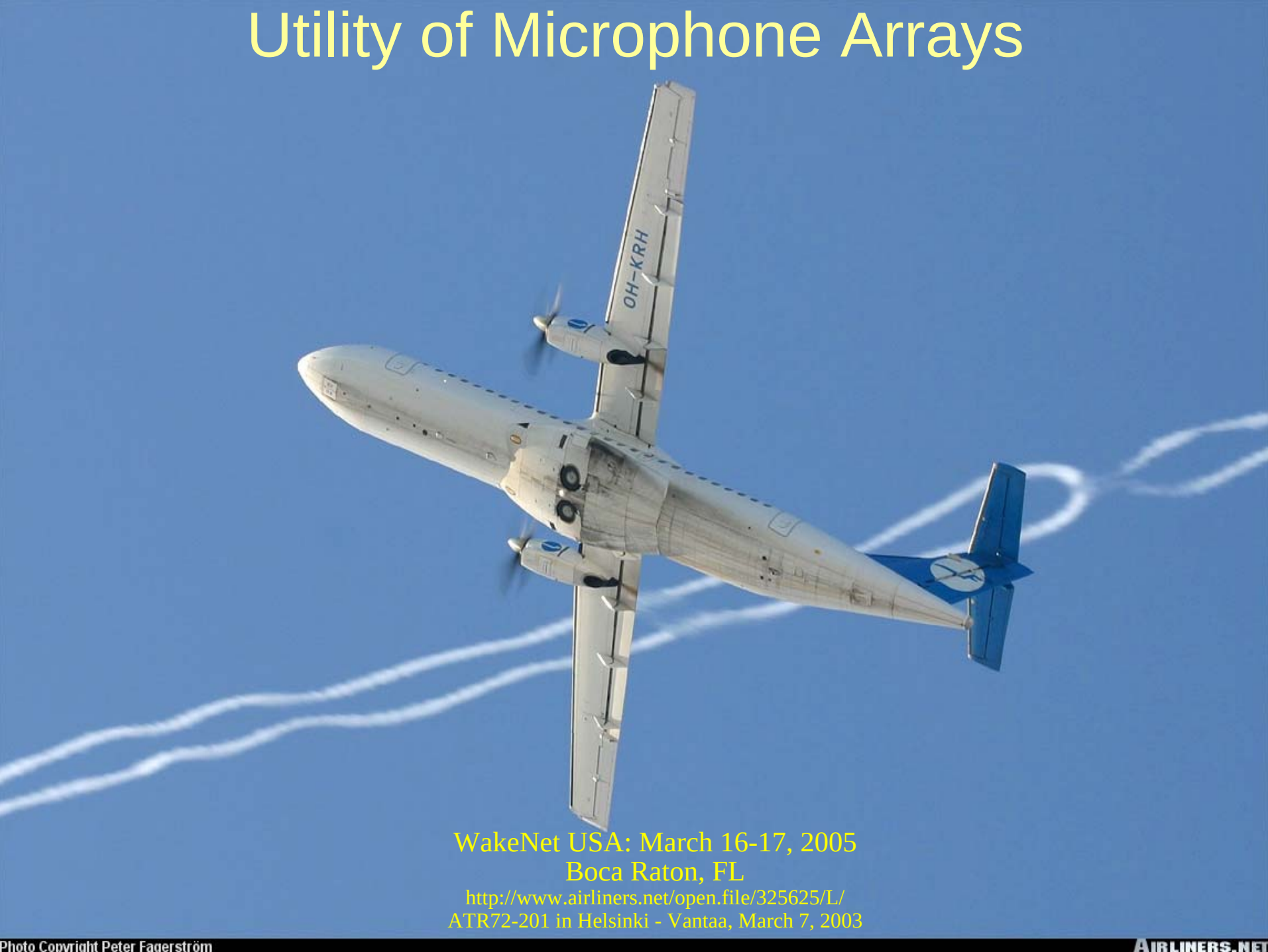
Utility of Microphone Arrays



WakeNet USA: March 16-17, 2005
Boca Raton, FL

http://www.airliners.net/open.file/325625/L/
ATR72-201 in Helsinki - Vantaa, March 7, 2003

Utility of Microphone Arrays

Sponsored by:

National Aeronautics and Space Administration

POC: Wayne Bryant

Prepared by:

DOT Volpe Center

Surveillance and Assessment Division (DTS-53)

Contributors

- Andrew Gulsrud - *Volpe Center*
- Frank Y. Wang - *Volpe Center*
- Hadi Wassaf - *Volpe Center*
- Donald Delisi - *NWRA*
- Robert Dougherty - *OptiNav*

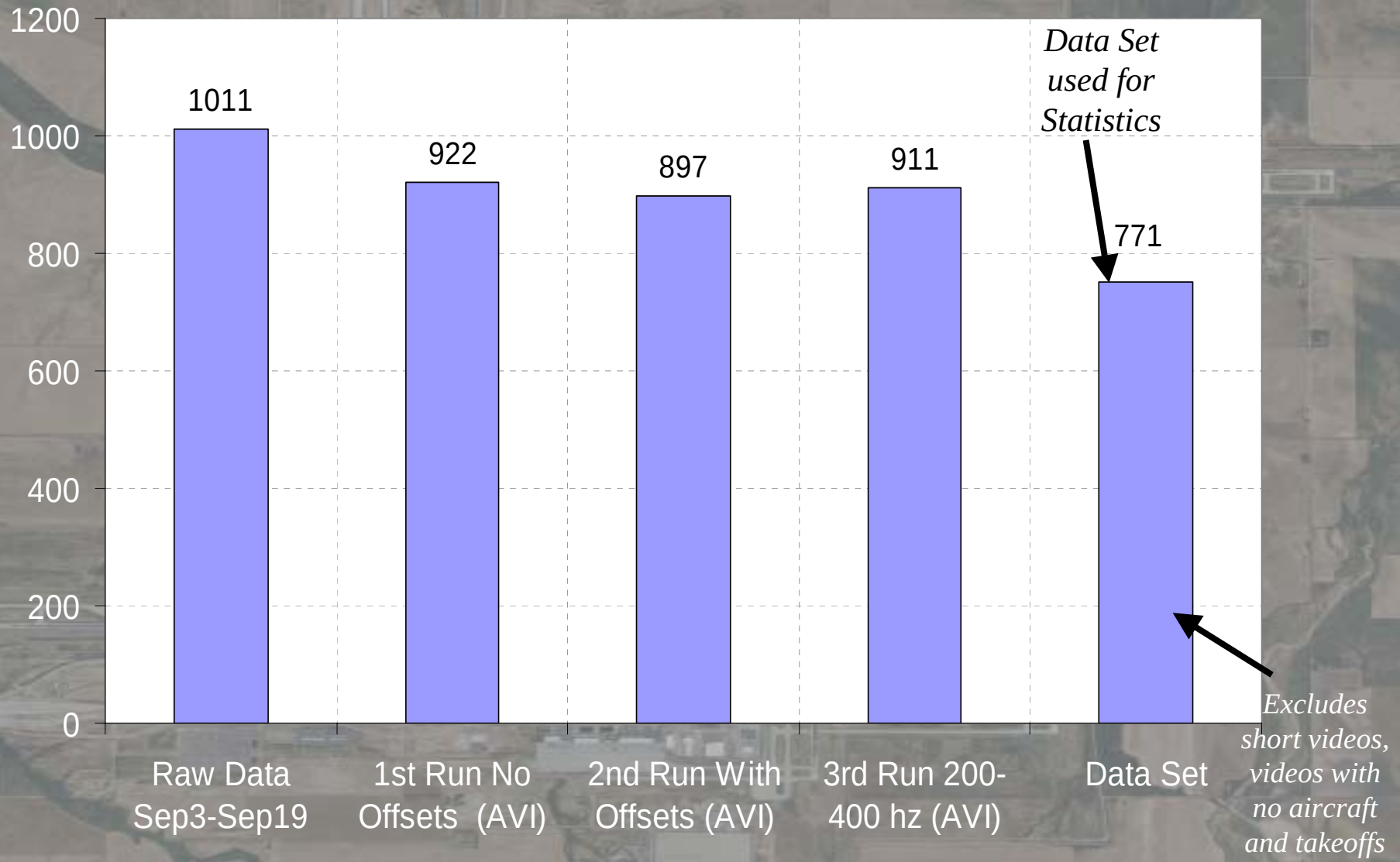
Sensor Development Efforts Since the 1990s

