



SLS
Space Launch System

**ESD & SLS Natural Environments Update &
SLS Day-of-Launch (DOL) Wind Biasing Launch
Availability with Launch Window Effects**

Mr. Ryan Decker MSFC/EV44

Mr. Frank Leahy MSFC/EV44

Dr. Greg Dukeman MSFC/EV42

Mr. Ashley Hill MSFC/EV42/ESSSA/DCI

Dr. Roger Beck MSFC/EV42/ESSSA/DCI

11 September 2014 DOLWG

- ◆ **NASA Exploration Systems Division (ESD) Milestone update**
- ◆ **ESD Natural Environments updates**
- ◆ **SLS Natural Environments updates**
- ◆ **SLS Day-of-Launch (DOL) Wind Biasing Launch Availability with Launch Window Effects**

- ◆ **Orion/MPCV delta PDR: August 2014**
- ◆ **EFT-1: December 4, 2014**
- ◆ **SLS Critical Design Review (CDR): Planned March 2015**
- ◆ **Orion/MPCV CDR: Summer 2015**
- ◆ **SLS Design Certification Review (DCR): Planned October 2016**
- ◆ **EM-1 Launch: December 2017**
- ◆ **AA-2 Launch: 2018**
- ◆ **EM-2 Launch: 2021**

◆ **SLS-SPEC-159 Cross-Program Design Specification for Natural Environments (DSNE) Rev B released August 2014**

- Document contains natural environment specifications for ESD programs.
 - Each program decides which specifications apply to them and address those that are applicable within their program specific documents.
 - Either address the environment in the design, operationally mitigate, or accept the risk of all or a portion of the environments.
 - SLS – SLS-SPEC-044-07, 'SLS Vehicle Design Environments Vol. 7: Natural'
 - MPCV – LM-ORN-0021-EDD, 'Lockheed Martin EM-1 Environments Definition for Design'
- Updates within Rev B:
 - Update Orbital Debris Environment Model from ORDEM 2000 to ORDEM 3.0.
 - Update KSC measured wind database to include measured wind tower from surface up to 500 ft.
 - Update to the sea salt environment.
 - Corrects discontinuity in an air & sky temperature profile within a specific Radiant Energy Environment table.
 - Adds coherence function associated with the spectral gust model.
 - Specifies use of Earth-GRAM 2010 in various aloft sections.
 - Specifies which database to use in the event of on-pad or near pad abort scenarios versus off-nominal descent and landing scenarios.

◆ Developed atmospheric profile databases for SLS and MPCV design assessments

- KSC Seasonal Atmospheric Profile Triplets
 - Combination of KSC DRWP database (both 50 and 915 MHz) and Earth Global Reference Atmospheric Model (Earth GRAM)
 - DRWP provides winds up to 15-18 km
 - Earth GRAM provides winds above DRWP plus temperature, pressure, and density
 - 4000 triplets per season (Summer, Winter, and Transition)
 - Each profile separated by an hour
 - Triplets used by SLS for development of 6-DOF dispersed trajectories and by MPCV for ascent abort assessments
- KSC Seasonal Atmospheric Profile Quintuplets
 - 2000 quintuplets per season
 - Subset of KSC Seasonal Atmospheric Profile Triplets
 - Additional two profiles are used to assess launch window effects (~2hr window)
- KSC Low-Altitude Seasonal Atmospheric Profiles
 - 2000 profiles per season
 - Wind, temperature, pressure, and density data from surface to 2000 ft
 - Wind profiles are combination of KSC 500-ft tower and 915 MHz DRWP
 - Profiles used by SLS for liftoff clearance and plume impingement assessments

