# Do Vortices Behave Differently Under Non-Lidar-Friendly Weather?

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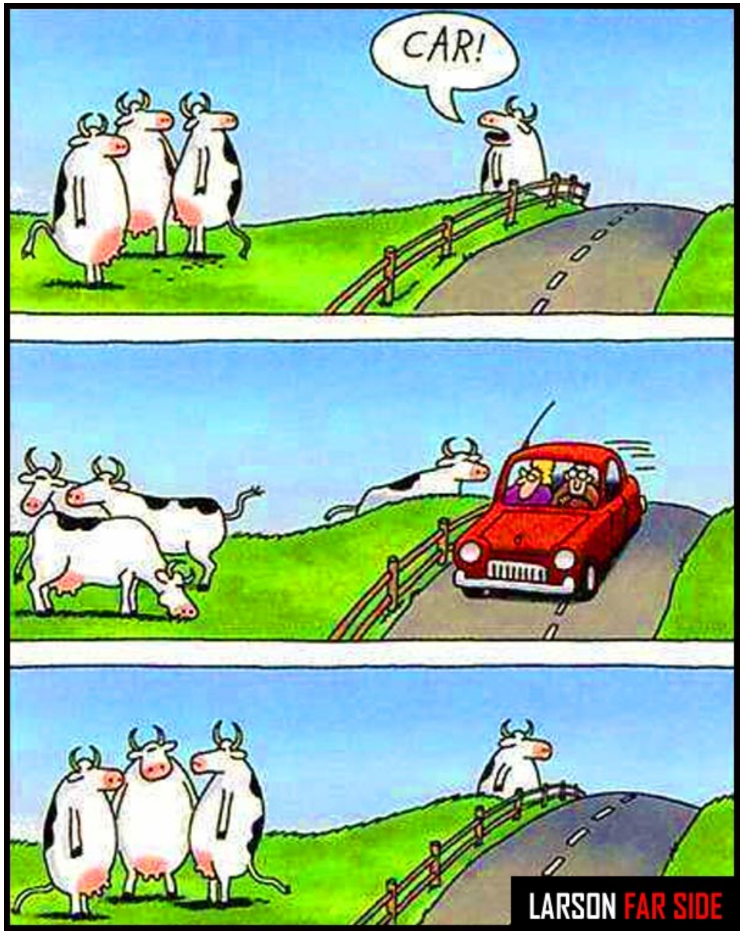
# Why? – 1/2

- Pulsed-Lidars have evolved to be the primary wake turbulence data collection tools globally for determining the safety of new wake turbulence procedures and standards
- Pulsed-Lidars are not all weather ; measurements are possible only under Lidar-friendly weather conditions
  - Lidar measurement has a "Goldilocks Zone" – needs to be "Just Right"
  - The "Goldilocks Zone" is not Unique to Pulsed-Lidar measurements
  - If the air is too clear, signals are too weak to process
  - If the air is too densely populated with light scatter particles, Lidar signal attenuates too much to make a measurement (low visibility)
  - If the ceiling were too close to measurement altitude of interest, returns from cloud greatly complicates the wake signature as seen by the Lidar processing (low ceiling)

# Why? – 2/2

- Overall it is important to continue building the confidence that Lidar based wake measurements can be used to develop wake solutions for all weather conditions
- Scientifically it is of interest to know if vortices behave differently when not observable by Lidar



# Wake Turbulence Risk – 1/2

- Wake encounters near the ground are the primary focus of most wake safety analyses
- Wake decay near the ground is dominated by interaction with the ground, with possible acceleration by atmospheric turbulence and/or stratification
  - Stratification can be related to low visibility and/or low ceiling
- Thus, conditions where a pulsed-Lidar cannot operate could be *assumed* to produce wake durations no longer than under Lidar-friendly conditions
- Nevertheless, this *assumption* is worth testing, if we have the data to make such a test

# Wake Turbulence Risk – 2/2

- Fortunately, the windline installed at SFO in 1999-2002 is a true all-weather sensor and not affected by low ceiling or low visibility, and can provide measurements for such a test
  - SFO Windline installation was near runway threshold
  - The Windline measurements overall do have limitation on maximum detectable height
  - However, the limitation is identical for both Lidar-friendly as well as non Lidar-friendly weather conditions