- **Optical : Pulsed Lidar**
- **EM : Radar**
- **Active Acoustic-EM : RASS**
- **Passive Acoustics : Opto-Acoustic, Phased Microphone Arrays**

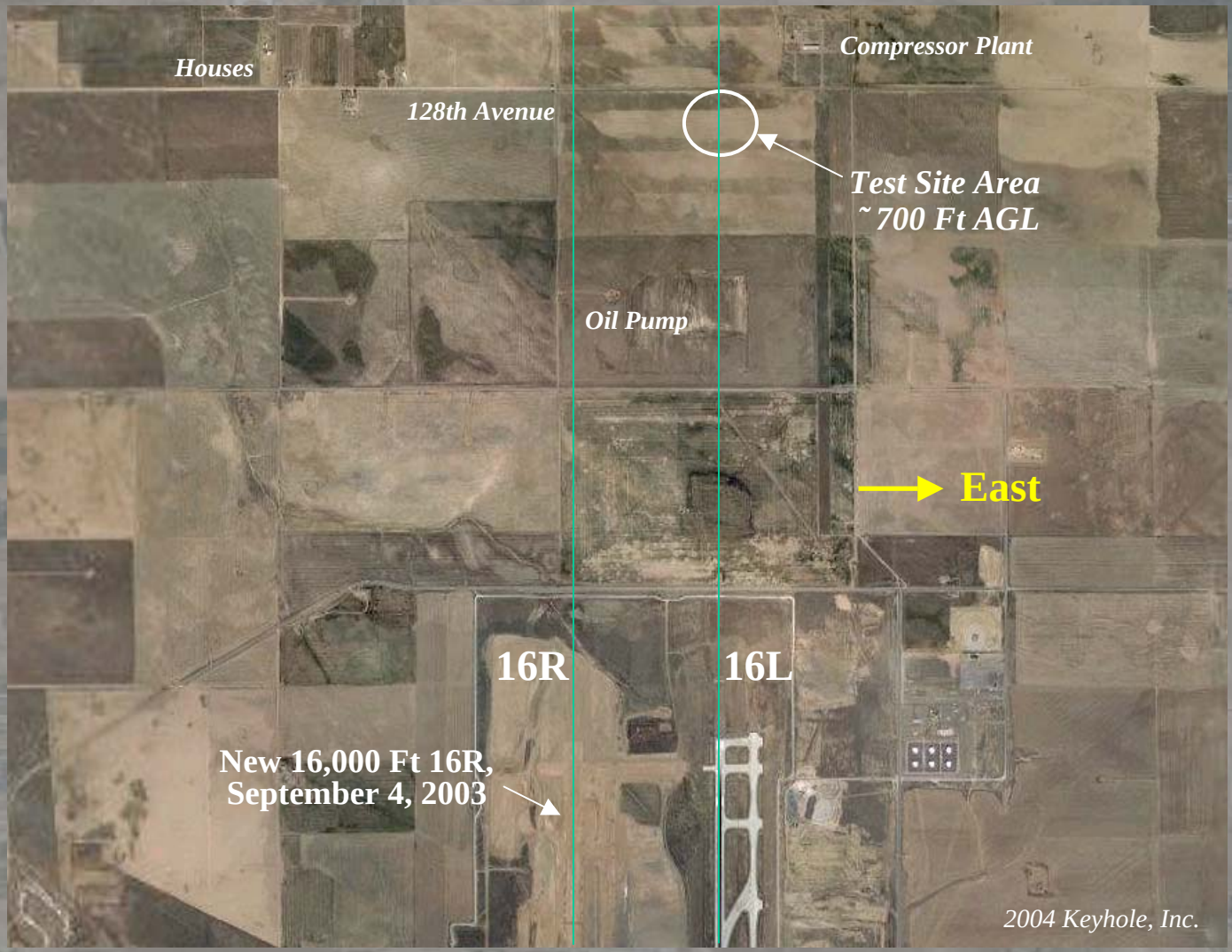
Passive Wake Acoustics Research - Background

- NASA Conducted a Data Collection Campaign at DEN on the Phenomenon of Acoustic Emission of Wake Vortices.
- August 18 to September 26, 2003 (System Stable from September 3 – 19, 2003).
- Recorded About 1200 Flybys (Mostly for Aircraft in Landing Configuration).
- Included Some Departures as Well.

Mic. Array – Horizontal Beamforming Database



DEN03 Test Site



The first operation on 16R/34L was a United Airlines 777 departure, flight 244 to Chicago at 10:38AM local time.

Instrumentation and Data Sources in DEN03

Primary Acoustic Sensor

- ✓ 252 Element NASA Phased Microphone Array

Wake Sensors (Reference Data)

- ✓ Pulsed Lidar (Laser Radar)
- ✓ Continuous Wave Lidar (Laser Radar)

Meteorological Sensors

- ✓ Wind Sodar (Acoustic Radar)
- ✓ Tower Instrumented with Propeller Anemometers, Point Temperature, and Relative Humidity Sensors
- ✓ Temperature Profiler (Microwave Radiometer)
- ✓ Sonic Anemometer

