 focuses on two or more interacting consoles, and Tier 3 focuses on the integrated launch team. Additionally, there is Mission Management Team (MMT) training that focuses on the management of the total mission and interaction with the launch, mission control, and other supporting teams. Each training tier requires a large amount of preplanning, a support team of trainers and evaluators, and, for Tiers 1-3, the use of firing room consoles. MMT training, however, might not always require the use of firing room consoles. (One likely short term benefit described later in this paper is a lower fidelity yet very useful stand alone Tier 0 training that focuses on the individual and does not require a support team or a firing room console. The higher fidelity, higher tier, integrated training will still be required.)

Goals of this Research Team

Peaden (2005) made several preliminary recommendations regarding launch team simulation including:

- 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.

- Consider whether it might be possible and beneficial to add some low fidelity, software simulated humans to certain training curriculums. Research into simulated humans might eventually allow on-demand simulations of absent teammates and improve the availability of some training while reducing costs.

For complex systems, a comprehensive systems engineering approach must include the simulation of human operators, since they are significant components within the total system and are significant sources of errors. As reported by Chandler (2005), "57% of Type A mishaps [are] caused by human error" and "78% of the Shuttle ground-support operations incidents resulted from human error" (Perry, 1993). [Type A mishaps are those that cause a fatality or property damage greater than $1,000,000.]

To address the aforementioned statements, and to meet some needs of NASA KSC, a Simulation and Analysis of Launch Teams (SALT) effort was initiated in late 2005. The major goals of SALT were to investigate and develop proof-of-concept demonstrations of human behavior modeling and simulation technologies and capabilities for launch team analysis, training, and evaluation. This paper describes the SALT team's initial work.

A spiral or iterative model of development was chosen by the SALT team because it allowed the team to make progress and adjust its course as it progresses based on what it learns and on the feedback it obtains from others. The initial work described in this paper should be considered SALT Iteration 1.

Some Preceding Work

Before we discuss progress on the SALT effort, we need to mention some important preceding work. John, Remington, and Steier provided An Analysis of Space Shuttle Countdown Activities: Preliminaries to a Computational Model of the NASA Test Director in 1991. Cary is still working on this subsection.

SIMULATION AND ANALYSIS OF LAUNCH TEAMS – ITERATION 1

Several products were developed during the initial SALT effort including a nominal case task analysis and discrete event model and simulation of the launch team during the last 20 countdown clock minutes prior to a shuttle launch, and a proof-of-concept launch communications training application. These products are described in more detail in the following subsections.

For this first iteration, the focus was on the nominal case. The nominal case refers to when the launch team performs all the requisite system checks and procedures as planed without error. An off-nominal case can be caused by any number of system malfunctions or asynchronous procedures that challenge the launch team and impact performance and readiness during real and simulated launches. Our team chose to start with the nominal case since it serves as a nice introduction to the launch system and is relatively less complex than an off-nominal case. We focused on the last 20 minutes of countdown clock time prior to a launch because the Space Shuttle Program considers that the most critical time period of the launch. We focused on the SSP because it is the only available operational NASA manned spaceflight program and it serves as an excellent baseline to research future launch design.. The Exploration Program must improve upon (or at a minimum do as well as) what NASA is doing with the shuttle today. (In future iterations, the SALT team may also explore unmanned baselines, for example the expendable launch vehicle programs.)

Task Analysis

The first product that the SALT team produced was a nominal case task analysis. We created this by reviewing shuttle documentation including the operational maintenance instructions for launches and simulated launches, observing training simulations, listening to audio recordings of real and simulated launches, and interviewing experts. We iteratively developed our task analysis with the help of domain experts.

