



Use of DES Modeling for Determining Launch Availability for SLS

Dr. Michael Watson (NASA/MSFC)

Eric Staton - Presenting Author (Jacobs ESSSA Group/Jacobs/MSFC)

Grant Cates (The Aerospace Corporation/KSC)

Ronald Finn (ARES Corporation/JSC)

Karen M. Altino (NASA/MSFC)

Dr. K. Lee Burns (Jacobs ESSSA Group/Raytheon/MSFC)

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Introduction

- NASA is developing a new heavy lift launch system for human and scientific exploration beyond Earth orbit comprising of the Space Launch System (SLS), Orion Multi-Purpose Crew Vehicle (MPCV), and Ground Systems Development and Operations (GSDO).
- The desire of the system is to ensure a high confidence of successfully launching the exploration missions, especially those that require multiple launches, have a narrow Earth departure window, and high investment costs.
- This presentation discusses the process used by a Cross-Program team to develop the Exploration Systems Development (ESD) Launch Availability (LA) Technical Performance Measure (TPM) and allocate it to each of the Programs through the use of Discrete Event Simulations (DES).

Background

- 2010/2011 the Human Explorations Framework Team (HEFT) developed a set of suggested objectives for SLS.
 - One objective was Launch Processing which was focused on launch countdown.
- The launch processing objective was then proposed to be an ESD LA requirement that would be imposed upon the SLS, GSDO, and MPCV Programs.
- Desire to have the LA requirement be more quantitative and related to Near Earth Object (NEO) and Mars Design Reference Missions (DRMs).
- In mid 2011 ESD established LA as requirement R-19 (see next slide).
- In late 2011 a Cross-Program team was started to determine the path forward for meeting the LA requirement and to resolve the To Be Determine (TBD) and To Be Resolved (TBR) values.

Background (continue)

R-19 Launch Availability

- R-19: Launch Availability. The Architecture shall have a 95% (TBR-ESDR-010) likelihood of launching within 30 days of the planned launch date evolvable to (TBD-ESDR-010) at the start of launch countdown and allocated per Table R-19. This requirement is not applicable to the Tactical Timeframe.

| SLS | MPCV | 21CGS |
|--------------|---------------|--------------|
| TBD-ESDR-011 | TBD- ESDR-011 | TBD-ESDR-011 |

- Rationale: The CDF DRMs involve challenging launch constraints driven by previously launched hardware loitering on orbit with a limited lifetime and/or limited injection window opportunities for beyond-LEO destinations. Launch availability will have to evolve to a (TBD-ESDR-010) higher level to support the NEA and Mars DRMs, which have the greatest loiter durations for previously launched hardware and most challenging injection windows. This requirement includes all launch delay sources including, but not limited to, ground systems, launch systems, launch site weather, SLS, MPCV, range constraints, crew and payload. This requirement will be used to derive requirements for probability of launch, turn-around times post launch scrub, and number of consecutive launch days. **The TBR/TBD values will be reconciled via future integrated trade studies.**

Use of Discrete Event Simulation

- Discrete Event Simulations:
 - A DES is an efficient tool for modeling complex systems and analyzing how real world activities will perform under different conditions.
 - Benefits of using a DES is that the model can continuously be refined over time as more additional data becomes available, therefore increasing the understanding of how the system will respond.
 - The process of continual refinement allows for a more accurate approximation to be achieved relatively quickly and at a low cost.
 - Kennedy Space Center (KSC) / Marshall Space Flight Center (MSFC) / Johnson Space Center (JSC) have a long history of using DES.

Model Development

- Dr. Michael Watson (SLS Operations Discipline Lead Engineer) initiated the Cross-Program face-to-face meeting at MSFC and brought participants from each of the Programs together for a 2 day Technical Interchange Meeting (TIM) to determine how to implement the LA requirement.
- Cross-Program team decided that the Integrated Launch Probability Model developed by GSDO would provide the “official” integrated assessment of LA with inputs from each of the Programs.
- Major elements of SLS trace their heritage directly to the Space Shuttle.
 - 5-Segment SLS Solid Rocket Boosters (SRB) are nearly identical to the 4-Segment SRBs used by the Space Shuttle.
 - SLS RS-25 engines used on the first few SLS missions are former Space Shuttle Main Engines.
 - The SLS Core Stage is analogous in function and form to a combination of the Space Shuttle external tank and orbiter’s aft engine compartment.
 - The MPCV spacecraft is roughly analogous to the Space Shuttle orbiter’s crew compartment.