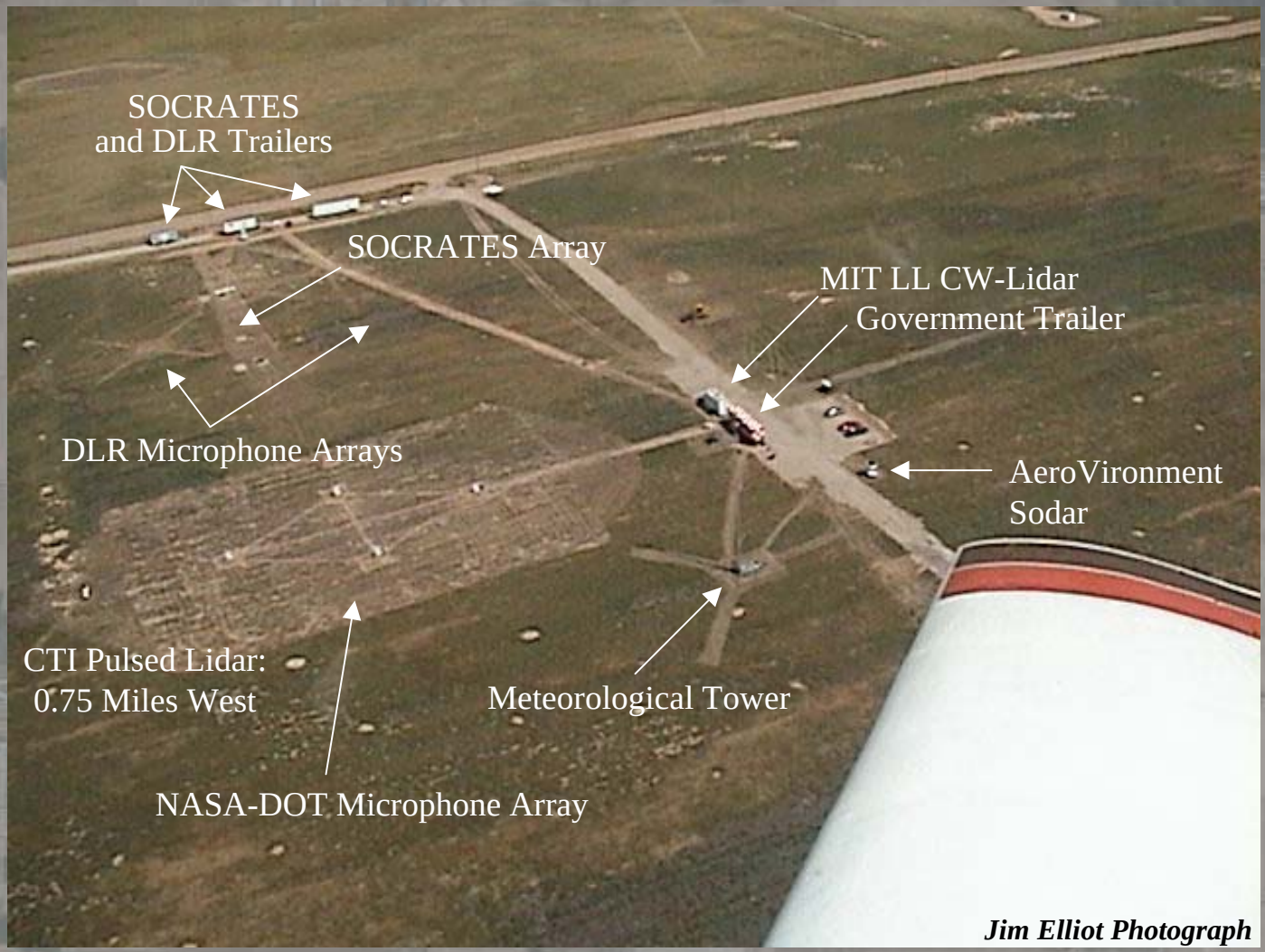
Airport Operational Data

- ✓ ARTS Radar Tracks
- ✓ ASOS

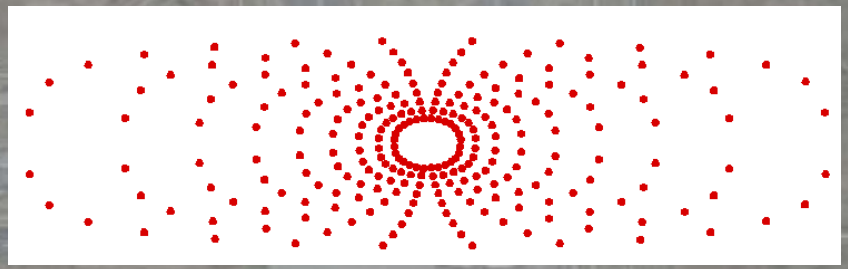
Additional Measurements

- ✓ SOCRATES Laser Array
- ✓ DLR Phased Microphone Arrays
- ✓ WLR Shotgun Microphones

Test Site Aerial Photograph



NASA-DOT Phased Mic. Array



Array Pattern Optimized for Horizontal Beamforming from 50-1000 Hz
Dimension: 265 Ft E-W by 95 Ft N-S

Array Pattern Designed by OptiNav Inc., Hardware Integration by Microstar Laboratories and OptiNav Inc.

Meteorological Characterization

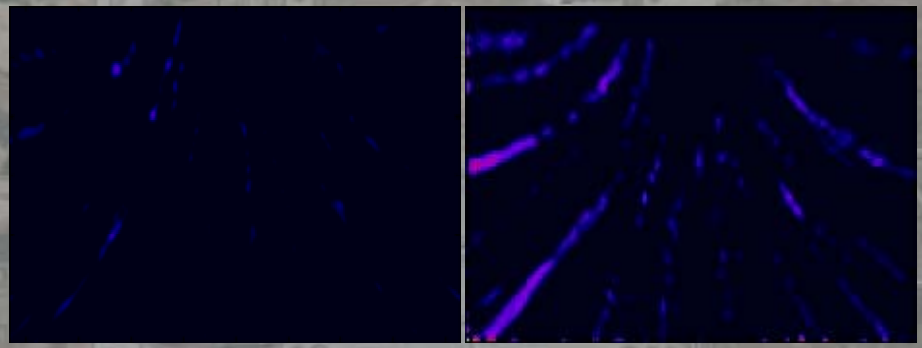
- Temperature Profiles
- Lapse Rate
- Brunt-Vaisalla Frequency
- Wind Profiles
- Wind Histories
- Wind Shears
- Richardson Number
- Rayleigh Number
- Relative Humidity
- Turbulent Kinetic Energy
- Eddie Dissipation Rate
- Ceiling
- Visibility
- Barometric Pressure

Microphone Array Data Analysis Teams

- NASA LaRC
- USDOT Volpe Center
- OptiNav
- Florida Atlantic University
- FST/Lockheed-Martin

Horizontal Beamforming Examples

Noise Source Localization Maps



10ft by 10ft Grid

20ft by 20ft Grid

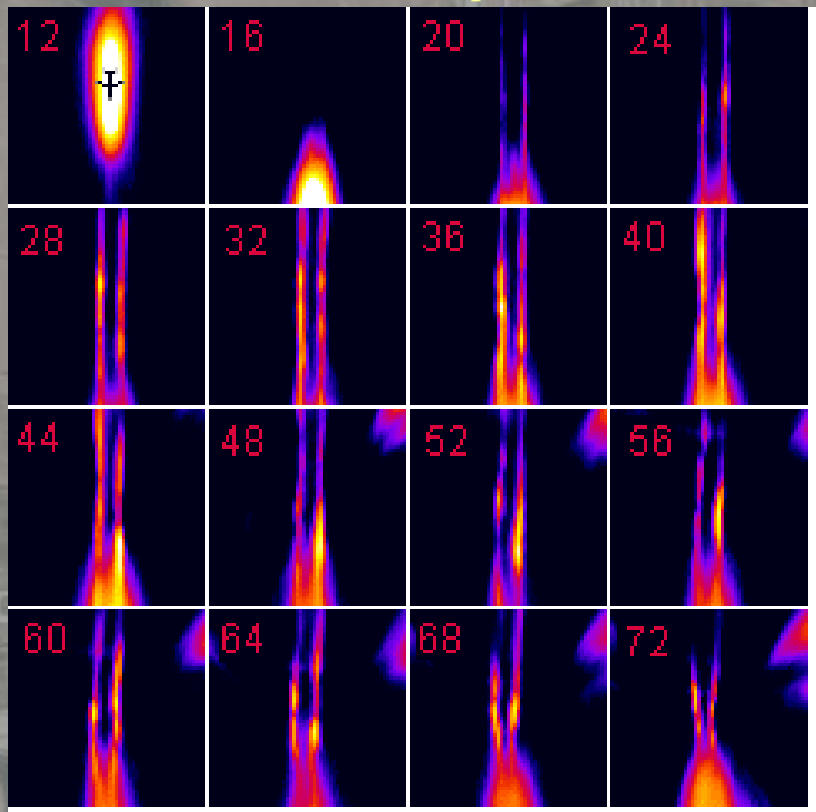
1500 by 1000 Ft Processing Area ; 200-400 Hz

