

Use of Smoothed Measured Winds to Predict and Assess Launch Environments

This paper describes an approach which was used to predict Ares I-X launch vehicle structural airloads and controllability prior to launch. This prediction along with the proper application of protection for variations in key environment and trajectory parameters was used to predict the potential for the launch trajectory to stay within the integrated vehicle certification envelopes. This data was applied by the launch team as a key element of the launch day go / no-go recommendation. NASA's Space Shuttle and the heavy lift versions of the Evolved Expendable Launch Vehicles assessments require the use of a high fidelity wind measurement which limits the number of wind measurement sources which can be used for a pre-launch go / no-go assessment. The approach described in this paper has the potential to allow the pre-launch assessment team to use wind measurements from a number of additional sources which will enhance launch availability and also has the potential to improve mission assurance and enhance safety.



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Agenda



- ◆ **Summary**
- ◆ **Space Shuttle Approach**
- ◆ **Weakness with the Shuttle approach**
- ◆ **Ares I-X approach**
- ◆ **Planned refinements for future NASA launch vehicles**
- ◆ **Conclusion**

Summary

- ◆ **Larger launch vehicles tend to be flown near the edge of their performance envelopes to maximize payload to orbit**
 - Fallout is that a launch day performance and loads assessment is often required to verify that the launch will be within vehicle certification
- ◆ **Shuttle approach was somewhat compromised by the available technology**
 - Winds aloft measurement systems and computational capabilities
 - Balancing performance compromises with safety required additional placards to account for inherent uncertainties
- ◆ **Ares I-X approach attempted to address a number of issues associated with spatial and temporal uncertainties**
- ◆ **Planned refinements are in work to improve on the approach used for Ares I-X that can be applied to future launch vehicles**

Wx Balloons



Space Shuttle Approach

- ◆ **Approached relied on a balloon system designed to measure high frequency content of the winds aloft**
 - Concern being addressed was that the high frequency content of the winds aloft drove peak ascent aerodynamic structural loading
 - Unfiltered winds aloft are fed in to a high fidelity ascent computer simulation to estimate air loads during ascent
- ◆ **Wind measurement system is designed to measure wind features with wavelengths as small as 500'**
- ◆ **Computed airloads are incremented for dispersions and unknowns**
 - Systems dispersions
 - Wind in-persistence due to temporal variations between the measurement of the winds aloft and the actual launch environment

