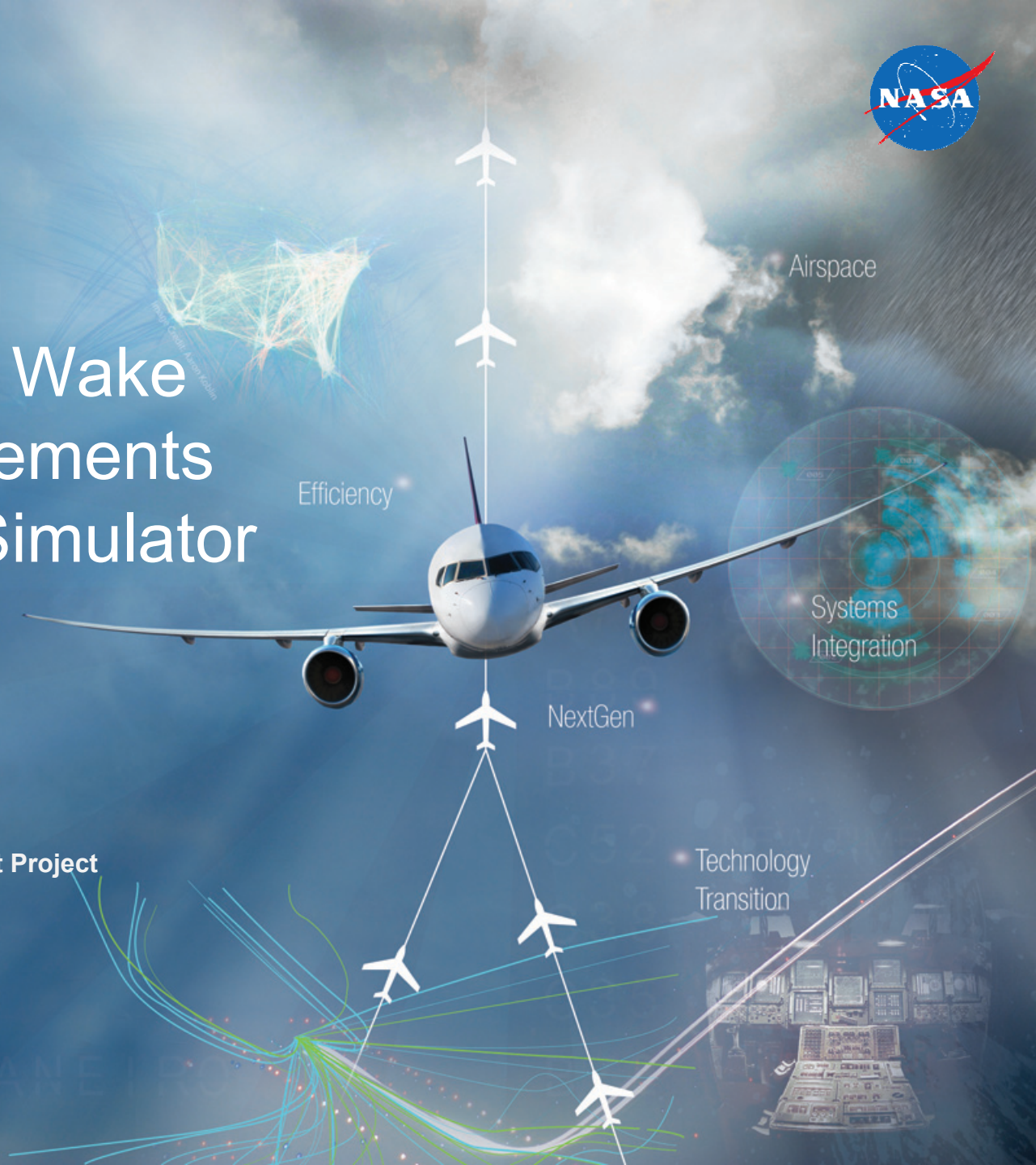


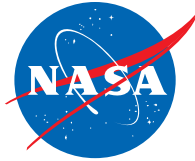
Assessment of Wake Vortex Measurements Using a Lidar Simulator

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OUTLINE



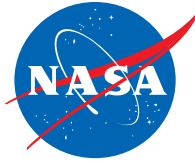
- Background
- Identification of the challenge
- Approach
- Concept
- Lidar Simulator Tool
- Evaluation
- Outcome
- Future work

