Space Shuttle Day-of-Launch Trajectory Design and Verification

Operational Concepts

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Ascent / Descent Flight Design

USA United Space Alliance

Objective

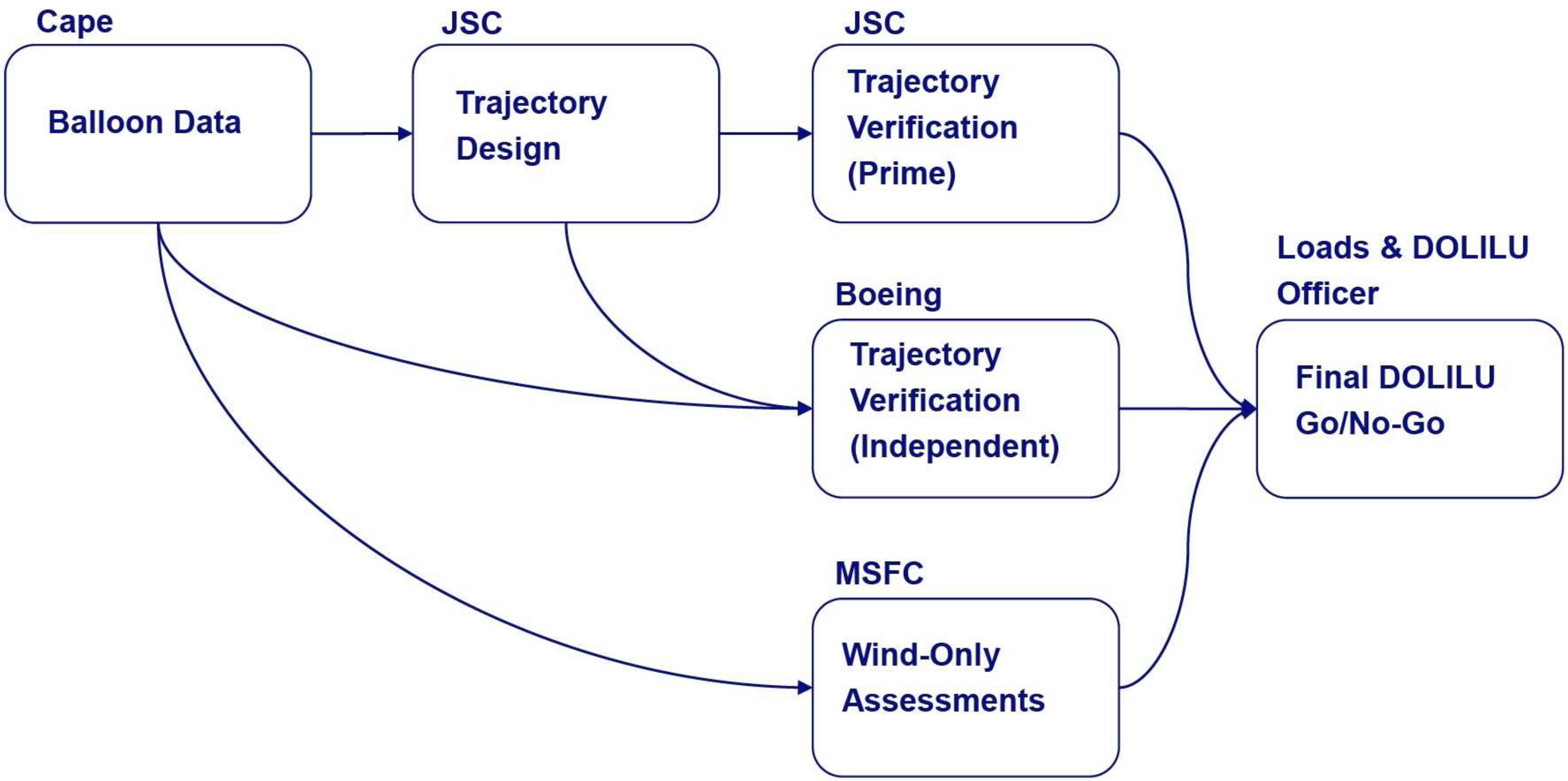
- Review Space Shuttle day-of-launch trajectory optimization operational concepts
- Demonstrate how the Day-of-Launch Initialization-Load Update process, or DOLILU, can improve launch probability three-fold
- Offer Shuttle DOLILU methodology for future launch vehicles to build on

Background

- Space Shuttle is not certified to lift-off in all weather conditions
- Vehicle's trajectory is optimized to that day's wind and environmental conditions
- Designed trajectory must be rigorously assessed to ensure crew and vehicle safety, while accomplishing mission objectives
- DOLILU process results in a trajectory that protects vehicle structural margins and maximizes performance given other factors
- Similarity will transition to future launch vehicles

DOLILU Overview

Since the environment (wind) changes, the DOLILU design and assessment process is repeated every hour from about launch minus 6 hours to lift-off



Balloon Systems

- **Shuttle makes use of weather balloon data on Day-of-Launch (DOL)**
  - **Wind speed and direction from 0 to ~58,000 ft.**
  - **Thermodynamic atmosphere data (temperature, humidity, density) from 0 to 100,000 ft**
- **Weather Balloons are released about 10 miles from the launch pads by Air Force contractors**

