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SUPPORTING THE VISION FOR SPACE WITH DISCRETE EVENT SIMULATION

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ABSTRACT

On January 14, 2004 President George W. Bush announced a new Vision for Space Exploration. This vision called for NASA to complete the assembly of the International Space Station by 2010 and retire the Space Shuttle immediately thereafter. A discrete event simulation (DES) based tool has been built to assess the viability of NASA accomplishing all of the Space Shuttle missions required to assemble the Space Station by the end of the decade. This paper describes this DES tool i.e. the Manifest Assessment Simulation Tool (MAST).

1 INTRODUCTION

President George W. Bush delivered his Vision for Space charge to NASA on January 14, 2004. That vision called for NASA to complete the assembly of the International Space Station by 2010 and retire the Space Shuttle.

NASA was working to return the Space Shuttle to flight after the loss of Columbia, which occurred on February 1, 2003, when President Bush announced the Vision for Space. At that time it was anticipated that a total of 30 Shuttle missions would be required to complete the Station. NASA subsequently planned the ISS assembly to be accomplished with 28 missions. The sequence for these 28 missions—mission STS-114 through mission STS-141—along with the orbiters that fly them are specified in the Space Shuttle Manifest. Table 1 shows an excerpt from a manifest. An actual manifest specifies additional information such as the processing durations for each mission.

Space Shuttle Manifests are inherently subject to uncertainty. Preparations for launches may be impacted by added work or problem discovery. Launch delays can be caused by weather, hardware, or infrastructure problems. A space shuttle orbiter's return from space to Florida can be delayed when an orbiter is diverted to California due to inclement weather. The availability of critical resources e.g. flight hardware, facilities, and personnel, is also a factor in manifest uncertainty. All of this uncertainty influences planned launch dates, typically causing them to be later than planned. The total impact to the ISS assembly completion may be a delay of several months or greater.

2 MAST OVERVIEW

The Manifest Assessment Simulation Tool (MAST) provides a structured methodology for assessing the uncertainty of Space Shuttle manifest options in order to determine the cumulative launch probability function for a shuttle launch of interest versus the planned launch date. MAST is a specific application of the more general Project Assessment by Simulation Technique (Cates 2004).

Table 1: Space Shuttle Manifest (STS-Missions by Orbiter)

<table>
<tr><td>Year (CY)</td><td colspan="4">2005</td><td colspan="4">2006</td><td colspan="4">2007</td><td colspan="4">2008</td><td colspan="4">2009</td><td colspan="4">2010</td></tr>
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Manifest uncertainty resides in the processing flows of each Shuttle mission in the manifest. Figure 1 shows a simplified diagram of the orbiter processing flow and mission cycle for a typical Shuttle mission. A more complete Shuttle Flow has been previously described and modeled (Cates et al. 2002).

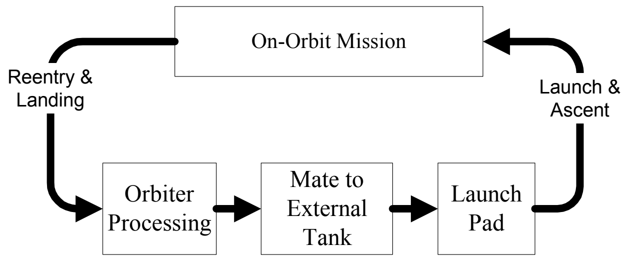

Figure 1: Shuttle Processing Flow

The durations of the Space Shuttle orbiter processing phases—processing through the Orbiter Processing Facility (OPF), mate to the External Tank in the Vehicle Assembly Building (VAB), and launch preparations at the Launch Pad—are all specified in the Manifest. Generally speaking approximately 3 months are afforded for orbiter processing. The mate to the External Tank, along with other operations in the VAB is planned over a one-week period. Launch preparations through launch at the launch pad are generally planned to take one month. Work is generally scheduled Monday through Friday with weekends available for planned work or margin.

Figure 2 shows an overview of how MAST works.