Our current task analysis includes functions, tasks, call signs, call words, and some "as run" transcriptions. For each task, the analysis includes step number (i.e. unique task number), estimated kickoff times, predecessors (i.e. preceding tasks that must be accomplished before executing the current task or an exact time into the launch), initiating call signs (i.e. task operator), involved call signs (i.e. whom the task operator communicates with, if communicating), required channels (i.e. the intercom channels used for communication, if communicating), mean times and standard deviations, and descriptions. Figure 2 illustrates how documentation, observation, and expert knowledge was used to produce the task analysis. This task analysis is the foundation upon which other elements of SALT are being built. We intend to expand upon this task analysis in future iterations.
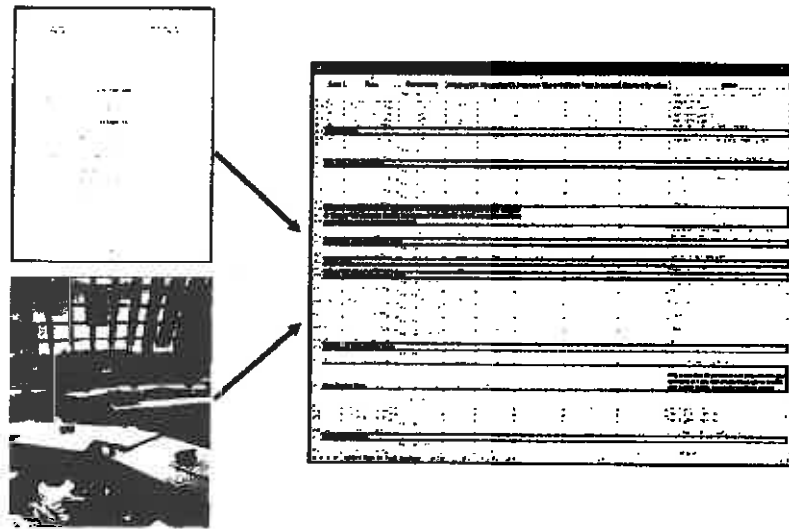

Figure 2. Task Analysis Created Using Documents, Observations, and Experts

Discrete Event Simulation

The second product produced by the SALT team during the first iteration was a discrete event simulation (DES) of the launch team's activities. It was developed using the task analysis data. The DES tool selected for this effort was the Army Research Lab's (ARL)'s Command, Control, and Communications - Techniques for the Reliable Assessment of Concept Execution (C3TRACE) tool. This tool was developed for ARL by Micro Analysis and Design (MA&D) and is built upon their Micro Saint Sharp simulation engine. C3TRACE is owned by the US Government, is free for NASA, and is one of a family of ARL tools targeted at human performance modeling.

According to the MA&D Military Consulting Website (2003):

> The purpose of C3TRACE is to evaluate the effects of different personnel architectures and information technology on systems. ... [C3TRACE is] a general-purpose Command and Control (C2) modeling environment that can be used for a number of different organizations, ... as they are defined. ... The purpose of C3TRACE

is to evaluate the effects of different personnel architectures and information technology on system and human performance. ... [It] contains four integrated software modules: the database, the C3TRACE graphical user interface, the Micro Saint runtime engine, and the data analysis tool. A primary strength of this tool is that the modules support a flexible analysis approach.

Figure 3 shows one view of the SALT C3TRACE Simulation. The simulation demonstrates the complex network of tasks that are executed by launch team-members, and their competition for shared resources (including communication channels).

C3TRACE allows for output paths to be forked simultaneously, probabilistically, or based on tactical considerations. Within tasks it allows for the collection of metrics that can be very helpful in analysis. It has built-in capabilities for tracking visual, auditory, cognitive, and psychomotor (VACP) utilization by individuals, intended for cognitive workload studies. Many of these C3TRACE capabilities have not yet been required for SALT, but are available for use in the future as our model analysis requirements and fidelity increases.
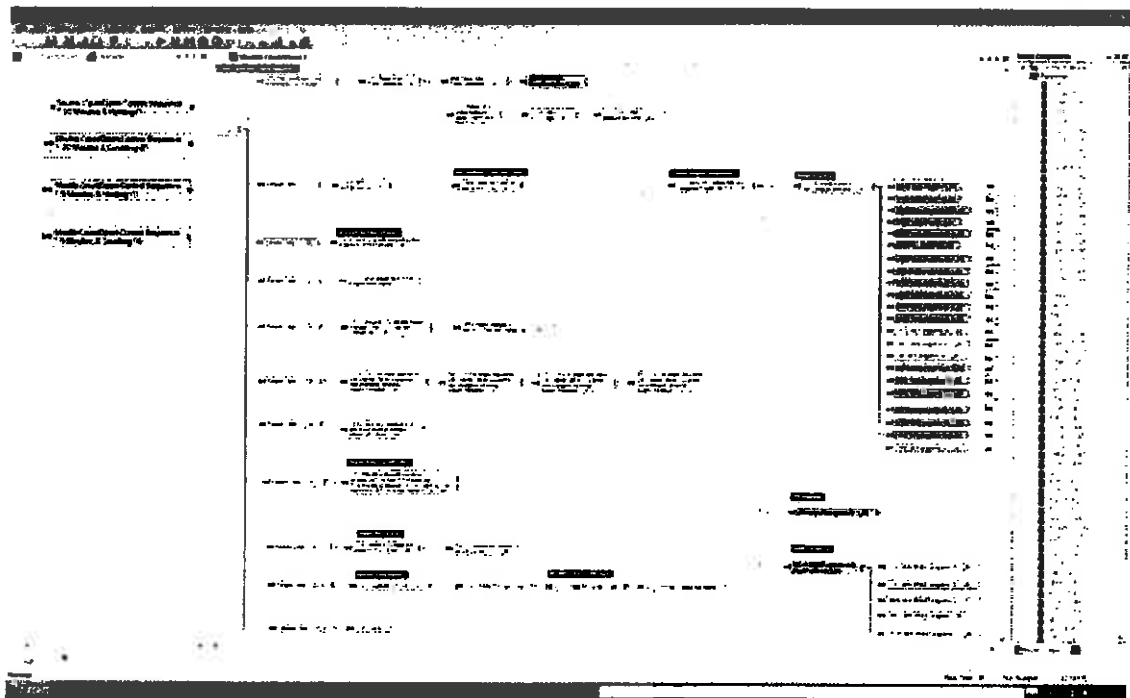
Figure 3. C3TRACE DES Includes Network of Functions, Tasks, and People