Background



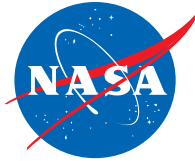
- Why do we perform research on wake vortices?
 - Current separation spacing is wake dependent
 - Based on worst-case wake vortex expectations
 - Safe, but typically conservative with respect to wake vortices
 - Wake-informed spacing could potentially be reduced compared to current standards
 - NextGen Super Density Operations will be dependent on a wake vortex solution

Identification of the Challenge



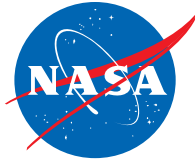
- Lidars are used to measure the atmospheric wind field—there are no direct measurements of the wake vortices
- Measurements are post-processed using independent algorithm(s) utilizing pattern matching to search for wake vortices
 - Locate lateral and vertical positions
 - Estimate circulation strength
- Accuracy of Lidar wake measurements is difficult to evaluate
 - Limited independent data for comparison

Lidars as Used for Wake Vortex Measurements



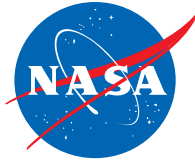
- Two basic types:
 - Continuous Wave (CW) Doppler Lidar
 - Primarily used in NASA's AVOSS project and older data collection programs
 - High spatial resolution
 - Limited range and operational utility
 - Pulsed Doppler Lidar
 - Extensively used in more recent data collection programs
 - FAA and in NASA projects during this decade. European—DLR
 - Represents state-of-the-art wake vortex detection

Approach



- Develop “Lidar Simulator Tool” (LST) to simulate operation of Lockheed Martin Coherent Technologies WindTracer system
 - Nearly all available wake vortex lidar based data measured by WindTracer systems
- Evaluate effectiveness of the LST as a proxy for the WindTracer
 - Use TASS-derived Large Eddy Simulation (LES) data as “truth” data
 - With or without embedded wakes

Lidar Simulator Tool



- Integrated software system combining:
 - Production WindTracer software
 - New software modules replicating functions of WindTracer hardware
- Wake vortex post processing software also integrated into the LST
 - Can interchange versions
 - Allows evaluation of the post processing software

Concept



TASS MODEL RUNS



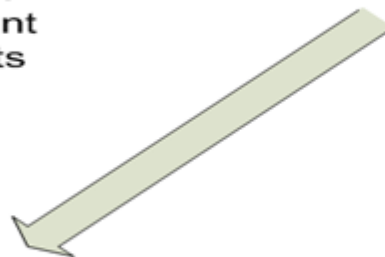
3-D Time
Dependent
Data Sets



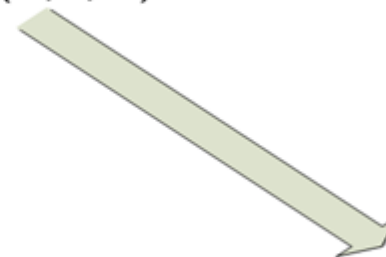
2-D Time Dependent
Velocity (U,V,W)