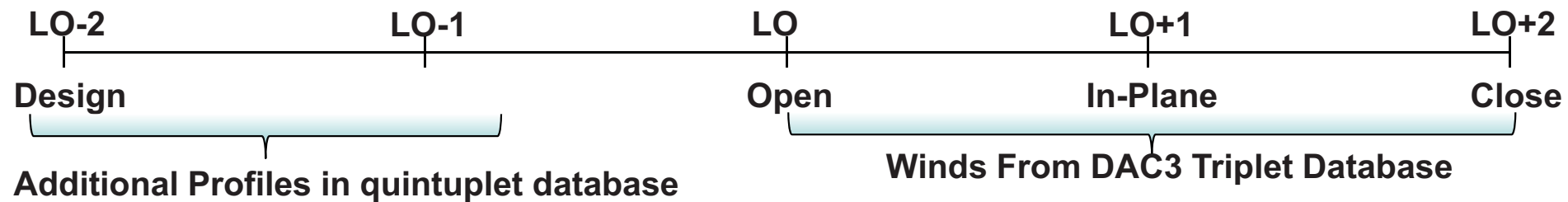
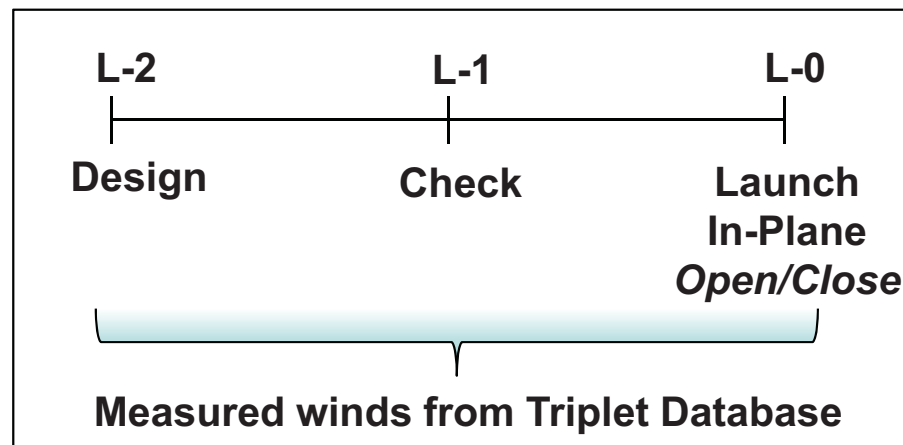


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SLS Day-of-Launch (DOL) Wind Biasing Launch Availability with Launch Window Effects

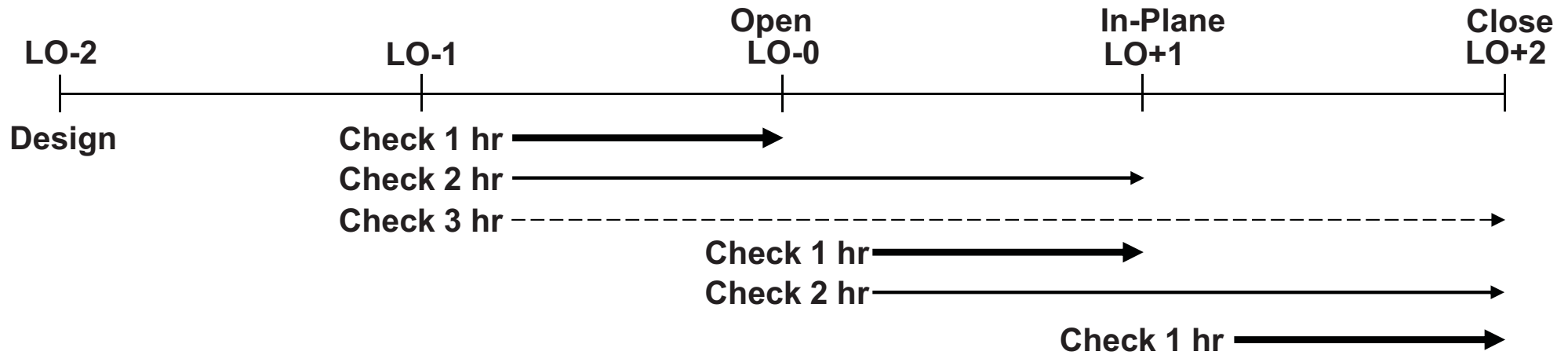
*Dr. Greg Dukeman MSFC/EV42
Mr. Ashley Hill MSFC/EV42/ESSSA/DCI
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- ◆ **DOL wind biasing trade study determined that a L-2/L-1/L-0 timeline could be used to maintain α -total less than a set value over M0.8-M2.0**
 - Design with 5000m filtering/wind knockdowns set at 99.5/50% met α -total and launch availability goals
 - Ground rules did not consider launch window effects
- ◆ **L-2/L-1/L-0 Timeline has been subsequently used for 6-DoF dispersed trajectory analysis**
 - Trajectory effects at the open and close of the launch window are simulated using the same database.
- ◆ **Need to examine the impact of an additional period of wind-variation after the open of the launch window on α -total, and the effect of adjustments to first stage guidance yaw steering over the window.**
 - Current guidance/trajectory analysis considers a maximum window limited by performance (not operational, range, etc)—roughly a 2 hour window
- ◆ **This analysis duplicates current DAC3 analysis but with additional modeled wind variation**
 - New Quintuplet measured winds database—approximating open/in-plane/close with 1 hour spacing.