# Presentation Roadmap

- Conclusions
- Sample Wake Behavior Comparisons: B733
  - Low Ceiling
  - Low Visibility
  - Emphasis on wake decay
- Lidar-Unfriendly Selection Criteria
- Windline Characteristics

# Overall Final Conclusions

- No indications were found to suggest that NGE wakes at SFO might be more hazardous or behave differently under conditions unfriendly to pulsed-Lidar measurements
- Thus, pulsed-Lidar measurements can capture reasonable near-worse-case wake turbulence hazard in routine data collections
- This study covered many scenarios:
  - Two conditions unfavorable for Lidar operation: low ceiling and low visibility
  - Several aircraft types
  - Various crosswind conditions
  - Various headwind conditions

# Comparison Methodology

- Wake behavior near the ground is known to be strongly influenced by the wind, particularly the crosswind component
- To remove the influence of wind mismatching on the comparison of wake behavior under low/high visibility and low/high ceiling conditions, data are selected for the same wind conditions
  - Crosswind rounded off to 1 kt
  - Headwind rounded off to multiple of 4 kt

# Conclusions on the Low Ceiling Study

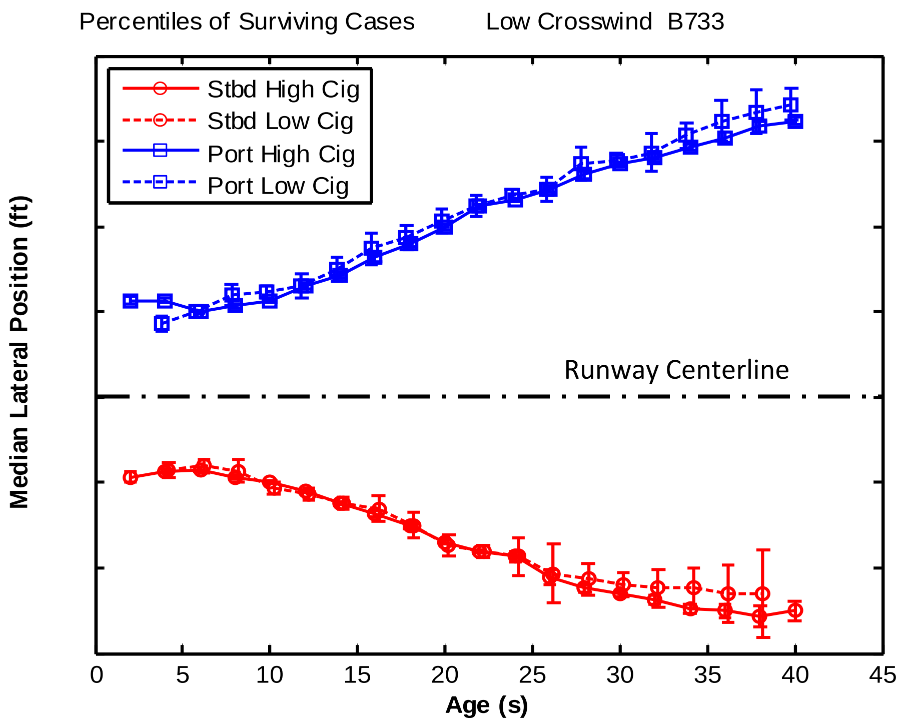
- Low ceiling has a significant impact on SFO operations
  - Visual operations no longer permitted
- Whereas low visibility is typically associated with low wind conditions, low ceilings typically have higher headwinds
- But wake behavior, *for the same wind conditions*, is similar for both low and high ceiling conditions
  - For zero crosswind, wake decay shows up as slightly faster for low ceiling conditions
- Thus, pulsed-Lidar measurements give a conservative measure of the wake hazard during conditions where direct Lidar measurements are not possible

# Conclusions on the Low Visibility Study

- Low visibility has a significant impact on SFO operations
- Low visibility is typically associated with low wind conditions
- But wake behavior, *for the same wind conditions*, is essentially similar for both low and high visibility conditions
  - Decay is not systematically different

