SLS
Space Launch System

National Aeronautics and Space Administration

NASA

SLS Trade Study 0058: Day of Launch (DOL) Wind Biasing

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NE DOLWG 3/19/2014

Trade Background

- **SLS heritage hardware and legacy designs have shown load exceedances at several locations during Design Analysis Cycles (DAC).**
  - MPCV Z bending moments.
  - ICPS Electro-Mechanical Actuator (EMA) loads.
  - Core Stage loads just downstream of Booster forward interface.
- **SLS Buffet Loads Mitigation Task Team (BLMTT) tasked to study issue. Identified low frequency buffet load responses are a function of the vehicle's total angle of attack (AlphaTotal).**
  - Ascent loads contribute to several load contributors.
    - STEL, Gust, TO, Buffet
  - STEL loads are a large contributor to MPCV loads challenges.
  - BLMTT recommended controlling STEL on DOL by limiting AlphaTotal to less than a set value as means to mitigate load concerns.
- **SLS DOL Wind Biasing Trade team to analyze DOL wind biasing methods to limit maximum AlphaTotal in the M0.8 - 2.0 altitude region for EM-1 and EM-2 missions through investigating:**
  - Trajectory design process
  - Wind wavelength filtering options
  - Launch availability
  - DOL process to achieve shorter processing/uplink timeline
- **Trade Team consisted of personnel supporting SLS, MPCV, GSDO programs.**

Trade Analysis Steps

- **Identify Ground Rules and Assumptions (GR&A).**
- **Perform Flight Mechanics (FM) assessment.**
- **Define functional outline of a DOL concept of operations.**
- **Evaluate potential DOL timeline options.**
- **Show team evaluation of DOL timelines & recommend a "go forward plan".**
  - Proof of concept NOT a design solution.
- **Outline preliminary schedule to have a DOL process in place for EM1 (Fall 2017).**

Ground Rules and Assumptions

- **Start with four timeline options.**
- **Show feasibility that, from a Flight Mechanics (FM) perspective, SLS can be operated so that AlphaTotal less than a set value in the range 0.8 < M < 2.0.**
  - Evaluate sensitivity of AlphaTotal to various FM factors.
  - Goal of 90% Launch Availability (LA), in winter, due to winds aloft to preserve margin when factoring all natural environments impacts to launch probability.
    - For winds aloft, winter is worst-case; corresponding summer launch availability would approach 100%.
  - Goal of P99.865/C50 AlphaTotal, in relevant Mach range, staying less than set value.
- **DOL timelines evaluated based on nominal processing scenario. (No contingency procedures)**
  - DOL assessments will include an I-load design run followed by a constraint check run (different wind & wind persistence value) to validate I-load design run results.
  - One team to do primary assessment w/ second team performing independent check.
- **Liftoff at the open of the launch window. (No launch window)**
  - Maintains consistency between launch availability results in FM analysis to the evaluation of candidate DOL timelines.

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DOL Trade Study: Flight Mechanics Results

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3/19/2014

Agenda

- Flight Mechanics Overview
- Launch Availability Approach Overview
- Knockdown Assessment
- Launch Availability Results
- Design Wind Filter Assessments
- Summary