High Resolution Gov. Array Sample

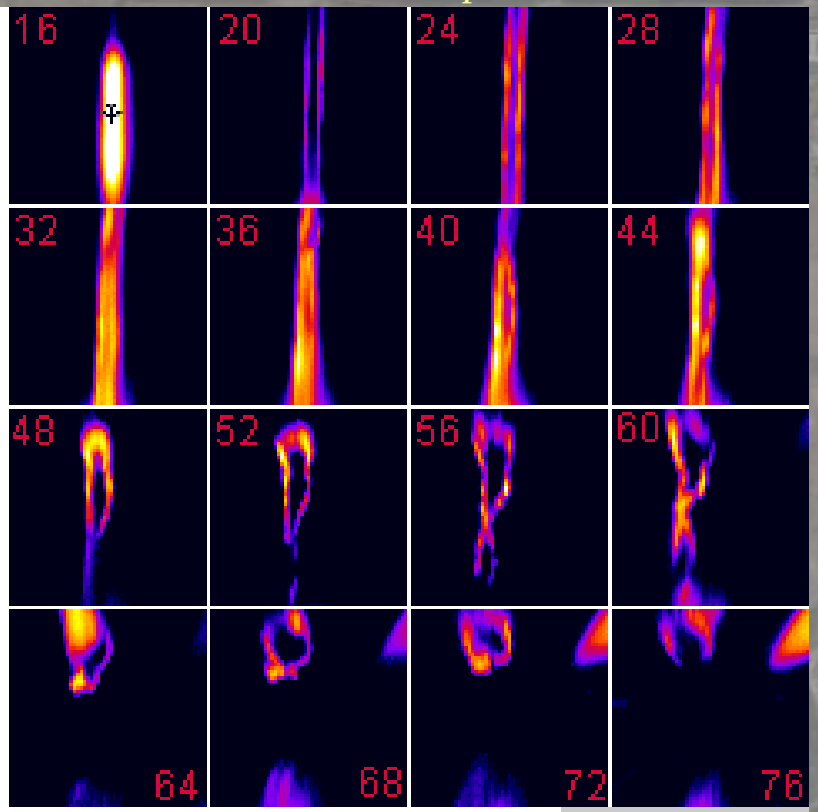
5 Ft by 5 Ft Grid

Acoustic Power Integrated from 0-300 Hz ; Horizontal Beamforming at 500 Feet

767 Example

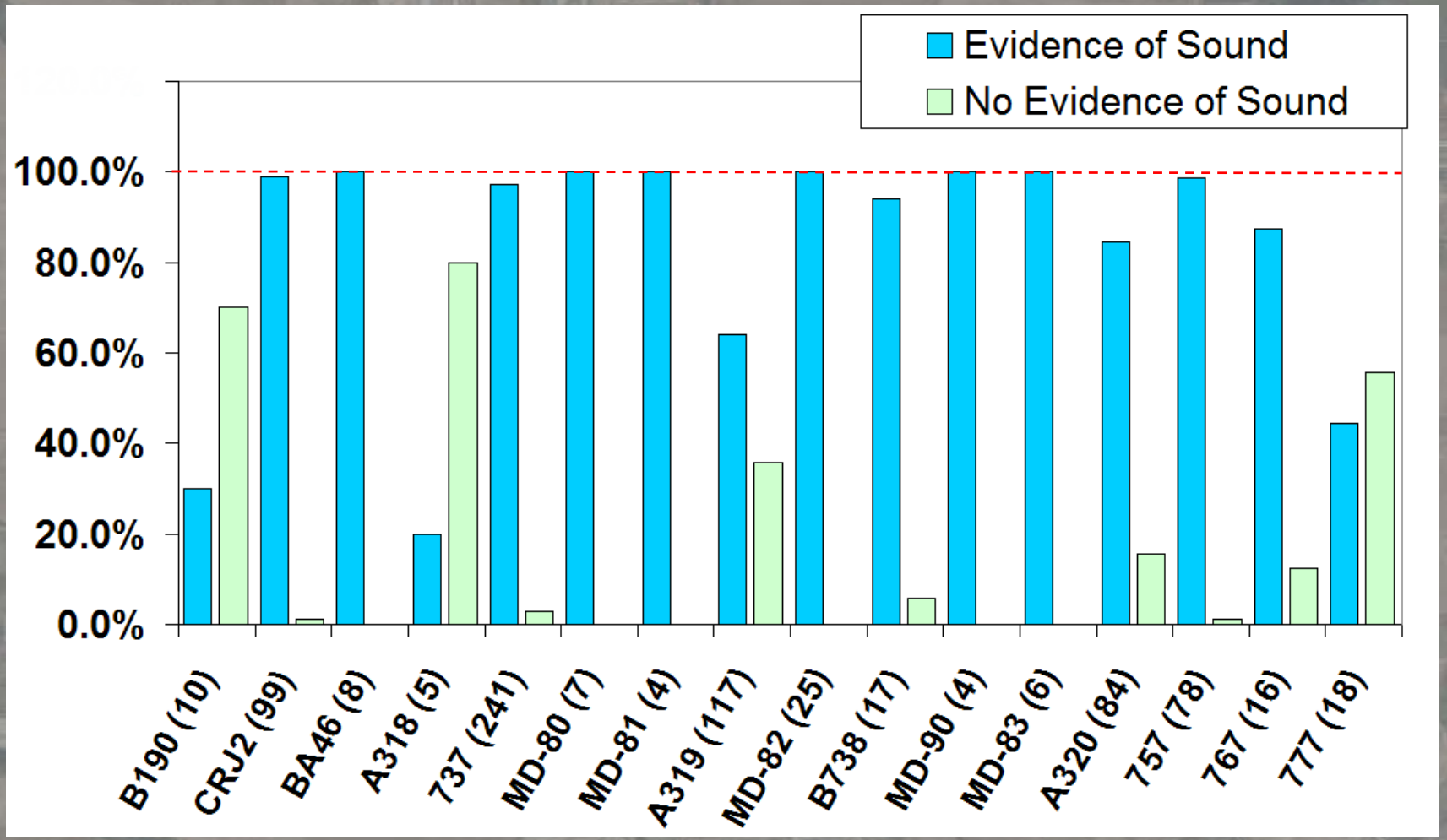


737 Example



AIAA-2004-2880

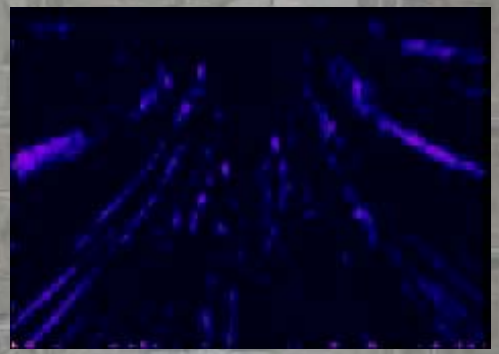
Summary of Aircraft (200-400 Hz Shown)