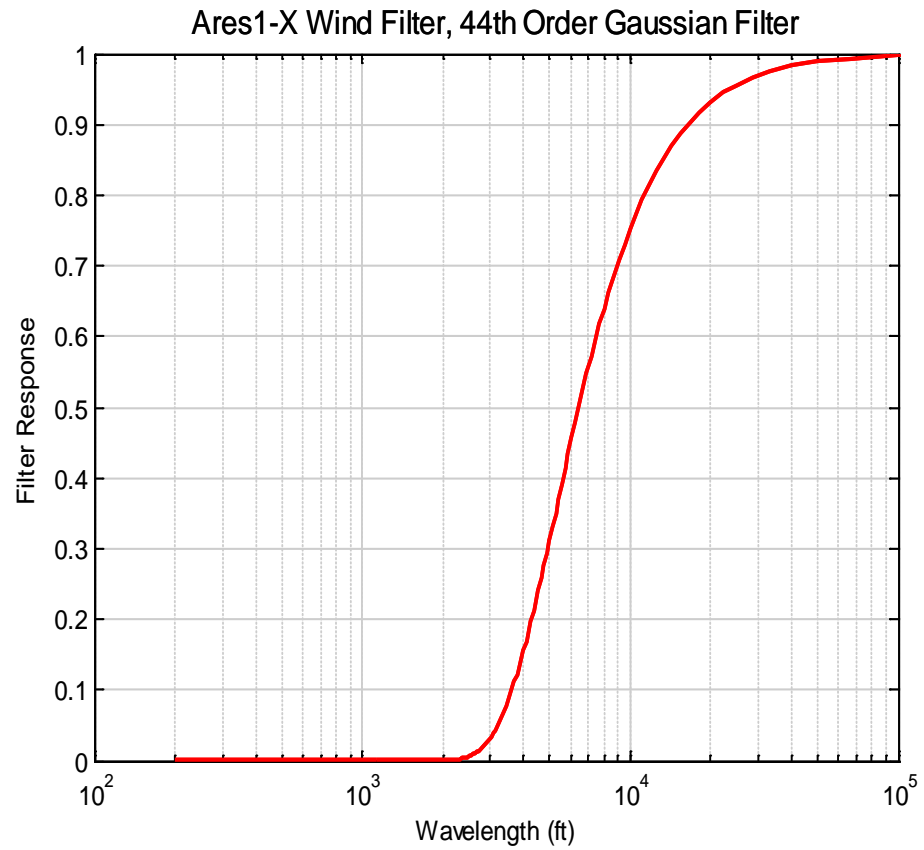
Weakness with the Shuttle Approach

- ◆ **Approach starts with the assumption that the balloon measurement is perfect**
 - Assessment and analysis has shown that this is not the case which has resulted in a process that is biased to produce a conservative result
- ◆ **Reliance on a specialized winds aloft measurement system available from a single provider**
 - Cost and supply issues
- ◆ **Historical high resolution balloon measurement sample size is small**
 - Overly conservative protection to protect for uncertainties in the probabilistic assessment induced by the small sample size, particularly for wind in-persistence
- ◆ **Requirement for high resolution data makes the process vulnerable to a small amount of data loss**
 - High resolution GPS based measurement system has been an issue
- ◆ **Short wavelength wind features that the current approach is designed to measure are not persistent over the ~1 ½ hours between the measurement and launch**
 - Conservative approach protects for a “design gust” throughout the high air loads region of flight. A design gust is analyzed pre-launch and the loads associated with it is decremented from the absolute capability to provide the launch day redlines
 - An additional decrement is applied via RSS with a systems dispersion increment to account for wind in-persistence between launch time and the balloon measurement. A significant portion of the 1 ½ hour wind change increment is due to changes in the high frequency content of the wind profile
 - Result is to somewhat double book-keep protection for changes in the in-persistent (short wavelength) content of the wind aloft profile
- ◆ **Differences in winds aloft due to spatial variations are not accounted for explicitly**
 - The launch vehicle flight path and the measurement balloon flight path may be significantly different due to the prevailing winds