Jimsphere

•Radar tracked, no package

•Measures Wind Speed and Direction

High-Res

•GPS tracked, attached to clear Jimsphere

•Measures Wind Speed and Direction

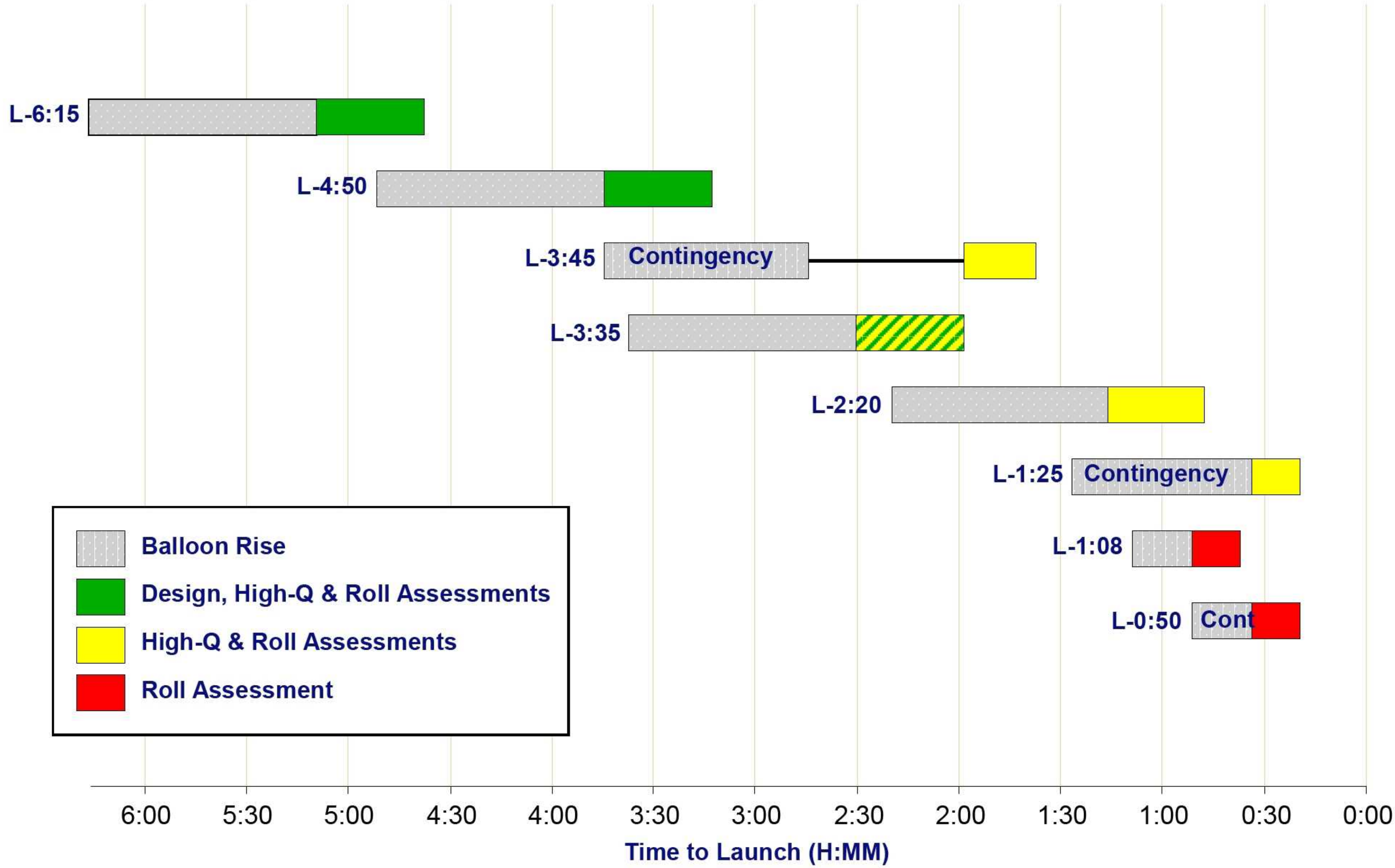
Low-Res

•GPS tracked

•Measures Wind Speed and Direction

•Measures Thermodynamic data

Balloon Timeline



DOLILU Design

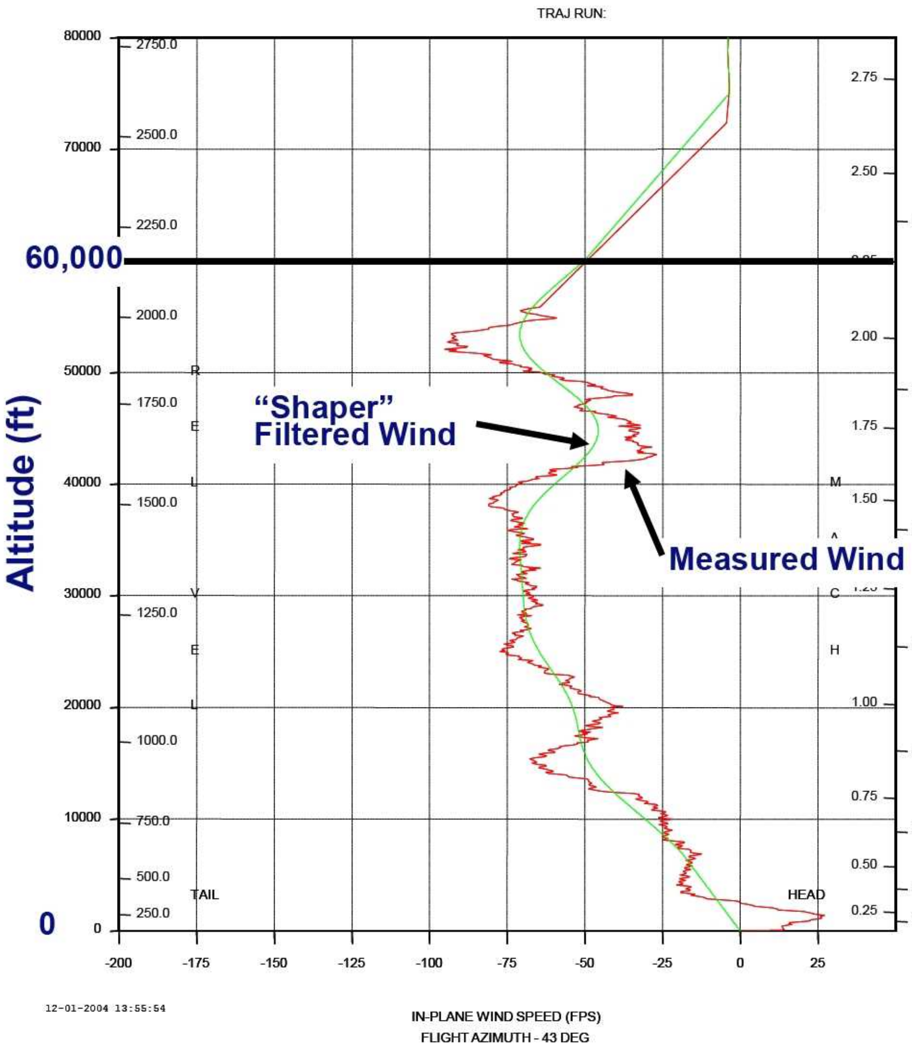
- Shuttle first-stage is “Open-loop”; “Closed-loop” second-stage will fly itself to a target

- DOLILU software optimizes the first-stage trajectory in order to minimize vehicle structural loads and maximize abort capability
  - Targets angle of attack (Alpha), angle of sideslip (Beta), and dynamic pressure (Qbar)
  - Targets staging conditions: altitude rate and optimum azimuth