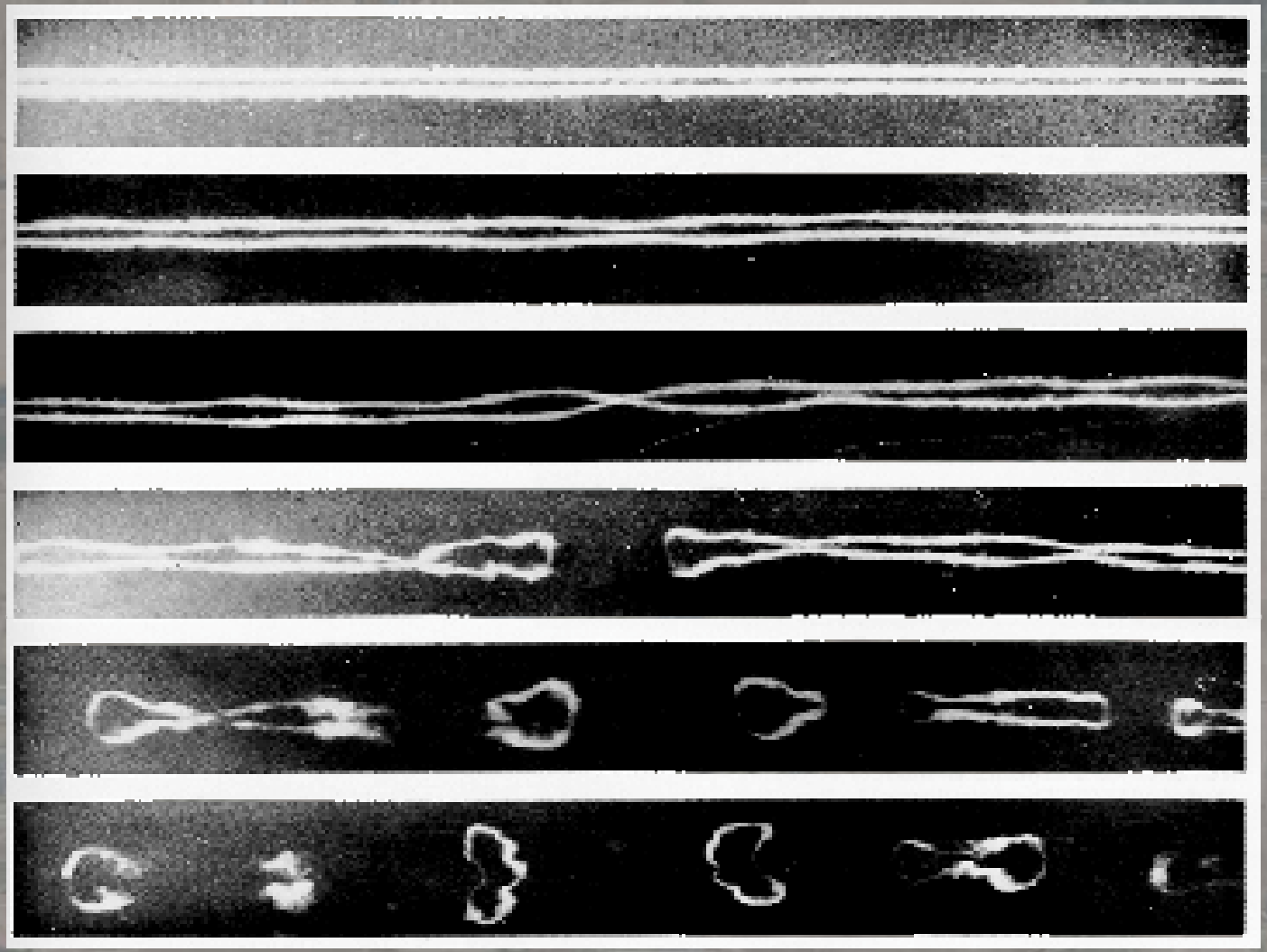
Utilities, Some Pros and Cons, Thoughts…

- Smoke / Condensation Trail Like Flow Visualization of Wake Dynamics
- 3D Volumetric Visualization ; 4D Possible with Algorithm Enhancement
- Shown to Have 3D Tracking Possibility (Yield May Increase with Other Processing or Alternative Array Design)
- Crow Instability Process Acoustically Imaged ; Evidence of Vortex Burst
- Study of Axial Coherence of Line Vortices ; Initial Vortex Separation (Good Horizontal Resolution but Poorer Vertical Resolution)
- Enhancing Understanding/Interpretation of Lidar Data
- Visualization Study of Wakes with Atmospheric Effects (Shear, Turbulence and Stratification) on Dynamics of OGE Wakes
- Benchmark Cases for Numerical Wake Vortex Simulation
- Postprocessing Flexibility (ROI, Beamforming Grid Resolution, Mesh Type)
- Hardware and Deployment Relatively Inexpensive
- Hardware Need Better Weather Proofing
- Conceptually Capable of Operating in Fog and Rain
- Inference to Wake Strength Difficult (No Simple Correlation Found)
- Conceptually Difficult to Operate in High Noise Environment
- Real Estate Issue

Sequence of Four Landings

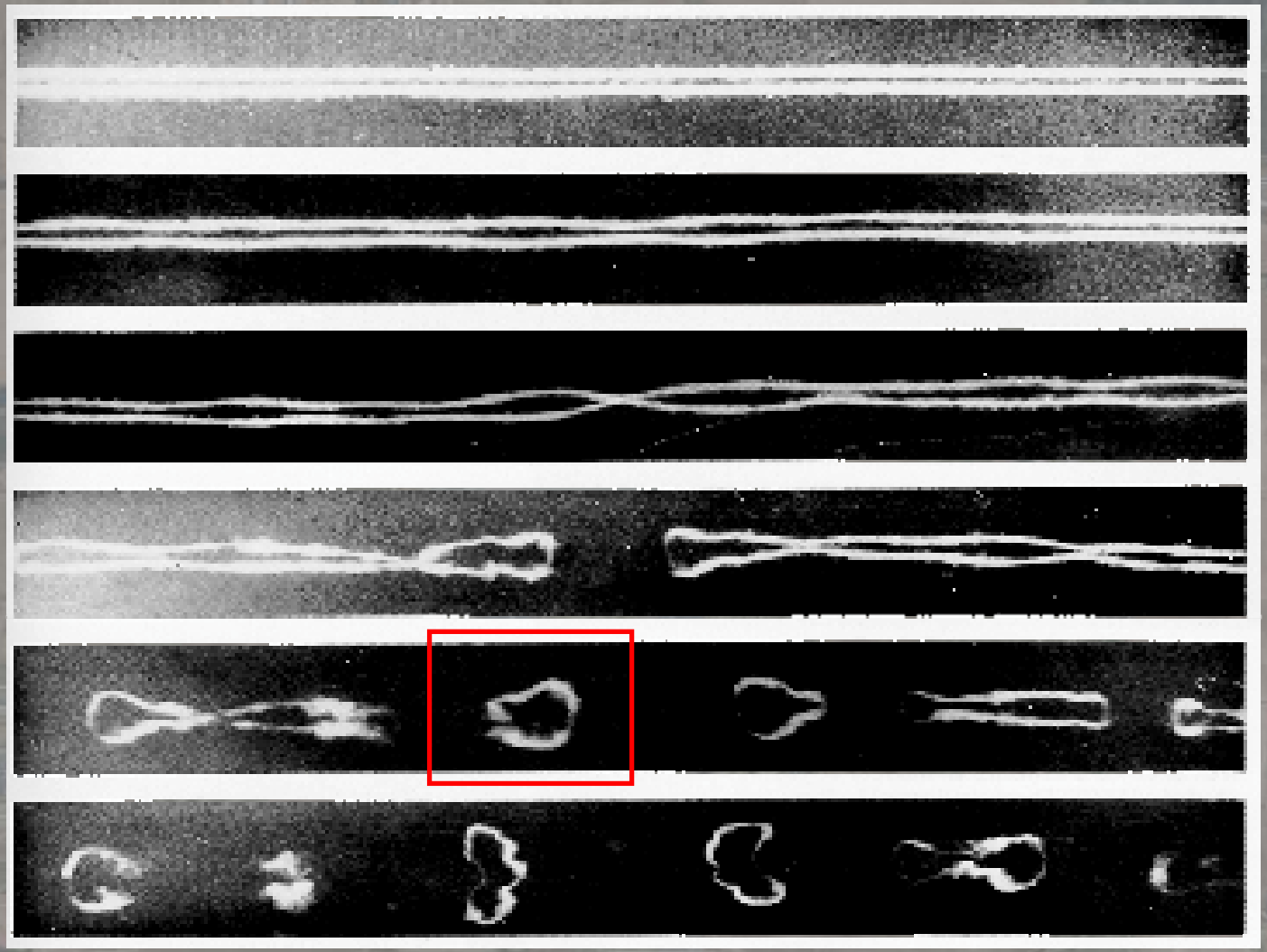


Crow Instability Visualization



Van Dyke, M. (Ed), An Album of Fluid Motion, The Parabolic Press, 1982, p.69.