# Sample Transport Plots – High/Low Ceiling

- Only B733 plots
- "Zero" Crosswind
- Compare Low/High Ceiling
- Median Lateral Position
- Number of low ceiling cases is much smaller than number of high ceiling cases
  - Hence Low Cig data has more fluctuations, larger error bars
  - Nevertheless, behavior of same vortex is similar for low and high ceiling

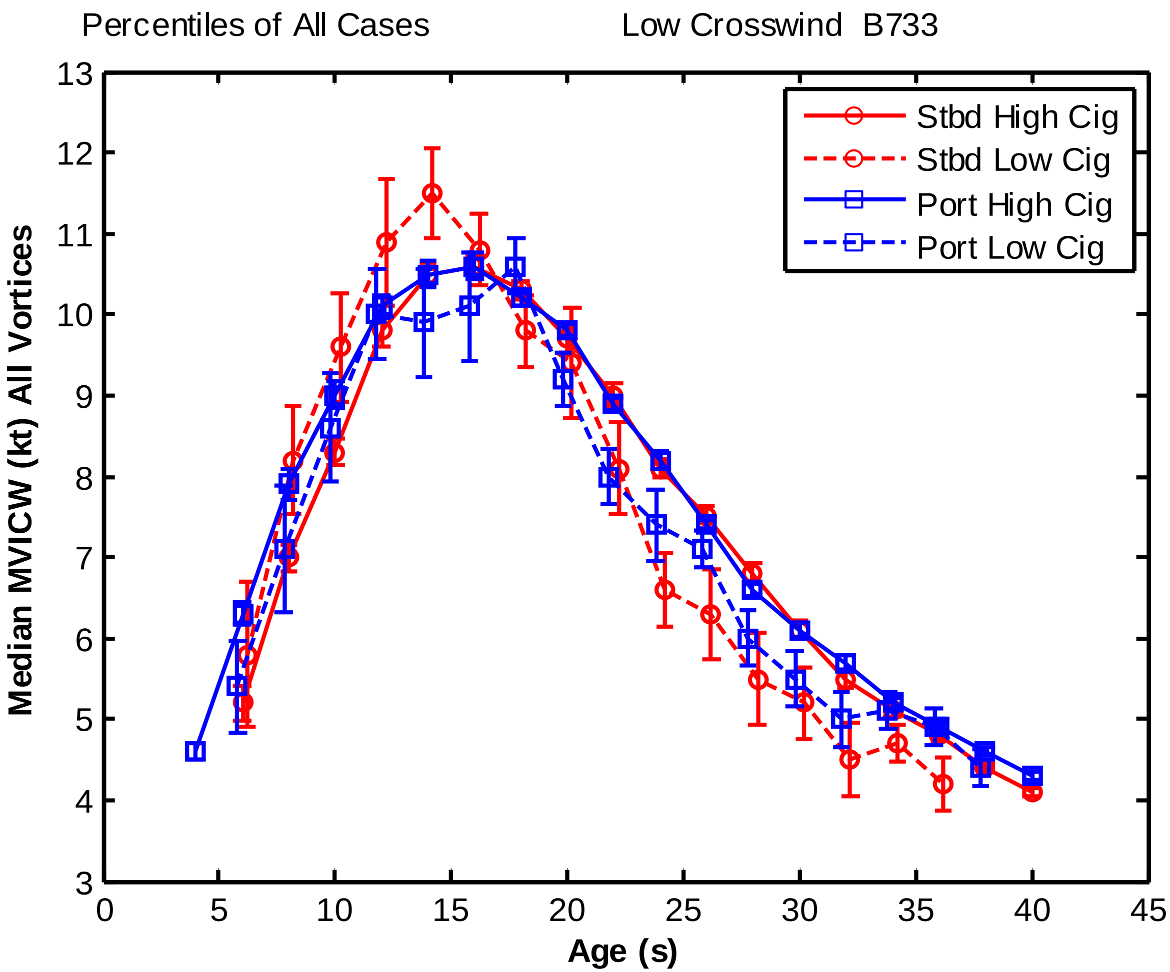


# Sample Decay Plots - Introduction

- Primary decay parameter will be median value of maximum vortex-induced crosswind (MVICW), which is the raw measurement of Windline
- Only one set of examples will be shown (B733 for ceiling; Cat-D for visibility)
- "Zero" and Moderate Crosswind
- Separate analyses for low ceiling and low visibility
- Median taken for all vortices