Flight Mechanics Overview

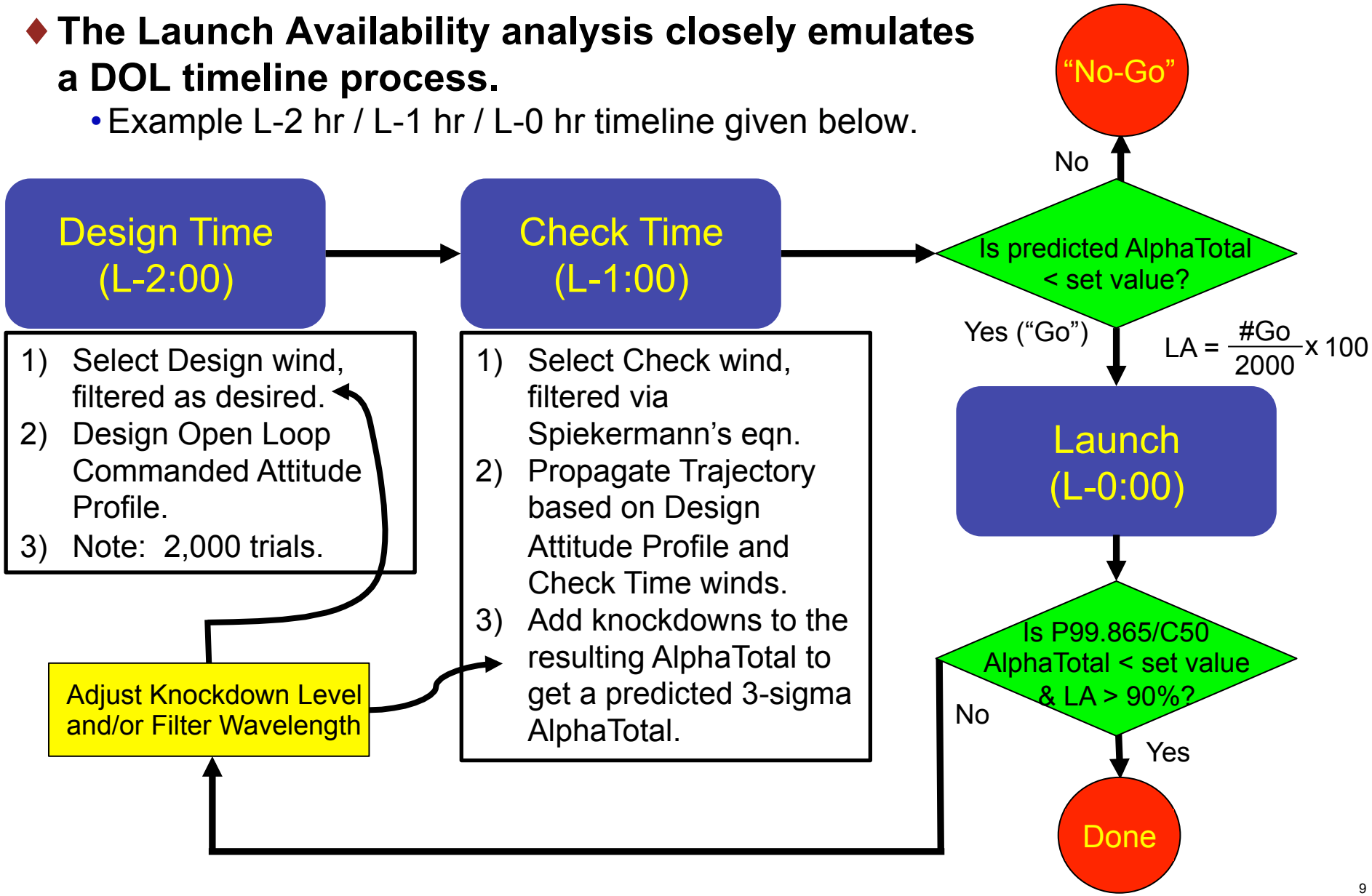
- **Objective: Show feasibility that, from a FM perspective, SLS can be operated so that AlphaTotal < set value in the range 0.8 < M < 2.0.**
  - The initial Mach 0.6 lower limit came from STEs first transonic Mach bin which is Mach 0.6 to 0.85 (includes the Mach 0.8 buffet forcing function.)
  - STE does not anticipate Mach 0.6 – 0.85 to be a problem so the trade study modified the lower Mach value to 0.8.
- **Examine sensitivities of AlphaTotal to trajectory generation, wind filter wavelength, and day-of-launch timelines.**
- **Evaluate against approved trade goal of 90% launch availability in the winter season & P99.865/C50 AlphaTotal, in relevant Mach range, staying under set value.**

Launch Availability Approach Overview

- **MSFC Natural Environments (NE) delivered combined Doppler Radar Wind Profiler (DRWP) databases for four different timelines for the winter, summer and transition periods.**
  - Timelines of L-3.5 hr/L-2 hr/L-0, L-2/L-1/L-0, L-1.5/L-1/L-0, and L-1/L-0.5/L-0.
  - 4000 sets of triplets each database: 2000 to compute knockdowns, 2000 to perform the Go/No-go Check and Verification.
- **The winter triplet databases have been utilized in Go/No-go analyses using trajectory TD2E-R (Hybrid Loads Feb) in MAVERIC 4.1.061.**
  - Winter shows the most divergence in winds, so if we are good for winter we should be good for the rest of the year as well.
- **For the initial analyses, Spiekermann's equation was used to compute filter wavelengths to be applied to the Design and Check winds to remove higher frequency wind features that are not expected to remain at L-0.**
  - Spiekermann's equation provides the wavelength boundary between relatively slowly varying components of wind profiles and more rapidly varying components.
  - For example, for the L-2/L-1/L-0 triplet, wavelengths of 1536 m and 1086 m were applied to the Design and Check winds, respectively.
  - The L-0 wind is not filtered in this analysis.
- **Statistically derive uncertainty factor (knockdown) to protect for potential change in AlphaTotal between last assessment and launch.**