Model Development (continue)

- Due to the similarity of SLS Elements and the Space Shuttle, the data associated with the Space Shuttle 135 launches and 255 launch attempts were used to develop a number of basis-of-estimates for each of the Programs and SLS Elements.
- Each launch scrub and delay was analyzed to determine if that particular scrub/delay was relevant to SLS.
- The mapping process included determining which major elements, SLS, MPCV, GSDO, Range, or weather the delay may apply to.
- Based on the mapping process, a basis-of-estimate was developed and sub-divided over seven phases of a 72 hours countdown period, consistent with how the Space Shuttle operated.

Model Development (continue)

| STS | Delay Duration (Days) | Delay Duration (Minutes) | Time of Decision | Time of Decision | Reason for Delay | Core-Stage Rollback Required? | Factor | Factor Rationale |
|-----|-----------------------|--------------------------|----------------------|------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-------------------------------|--------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 1 | 2 | 0 | MMT Commit to Launch | T-9 minutes | Timing skew between primary and B/U FLT computers | No | 0.2500 | Factor based upon perceived complexity difference between Core-Stage Avionics flight computer's and STS orbiter's 5 GPC's. Also this was a first launch occurrence. |
| 2 | 8 | 0 | GLS | T-31 sec | Launch delayed due to an apparent low reading on fuel cell oxygen tank pressures. Countdown proceeded but was aborted at T-31 seconds when clogged APU fuel filters caused high oil pressures and over-temp in two of three APUs. Gear boxes flushed and filters replaced. | Yes | 0.5000 | Presence of batteries on Instrument Unit (analog to Fuel Cells). Factor based upon perceived complexity / risk difference between: (1) fuel cell base system and battery based system; and (2) Core-Stage TVC system and STS hydraulic system. |

- The basis-of-estimates needed to be adjusted to account for the difference between the Space Shuttle and SLS/MPCV.
- The approach for addressing these differences was to assign a factor ranging from 1 to 0.
 - 1 indicates that the Space Shuttle scrub/delay mapped directly.
 - 0 indicates that the Space Shuttle scrub/delay has no applicability.
- Subject matters from each of the Program and SLS Element were asked to review and comment on the factors.
- Multiplier values was also assigned to address differences in the numbers of the Elements. Example: SLS will have 4 main engines as opposed to 3 on the Space Shuttle.

Model Development (continue)

- The Delay Category Assignments summarizes all of the delay categories that were considered when developing the LA TPM and which program or Natural Environments they were assigned to.

| SLS | MPCV | GSDO | Environments |
|-----------------------------|-----------------|------------------|------------------------------------------------------------------|
| Twin SRB | Orion | Ground Systems | Range Weather |
| 4 Core Stage Engines | Crew Health | Human Errors | Launch Weather |
| Core Stage | Crew Ingress | Range Conflicts | Abort Weather (for "on pad" or near pad aborts) |
| Instrument Unit | Crew Actions | Range Systems | Sea State (and other environments in abort landing locations) |
| <u>iCPS</u> | COLAs | Range Intrusions | Winds Aloft* |
| <u>iCPS</u> RL-10 Engine | Mission Systems | Hurricanes | Wind Placard** |

- Natural Environments was added to the Delay Categories because none of the Programs have control over the weather on the day of launch and therefore none of the Programs were penalized for weather.

* The current Environments analysis does not include Winds Aloft. Potential that winds aloft could cause a scrub is currently modeled under SLS with the assumption that SLS will implement a system analogous to the STS DOLILU capability.