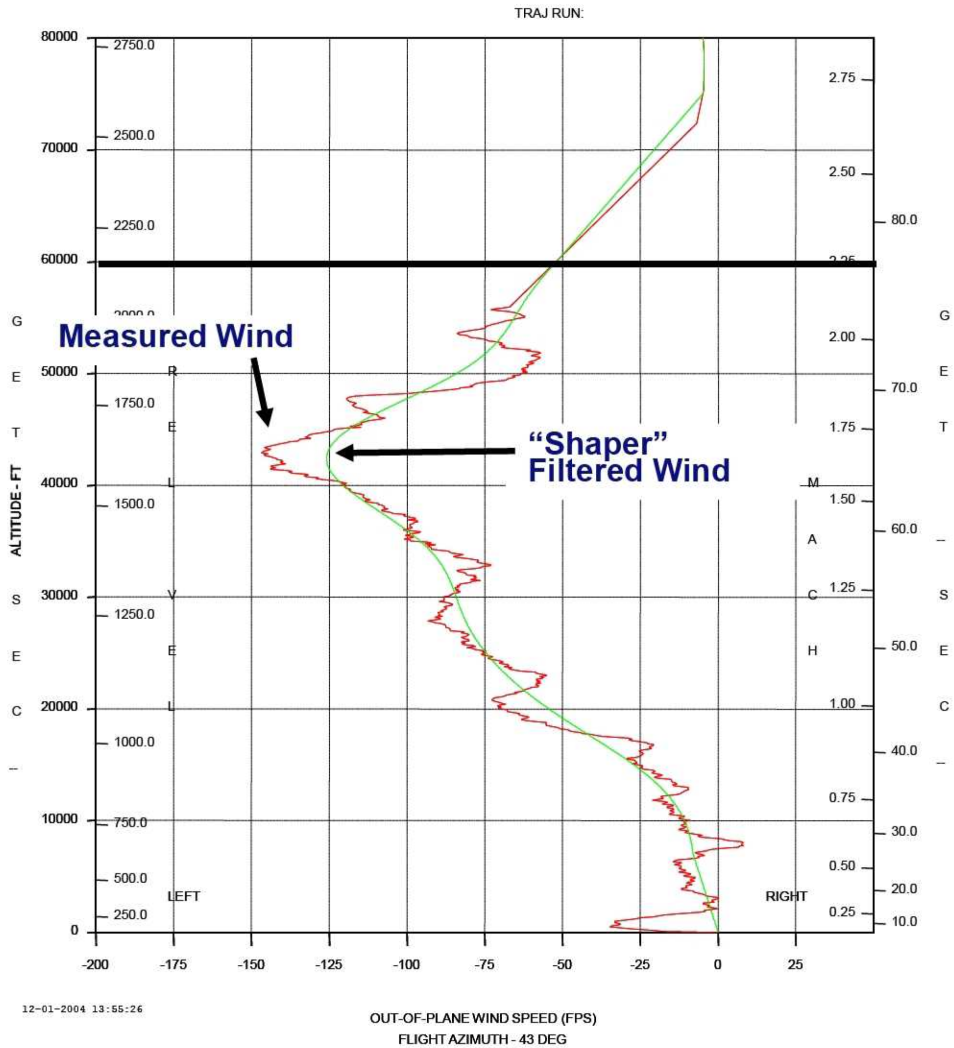
- Design consists of two elements
  - “Shaper” software uses a low pass filtered wind to obtain
    - Initial pitch and yaw steering commands
    - Throttle up and down table
    - On-board wind table
  - “Biaser” software uses the actual wind to fine-tune the pitch and yaw command by centering the wind-induced Alpha and Beta spikes