The SALT team believes this type of DES could be used for constructive analysis simulations of alternative launch team configurations and workloads in a manner similar to that described by Kilduff, Swoboda, and Barnette (2005). {Perhaps an elaboration on this report and why it would help NASA}. The team also believes that this type of DES could be used to represent the cognitive engines behind team training communication simulations similar to the way the Air Force Research Laboratory's Combat Automation Requirements Testbed Program is using ARL's Improved Performance Research Integration Tool as described by Brett and Doyal (2005). {Perhaps an elaboration on this report and why it would help NASA}.

Communications Training Application

A third product produced by the SALT team during this initial iteration was a proof-of-concept launch team communications training application. The application was developed using Visual C++, OpenGL, and the Microsoft Speech Software Development Kit and Speech Application Programming Interface (SAPI). The application was designed using object oriented methodologies and offers a set of callable services so that can be easily utilized by other simulations and possibly integrated with the C3TRACE simulation.

Figures 4 and 5 provide snapshots of the two windows that appear during the application's execution.

The window in Figure 4 represents an Operational Intercommunication System (OIS) end instrument that launch team-members use for communications during operations. In this window, trainees enter their channels and select whether the channels should be in monitored or active mode. The trainees are only able to hear communications on their monitored and active channels and are only able to transmit on their active channel. The communications system is very important to the SALT team because it provides the primary interface from trainees to other real or simulated launch team members.

The window in Figure 5 represents a top down view of team seating positions within a firing room, orbiter, and master console. It represents the locations of team-members and their communications. In Figure 5 the trainee can see that the countdown clock is at T-4:22, the console-ground-launch-sequencer (CGLS) operator is saying "Go for ET LO2 Pressurization" on channel 212, and his location is indicated by the green circles (which are used to highlight communicating consoles). The trainee can also hear the CGLS simulated operator saying "Go for ET LO2 Pressurization."