TASS MODEL
DATA SLICE



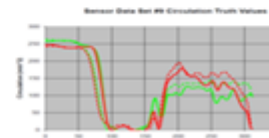
LIDAR Simulation
Tool



Vortex Truth Parameters



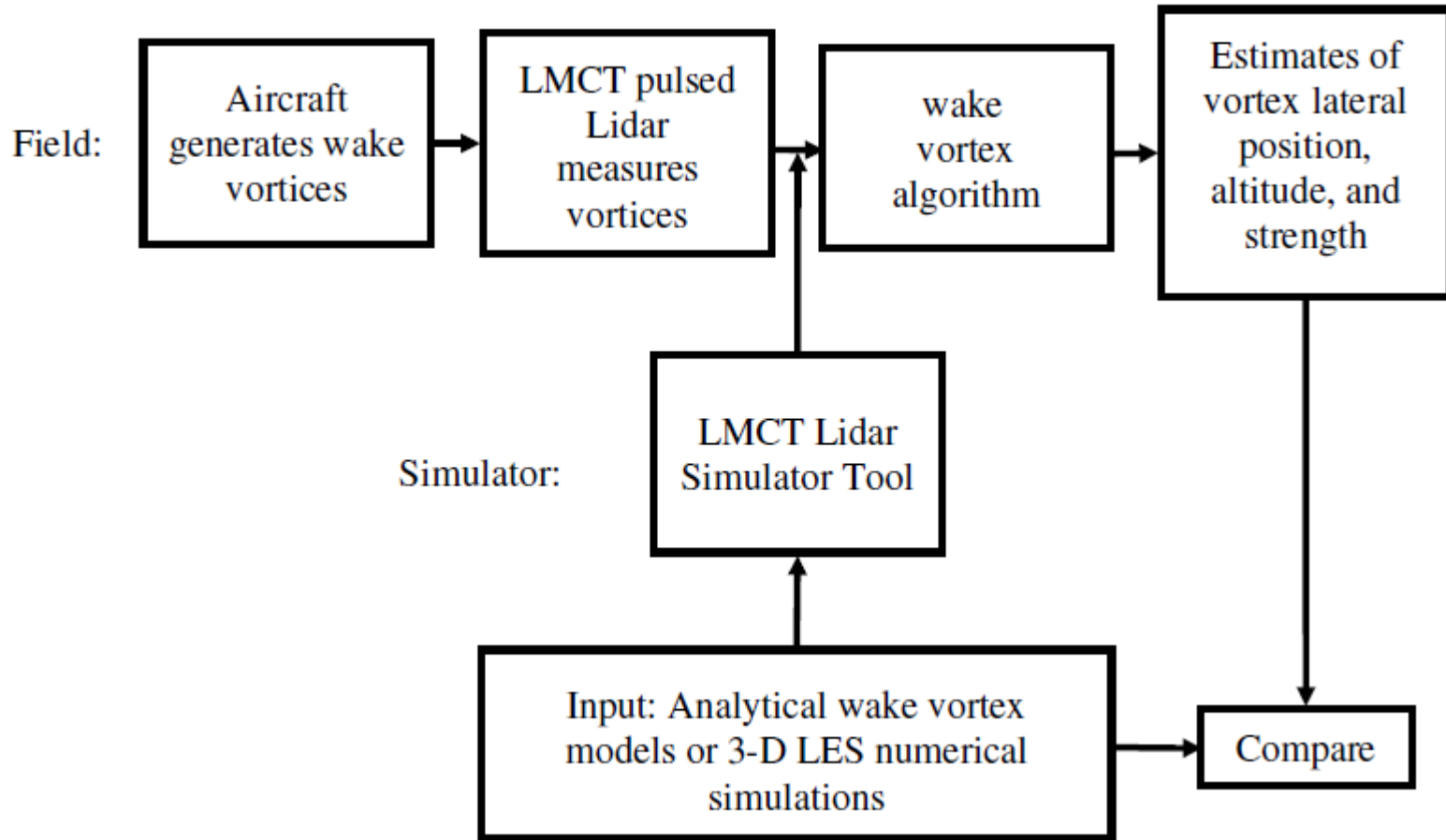
Data Comparison



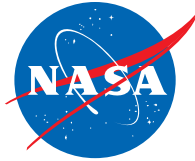
Position, Circulation

- TASS LES data used in parallel process
 - Baseline atmosphere
 - “Truth” for results comparison