Example Wind

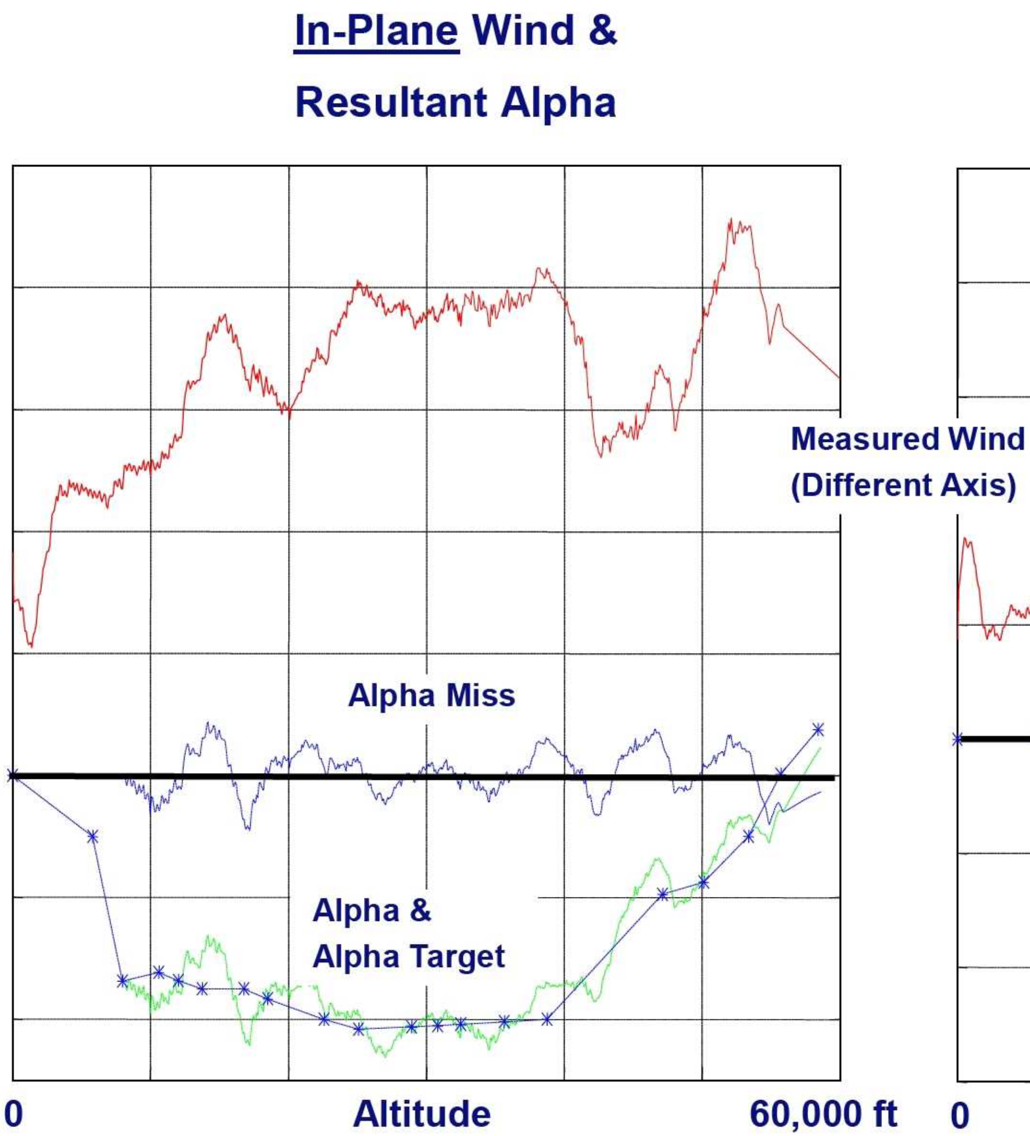
In-Plane Wind

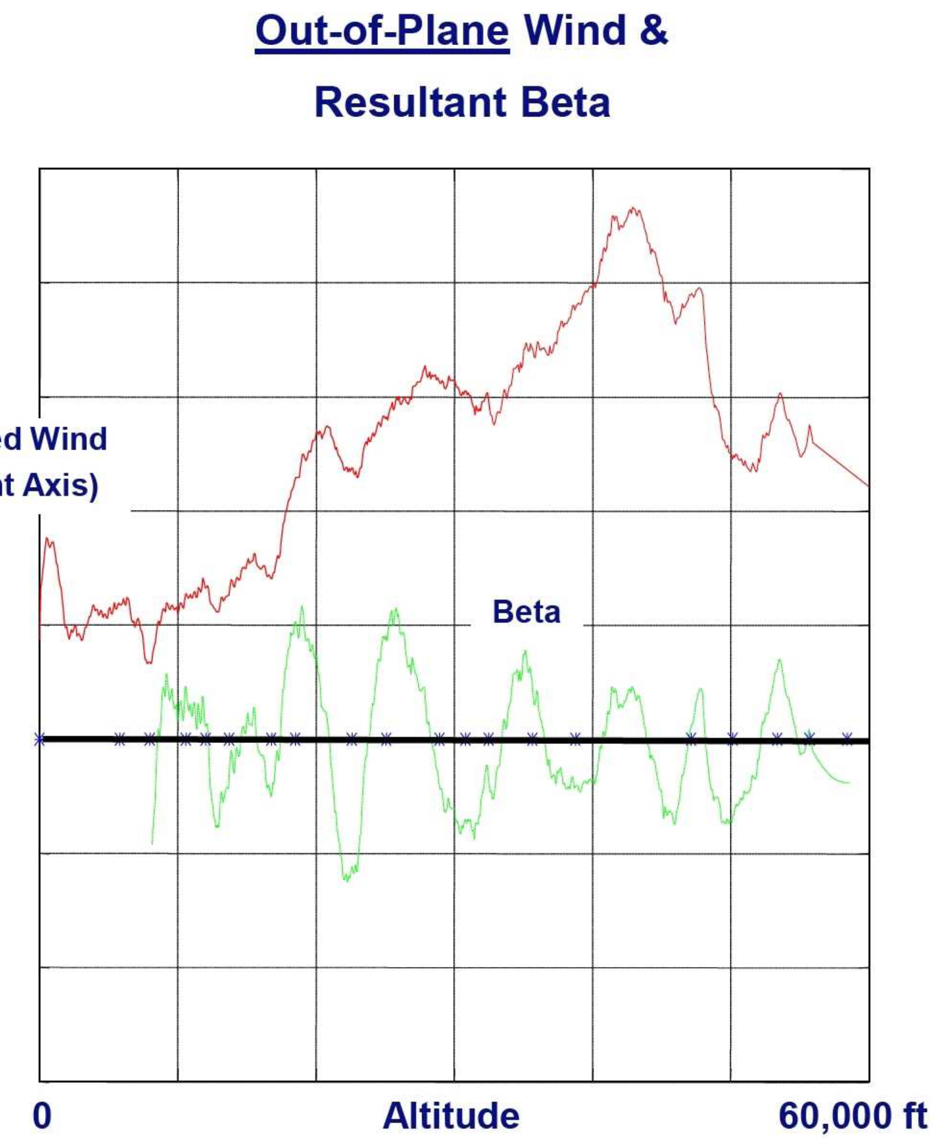


Out-of-Plane Wind



Resultant Alpha, Beta, Qbar

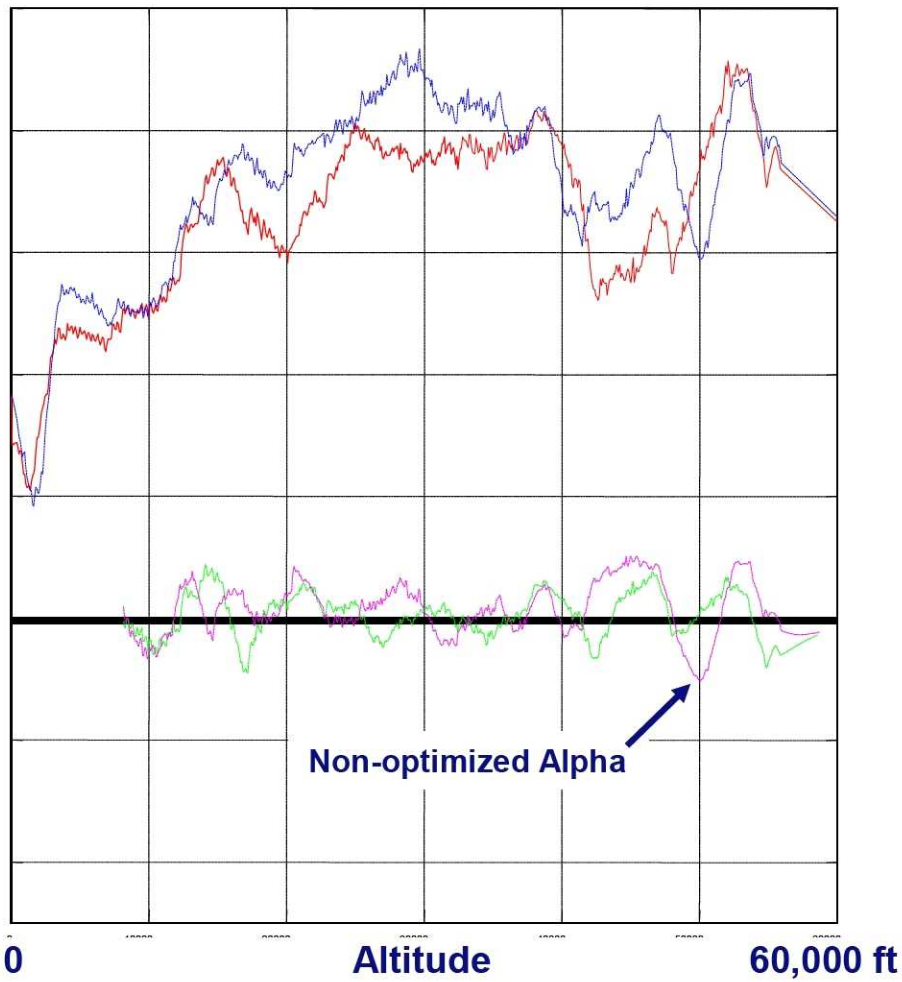




Now with a wind 3 ½ hours later

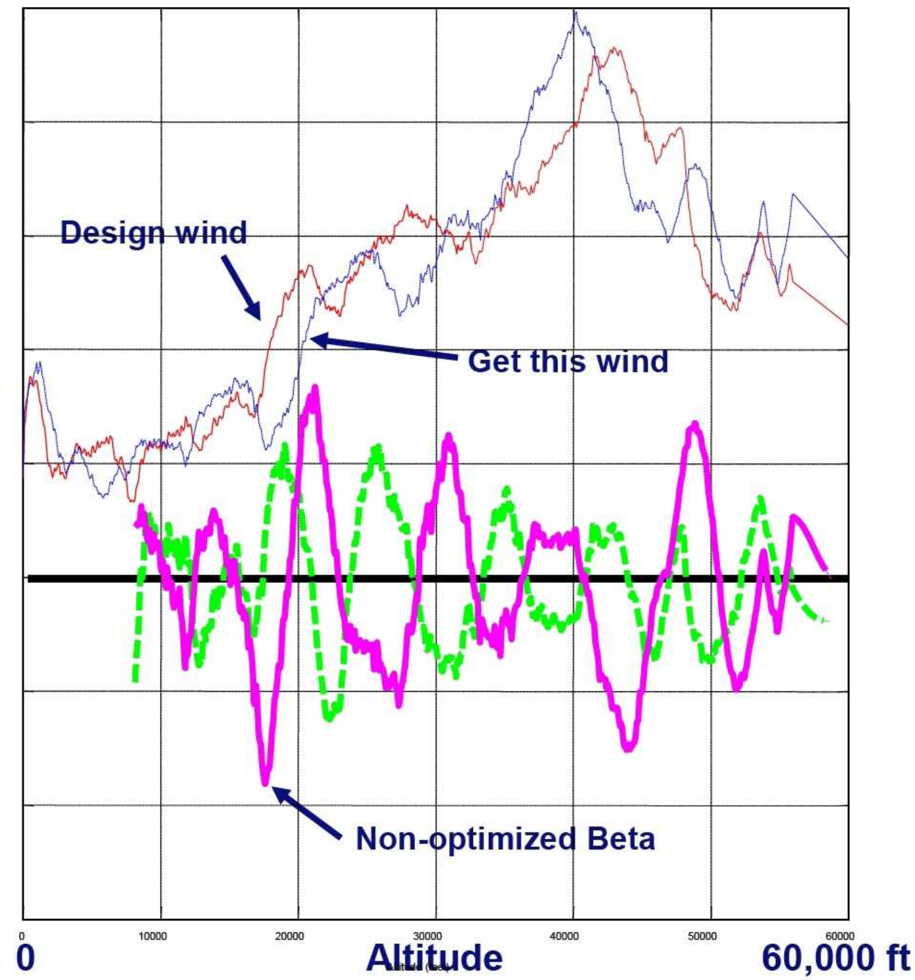
<u>In-Plane</u> Wind

Resultant Alpha



<u>Out-of-Plane</u> Wind

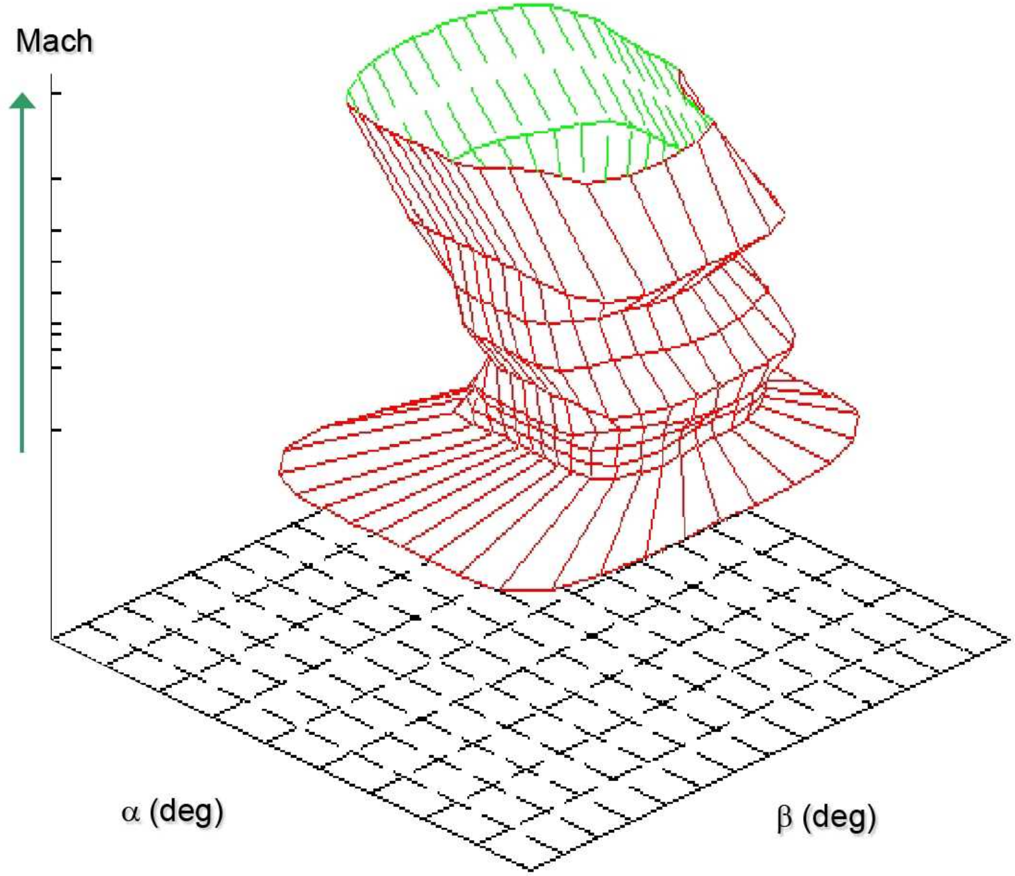
Resultant Beta



Constraints: Alpha/Beta/Qbar

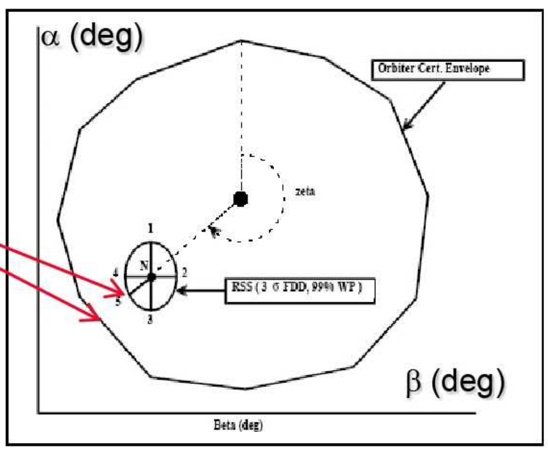