Launch Availability Analysis Overview

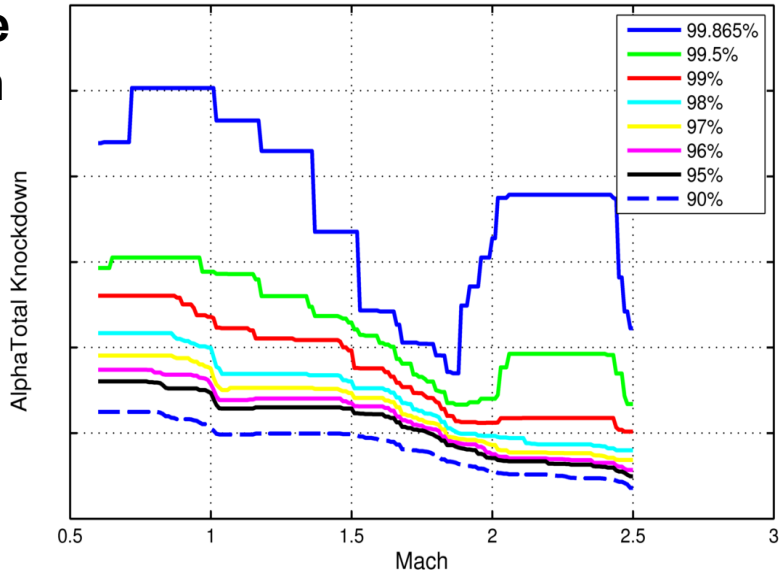
- **The Launch Availability analysis closely emulates a DOL timeline process.**
  - Example L-2 hr / L-1 hr / L-0 hr timeline given below.



Knockdown Assessment

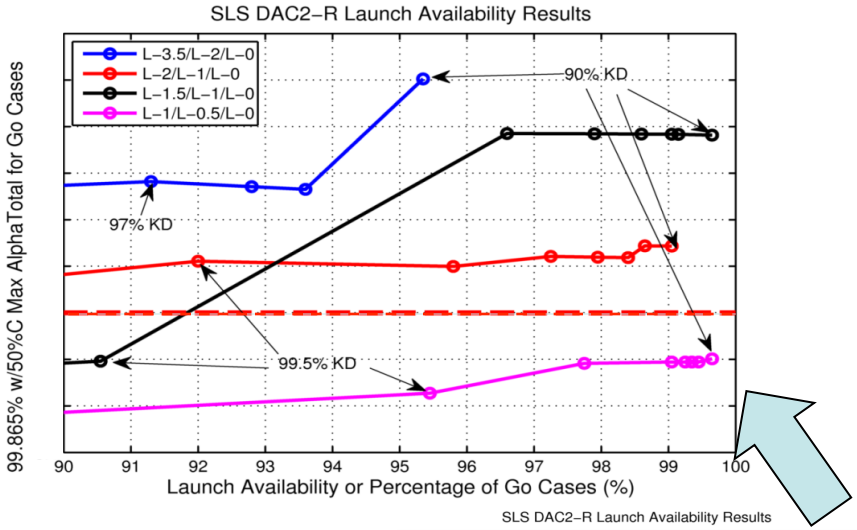
- **Knockdowns used in the Go/No-Go Check are computed to cover for the potential change in AlphaTotal due to wind change from Check time to Launch. First, the Design winds are used to compute the open loop commanded attitude profile for each of the 2000 cases.**
- **Each of the 2000 trajectories are flown using the Check time winds and another 2000 trajectories are flown using the Launch winds**
  - The same commanded attitude profile is used for both Check time and Launch trajectory.
- **Knockdowns are computed by inspecting the change in the AlphaTotal profile peaks from the Check time to Launch as a function of Mach.**
- **As shown, using P99.865/C50 statistics for the knockdown can yield rather large knockdowns which result in low Launch Availability (high % of No-go cases).**
- **Decreasing slightly to P99.5/C50 for the knockdown calculation drops only 7 cases (from 3rd to 10th), but the knockdown level is considerably less.**
  - Similar results are seen for all timelines inspected.