◆ **Analysis of the DOL process across the Launch Window includes multiple Go/No-Go analysis across the launch window**

- In order to cover the entire window, a check at LO-1 would need knockdowns to cover 3-hours of wind impersistence
- Results presented assume multiple checks across the window
 - Baseline assumption is checks with one hour knockdowns (impact of assuming a two hour knockdown was also examined)



◆ **Simulation results presented use 2000 run Monte Carlo simulations at each of the check and verification (launch) timelines**

- Same MAVERIC Heavy/Slow/February cases as current DAC analysis but using new quintuplet wind database
- Seasonal SLS DAC-3 database contains 4,000 triplets
 - 2,000 used for Knockdowns/2,000 used for Launch Availability
- Quintuplet database is built from a subset of 2,000 from the triplet database
 - Knockdowns triplets not used in the quintuplets—statistics and results were shown to be in family w/ original knockdown

The approach for processing input winds and filtering is identical to previous analyses.

- Quintuplet Database used for Go/No-Go analysis (Design/Check/Verify)
- Triplet Database used for Knockdowns
 - (Triplet database is superset of times in Quintuplet so unique profiles can be used)

Wind processing

◆ Design Wind:

- Filtered based on at 5000m wavelength from DOL trade study result
- Ramped to zero below 2,700m: Improves convergence of the open-loop steering table generator.
- Measured wind weighted with mean monthly wind to take advantage of mean-reversion tendency observed in measured winds databases: Empirically-derived weighting—biases outliers toward mean.

◆ Check Winds:

- Filtered based on wind persistence using Spiekermann's Equation ($\lambda = 1086m\sqrt{T_{hr}}$)
- 1hr—1086m; 2hr—1536m

◆ Launch/Verify Winds:

- Not Filtered.

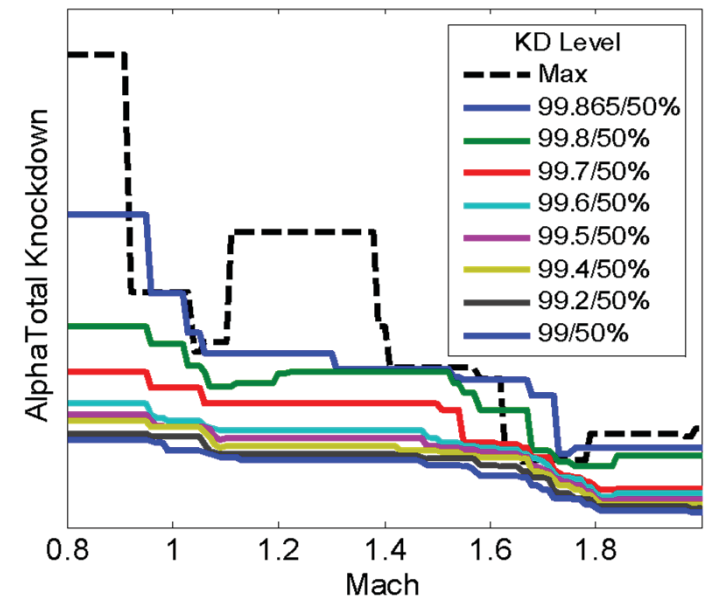
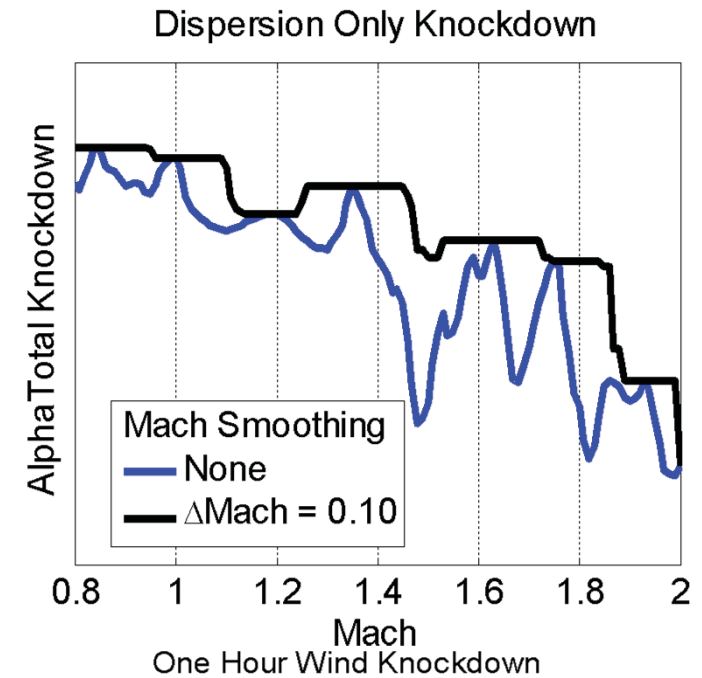
◆ Knockdowns: Use Check and Verify winds filtered as above.