- **“Q-planes” constrain the flight envelope to alleviate structural concerns**
- **Each trajectory point is dispersed by the Root Sum Square of wind persistence, flight derived system dispersions, and atmosphere persistence (Qbar only)**
- **Limits are reduced for engine out and gust effects**

Alpha-Beta varies with Mach



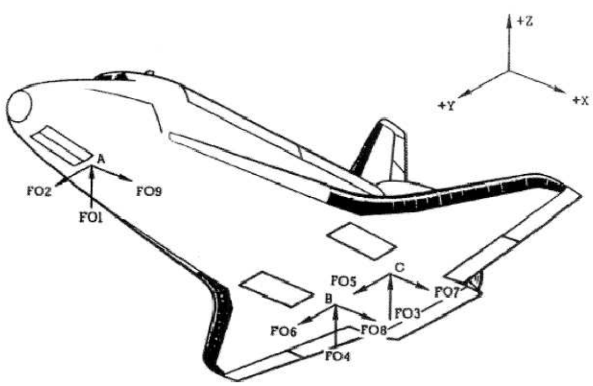
Alpha-Beta Slice or Plane

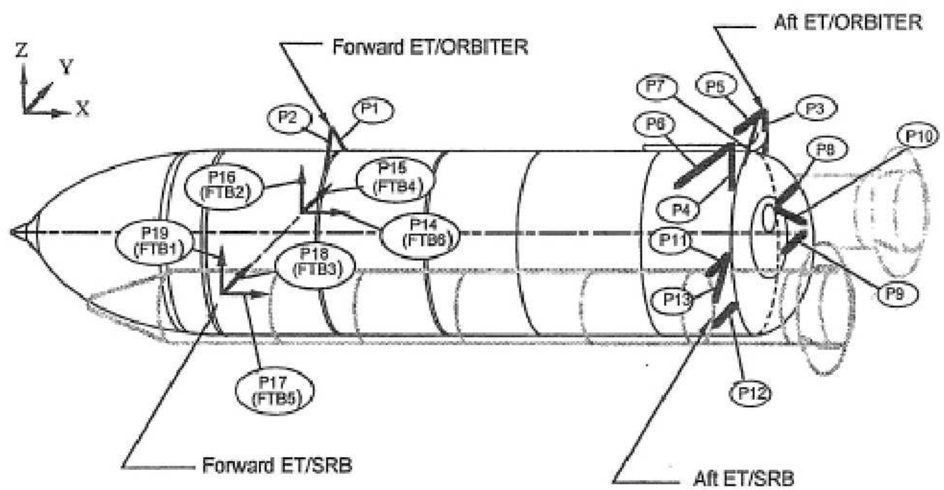
Alpha-Beta Margin



Constraints: Structural Loads and Trajectory

