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CARGO TRANSFER AND RETURN VEHICLE AND PERSONNEL LAUNCH SYSTEM LAUNCH PROCESSING MODEL

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ABSTRACT

Simulation software was designed to model a cargo transfer and return vehicle (CTRV) and personnel launch system (PLS) mixed fleet launch processing system. The purpose of the CTRV and the PLS is to provide all transportation services, separating cargo and crew, to *International Space Station Alpha* after a Space Shuttle program phase out period.

The results presented in this report provide an expected bracket for important CTRV and PLS launch processing statistics during a steady-state period. Simulation experiments indicate that modifying current Space Shuttle facilities and resources will be sufficient to support the CTRV and PLS concept. The simulation experiments show that mobile launch tower (MLT) utilization is expected to be very high, which could lead to a launch processing choke point should an MLT become unavailable for some reason. NASA may want to consider building another MLT to provide CTRV and PLS launch processing margin. Additionally the simulation experiment results indicate that Vehicle Assembly Building (VAB) utilization is expected to be high. NASA may want to consider providing capability for a third CTRV/PLS launch vehicle integration cell. Further study and analysis of MLT and VAB utilization are recommended. This is needed to determine whether or not three MLTs and two VAB launch vehicle integration cells are sufficient to support the CTRV and PLS launch processing concept.

KEY WORDS

Simulation, general application, aerospace systems, launch system processing, cargo transfer and return vehicle (CTRV), personnel launch system (PLS).

1 PROBLEM STATEMENT

The purposes of the cargo transfer and return vehicle (CTRV) are to transport logistics modules to *International Space Station Alpha* and, after docking at the space station for an appropriate time period, to return down payloads to earth. The purpose of the Personnel Launch System (PLS) is to transport the human crew to and from *International Space Station Alpha* as required per the crew rotation schedule.

An advanced NASA planning concept calls for the CTRV and PLS to provide all transportation support to the space station after a Space Shuttle program phase-out over a two year period. The CTRV and PLS concept is expected to be flight tested and fully operational by the end of the Shuttle program phase-out. NASA desires to maximize utilization of current Space Shuttle facilities and resources in support of the CTRV and PLS concept. As such NASA would like to know if current Shuttle program facilities and resources, once modified to support a CTRV and PLS concept, would be sufficient to process the CTRV and PLS mixed fleet and meet the required launch schedule. Additionally NASA would like to know what the expected CTRV and PLS concept facility and resource utilizations are and what is the expected average annual touch labor required for the concept (i.e., measure of effectiveness).

The objective of this project was to design simulation software to model a CTRV and PLS mixed fleet launch processing system. The SIMAN/Cinema IV MicroLab simulation application was used to accomplish the design. The purpose of the CTRV and PLS launch processing model is to permit the user to perform simulation experiments that will aid in determining whether modifying current Space Shuttle facilities will be sufficient to support the planned CTRV and PLS launch rate, and determining the expected CTRV and PLS concept facility and resource utilizations and average annual touch labor requirements.

2 PROCEDURES USED IN PROBLEM SOLVING AND MODEL BUILDING

Both the CTRV and PLS are an aggregation of six vehicle subsystems. These subsystems are:

- Structure
- Thermal protection system/heat shield
- Landing system
- Avionics
- Power generation
- Propulsion

The CTRV and PLS launch processing scenario, for project modeling purposes, is described below. The new CTRV or PLS arrives from the factory to the Kennedy Space Center (KSC) landing facility aboard a transport aircraft. A CTRV or PLS returning from a mission may either be brought from its landing site to the KSC landing facility aboard a transport aircraft, or may land directly at the KSC landing facility. All vehicle hazards are made safe at the landing facility.

After being removed from the transport aircraft, the CTRV or PLS moves to a horizontal processing facility (HPF) where all the vehicle subsystems are processed, checked-out, and integration tested. The logistics payload, intended for delivery to *International Space Station Alpha,* is transported in a canister from the Space Station Processing Facility (SSPF) to the HPF while the CTRV receives horizontal processing. The payload is removed from the canister and installed into the CTRV cargo bay and checked-out. The CTRV or PLS vehicle is closed-out and completes horizontal processing.

The completely tested CTRV or PLS is next transported to the Vehicle Assembly Building (VAB). In a VAB high bay integration cell, the CTRV or PLS mates on top of the core stage booster. The booster was previously tested and installed on a mobile launch tower (MLT) in the VAB high bay. The MLT is a platform with an access tower that supports the launch vehicle and is moved about the launch site by a crawler-transporter.