LST Flow Chart

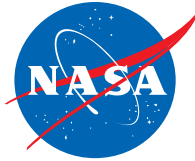


Wide Range of Parametric Evaluations



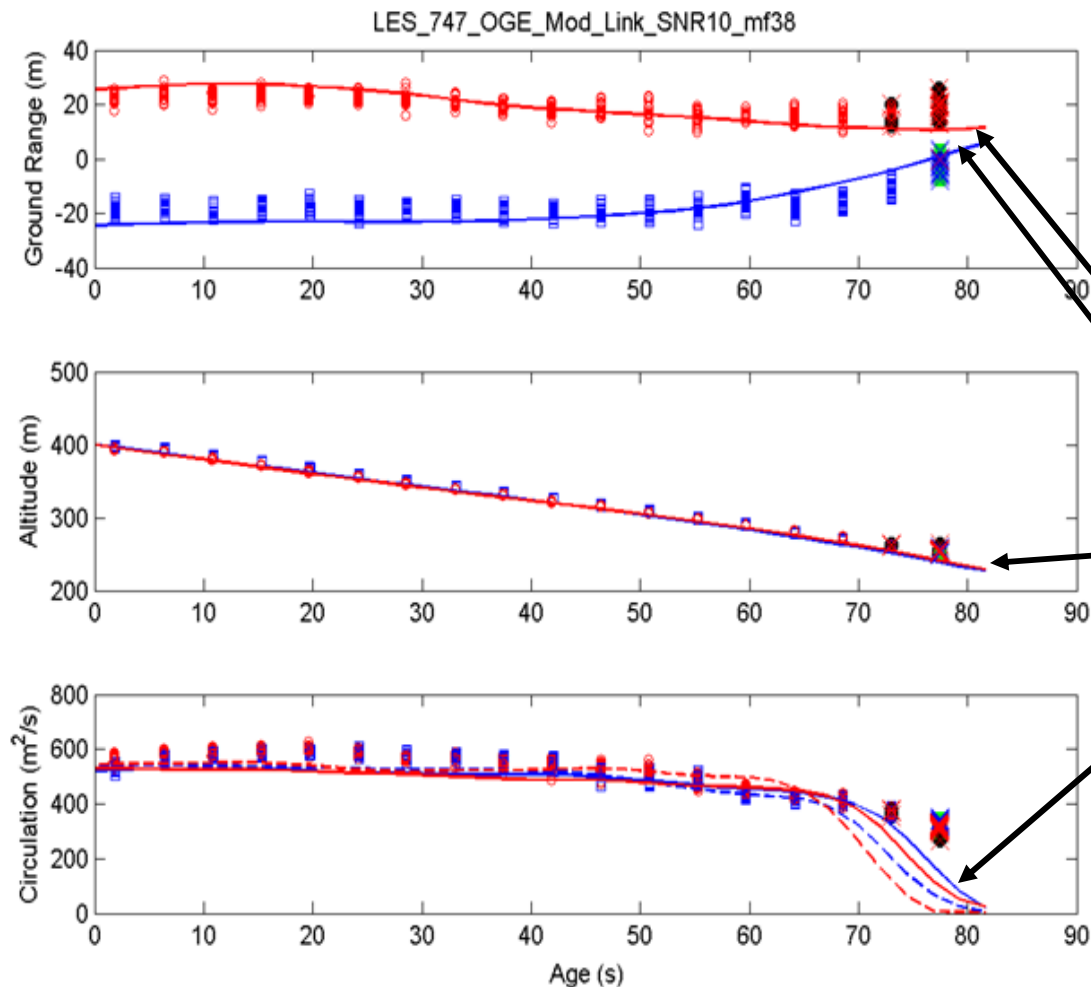
- Environmental and operational aspects
 - Different aircraft
 - Different weather conditions (e.g., atmospheric turbulence levels, crosswind)
 - Lifetime of vortex evolution, including linking and ring vortex phases
 - Different Signal to Noise Ratios (SNR)
 - In ground effect (IGE), as well as out of ground effect (OGE)
 - Cruise altitude
 - Different viewing angles and ranges
- System aspects
 - Lidar parameters
 - Scanning and processing configurations
 - Pattern matching filter—wake algorithms estimate wake characteristics and search for that pattern
 - Atmospheric scattering parameters

How Do We Use the LST?



- Comparison of simulation output with TASS LES “truth” data
 - Generate an assessment of the accuracy of pulsed lidar for tracking wake vortices and estimating their strength
 - No data exists for direct comparison
- Next few slides present some results

Example of Lidar Simulation Output: B747 OGE (LES Model)