Knockdown approach has been modified from previous analyses:

- ◆ Previously the impact of flight-day system dispersions and wind variation, and launch window effects were coupled into a single knockdown.
- ◆ New approach is to separate effects.

Knockdowns are RSS'd before applying them to the check run.

- ◆ First stage yaw steering adjustments are not covered by a knockdown because the check case is flow with yaw steering included.
- ◆ Flight Day System Dispersions based on difference between nominal run and Monte Carlo set with all wind & atmosphere dispersions disabled.
 - Using mean monthly winds.
 - Simulation setup for in-plane (TD3A) case.
- ◆ Wind Variation Knockdown computed from independent winds from Check/Verify quintuplet
 - Using In-plane case.
 - 1hr knockdown From L-2/L-1/L-0 Triplets not included in quintuplet:
 - Design at L-2 (5000m filter)
 - Check at L-1 (1086m filter)
 - Launch at L-0 (unfiltered)
 - Separately showed that knockdown variations between different 1-hr time periods are within the expected statistical variation.



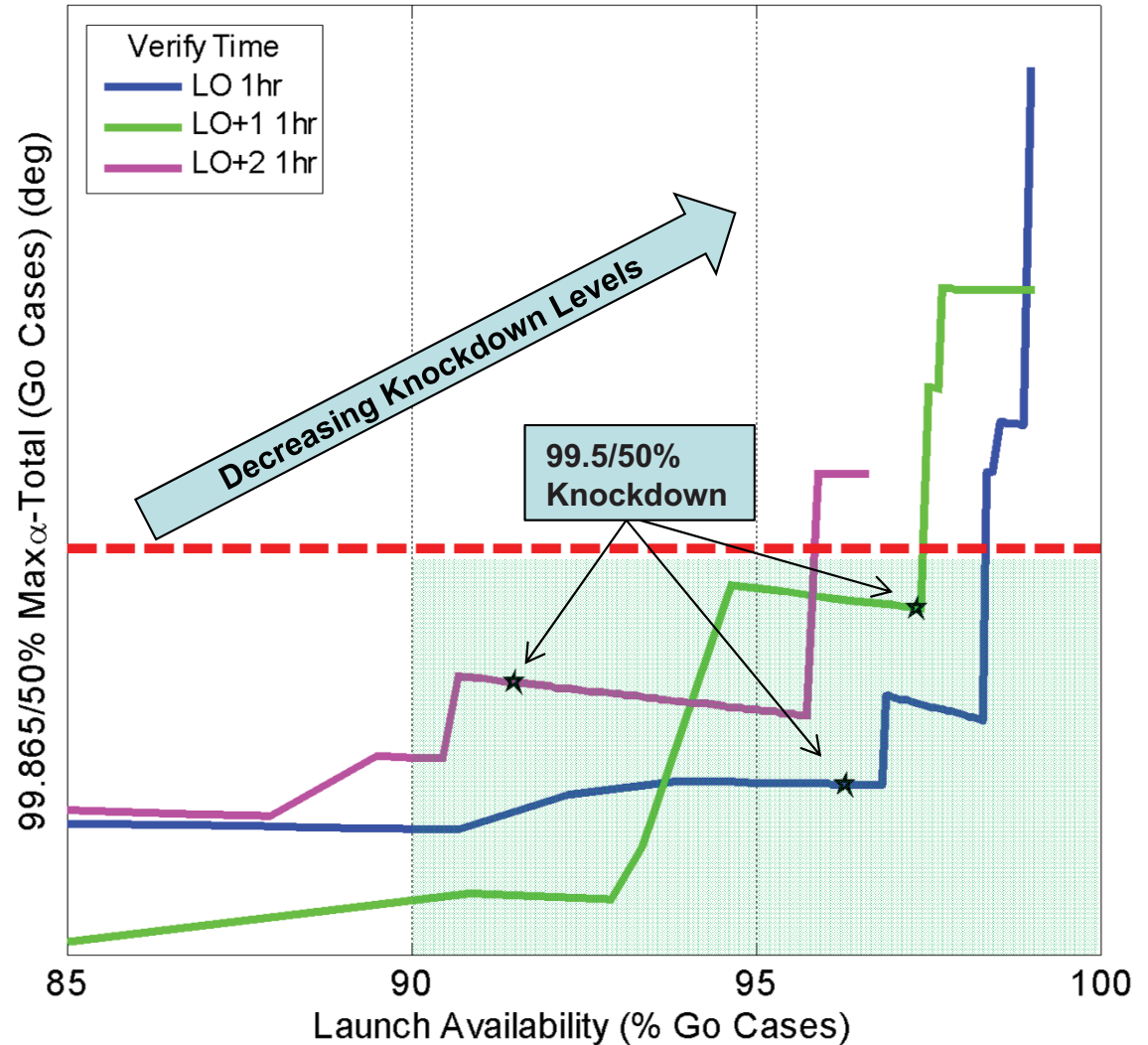
1 Hour Check Across Launch Window
Go/No-go Results