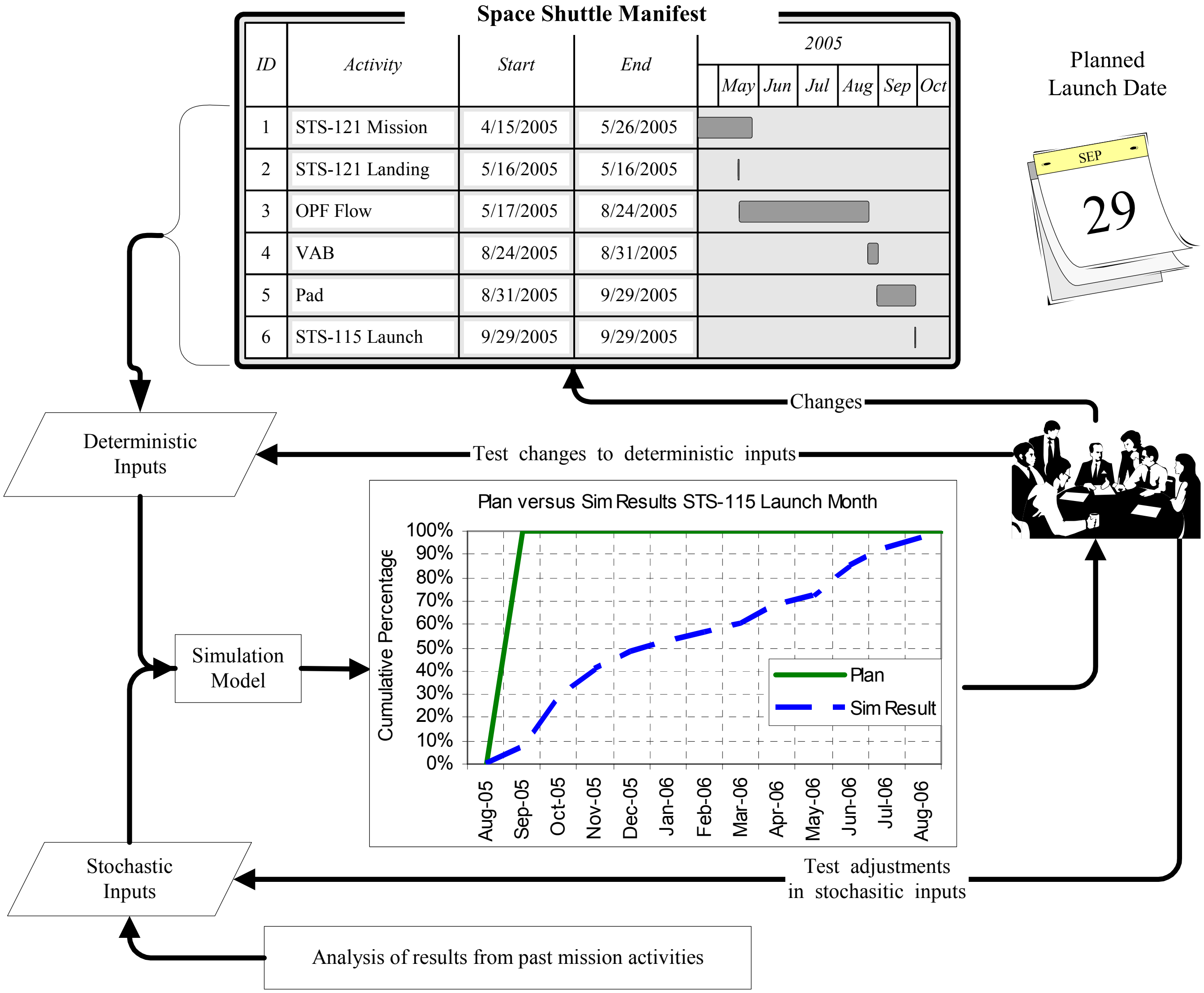

Figure 2: MAST Overview

The information in the Space Shuttle manifest forms the deterministic inputs for the simulation model. Manifest data has been displayed in Figure 2 using the more familiar Gantt chart from project management. For simplicity the manifest information shows only STS-115 and its predecessor mission STS-121. This information is then entered into an Excel file that is read by the simulation model.

The simulation engine for MAST is Arena—a commercial-off-the-shelf discrete event simulation package manufactured by Rockwell Automation. The MAST model has connectivity to Excel files for reading in manifest information and writing results. Figure 3 shows the connectivity of the simulation model.

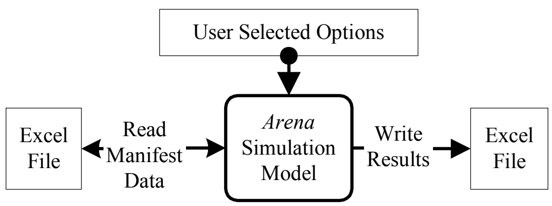

Figure 3: Simulation Model Connectivity

The "Plan Versus Sim Results" chart shown in Figure 2 is produced in Excel using the results from the simulation. The "Sim Results" line is a Completion Distribution Function (CDF). This notional chart shows that the simulation results for the STS-115 launch date are typically to the right i.e. later than the planned month of September. There is approximately a 7 percent chance of launch by the end of September. The cumulative probability of launching by December is approximately 50 percent. A manifest stakeholder could react to this information with an action or proposed action that would pull the likely launch date closer to the planned launch date.