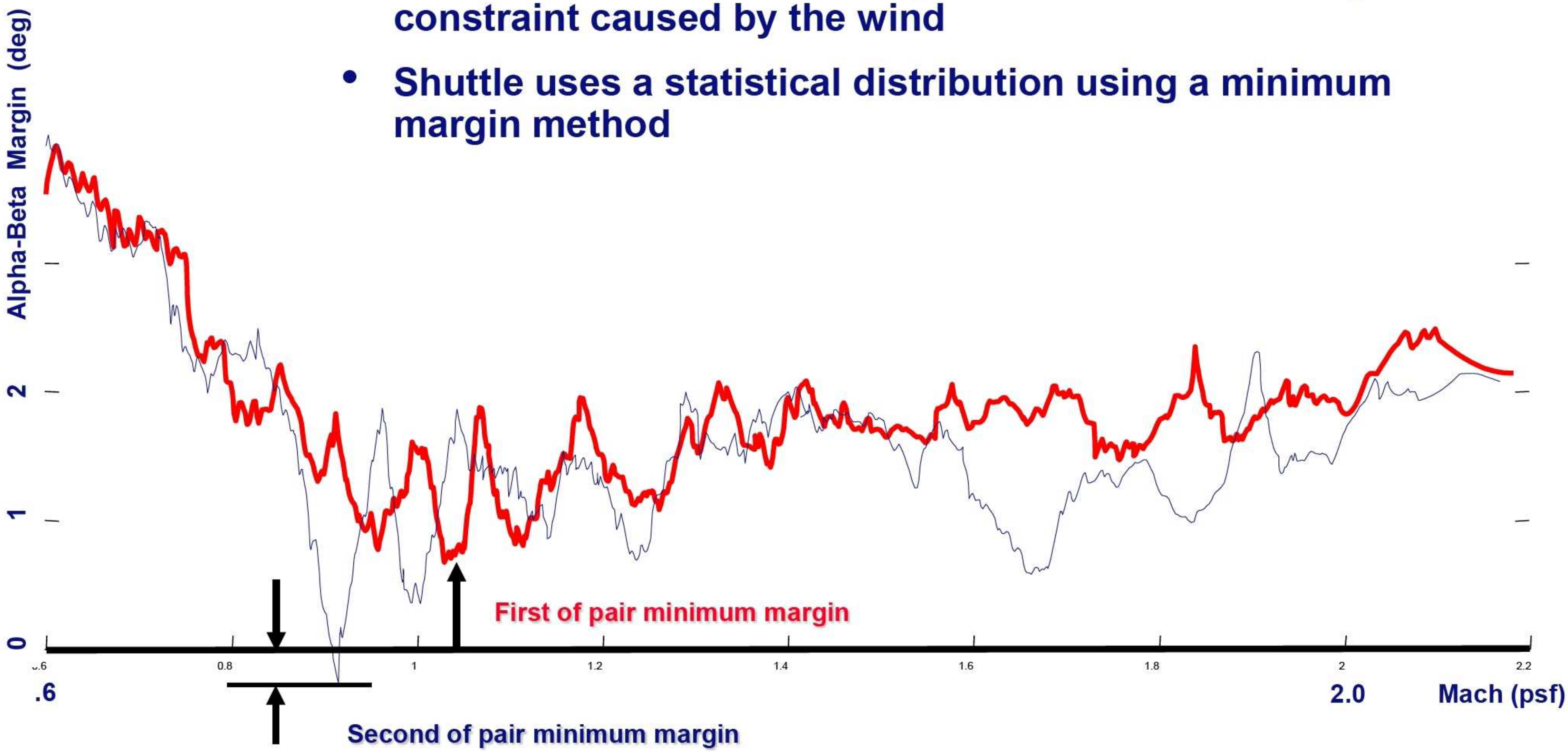
- Structural Load Indicators (SLI) protect critical load points on the vehicle
  - Each SLI is dispersed for the Root Sum Square of wind persistence, system dispersions, and gust
- Trajectory System Rules protect staging limits, pitch/yaw/roll rates, Range Safety limits, and throttle limits
- Trajectory Experience Rules assess attitude errors, angular accelerations, SSME and SRB commanded positions, and on-board wind table