L-2/L-1/L-0 Knockdowns Statistics

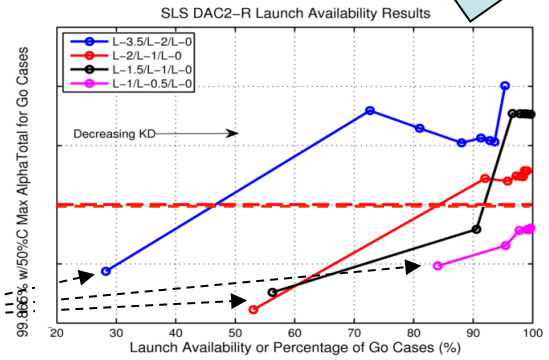


AlphaTotal Go/No-Go Analysis

- **With the knockdown profiles computed for different percentiles, the Go/ No-Go check analysis is performed using a separate set of 2000 wind triplets to avoid correlation of the winds.**
- **The four given timelines are compared via the plots below, which are the P99.865/C50 value of the maximum AlphaTotal for Mach 0.8 to 2.0 versus Launch Availability (or percentage of "Go" cases) based on different knockdown levels.**



Decreasing KD



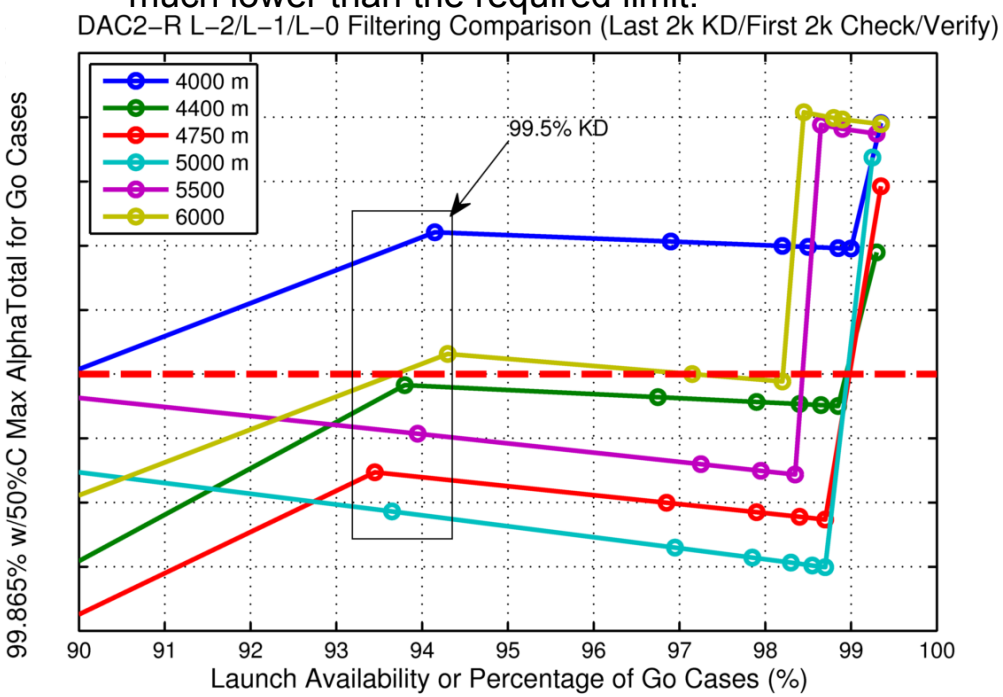
99.865% KD

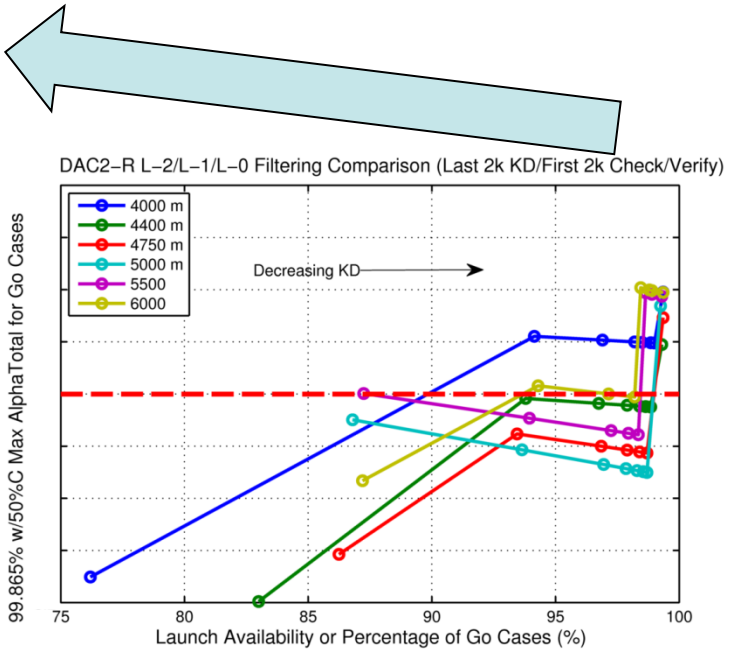
Trade Team Timeline Down-Select & Refocus