Crow Instability Visualization

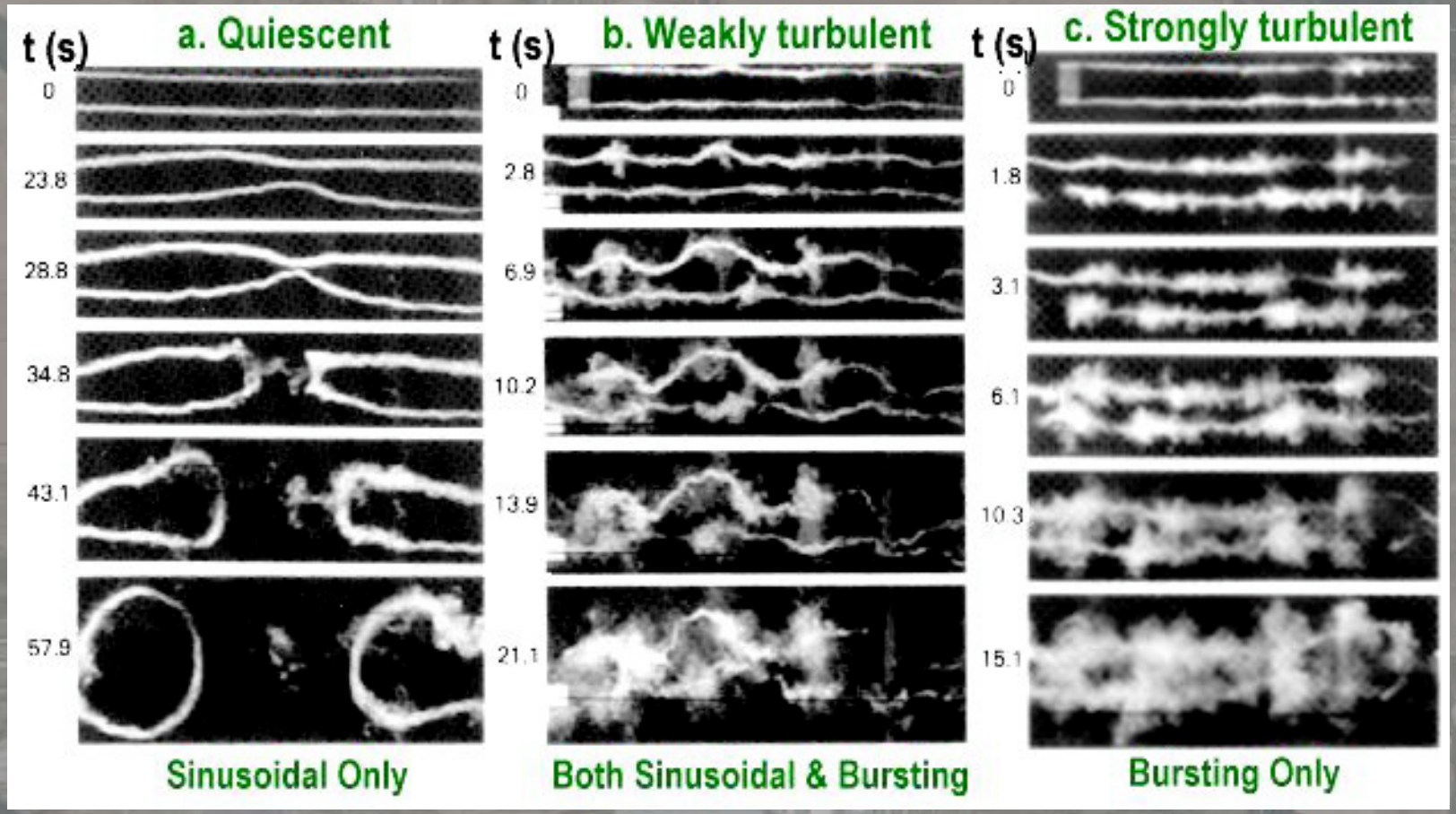


Van Dyke, M. (Ed), An Album of Fluid Motion, The Parabolic Press, 1982, p.69.