Wind Persistence

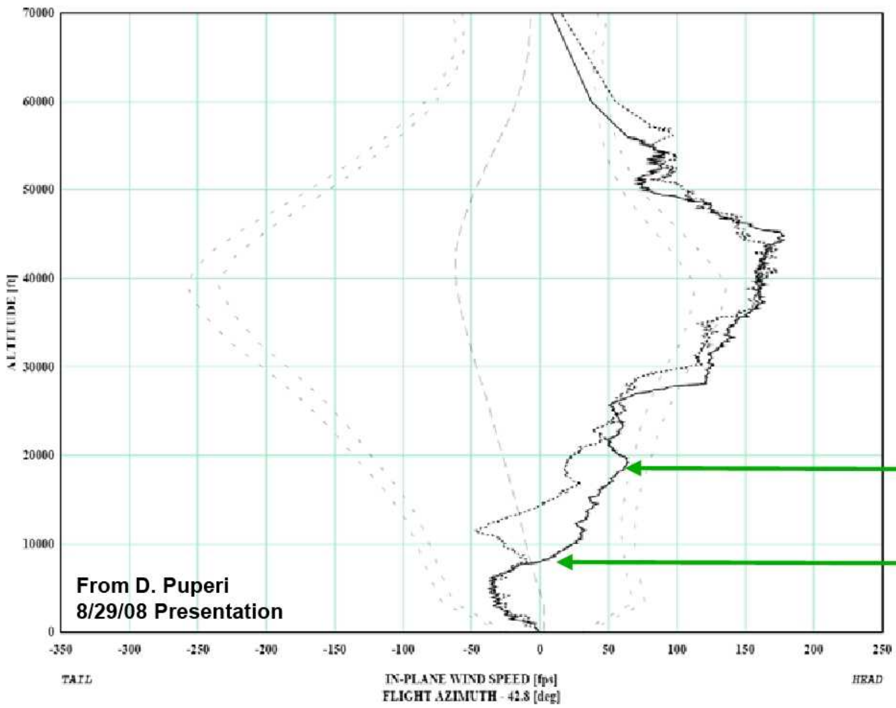
- Wind will continue to change after the final assessment
- Wind Persistence statistically accounts for the change on a constraint caused by the wind
- Shuttle uses a statistical distribution using a minimum margin method



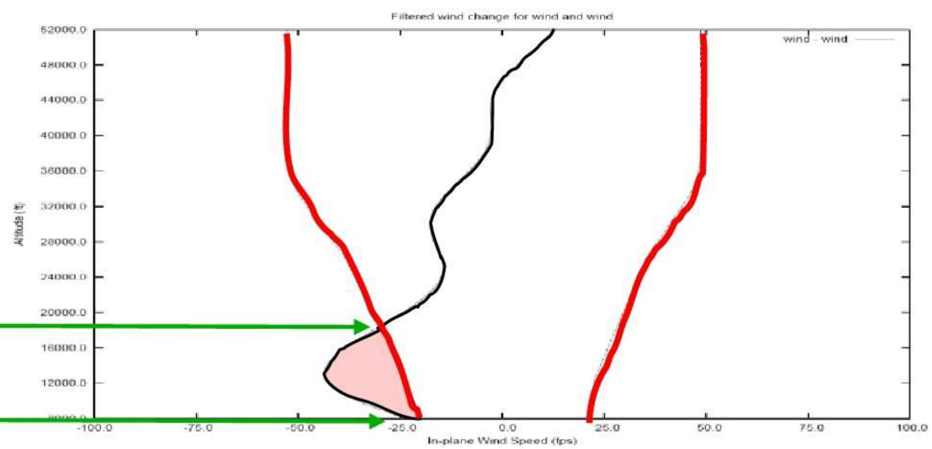
MSFC Wind-Only Assessments

- **Wind Shear Limits protect the Orbiter Tail**
- **Measurement Reasonableness Assessment ensures the balloon represents the current environment**
- **Wind Change Redline Assessment ensures that no late-in-the-count large shift in the wind might invalidate the design:**