After launch vehicle check-out and integration testing, the launch vehicle on the MLT is picked up by a crawler-transporter and moved to the launch pad. The launch vehicle receives processing at the launch pad and then launches into space. Any hazardous materials are loaded into the launch vehicle or payload at the launch pad, using the MLT access tower if necessary.

After lift-off, the launch pad and MLT are refurbished, the core stage booster is expended and disposed, and the CTRV or PLS performs on-orbit maneuvering and docks at the space station. After station docking operations, the CTRV's payload or PLS's crew is delivered to the space station. The CTRV remains docked at the space station for a short time and has down payload placed in its payload bay. The PLS remains docked at the space station long enough to rotate the station crew.

When ready to return to earth, the CTRV or PLS releases from the station and performs reentry maneuvering. The CTRV or PLS lands at a landing site where it is safed, deserviced, and the down payload may be accessed. A CTRV or PLS that did not land at KSC is brought to the KSC landing facility aboard a transport aircraft to begin the next launch processing flow.

The core stage booster processing mentioned above begins with a barge delivering the core stage from the manufacturer to the KSC Turn Basin. Another facility, which is not modeled, is used for receiving inspection and testing of the core stage. At KSC the MLT prepares to receive the launch vehicle in a VAB high bay integration cell. The core stage is transported to the VAB and stacked on top of the MLT. After core stage/MLT interface verification tests are complete, the launch vehicle is ready for the CTRV or PLS to be mated.

2.1 Data Dictionary

The data dictionary contains the description for all modeling entities:

Avionics
: A subsystem of the CTRV or PLS consisting of guidance, navigation, and control, and communications and data handling equipment.

Cargo Transfer and Return Vehicle (CTRV)
: A space cargo vehicle used to deliver logistics modules to the space station and to return down payloads to earth.

Crawler-Transporter
: A large tracked-vehicle used to move a space launch vehicle on a platform from the VAB to the launch pad.

Core Stage
: The main component of the launch vehicle booster containing tanks and engines. The booster core stage components are received, inspected, assembled, processed, and

integration tested prior to entering the VAB.

Horizontal Processing Facility (HPF)
The facility that supports horizontal operations associated with CTRV and PLS processing (i.e., modified Orbiter Processing Facility). There are three processing bays in the HPF.

International Space Station Alpha
The human-inhabited facility in low-earth orbit where logistics payloads are delivered to and down payloads are returned to earth from.

Kennedy Space Center (KSC)
The launch site where the CTRV or PLS is processed in preparation for launching into space.

KSC Landing Facility
The runway located northwest of the VAB used by transport aircraft in delivering the CTRV or PLS to KSC. The facility may also be used by a CTRV or PLS returning from a mission. This facility has capabilities for safing the space vehicle after returning from a mission. The landing facility serves one vehicle at a time.

Landing System
A subsystem of the CTRV or PLS consisting of landing gear and recovery equipment.

Launch Pad
An elevated, roughly octagonal in shape facility where the MLT is placed on pedestals. Fuel, oxidizer, high pressure gas, electrical, and other pad service lines connect with the MLT. There are two launch pads.

Mobile Launch Tower (MLT)
A transportable launch base with exhaust holes and a fixed service structure for the launch vehicle. There are three MLTs (which are modified mobile launch platforms).

Personnel Launch System (PLS)
The space vehicle that transports personnel to and from *International Space Station Alpha.*

Power Generation
A subsystem of the CTRV or PLS consisting of fuel cells and/or batteries.

Propulsion
A subsystem of the CTRV or PLS consisting of propellant tanks, orbital maneuvering system, and reaction control system.

Space Station Processing Facility (SSPF)
A large facility at KSC where non-hazardous space station payloads are processed in preparation for delivery.

Structure
A subsystem of the CTRV or PLS consisting of the primary structural elements.

Thermal Protection System (TPS)/Heat Shield
A subsystem of the CTRV or PLS consisting of thermal control equipment.

Vehicle Assembly Building (VAB)
A giant building used for the vertical assembly of space launch vehicles. The VAB has two high bay integration cells.