**TASS
LES
Model**

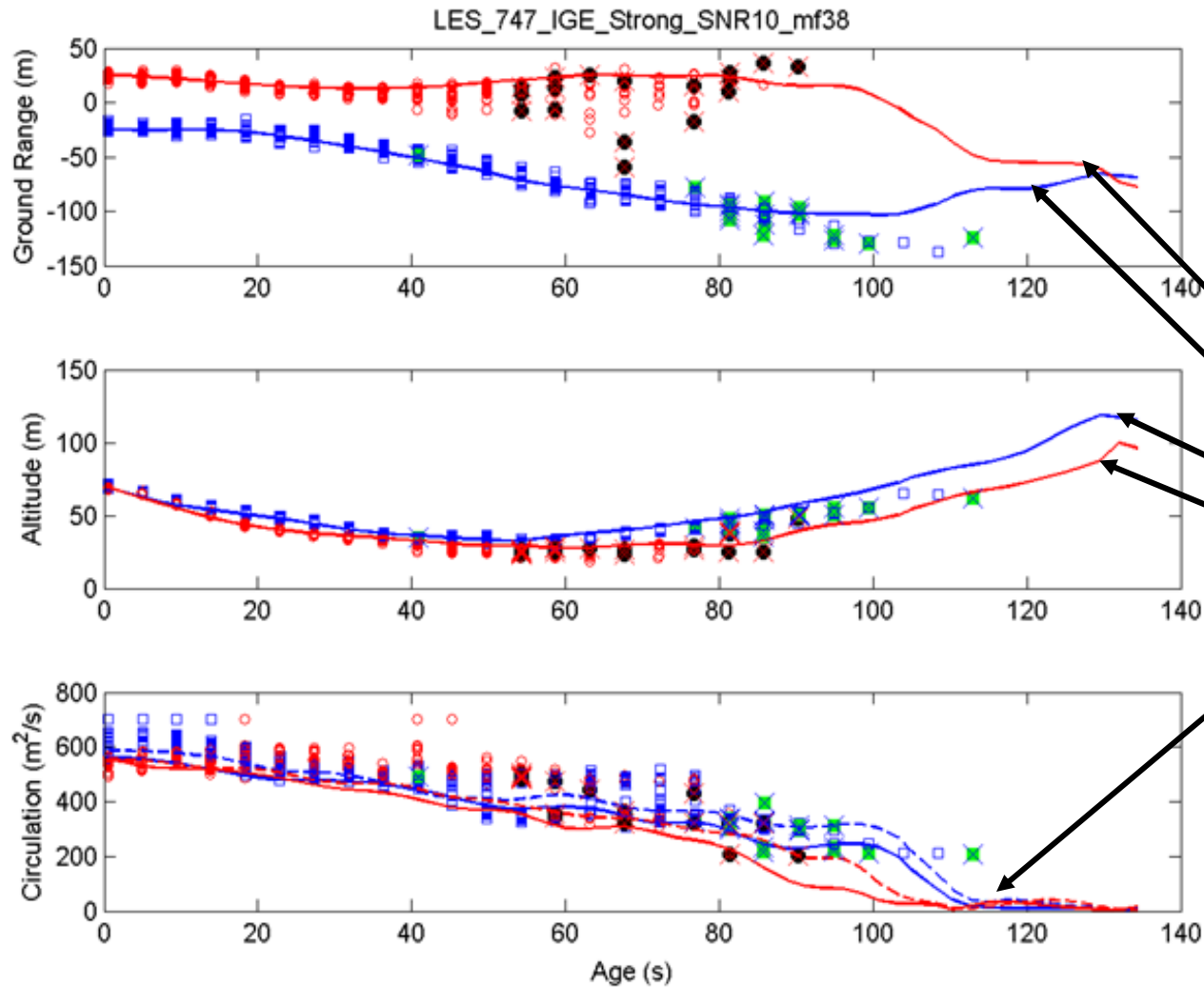
Review of Major Findings for Lateral and Vertical Position Estimates in OGE



- Lateral and vertical position estimates are
 - Insensitive to SNR (0 to 15 dB)
 - Insensitive to combinations of vortex core size and matched filter core size
- Mean bias for vertical position: 2-4 m
- Mean bias for lateral position: 4-8 m
- Errors are similar for different crosswinds, and under weak and moderate turbulence conditions
- Errors are larger for strong turbulence conditions