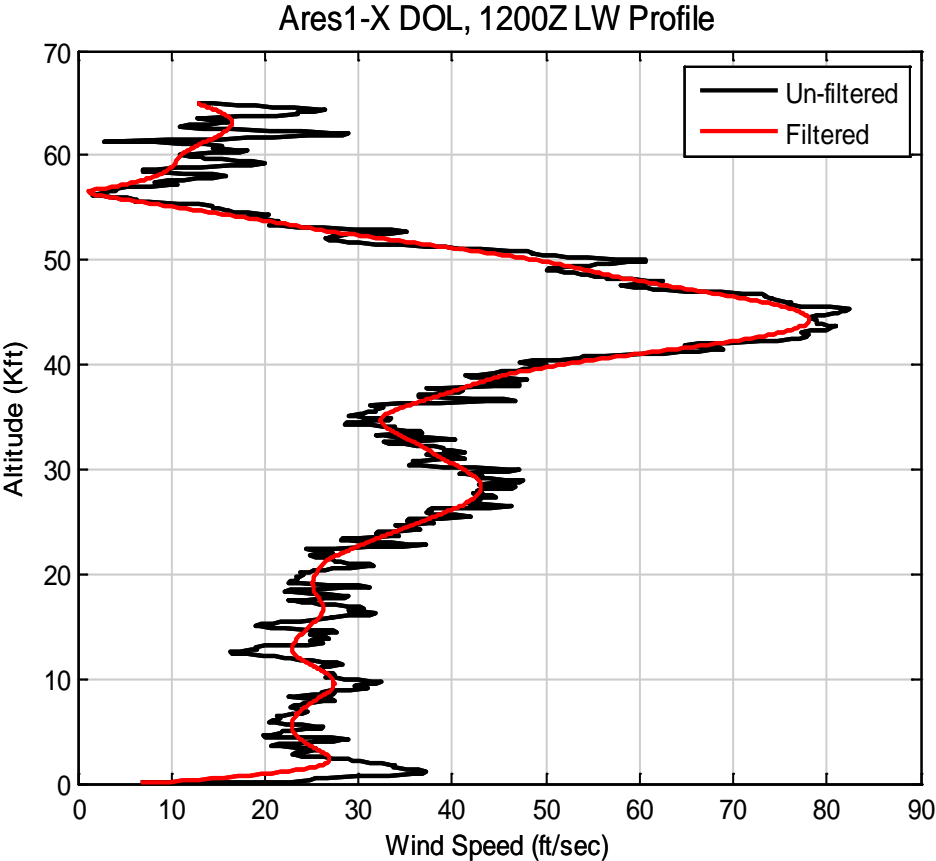
- ◆ **Used Ares I-X support operations as a test case for a revised approach**
- ◆ **Started with the assumption that a high resolution balloon based wind aloft measurement was not a perfect measurement of the actual launch environment due primarily to spatial and temporal differences**
- ◆ **Previous work (C.E. Spiekermann, et al - reference) established that wind features with wavelengths less than ~6,700' are not persistent over a two hour time span**
 - ◆ 2 hours time interval was chosen to coincide with the high resolution wind pairs database available for analysis
- ◆ **Launch day assessment was planned to be completed with a low resolution winds aloft measurement which was smoothed to remove wave lengths considered in-persistent over the time between the wind measurement and launch**
 - Low resolution GPS sonde is rated accurate for features whose wavelength is greater than 1,000'
 - Allows the use of a more common weather sonde relative to a high resolution GPS sonde



Magnitude Response of the Filter used to Smooth Wind Profiles for Ares I-X Launch Assessments