Total Angle of Attack statistics and Launch Availability are a function of the chosen wind-variation knockdown level.

Seek a constant set of parameters that work across the launch window

DOL trade knockdown of 99.5/50% works for a one-hour check at all three points across the window.

- ◆ **.99865/50 α -total < Limit Value for Knockdown > ~99.4%**
 - In-plane is limiting case due to low check- α and high launch availability.
- ◆ **Launch availability is > 90% for Knockdown < ~99.6%**
 - Close of window is limiting case due to higher check- α 's



Success in satisfying the total-alpha limit is defined in terms of a statistical criteria and associated confidence interval.

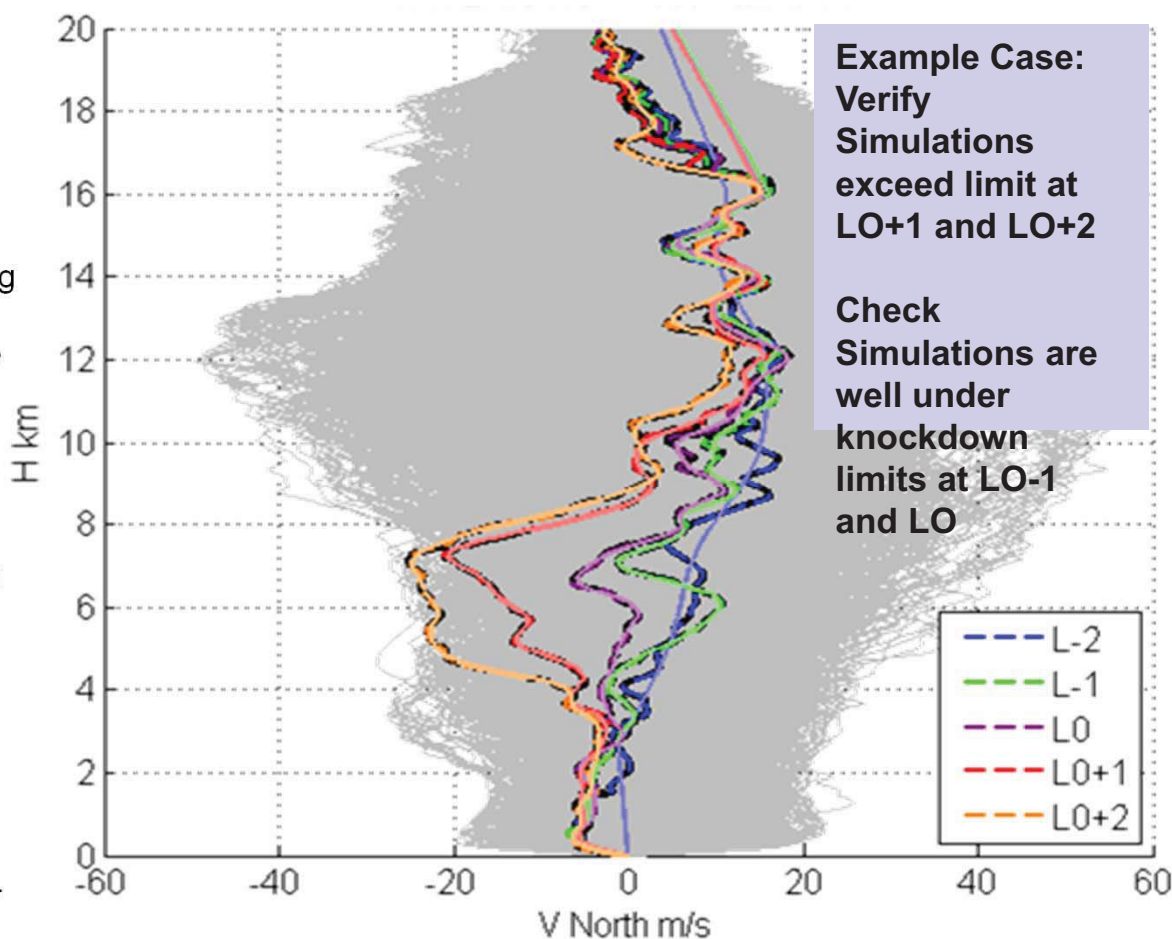
- The 99.865%/C50 criteria inherently allows for the existence of outlying “False-Go” cases that potentially exceed the target value.
- Inspection of the wind profiles may improve understanding of how to reduce the chance of occurrence on actual DOL—*Detailed examination of these cases is beyond the scope of the presented analysis*