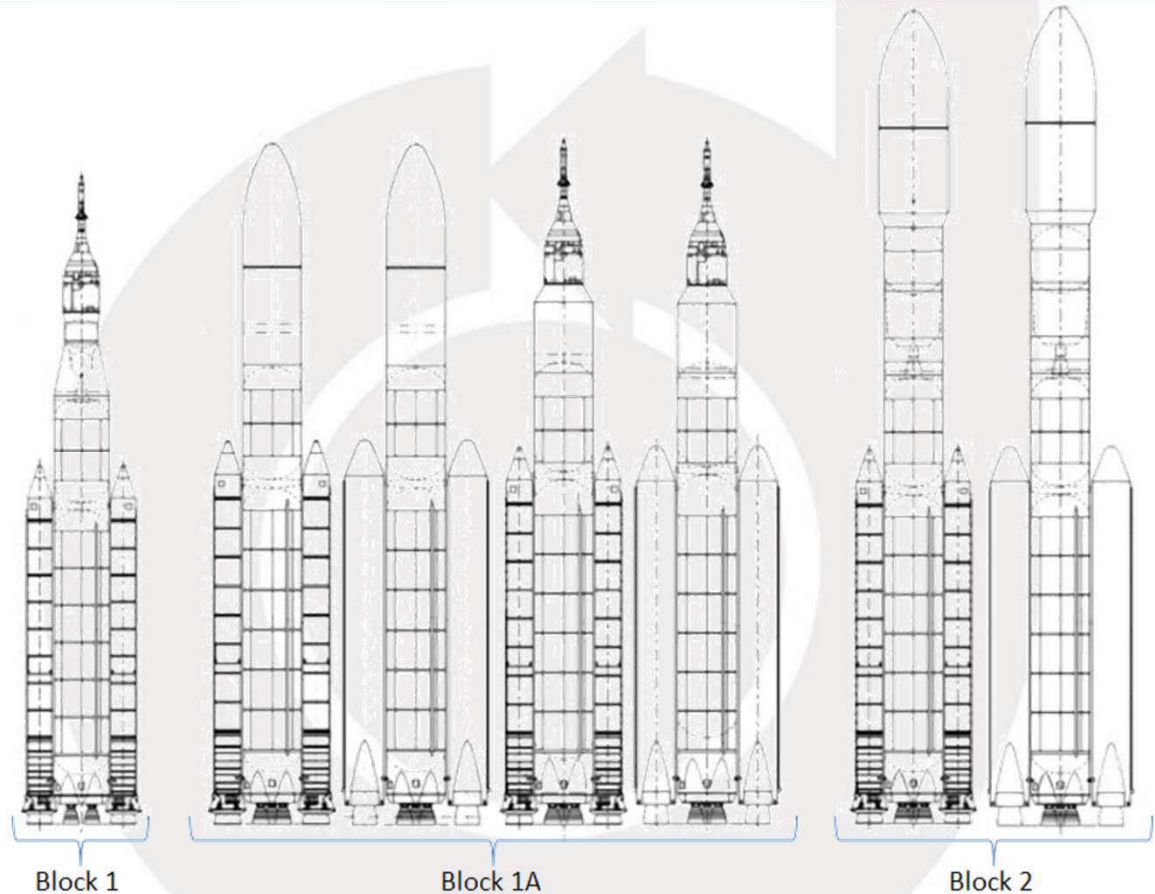
** The current Environments analysis does not include wind placards. Wind placards are a potential new constraint on launch.

Model Development (continue)

- For launch vehicles, design engineers and mission planners need to understand launch site weather in order to develop robust vehicle design and operational concepts that will allow high launch probabilities.
- For the ESD LA, two different scenarios were analyzed; SLS Cargo only missions, and SLS-Orion missions.
- For Cargo missions the following natural environment parameters were assessed; surface peak winds at/near launch pad, temperature, and presence of thunderstorms in the area.
- For Orion missions the following parameters are also assessed; significant wave height, sea surface mean wind speed, and average wave period.
- MSFC has developed the Probabilities of Atmospheric Conditions and Environmental Risk (PACER) analysis tool to compute integrated climatological availabilities based on given set of parameter constraints.
- PACER is used to provide both monthly and annual results for inclusion in the LA TPM analysis.