- **Based on the initial set of analyses of the four timelines, the L-3.5/L-2/L-0 and L-1.5/L-1/L-0 timelines were dropped from further analysis.**
  - The L-3.5/L-2/L-0 triplet had relatively low Launch Availability and high AlphaTotal for the Go cases at the lower Knockdown levels.
    - A knockdown between P99.5/C50 and P99.865/C50 may have provided an AlphaTotal just below set value, but Launch Availability would have been less than 70%.
  - The L-1.5/L-1/L-0 triplet had results similar to L-2/L-1/L-0 and didn't provide much added value for further analysis.
- **The L-2/L-1/L-0 and L-1/L-0.5/L-0 timelines were recommended by the trade team for further analysis to provide a pair of timelines to choose from.**
- **The L-1/L-0.5/L-0 timeline meets set value limit with margin for applicable design wind filter and knockdown level.**
- **Since the L-2/L-1/L-0 triplet did not meet the set value limit, adjusting the design wind filter was pursued to meet this design goal.**
  - As long as the "Go" trajectories assessment meets the set value requirement at the P99.865/C50 level, there is no undue increase in risk due to different filter wavelengths.

L-2/L-1/L-0 Design Wind Filter Assessments

- **Filtering the wind to remove small wavelength features is not an issue in trajectory design as the vehicle's natural attitude response is more consistent with larger wavelength winds which are persistent.**
  - Raising the filter wavelength will remove more wind features and also yield a smoother commanded attitude profile for the vehicle to follow, possibly reducing AlphaTotal excursions due to overshoot.
- **Higher filter wavelengths do show increased launch availability and reduced maximum AlphaTotal.**
  - A wavelength of 4.4 km results in max AlphaTotal values just below the set value limit with Launch Availability above 93% for the P99.5/C50 Knockdown.
  - Wavelengths in the 5 km range appear to provide a minimum value in max AlphaTotal, though not much lower than the required limit.





Flight Mechanics Summary

Timeline	Design Wind Filter Wavelength	Knockdown	Launch Availability	P99.865/C50 AlphaTotal
L-2/L-1/L-0	5 km	P99.5%/C50%	PASS	PASS
L-1/L-0.5/L-0	1.086 km	P99.5%/C50%	PASS	PASS

- **Recommendation by FM is to use the P99.5/C50 for knockdowns.**
  - Discarding outliers by going to lower percentiles of knockdown results in knockdowns and AlphaTotals that are more consistent across winds databases and yield higher launch availability.
- **Although the AlphaTotal results are below set value, it is preferred to design to the set value to maintain a small margin.**
  - Changes in winds or vehicle response may increase the resulting AlphaTotal, so some margin is desired.
- **Desired goals are met for both timelines above, therefore from a flight mechanics perspective, either one is acceptable.**

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DOL Trade Study: Timeline Evaluation Results