2.2 Processing Flow Assumptions

The following assumptions were used in developing the CTRV and PLS concept processing flow scenario:

1. It is a post Space Shuttle program "steady-state" scenario.
2. There is maximum vehicle subsystem commonality between the CTRV and the PLS.
3. The required CTRV launch rate is 6 to 7 flights per year (uniformly distributed).
4. The required PLS launch rate is 3 flights per year.
5. All CTRV and PLS launch processing complies with environmental and safety regulations.
6. HPF bays are converted from the Orbiter Processing Facility (OPF) bays.
7. The vehicle propulsion subsystem is safed at the landing facility and deserviced in the HPF.
8. The payload logistics module is transported from the SSPF to the HPF for CTRV integration.

9. There is only one payload installation and check-out process into the CTRV in the HPF per flow.
10. VAB high bays #1 and #3 are converted into CTRV/PLS launch vehicle integration cells.
11. The CTRV and PLS are designed to be rotated to the vertical attitude in the VAB transfer aisle.
12. The SSPF and VAB are non-hazardous processing facilities.
13. The MLT is modified from a mobile launch platform (MLP).
14. All hazardous fueling operations are performed at the launch pad.
15. There are 250 work-days per year and 8 hours per work-day (except for a 24-hour work-day at the launch pad).
16. The current Space Shuttle program 21-day minimum launch interval does not apply.
17. No simultaneous missions are allowed (only one vehicle may be going up or down at a time).
18. Multiple vehicles may be simultaneously docked at the space station.
19. The vehicles are designed with maximum utilization of built-in test equipment (BITE) and vehicle health management technology.
20. The vehicles are designed for efficient processing operability and ease of maintainability.
21. Reusable vehicle structures do not require extensive post-landing structural inspection.
22. CTRV and PLS recovery operations are similar to those used by the Space Shuttle.
23. The CTRV and PLS are designed to store any non-hazardous fluids in both the horizontal and vertical attitude during launch processing.

2.3 Model Control Variables

The model control variables, listed in each experiment source file, are shown below. All other model parameters are considered fixed.

1. Core stage touch labor processing hours
2. MLT preparation processing time
3. Booster preparation processing in the VAB time
4. Landing facility processing time
5. Structure subsystem processing time
6. TPS/heat shield subsystem processing time
7. Landing subsystem processing time
8. Power subsystem processing time
9. Propulsion subsystem processing time
10. Serial subsystem processing time
11. Vehicle close-out processing time
12. Launch vehicle integration in the VAB time
13. Launch pad processing time
14. Launch pad and MLT refurbishment time
15. Unplanned maintenance action's mean time to repair (MTTR)
16. Spares probability of sufficiency (POS) multiple
17. Average touch labor head-count for booster processing
18. Average touch labor head-count for landing facility processing
19. Average touch labor head-count for structure subsystem processing
20. Average touch labor head-count for TPS/heat shield subsystem processing
21. Average touch labor head-count for landing subsystem processing
22. Average touch labor head-count for avionics subsystem processing
23. Average touch labor head-count for power subsystem processing
24. Average touch labor head-count for propulsion subsystem processing
25. Average touch labor head-count for serial subsystem processing
26. Average touch labor head-count for vehicle close-out processing
27. Average touch labor head-count for launch vehicle integration processing
28. Average touch labor head-count for launch pad processing
29. Average touch labor head-count for launch pad and MLT refurbishment

3 INPUT DATA ANALYSIS

The required CTRV launch rate is six to seven flights per year and the required PLS launch rate is three flights per year. CTRV entities were modeled to be created six to seven times per year distributed uniformly, and PLS entities were modeled to be created three times per year at a constant interval.

CTRV and PLS concept launch processing data was obtained from several sources. Because there is no actual processing data for either a CTRV or PLS, a relevant subsystem processing time bracket was established. The optimistic end of the launch processing bracket was estimated by assuming the CTRV and PLS could be processed using current aircraft processing methodologies, called the "as-aircraft" approach. The pessimistic end of the bracket was estimated by assuming the CTRV and PLS would be processed using current Space Shuttle processing methodologies. This approach is called the "as-Shuttle" processing approximation. The vehicle subsystem "as-aircraft" processing timelines were obtained from a NASA Langley Research Center/Rockwell Aerospace PLS study report [Personnel Launch System/Advanced Manned Launch System Operations Support Analysis]. The vehicle subsystem "as-Shuttle" processing timelines are based on the Space Shuttle STS-37 OPF planning assessment. The vehicle subsystem touch labor estimates were derived from a Teledyne Brown/Pan Am Shuttle II Data Base Development report (based on the STS-31 flow actual data reported). The core stage booster processing timelines and touch labor estimates were taken from a Lockheed Space Operations Company National Launch System (NLS) study report [Letchworth]. The input data is summarized in Table 1.