Wake Meandering Visualization

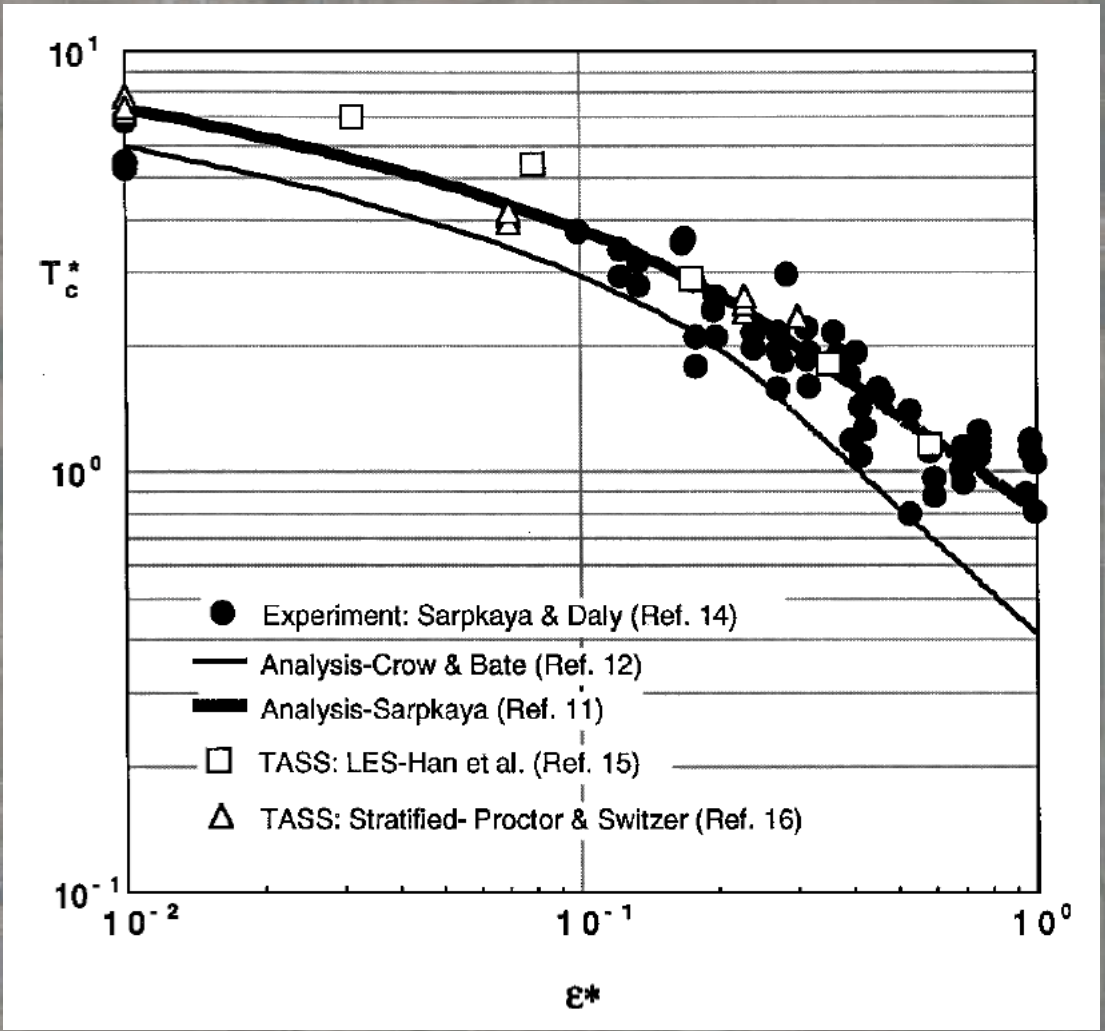
Idaho Falls Smoke Visualization

Ambient Turbulence and Vortex Instability



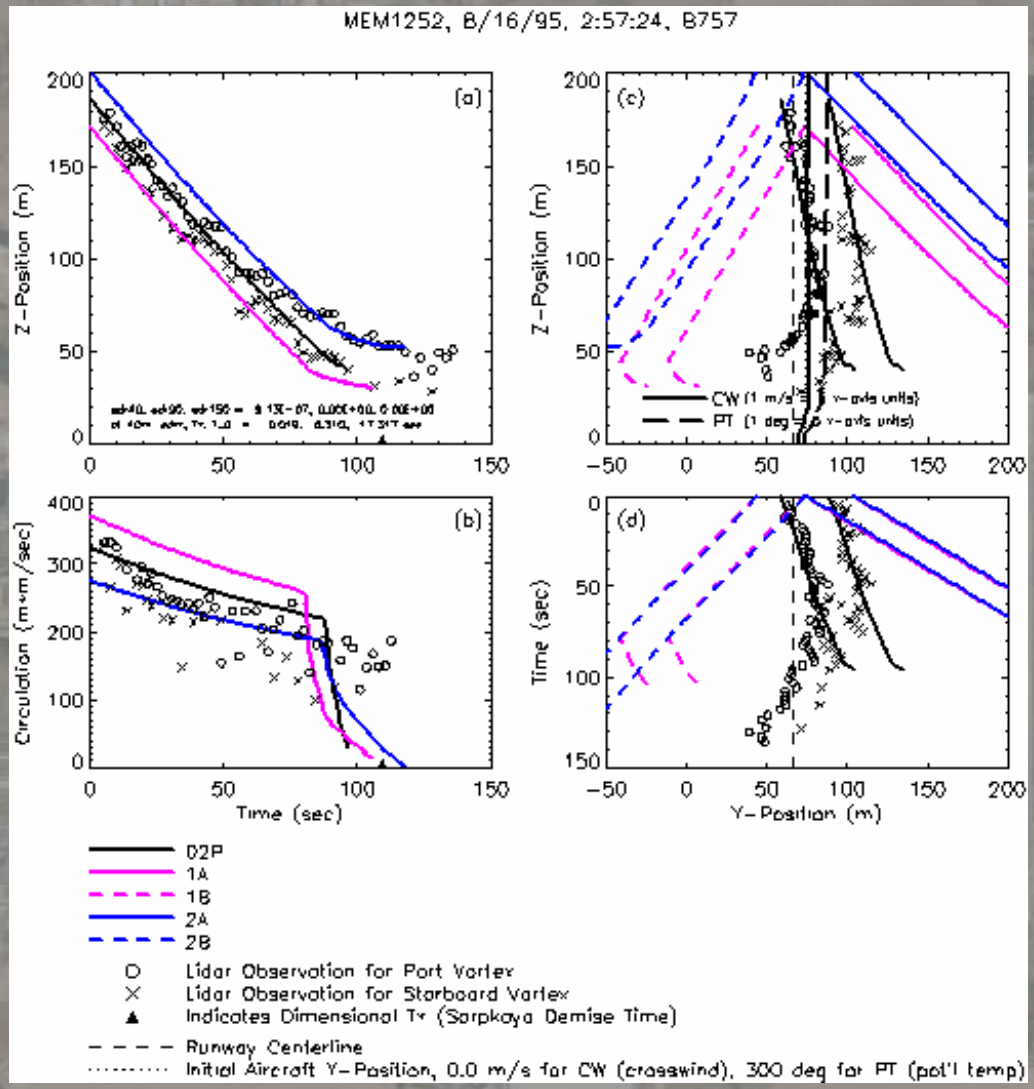
Liu, H.-T., "Effects of Ambient Turbulence on the Decay of a Trailing Vortex Wake," J. of Aircraft, 29, 1992, pp. 255-263.

Instability Time Scale vs. Ambient Turbulence

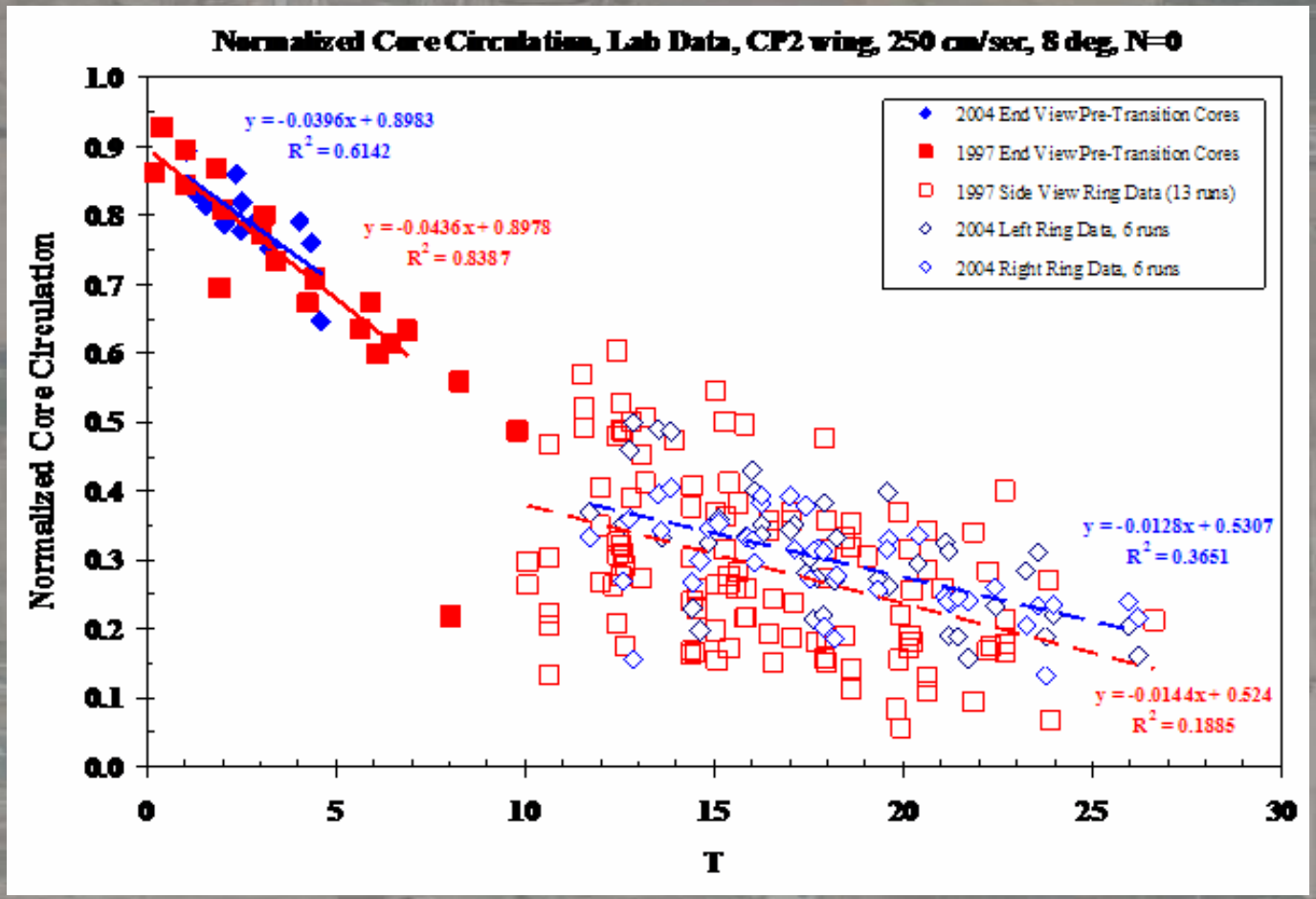


Sarpkaya, T., Robins, R. E., and Delisi, D. P., "Wake-Vortex Eddy-Dissipation Model Predictions Compared with Observations," J. of Aircraft, 38, 2001, pp. 687-692.