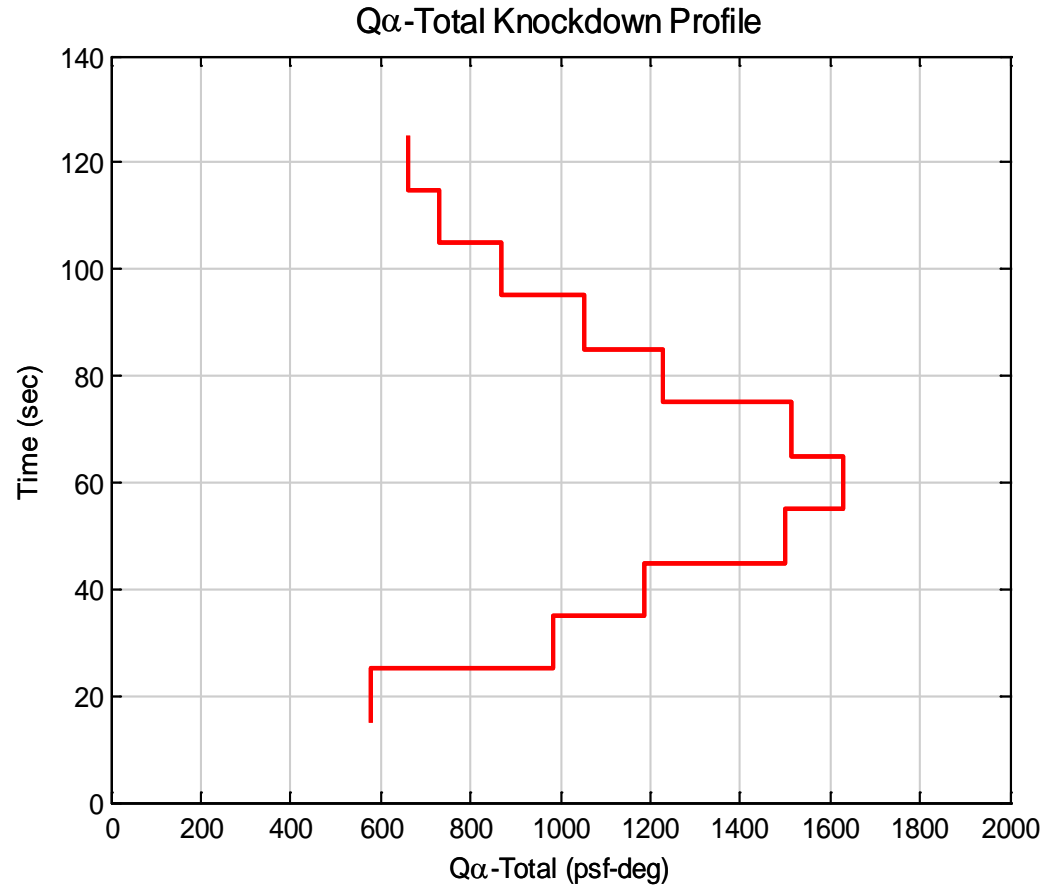
Wind Profile Example



$$DOL\ Sim\ Load(i) + \sqrt{(sys\ dispersion\ load\ inc(i) ** 2 + (wind\ in - persistence\ load\ inc(i) ** 2))} \\ < Load\ Cap(i) - Gust\ Load(i)$$

- ◆ **DOL Sim Load** = calculated undispersed element load at station i
- ◆ **Sys dispersion load inc** = increment to protect for vehicle system dispersions (aero data, propulsion system, thrust vector gimbal misalignment, etc.) at station i
 - Developed via a Monte Carlo dispersion assessment which varied each system dispersion randomly
- ◆ **Wind in-persistence load inc** = increment to protect for change in wind between measurement and launch time at station i
 - Used high resolution wind pairs
 - Developed statics from the differences between trajectory and loads results using the unfiltered first of the pair to trajectory and loads from a trajectory run which used a smoothed/filtered second wind from each pair
- ◆ **Load Cap** = ultimate load capability at station i
- ◆ **Gust Load** = load increment due to design gust at station i
- ◆ **i** = vehicle and trajectory parameters of interest -- (examples, dynamic pressure, dynamic pressure * total angle of attack (q_alpha), load at vehicle station locations (where stations are varied from the top of the vehicle stack to the bottom))

Example System Dispersion Increment



◆ Increase wind pairs database

- Current database is too small for meaningful statistical analysis
 - ~200 wind pairs for each season (summer, winter, fall/spring)
- Size requires application of a confidence factor to the wind change increments
- Plan is to augment the database using wind pairs measured by the CCAFS Doppler Radar Wind Profiler

◆ Analysis of spatial variations impact on load parameters

- differences in wind measurement due to the measurement system not following the launch vehicle flight path are either ignored or considered to be included in the wind in-persistence increment
- Recommending a study to quantify the loads and trajectory parameter differences due to spatial displacement of the measurement system relative to the

Future Refinements, cont.

- ◆ **Investigate the potential to reduce wind in-persistence protection as the measurement moves closer to launch**
 - Spiekermann, et al – showed that the persistent wavelengths grew shorter as the time increment to the launch time grew smaller
 - Reduces smoothing required
 - Potentially reducing wind in-persistence increment
 - Particularly applicable to the use of the DRWP for launch assessments

- ◆ **Develop methodology for the use of the DRWP for launch assessments**
 - DRWP provides much quicker wind measurement (5 minutes average vs. 60 minute rise time)
 - DRWP profile could be measured within 15 or 20 minutes of launch vs. 2 hours
 - DRWP can provide a wind profile from 7,500' to 60,000'
 - Methodology for the augmentation of the wind profile below 7,500' needs to be developed

Conclusion

- ◆ **Plan outlined addresses a number of weaknesses in the approach used to evaluate launch day winds**
- ◆ **Potential for enhanced safety by increasing the understanding of wind change and its impact to launch loads**
- ◆ **Potential for enhanced launch availability due to reduced conservatism**