2.1 Activity Construct

Each of the three major Space Shuttle mission preparation operations shown in Figure 1—Orbiter Processing, VAB, and Pad—are modeled in the same way using the activity construct shown in Figure 4. The model takes in as inputs planned processing days along with available reserve days for each of the three major mission preparation operations. During runs of the simulation, arrival of the orbiter entity at each of the locations is checked versus the planned arrival date and the amount of reserve is adjusted accordingly. The activity will end on schedule so long as there is enough reserve to accommodate delays attributable to starting late and whatever additional delta there is to the planned duration. The delta to the planned duration is one of the stochastic inputs to the model. Historical data is used to generate empirical and, where possible, theoretical distributions for added days to the OPF, VAB, and Pad activities.

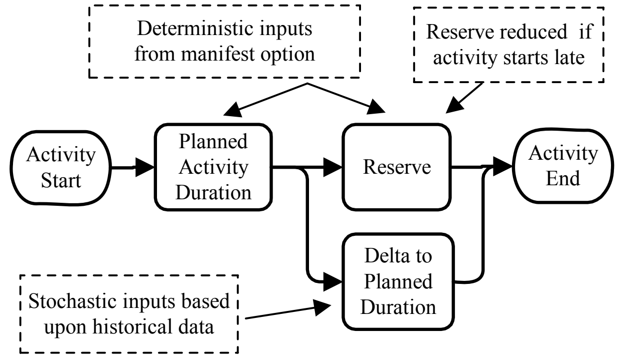

Figure 4: Activity Construct

The On-Orbit Mission phase is also modeled using the Activity Construct shown in Figure 4 with the exception that there is no reserve component. There is however the possibility that a mission will be extended to perform additional operations. This is modeled using an empirical distribution.

2.2 Launch and Landing

Launch of the shuttle is modeled using an event probability node containing probabilities for launching or being delayed and if so the delay type. The probabilities were determined from the available historical data. The delay type determines the length of time required to return to the next launch attempt.

Likewise, landing is modeled using an event probability node with paths for either landing as planned in Florida or being diverted to California. A cyclical component was added to allow the space shuttle orbiter to stay on orbit for up to 4 to wait for favorable weather in Florida.

2.3 User Selected Options

Figure 3 shows that the simulation model responds to "User Selected Options." These options give the model the ability to run under a variety of assumptions. For example, the Columbia Accident Investigation Board recommended that future space shuttle launches occur during daylight so that debris events can be more clearly seen. This new requirement coupled with the orbital mechanics of rendezvousing with the Space Station means that there are only a few launch windows per year. Once a window closes it may be several weeks before the next window opens. In MAST there is a user selected option for specifying how to model the daylight launch requirement. For example, the daylight launch requirement may only stay in-place for the first two shuttle missions

The possibility of a serious anomaly such as a loss of vehicle event or loss of mission event is included in the model. The user as the option of selecting the probability for such occurrences.

2.4 Running MAST

The model is first run in a deterministic mode to ensure that it will properly reproduce the planned manifest. After this step is successfully achieved the model is populated with the stochastic elements.

The simulation model is typically run for 1,000 replications so as to produce a large quantity of possible launch dates. This provides a fairly smooth Completion Distribution Function and a reasonably narrow confidence band. Equation 1 shows the Law and Kelton (2000) recommended equation for calculating the confidence interval for a mean from the data supplied by a simulation.

$$\overline{X}(n) = \pm t_{n-1,1-\alpha/2}\sqrt{\frac{S^2 n}{n}}. \quad (1)$$

Determining the confidence band along the entire CDF, as opposed to a mean completion date, requires that Equation 1 be performed for each month that the launch might occur. To facilitate these calculations, the data from the 1000 replications is divided into 10 sets of 100 replications. Consequently the value of n is now 10 instead of 1,000. Note that what the number of replications and sets should be will depend upon the specific project and desired level of accuracy. Once the data has been divided into the desired number of sets, a confidence interval is calculated for each month.

3 APPLICATIONS OF MAST

In March of 2004, NASA created manifest option 04A-29, which was subsequently used in support of developing the budget for the Space Shuttle program. The 04A-29 manifest assumed a return to flight in March of 2005, an annual flight rate of 5 flights per year, and a total of 30 missions to complete assembly of the Space Station with the last mission (STS-143) launched in March of 2011.