Reliability estimates were obtained from Rockwell Aerospace -- Space Systems Division Systems Engineering. The estimated mean time to repair (MTTR) for any unplanned maintenance action (UMA) in the model is 2.5 hours (or 0.3125 day for an 8-hour work-day). The mean number of UMAs per CTRV flow is estimated to be 2.07; the average number of UMAs per PLS flow is estimated to be 15.0. Because the random number of UMAs per flow must be an integer, the CTRV and PLS UMA distributions were modeled as parameter sets for each activity. There are ten activities in the model were a failure may occur during a vehicle processing flow. The failures which may occur in these ten activities are assumed to be independent. The CTRV UMA parameter distribution per activity is [0, 79.3%; 1, 20.7%], where the data in the brackets represent [number of UMAs, probability of occurrence; ...]. The PLS UMA parameter distribution per activity is [0, 25%; 1, 25%; 2, 25%; 3, 25%].

The mean downtime per UMA is estimated as a multiple of the MTTR as shown in Figure 1 (obtained from Rockwell Systems Engineering). A spares probability of sufficiency (POS) of 90% was assumed (which is the same as the current Space Shuttle POS requirement).

Table 1: Model Activity Touch Labor and Processing Time Estimates

Model Activity	Touch Labor Estimate (Equivalent Persons)	Nominal Processing Time "As-Aircraft" (Work-Days)	Nominal Processing Time "As-Shuttle" (Work-Days)
Core Stage	** 53,103 man-hours	N/A	N/A
MLP Prep.	10	1	1
Booster Prep. in VAB	10	4	4
Landing Facility	112	1	1
Structure Subsystem	12	6	27
TPS Subsystem	37	17	46
Landing Subsystem	1	2	17
Avionics Subsystem	5	9	34
Power Subsystem	3	11	24
Propulsion Subsystem	5	1	54
Serial Subsystem Activities	5 ("as-aircraft") 3.67 ("as-Shuttle")	1	6
Vehicle Close-out	17	3	3
Vehicle Integration in VAB	74	5	5
Launch Pad	137	14	14
Pad & MLT Refurbishment	10	5	5

** Note that core stage average touch labor estimate is in man-hours, not equivalent persons.

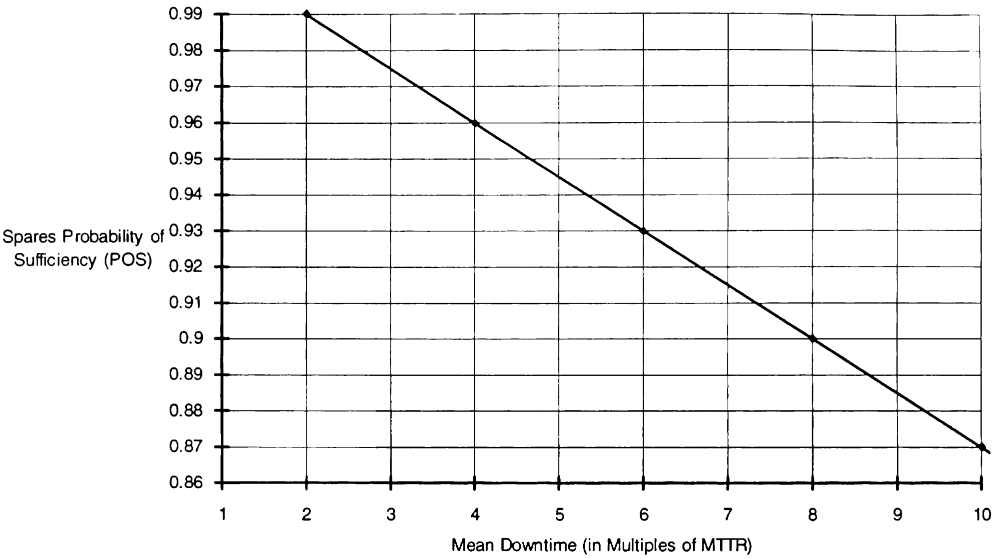

Figure 1: Downtime Variation as a Function of Spares Probability of Sufficiency (POS)

4 PRESENTATION OF RESULTS

An initial pilot simulation experiment was conducted to determine how long the launch processing model's transient phase lasted. Visual observation of the pilot run output and moving average plots indicated that the model transient phase was approximately 1,000 work-days (see Figure 2). Statistics generated during the transient phase were truncated from the following production simulation experiment runs.