Model Development (continue)

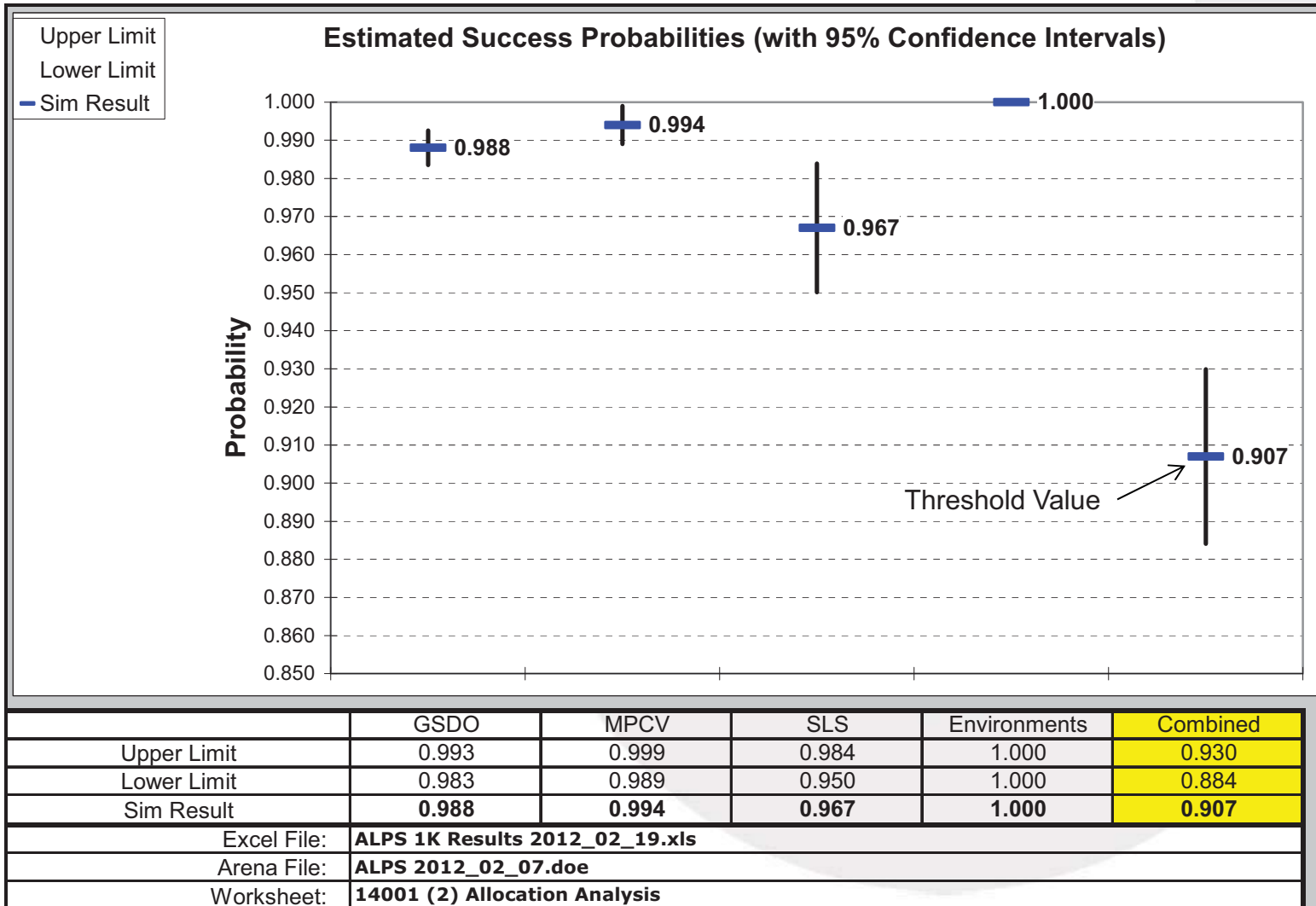
- The SLS block approach resulted in 9 different possible configurations to analyze.
- The Block 2 configurations with MPCV were discounted because the configuration violated the VAB height constraint.
- Block 1A with Liquid Rocket Boosters (LRB) and MPCV was chosen as the configuration to base the LA requirement on. This vehicle configuration represents the most challenging LA due to the increase likelihood of launch delays stemming from LRB to SRB.