5 of the 27 quintuplet profiles that exceed the alpha limit at some point in the window are incorrectly classified as Go at that point.

- 1 or 2 cases at each time with each of the 5 only showing up incorrectly once.
- Typically due to small wind change from the design to check followed by a large change from check to launch.

Tuning the 1hr Check to eliminate the worst of these cases requires large knockdowns, resulting in low launch availability

- Essentially equivalent to assessing the criteria to a higher percentage/confidence interval, but the result is still driven by a finite wind database.



While the approach outlined here meets the requirements and provides confidence for moving forward with the design, understanding any implications of wind profiles such as that shown for actual operations may require:

- Further study of the likelihood of such events to understand how representative the measured database is of the risk.
- Identification of operational steps, such as monitoring wind changes after the check simulation, that would flag the Check as potentially invalid.

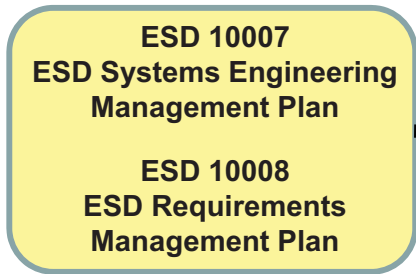
The Day-of-Launch Check / Launch Availability analysis was updated to reflect the potential for additional wind variation as the launch time progress through the launch window.

- ◆ **Initial Results show that the baseline solution from the DOL trade study meets the targeted criteria for alpha-total while maintaining > 90% launch availability with repeated one-hour check**
 - Launch availability based on limiting value for a single attempt—not cumulative probability (i.e. a no-go that turns to go)
 - Two hour checks required lower launch availability ((~85% in-plane dropping to <50% at close of window)
- ◆ **The number of False Go cases in the results is lower than the number of allowable failures.**
 - Wind profiles in the outlying cases help identify characteristics that are challenging for this 1hr Check to catch---tuning the results for the specific cases identified results in well under 80% launch availability and may still not cover all potential similar events.

Potential Future Work:

- ◆ **DOL wind biasing parameter tuning**
 - Filter wavelength, Monthly mean weighting, and Knockdown level are all coupled and were originally optimized based on L-2/L-1/L-0 timeline.
 - No need to adjust baseline parameters for the current cycle, but identifying sensitivities or potential improvements for future analysis.
- ◆ **Working with Day Of Launch I-Load Update Integrated Ad Hoc Team (DOLIAHT) to ensure Flight Mechanics results support DOL operations development**

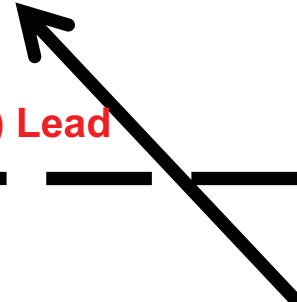
Backup



- ESD delegated to SLS (Part of the Integrated Product Library)
- Contains specs for all ESD programs (not all specs are applicable to SLS)
- Managed by the ESD NEIAHT (Includes reps from SLS/MPCV/GSDO/ESD)

ESD **Barry Roberts/EV44 Cross-Program NE Integration Ad-Hoc Team (NEIAHT) Lead**

SLS **Frank Leahy/EV44 SLS NE lead**



Tells what specs in the DSNE are applicable specs and how they are addressed:

- Design for all or part of the spec
- Mitigate all or part of the spec.
- Accept risk for all or part of the spec

Also includes additional spec. detail unique to SLS & not included in the DSNE