Ryan Decker (MSFC/Nat. Env.)
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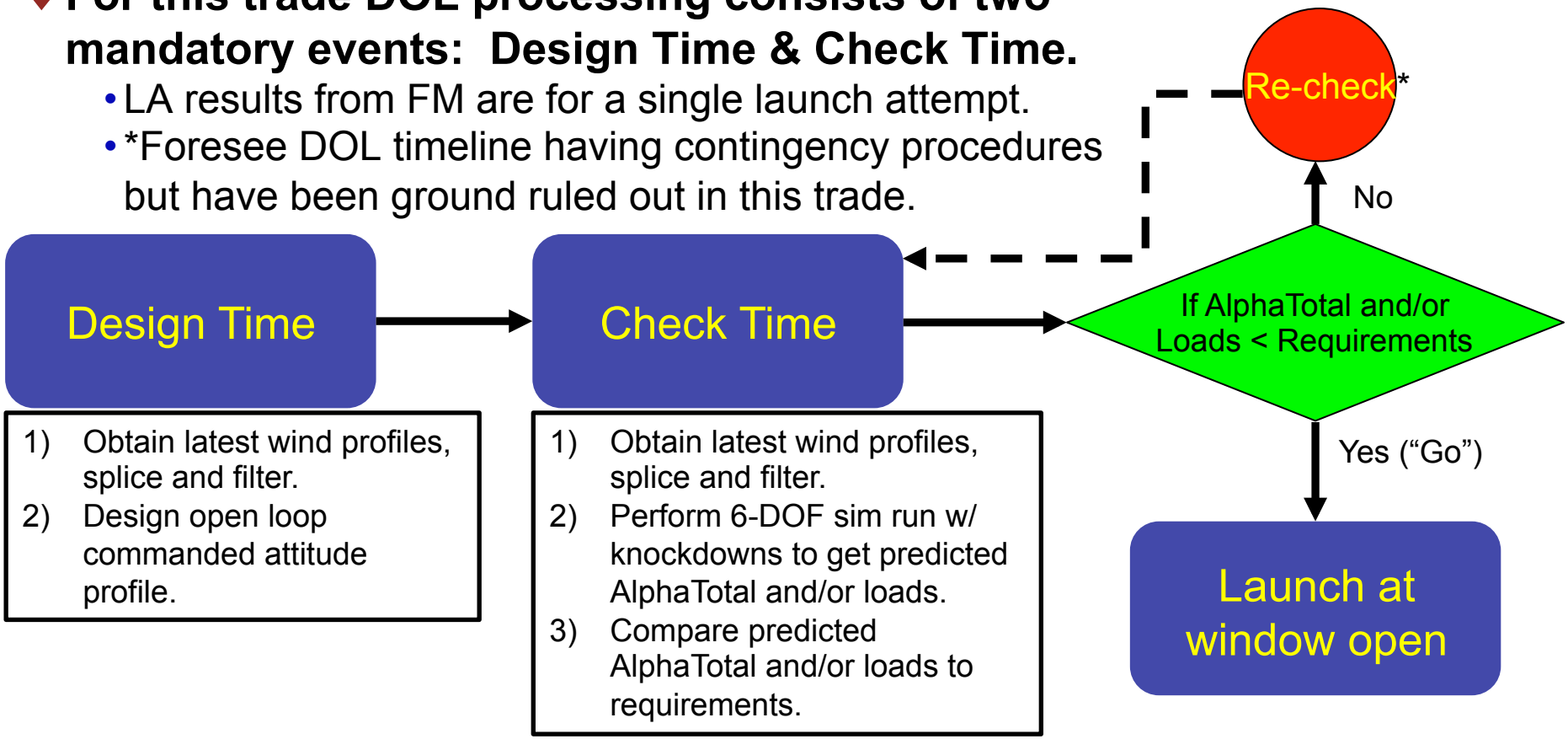
3/19/2014

Trade DOL Processing Scenario

- **For this trade DOL processing consists of two mandatory events: Design Time & Check Time.**
  - LA results from FM are for a single launch attempt.
  - *Foresee DOL timeline having contingency procedures but have been ground ruled out in this trade.



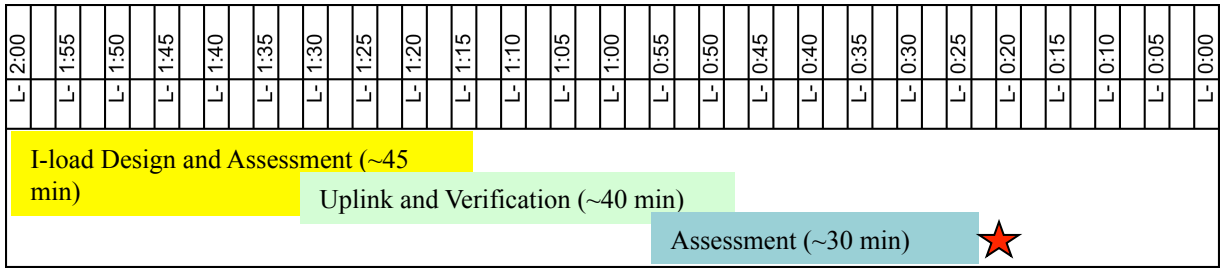
DOL Draft Roles

- **JSC/MOD generate chi table, perform trajectory, loads & performance evaluation along with go/no-go launch recommendation.**
- **MSFC perform Independent Validation & Verification (IV&V) on trajectory, loads and performance evaluation.**
- **JSC/MOD and MSFC will compare results for consistency.**
- **JSC/MOD run MSFC provided ILOADPGM to generate I-load file and transfer to KSC/GSDO.**
- **KSC/GSDO will perform uplink to vehicle with JSC/MOD verification.**
- **MSFC/NE perform winds data Quality Assurance (QA) & generate spliced wind profile.**
  - Splice winds from DRWP sources and balloons. ➔ Game changing capability.
  - Will require current Eastern Range (ER) low-resolution balloon capability for atmospheric thermodynamics and contingency situations.