Model Development (continue)

- **Launch Pad Access:**
 - For SLS NASA has taken a “Clean Pad” approach that has limited the access to the vehicle at the Launch Pad.
 - Access exists at; 1) Crew access level of the MPCV, 2) Core Stage forward skirt, 3) Mobile launcher deck.
 - Basis-of-estimates were updated because some of the Space Shuttle failure that were repaired on the Launch Pad would not require a rollback.
- **Countdown:**
 - The baseline assumption for SLS is a 24 hour countdown period versus the 72 hours based on Space Shuttle experience.
 - The basis-of-estimates associated with events and failures that occurred prior to T-24 hours were removed from the analysis.
- **Tanking:**
 - Due to propellant storage limitations at KSC a launch attempt could only be performed once every 48 hours.

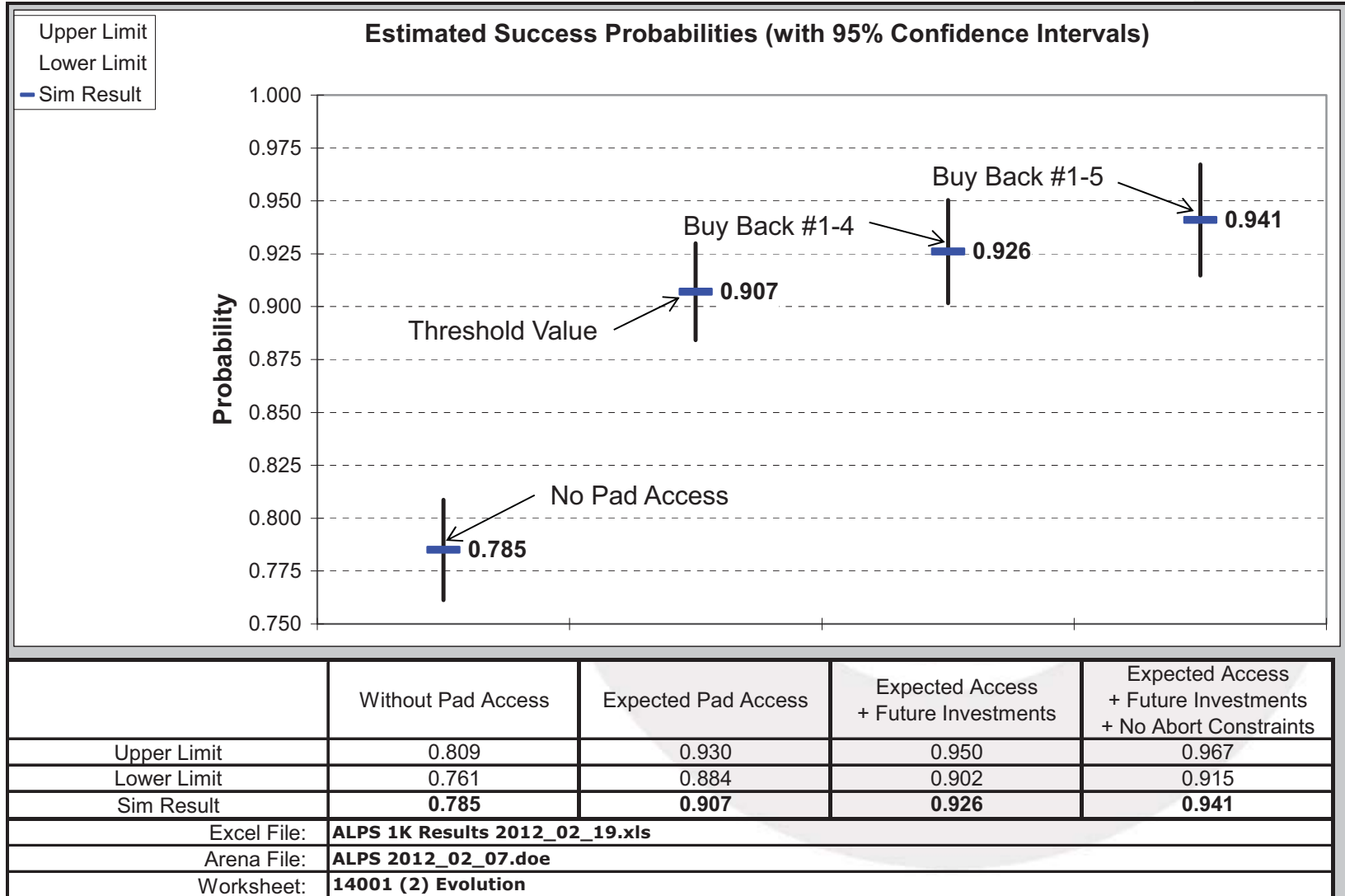
Launch Availability TPM Results



Launch Availability TPM Results (continue)

- LA buy-back options to increase the LA:
 1. Ability to perform consecutive cryogenic propellant tankings.
 2. Ability of range to support dual operations.
 3. Access to umbilicals at the Launch Pad.
 4. Having 2 Crawler/Transports.
 5. Ability of Orion, Crew, and Rescue Forces to support launch regardless of sea state conditions.
 6. SLS reliability improvements
 7. Program major Element spares.
 8. Ground based diagnostics.
 9. Wet Dress Rehearsal.
 10. Negative buy-back – 1 shift a day (8 hours) 5 days a week processing limitations.

Launch Availability TPM Results (continue)



Launch Availability TPM

- Requirement vs. TPM

- Program decided to convert the LA requirement into a LA TPM.
- Rationale for change;
 - Not clear what the driving DRM would be for SLS. The choice of mission has a significant bearing on what level of LA would be needed.
 - Any allocation of limited resources should take into consideration the most efficient way to improve over all mission success. Trying to maximize LA might well take away resources that might be better spent on improving the reliability and longevity of the payload elements being launched.



ESD Technical Performance Assessment