One method for estimating the variance of the mean in a non-terminating system (such as CTRV and PLS launch processing), is to generate independent replications of the model (as done with terminating systems). The main advantages of replication are its simplicity and the fact that direct use of all statistical procedures for a terminating system may be used. It then must be decided whether it is preferable to make a few long replications or many short replications. Long replications are less likely to have initial condition bias, and they waste fewer data than short replications. However if too few replications are made, the degrees of freedom for the t-statistic will be small, resulting in an increased half-width for the confidence interval. A reasonable number of replications to use in most situations is ten to twenty [Pegden, Shannon, Sadowski, p. 188].

For the production simulation experiments (i.e., both the "as-aircraft" and "as-Shuttle" runs), ten replications of ten years (2,500 work-days) plus 1,000 work-days transient period were made. All simulation statistics were cleared after the transient period in order to approximate a steady-state launch processing condition. A summary of important statistics obtained from the production simulation experiments is shown in Table 2.

An animation of the launch processing simulation model was designed using the Cinema IV application. This animation includes the CTRV, PLS, and core stage booster entities, the landing facility, HPF, VAB, launch pad, and MLT resources, and the crawler-transporter (see Figure 3). An observer of the animation will see simulation events on the computer terminal as they occur during a launch processing simulation execution.

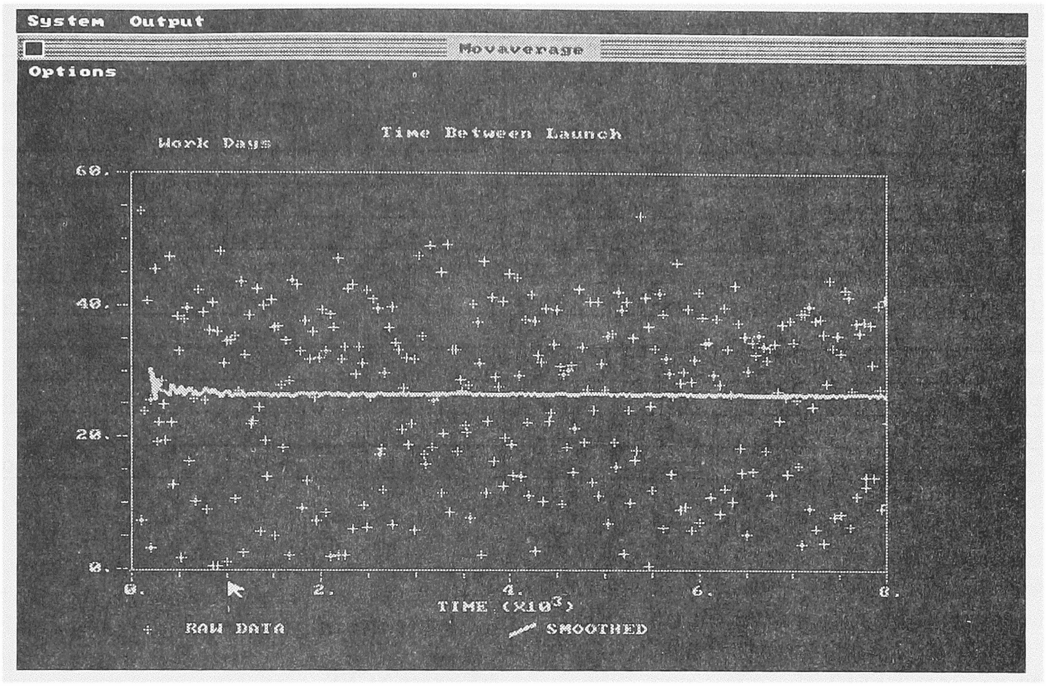

Figure 2: Pilot Simulation Experiment Moving Average Plot

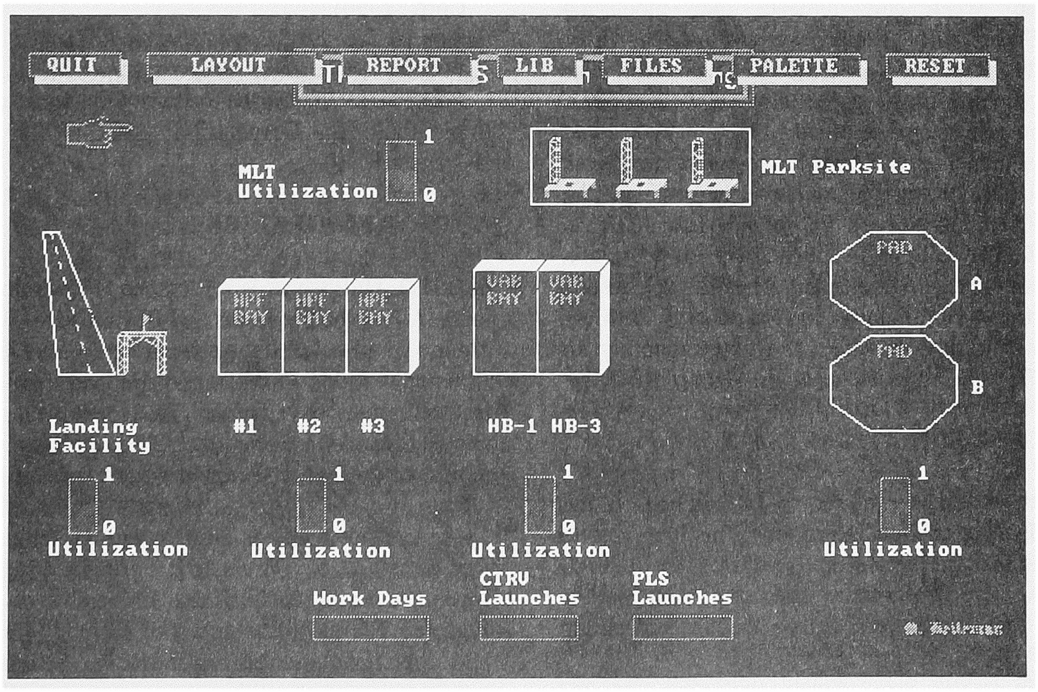

Figure 3: Animation Background Layout

Table 2: Launch Processing Simulation Experiment Results