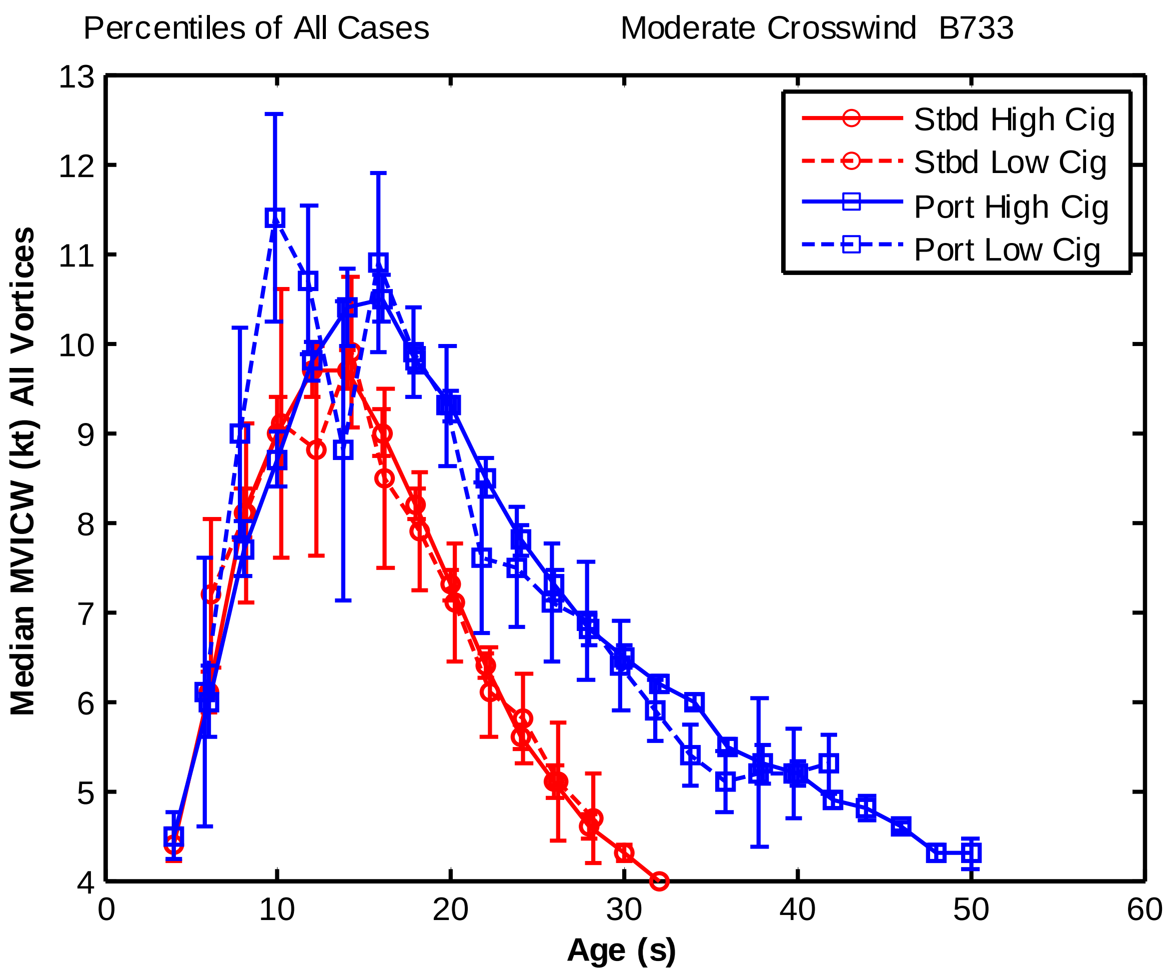
# High/Low Ceiling Comparison – "Zero" Crosswind