- ◆ **ESD TPM Description:**

- **ESD-7B Strategic DRM 30-Day Launch Probability:**

- **Description:** The probability of launching within 30 days from start of countdown for the initial launch attempt with a 95% confidence level. Provides an indication of the overall system architecture strategic capability to launch the crew in support of a deep space mission with a constrained earth departure opportunity.
- **Included Programs:** SLS, MPCV, GSDO
- **Reporting Unit:** Percent (%)
- **Threshold Value:** 90%
- **Objective Value:** 95%
- **Applicable DRMs:** Strategic
- **Flight phases:** L-1 through launch
- **GR&A's:**
 - Configuration: SLS = Block 1A (liquid boosters) with CPS, MPCV (with crew), GSDO = clean pad with 24-hour scrub recycle capability and no SLS engine pad change-out capability.
 - Central Atlantic ground track with an abort significant wave height (SWH) limit of 4-meters. CDF is an annualized average.
 - Threats & Opportunities shall also be identified and quantified.

Conclusions and Forward Work

- Cross-Program team successfully developed a methodology and tools for resolving the TBR and TBD in the ESD LA TPM, and allocated the LA TPM to each of the Programs and Natural Environments.
- Analysis associated with the ESD LA TPM is continuously being updated to see how the Block 1 design is measuring up against the threshold and objective values.
- Since the TPM was developed one major change to the design has been the removal of the Core Stage forward skirt access arm and the ICPS access arm.
- Effort under way to replace the Space Shuttle historical data associated with the Core Stage with reliability and maintainability data being developed by the Core Stage prime contractor.
 - First step of this process is to break the basis-of-estimates for Core Stage into two categories; 1) Delays associated with hardware/software failures, 2) All other delays.
 - Second step is to replace delays associated with hardware/software failures with reliability and maintainability data based on the design.

Questions?





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