Identifier	Lower 95% Confidence Limit	"As-Aircraft" Point Estimate	Upper 95% Confidence Limit	Lower 95% Confidence Limit	"As-Shuttle" Point Estimate	Upper 95% Confidence Limit
CTRV Time in System (Work-Days)	44.3	44.4	44.5	86.6	86.7	86.8
PLS Time in System (Work-Days)	58.3	58.8	59.3	100.0	101.0	102.0
Launch Interval (Work-Days)	26.4	26.4	26.5	26.4	26.4	26.5
Annual Touch Labor (Million Hours)	1.508	1.512	1.516	1.684	1.690	1.696
Landing Facility Utilization	0.042	0.042	0.042	0.042	0.042	0.042
HPF Utilization	0.323	0.326	0.329	0.853	0.857	0.861
VAB Utilization	0.645	0.648	0.651	0.931	0.935	0.940
Launch Pad Utilization	0.387	0.389	0.391	0.393	0.394	0.395
MLT Utilization	0.692	0.694	0.696	1.000	1.000	1.000
Crawler-Transporter Utilization	0.028	0.028	0.028	0.372	0.375	0.379

5 ANALYSIS OF RESULTS AND CONCLUSIONS

The results presented in Table 2 provide an expected bracket (i.e., optimistic and pessimistic estimates) for important CTRV and PLS launch processing statistics during a steady-state period. The simulation experiments indicate that modifying current Space Shuttle facilities and resources will be sufficient to support the CTRV and PLS concept. The simulation experiment results also show that MLT utilization is expected to be very high, which could lead to a launch processing choke point should an MLT become unavailable for some reason. NASA may want to consider building a fourth MLT to provide CTRV and PLS launch processing margin. Additionally the simulation experiment results indicate that VAB utilization is expected to be high. NASA may want to consider providing capability for a third CTRV/PLS launch vehicle integration cell.

6 RECOMMENDATIONS

Further study and analysis of MLT utilization and VAB utilization are recommended. This is needed to determine whether or not three MLTs and two VAB launch vehicle integration cells are sufficient to support the CTRV and PLS launch processing concept.

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