The window in Figure 5 also contains application control information. The trainee can choose to play any role in the simulation, and the computer will play the role of all other teammates. If the user does not select a role, then the computer plays all rolls. In this example, the trainee has chosen to play the role of the NASA-Test-Director (NTD). This training simulation can be run as fast as possible, at real time speed, or at multiples of real time.
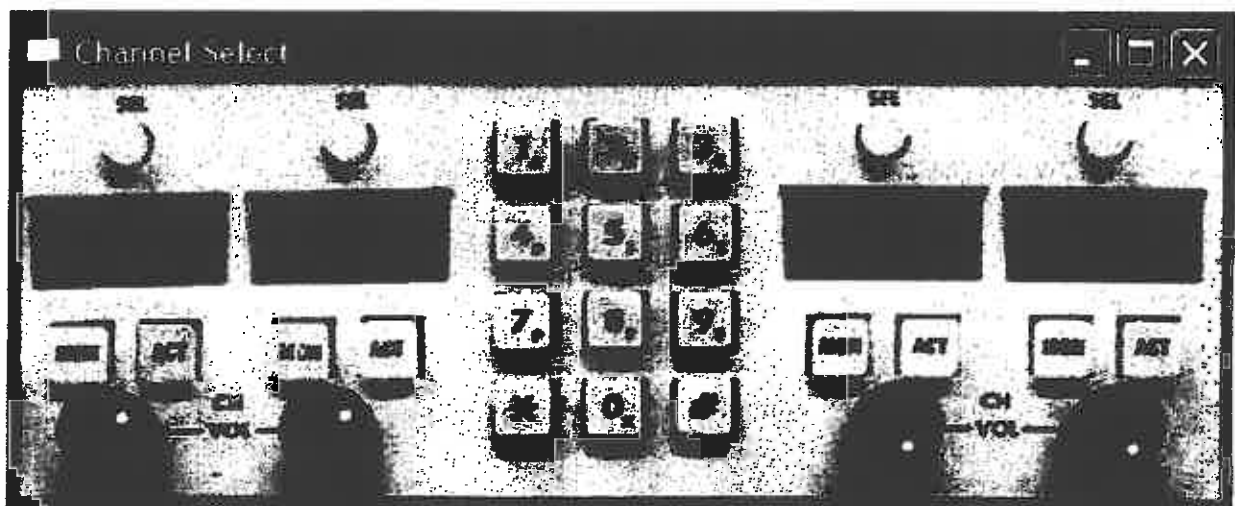

Figure 4. Prototype Training Application Window - OIS End Instrument
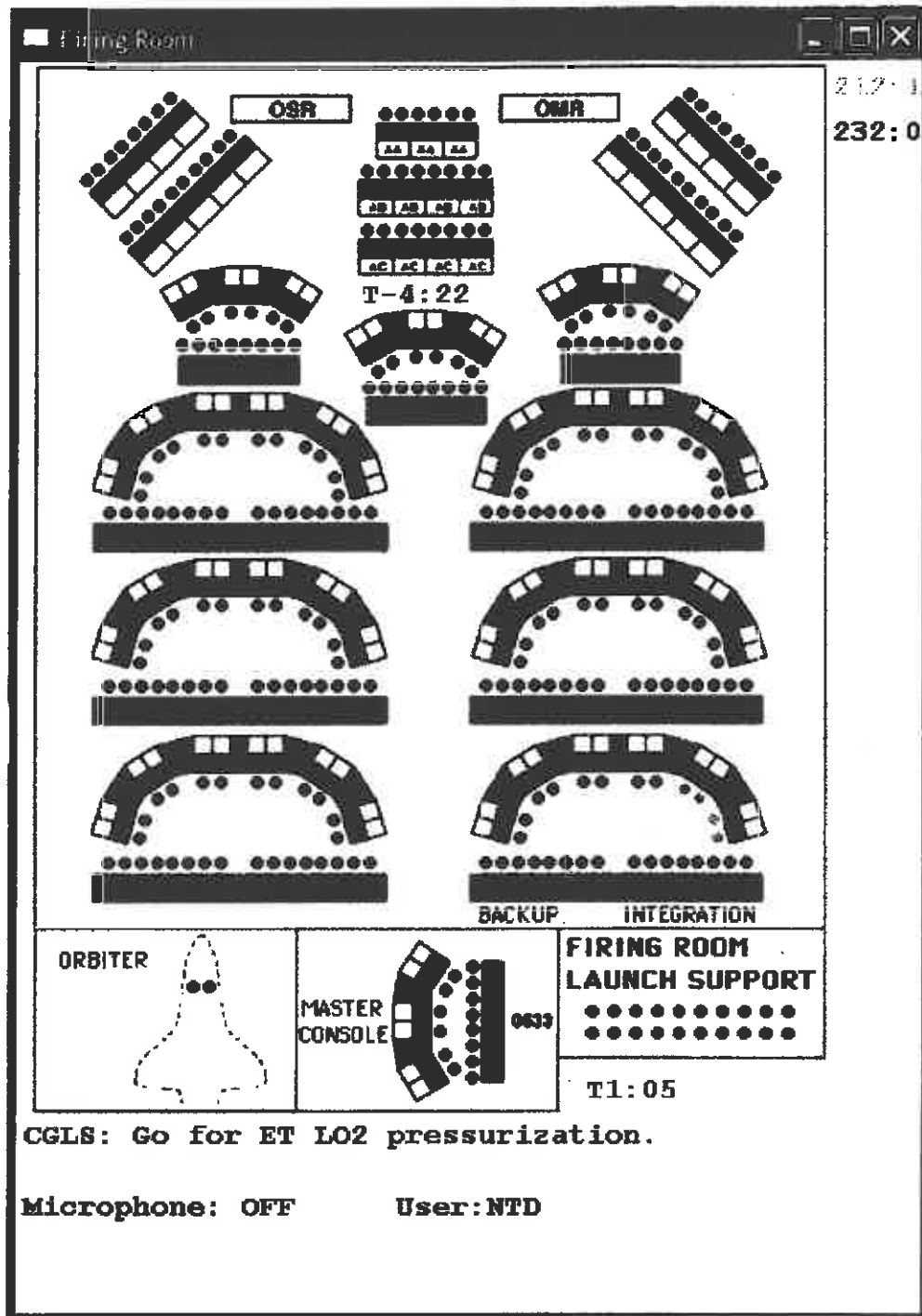
Figure 5. Prototype Training Application Window – Top Down View of Launch Team