MAST was used to analyze the 04A-29 option under a variety of additional assumptions. For example, MAST was used to determine the likely launch date of the 30th mission with and without augmentation of the ground processing workforce. The Columbia Accident Investigation Board indicated work force augmentation was desirable (Gehman 2003). Figure 5 shows the results.

The workforce augmentation results shown in Figure 5 represent the possible result of adding approximately 300 people to the space shuttle ground processing workforce. The results indicated that workforce augmentation

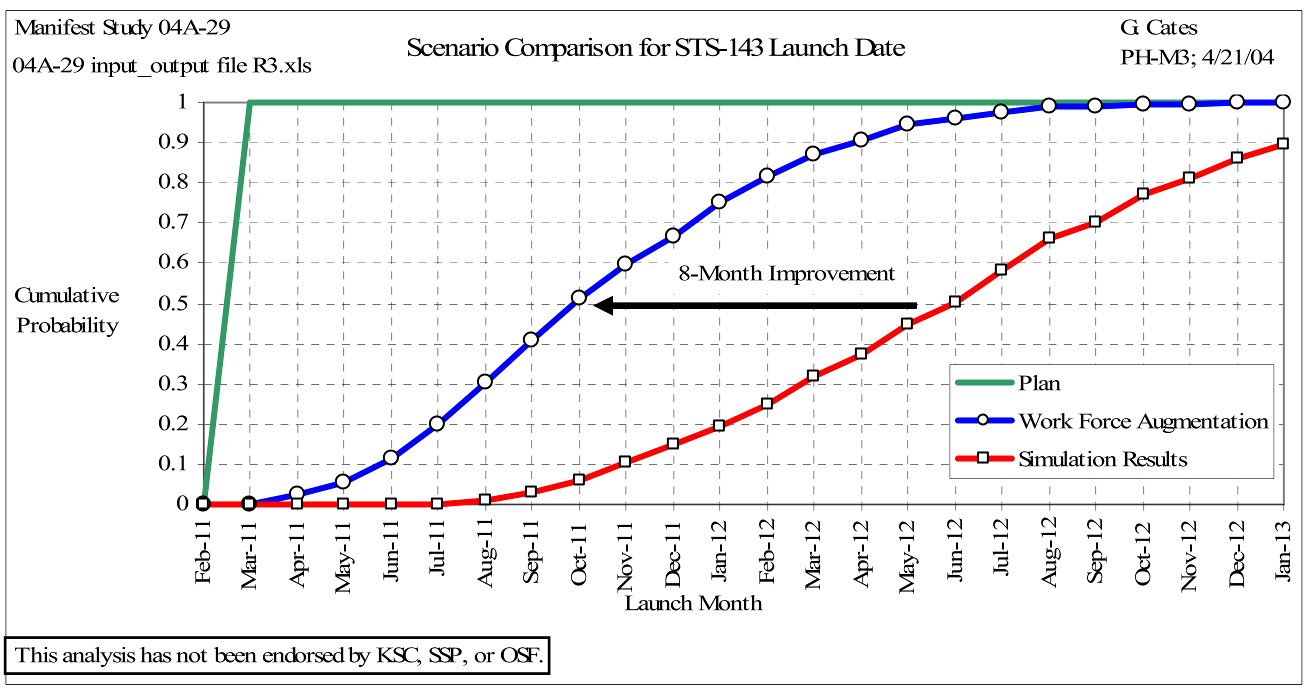

Figure 5: MAST Results for 04A-29 Option

would be very beneficial. Without workforce augmentation, the likely launch date for STS-143 (the 30^{th} mission), planned for March of 2011, could be anywhere from September of 2011 through the end of 2012 and beyond. The MAST analysis indicated that as much as an 8-month improvement could be gained by augmenting the workforce. Workforce augmentation was ultimately approved for implementation.

4 CONCLUSION

Discrete Event Simulation analysis as embodied in the Manifest Assessment by Simulation Tool has proven to be beneficial to NASA for implementing the Vision for Space Exploration. MAST is providing NASA with a important tool to enable NASA to complete the International Space Station as soon as possible and retire the Space Shuttle at that time. MAST has continued to evolve since its first use. User option features are added to MAST as the need arises. MAST will be modified as appropriate to analyze the processing life-cycles of future launch and exploration vehicles.

APPENDIX: ACRONYMS

CDF	Completion Distribution Function
DES	Discrete Event Simulation
OPF	Orbiter Processing Facility
MAST	Manifest Assessment Simulation Tool
NASA	National Aeronautics and Space Administration
STS	Space Transportation System
VAB	Vehicle Assembly Building

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