Lidar Simulation Example

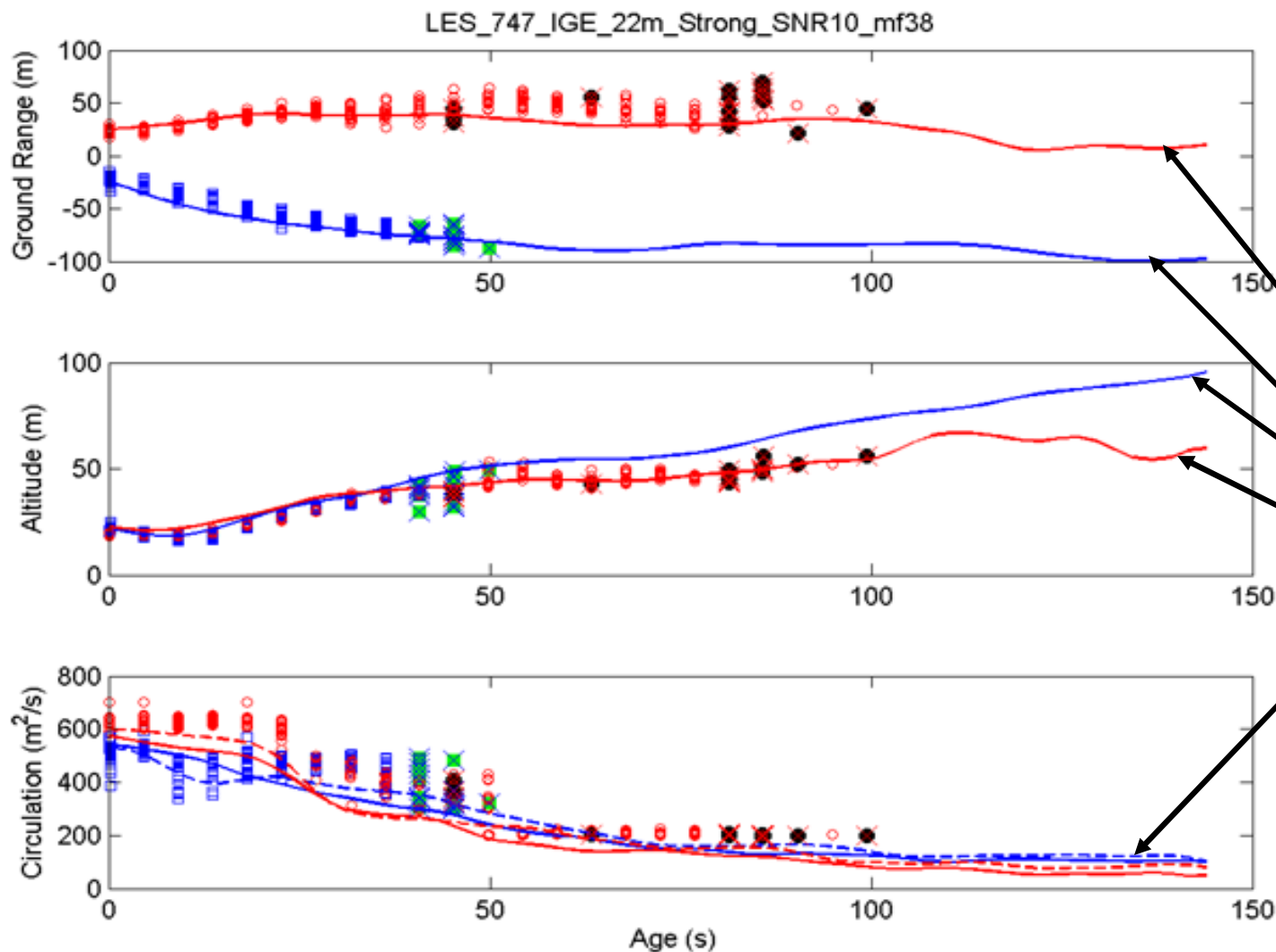
B747 IGE, $z_o=70\text{m}$, Strong Turbulence



**TASS
LES
Model**

Lidar Simulation Example

B747 IGE, $z_o=22\text{m}$, Strong Turbulence



**TASS
LES
Model**

Vertical Position Estimates in IGE



- Vertical position estimates in IGE are similar to those in OGE
 - Insensitive to SNR
 - Insensitive to combinations of vortex core size and matched filter core size
 - No significant differences in error estimates between positive (near) and negative (far) vortices
- Vertical position estimates are similar for different turbulence levels (at 22m cases)
- Larger vertical position errors at lower initial vortex altitude (22m vs. 70m)
- Mean bias $< 6\text{m}$ (except for a couple of cases with mismatched matched filter core sizes)

Lateral Position Estimates in IGE



- Lateral position estimates in IGE are
 - Insensitive to SNR
 - Insensitive to combinations of vortex core size and matched filter core size
 - Larger differences in error estimates between positive (near) and negative (far) vortices
- Lateral position estimates are similar for different turbulence levels (at 22m cases)
- Larger lateral position errors at lower initial vortex altitude (22m vs. 70m)
- Mean biases similar to OGE baseline

Summary for Position Estimates for IGE

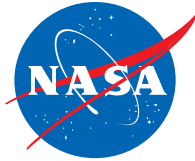
- Position estimates in IGE are slightly larger than in OGE
- Vertical position estimates in IGE: 0-6m
- Lateral position estimates in IGE: 0-8m

Outcomes



- LST enables
 - Independent evaluation of the WindTracer Lidar
 - Comparison and refinement of post-processing algorithms
 - Enhancement and validation of the fast-time wake models
 - Significant model development is possible based on LES data
 - Determination of practical limits for operational parameters including: range, signal to noise ratio, and viewing angle
- LST will build confidence in fidelity of
 - The WindTracer system
 - Field measurements
- Updated wake vortex models
 - Ultimately enable advanced Super High Density concepts
 - Can serve as foundation of dynamic wake-based spacing systems
 - Responsive to longer term FAA and JPDO objectives

Future Work



- Fully exercise LST to determine sensitivities of input variables
- Collect significant volume of measured wake vortex data suitable for model development
- Refine and validate fast-time models
- Integrate wake vortex knowledge into advanced NAS concepts