The audio output can be wave file utterances (recorded during previous launches or simulations), or optionally the audio output can be computer generated speech created using a text to speech engine (which could be useful when recorded wave file utterances are not available). The trainee's speech input is processed through Microsoft's SAPI speech recognition engine

using SALT team generated standards based XML grammar files.

This initial training application focuses on the nominal path, but also includes one off-nominal case of a launch shut down. If at any time the trainee keys the mike and utters a one context specific phrase, for instance in the last 31 seconds of the count, if the trainee says "CGLS Give Cutoff", then the simulation takes an abort path and the launch is shut down. This is what a real launch team would do if that phrase were transmitted during the last 31 seconds of a real launch countdown.

This application prototype highlights some significant rewards available to NASA from the utilization of these types of technologies. These technologies could be used for individual low-fidelity rehearsal training of launch team communications and test team discipline prior to starting higher fidelity tiered training. Launch team members could rehearse their roles at their desks prior to participating in integrated simulations or launches.

POSSIBLE NEXT STEPS

The SALT Team is preparing for future work. There are many potential next steps including the following:

- Adding off-nominal cases to the existing task analysis and C3TRACE DES. Off-nominal cases would initially be drawn from the large set of available preplanned procedures and emergency procedures. We might then consider addressing problems for which there are no planned procedures, but that is a much tougher problem.

- Adding metrics and possibly VACP workload estimates to the C3TRACE DES for improved analysis.

- Using task analysis and C3TRACE to create Exploration launch team alternative configurations for trade off analysis.

- Expanding the task analysis and C3TRACE DES of nominal case procedures. Currently we only focus on the last 20 minutes of countdown clock time, but the countdown is actually several days long.

- Improving the quality and detail of the prototype training application.

- Integrating the C3TRACE DES and the prototype training application.

- Integrating the C3TRACE DES or the prototype training application with the existing SGOS simulation of the shuttle and its ground support equipment.

- Utilizing elements of the Virtual Cockpit application with the prototype training application or the C3TRACE DES.

- Adding support for the High Level Architecture (HLA) standard to the prototype training application.

- Exploring the application of distributed intelligent agent simulation technologies to launch team analysis, training, and evaluation.

- Exploring the role of context in team decision making and in distributed intelligent agent simulation representations of launch teams.

CONCLUSION

The new NASA Exploration Program and its need for new launch vehicles present great challenges, but also great opportunities. When systems like the shuttle become operational, they develop complex processes and procedures that last for decades and changes become evolutionary and eventually very difficult and expensive because of the costs and risks associated with modifying verified and validated (V&V)'d processes and systems. When new launch vehicles and systems are developed (as NASA is doing now under the Exploration Program), the timing is great for introducing revolutionary technological changes since there are no V&V'd processes and systems that would be impacted.

Now is the time for NASA to rethink the way that it prepares for, and performs, launches. We believe that NASA can use some of these human simulation technologies for trade off analysis studies of Exploration launch team configurations. We also believe that NASA can use these technologies to revolutionize the way it trains and evaluates launch and ground processing teams. This automation of training and evaluation might help NASA meet its daunting challenge of training and evaluating launch teams on the whole new set of systems and procedures that a likely to be utilized within the Exploration Program.

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