In-Plane Wind Example

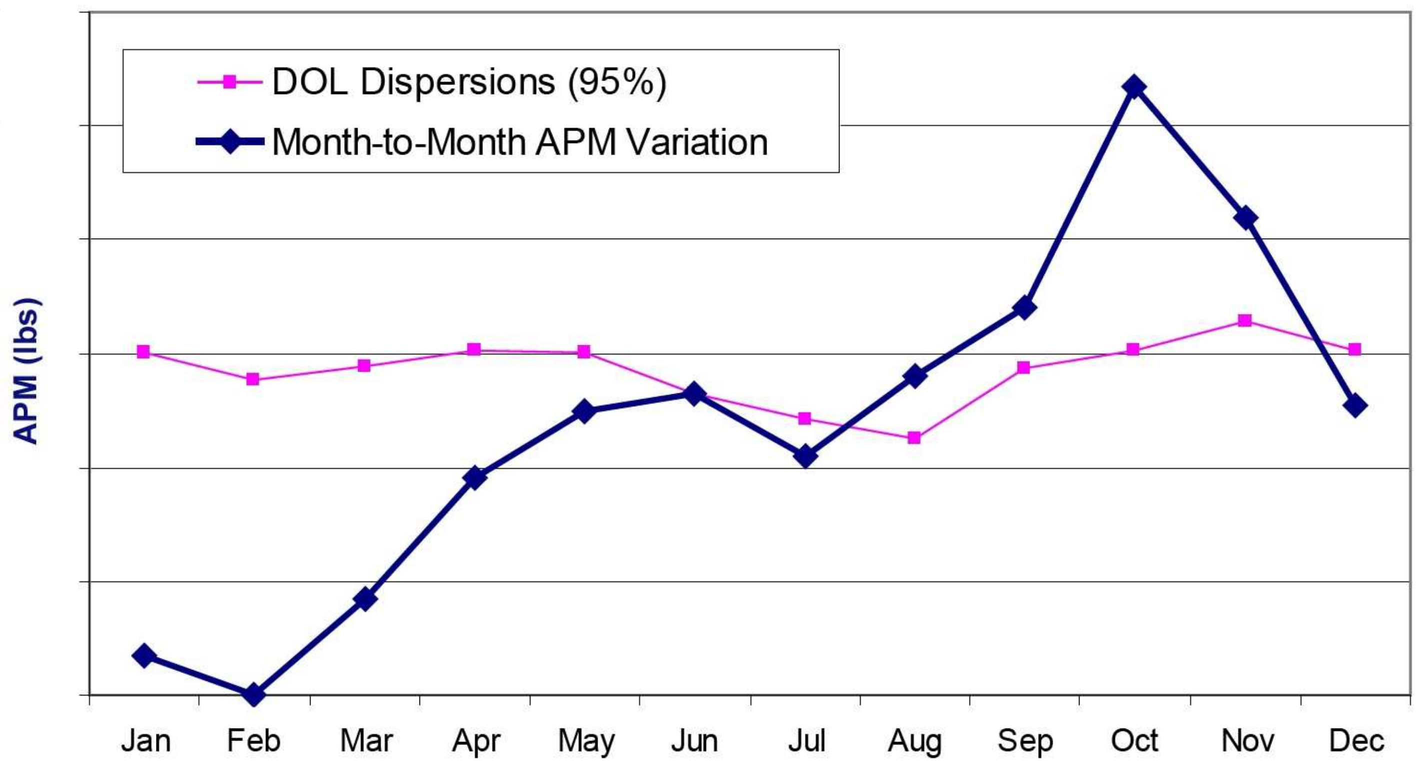


Wind Change Redline Assessment



Ascent Performance Margin (APM)

- **APM is remaining propellant in excess of that required to reach orbit**
- **DOL performance uncertainties influence pre-launch payload manifesting**
- **DOLILU designs tends to normalize APM which reduces in-flight dispersion protection**



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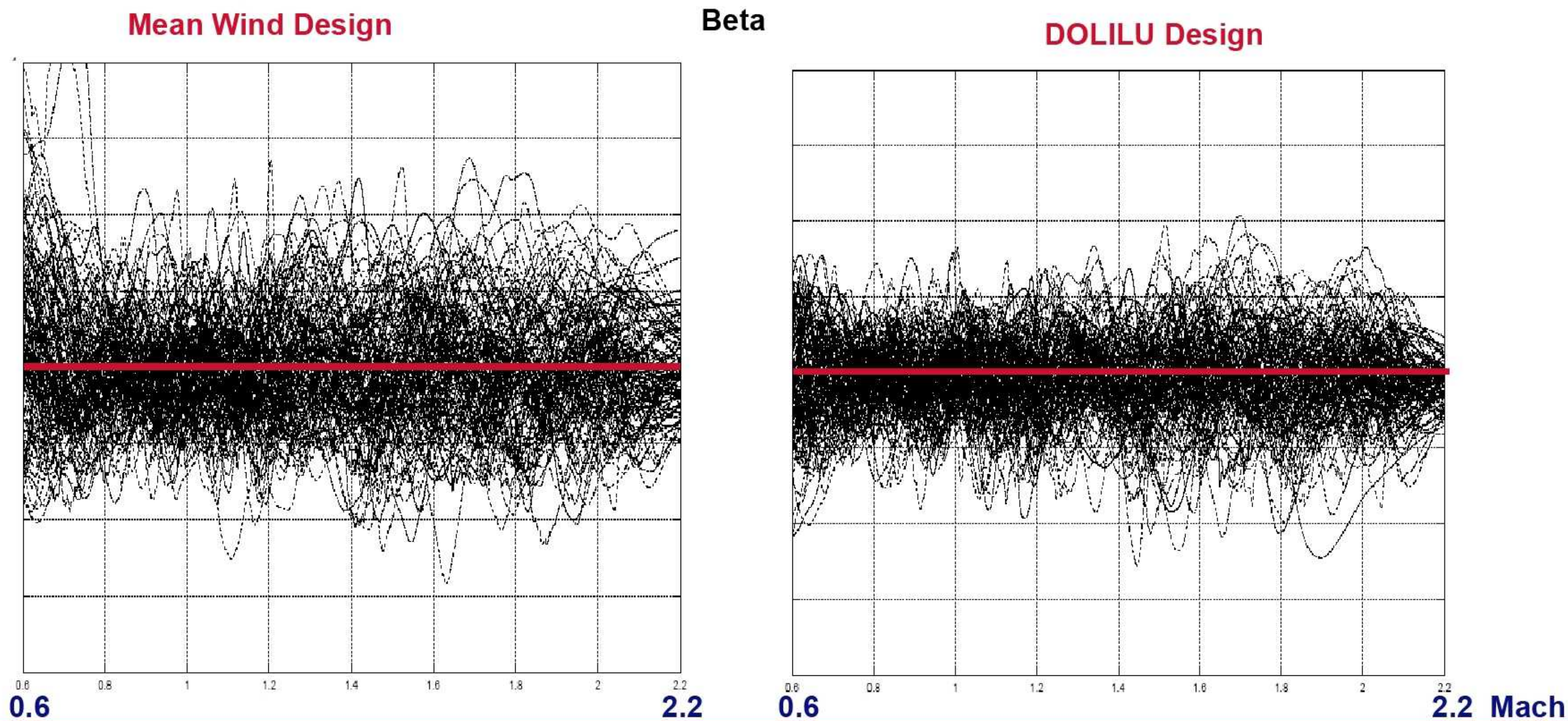
Launch Probability

- With the DOLILU process, the probability of launch increases over an average monthly wind design
- For example, what if Shuttle did not redesign on launch day, but used the monthly average wind/atmos design?
  - In February, the launch probability would be reduced from 90% to ~30%



Summary

- Day-of-launch design and assessment is important because it increases the probability of launch
- Winds always change and the Space Shuttle must have some means to account for those changes
  - Space Shuttle trajectory is redesigned on day-of-launch to minimize loads while maximizing performance
  - Many safety improvements and assessment refinements have been made
- The Shuttle concepts of operation can serve as a good basis for future NASA vehicles