Proposed DOL Timelines Details

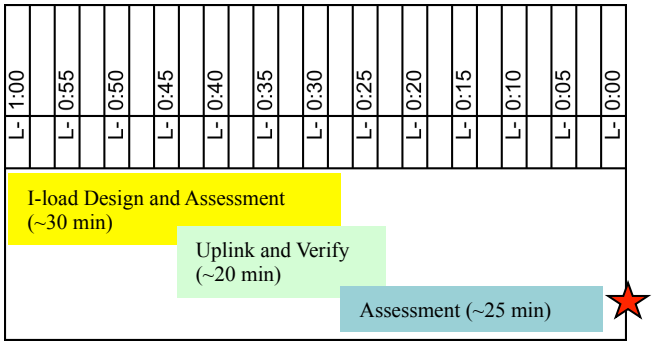
L-2/L-1/L-0

- Times based on Shuttle DOL experience.
- I-load design time includes wind splicing, running 3 DOF & 6 DOF simulations, QA checks, IV&V, data transfer, results compare and briefings.
- Uplink includes build commands, commands uplink and flight computer dump verification.
- Assessment time includes wind splicing, 6 DOF sim run, QA checks, IV&V, results compare and briefings.
- Launch recommendation at ~L-0:20.



L-1/L-0.5/L-0

- Same assessments but with reduction in time to perform.
- Design and assessment times are reduced by reduction in DOL QA and products.
- Launch recommendation inside of L-0:05.



Launch Recommendation

Team Evaluation of Proposed Timelines

L-2/L-1/L-0

Pro

- Accommodate some growth in design and assessment times as unknowns become known.
- Contingency and late assessments possible to increase possibility of launch.
- Supports a 1-hr launch window if additional 2-hr wind persistence utilized.
- Allows for contingency source of wind data.
- Least expensive.

Con

- Larger knockdown to protect for wind persistence.
- Lower launch availability

L-1/L-0.5/L-0

Pro

- Design and assessment closer to launch.
- Smaller knockdown to protect for wind persistence.
- Higher launch availability.

Con

- **JSC/MOD evaluation shows the results of commit-to-launch assessment are too close to open of launch window.**
- JSC/MOD evaluation shows the reduction in DOL constraint checks, I-load verification, and QA not possible.
- Shorter design and assessment time limits the ability to enact contingency procedures.
- No time to discuss results and investigate issues nor generate waivers (if No-Go, then No-Go).
- Increased cost to develop automation software to perform design and assessment in shorter time.
- Increased cost to add personnel for parallel assessment operations.

Conclusion: Trade team recommends pursuing the L-2/L-1/L-0 option.

Development Schedule

ESD Day-of-Launch Integrated Ad-Hoc Team (DOLIAHT) will develop optimal timeline that meets requirements while balancing gains, cost and risk.

- **Initial DOL CONOPS (approx. 7/2014)**
  - Outline operational concept
  - Identify and document gaps in requirements
  - Refine project planning
  - Refine hardware/software needs
- **Receive SLS DOL constraints to assess (end of SLS CDR 3/2015)**
  - SLS vehicle integrated loads, alpha/beta/Q-plane checks, VLI defined
  - Trajectory limits (AlphaTotal)/QA rules
- **Implement DOL process (start 4/2015 – end 10/2016 (end of SLS DCR))**
  - DOL software design and development (will likely begin earlier)
  - Constraint assessment requirements
  - Data requirements (SLS Program Requirements Document)
- **Test DOL process (start 10/2016 – end 4/2017 (~L-6 months))**
  - Integrated testing
  - DOL simulations