- low ceiling decays similarly or slightly faster at older ages



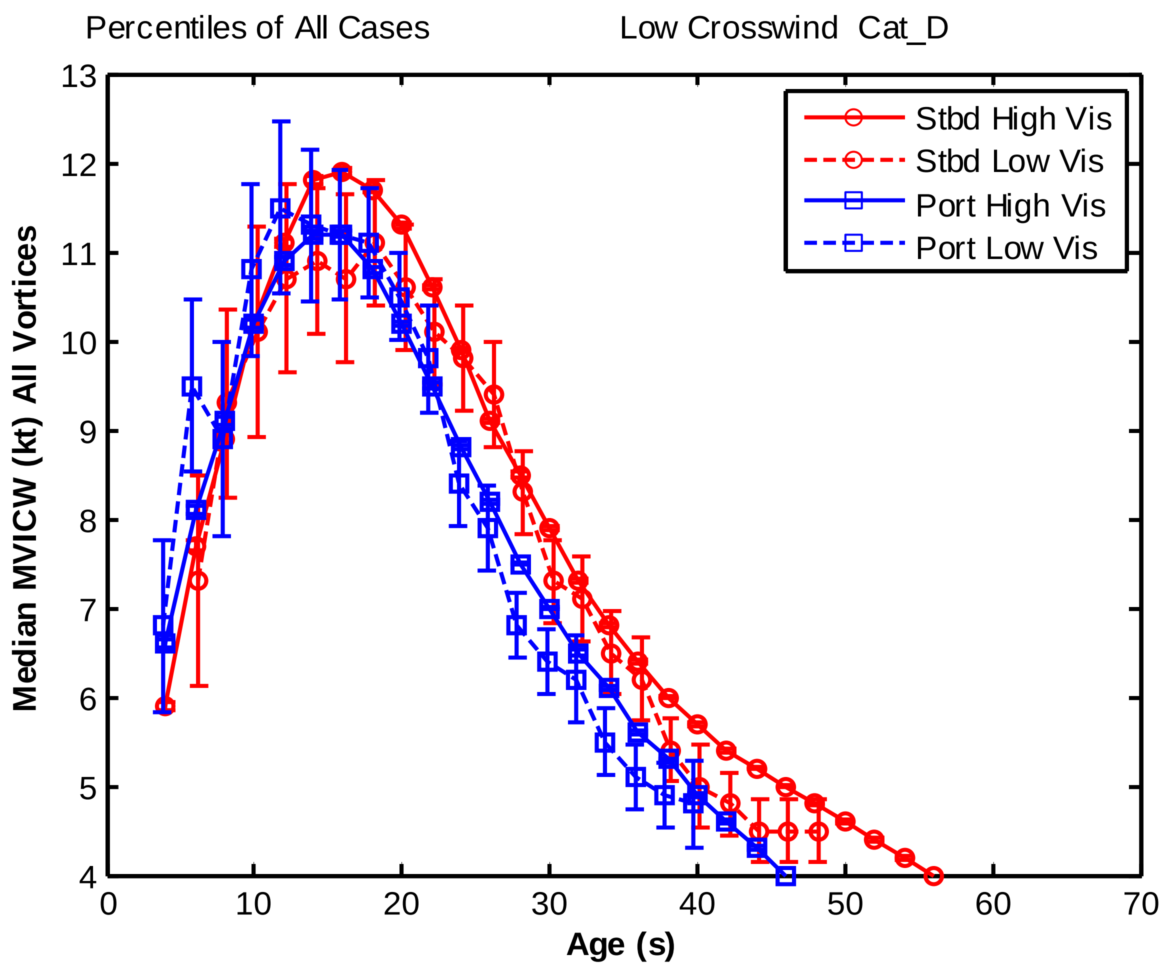
# High/Low Ceiling Comparison – Moderate Crosswind

- Low ceiling decays similarly or slightly faster at older ages



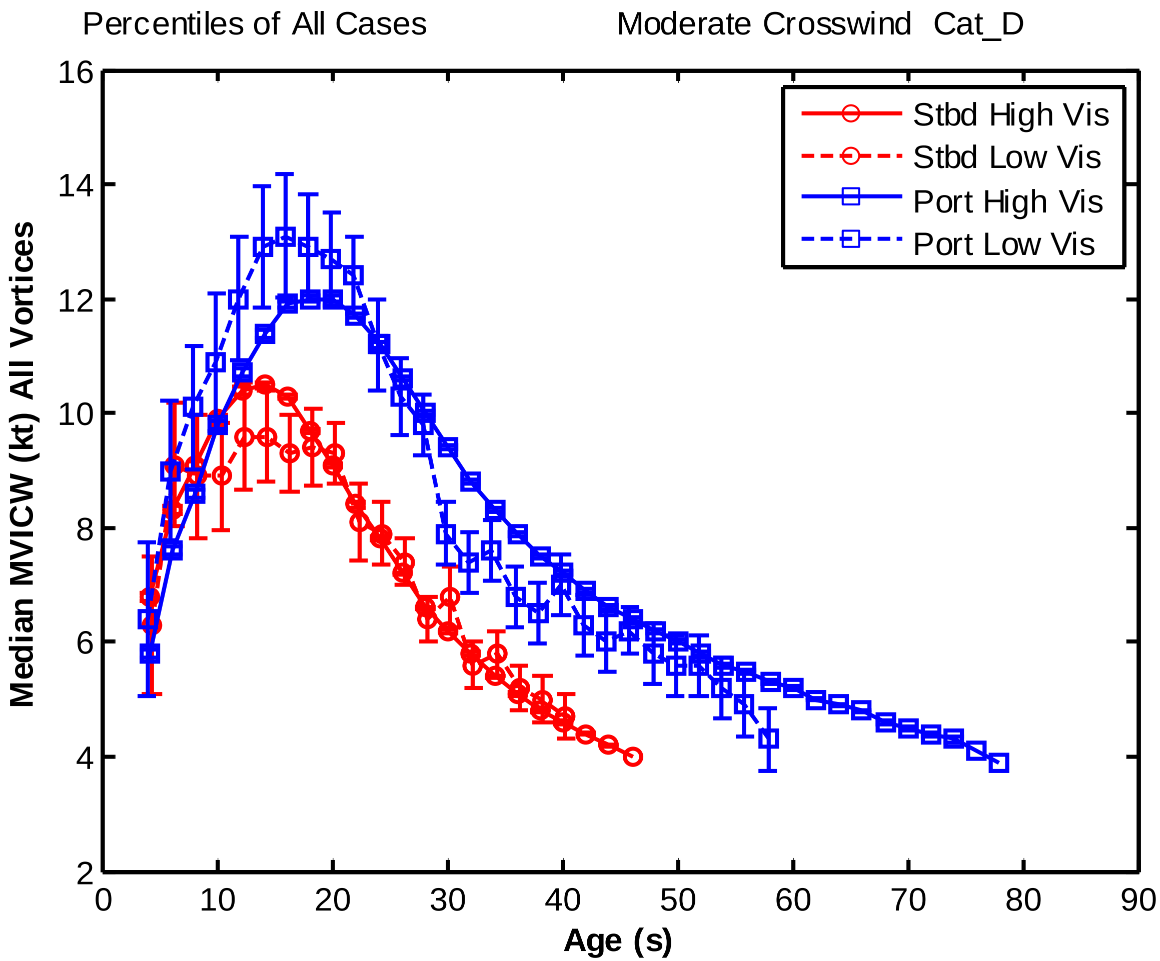
# High/Low Visibility Comparison – "Zero" Crosswind

- Low and High Visibility Cases Are Similar



# High/Low Visibility Comparison – Moderate Crosswind

- Low and High Visibility agree for same vortex



# Define Lidar-Unfriendly Low Ceiling Conditions

- Using ASOS ceiling (in five-minute ASOS archives, 100 ft increments)
- Criterion: ceiling = 100; termed “low ceiling”
  - “High ceiling” has ceiling > 500 ft; would not affect lidar performance for the ongoing WTMA-P and RECAT II data collection