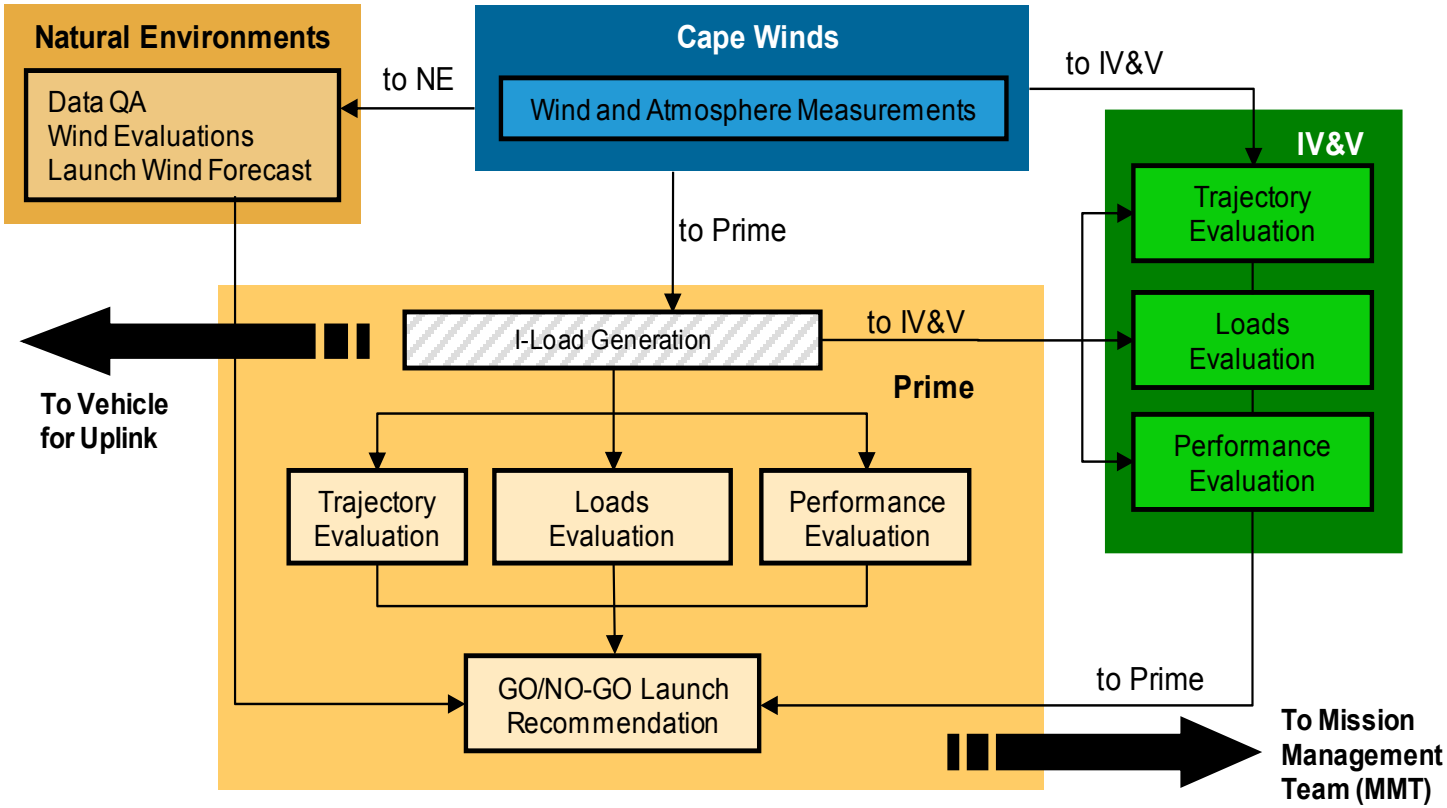
DOLIAHT wants to minimize wind persistence and design the shortest timeline possible

Conclusion

- SLS Chief Engineer approved the team recommendation of working towards a DOL I-load design at L-2 hr and a constraint check run at L-1 hr. (L-2/L-1/L-0 option)
- FM will assess impacts to launch availability as a function of AlphaTotal in future DACs.
- Forward work implementing DOL process will be conducted under the DOL I-load Update Integrated Ad Hoc Team (DOLIAHT)

Backup

SLS/MPCV DOL Con Ops (DRAFT)



Shuttle Timeline is Reasonable with Open Work

	I-Load Design
0:00	Wind profile complete
0:05	Wind in / start jobs
0:15	Jobs complete / I-Loads to IV&V
0:25	QA done / I-Loads on MCC
0:35	Products to MCC & RSO
0:40	Compare complete
0:45	Briefings complete
	Uplink
0:10	Build commands
0:20	Commands uplinked
0:40	GPC dump verified
	Assessment Only
0:00	wind profile complete
0:05	Wind in / start jobs
0:10	Jobs complete
0:20	QA done
0:25	Products to MCC
0:25	Compare complete
0:30	Briefings complete

Time Total	Time Delta	DOL Activity	SLS DOLILU Open Work (sample list)
0:00		**Wind profile complete**	Backup wind profile source Reliability in wind profile acquisition Propellant Loading When all inputs in
0:05	0:05	**Wind in / start jobs**	Number of Sim runs Sim/tool execution time Assessments throughout launch window
0:15	0:10	**Jobs complete / I-Loads to IV&V**	MPCV Pad Abort I-Loads ICPS DOL I-Loads SLS fly-away I-Loads Extent of DOL constraints
0:25	0:10	**QA done / I-Loads ready to Uplink**	Uplink process and verification Other Trajectory sim validation, e.g. SDF @ SIL Hardware failure contingency design
0:35	0:10	**Products to MCC & RSO**	DOLILU Customer List DOLILU Product definition, e.g. launch window
0:40	0:05	**Compare complete**	Compares required? DOLILU Go/no-go criteria definition
0:45	0:05	**Briefings complete**	DOL authority structure Waiver process Launch Window considerations, L-0 definition