# Define Lidar-Unfriendly Low Visibility Conditions

- Using extinction coefficient from two ASOS visibility sensors (in one-minute ASOS archives)
- Criteria: extinction coefficient > 2 $smi^{-1}$ for both sensors
- Number of low visibility cases is so small that all the ReCat Category D aircraft will be used to give enough vortices for a median analysis
- Daytime visibility conversion from extinction coefficient translates to 1.5 smi
- Theoretical Lidar SNR degradation is 10 dB for 1.5 smi visibility
- SFO Lidar measurement is 1.4 smi from the RWY 28R's wake transport

# Windline Characteristics

- For those who are involved in wake turbulence after 2005 (i.e., post pulsed-Lidar era), the present authors would like to introduce the audience to the Windline
- Windline was popular from the late 1970s to mid 2000s for NGE/IGE vortex characterization, especially for CSPR studies, before pulsed Lidar became the sensor of choice
- A Windline uses ground-based propeller or sonic anemometers (in the case of EDDF) to measure the crosswind induced by a wake near the ground

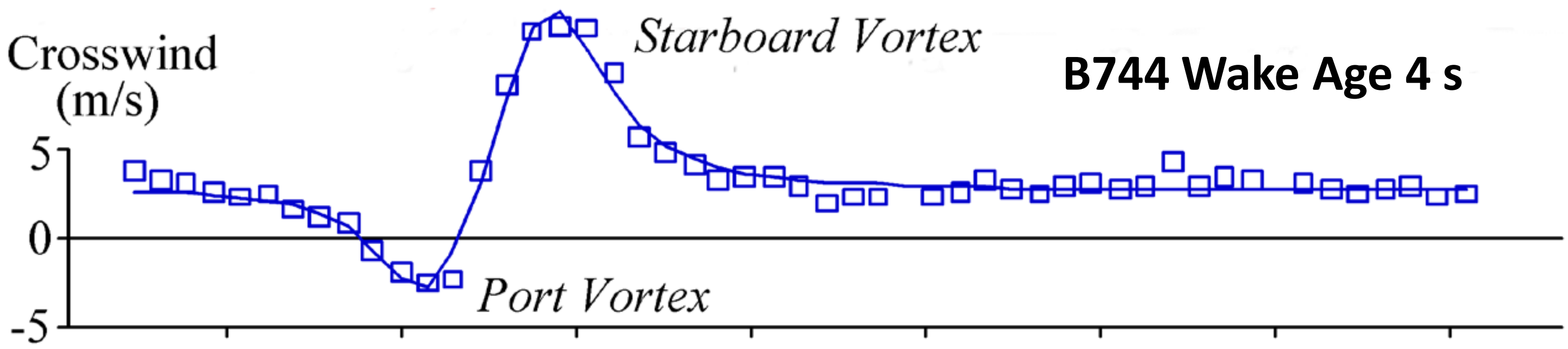
# SFO Windline

- Although three Windlines were installed at SFO, only the one located approximately at the runway thresholds (shown here) provided continuous wake measurements spanning across Runways 28L and 28R. Thus, our study will concentrate on this Windline

# SFO Windline

- Permission to install short 3-foot anemometer pole over the approach apron was permitted (but obviously not on the runway itself)
- Earlier tests at JFK airport from the 1990s had shown that the wake flow field has a very thin boundary layer at the ground, so that 3-foot anemometers can detect most of the vortex-induced flow
  - This fact was in contradiction to state-of-the-art simulation at the time

# SFO Windline Processing




- This plot shows a typical early-age wake signature
  - The sizes and positions of the crosswind peaks are well defined
- The wake parameters lateral position, height, and circulation are determined by a least-squares fit (line) to the measurements (squares)
  - The lateral position and the ratio : circulation/height = maximum vortex-induced crosswind (MVICW) are well defined
  - The height is determined by the width of the crosswind peak, which is less well defined
  - Hence the circulation is also less well defined.
- Our study of wake decay looked at both MVICW and circulation

# Questions?