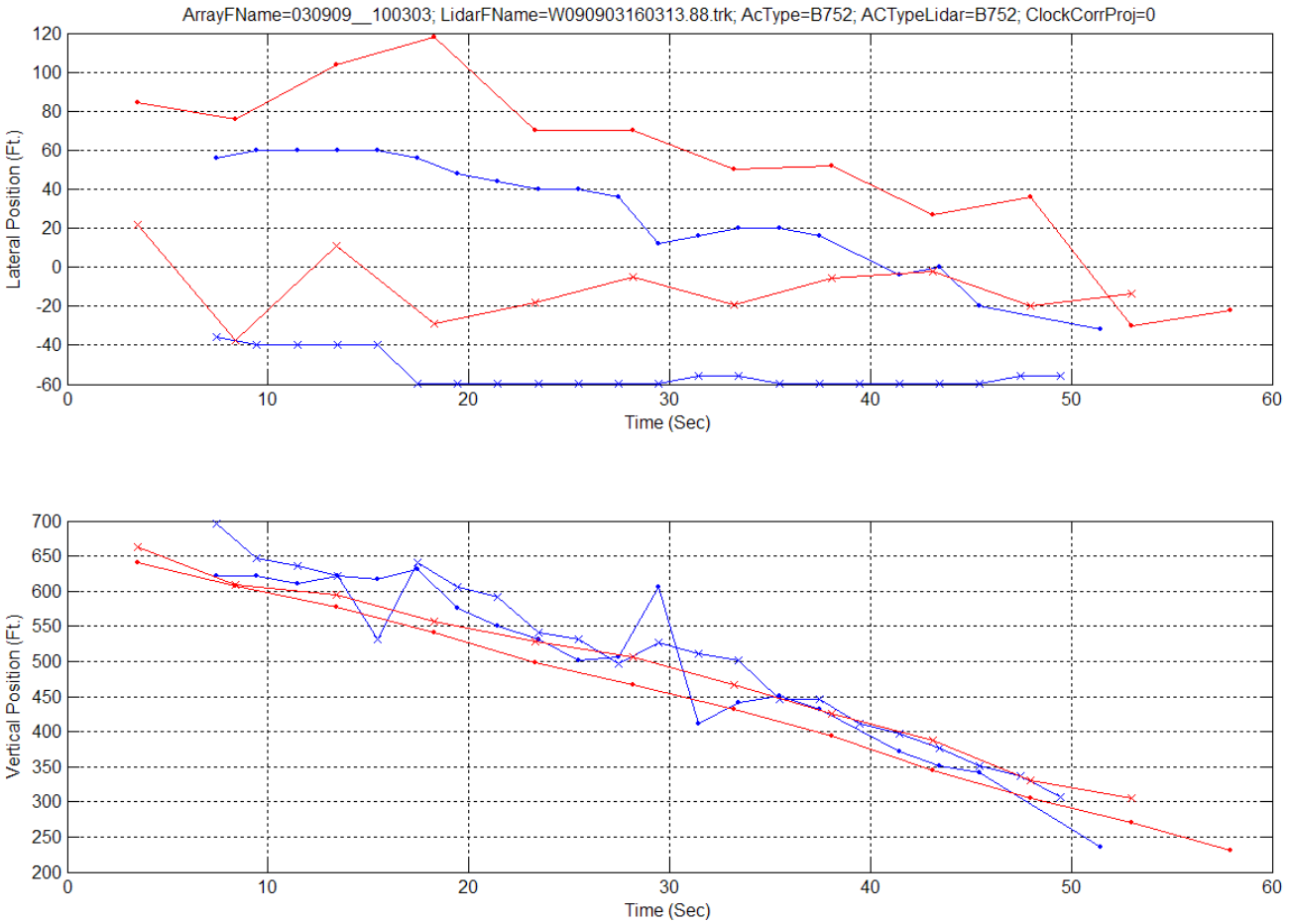
Rapid Phase Decay Research Question



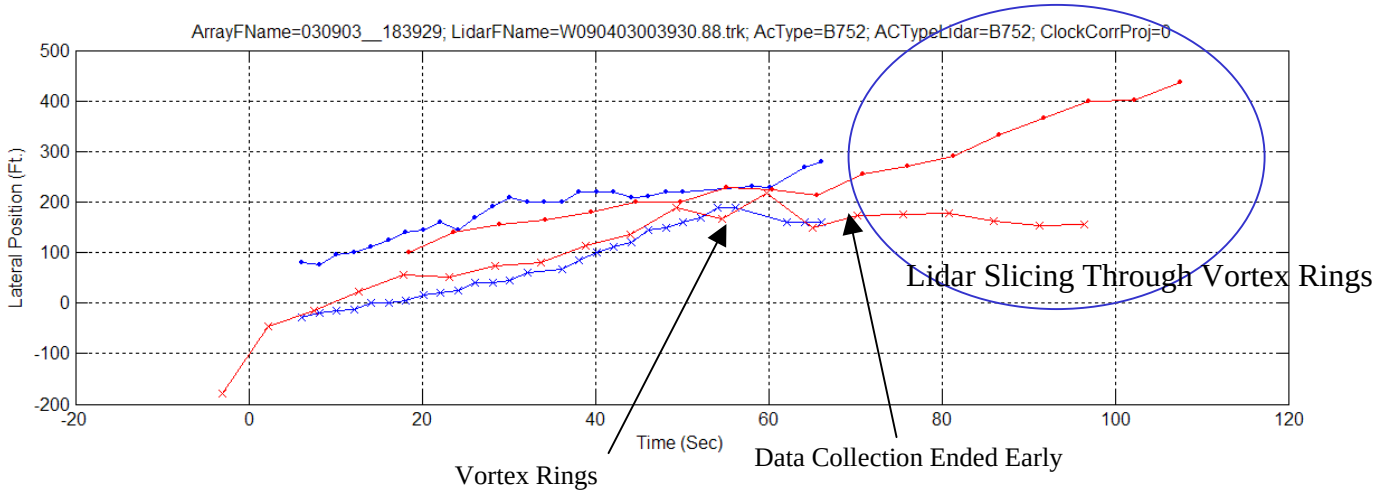
Line Vortex vs. Ring Vortex Circulation

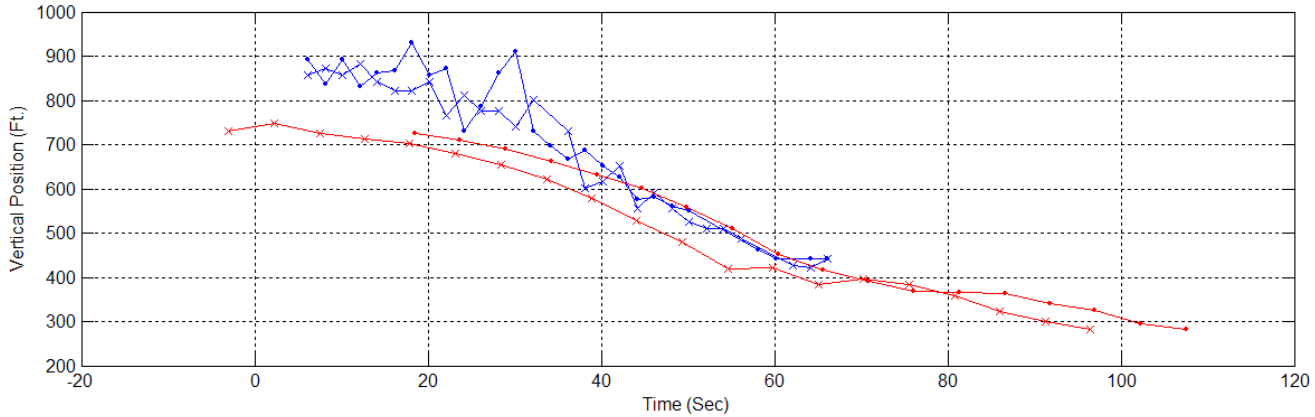


Pulsed Lidar and Mic. Array Comparison

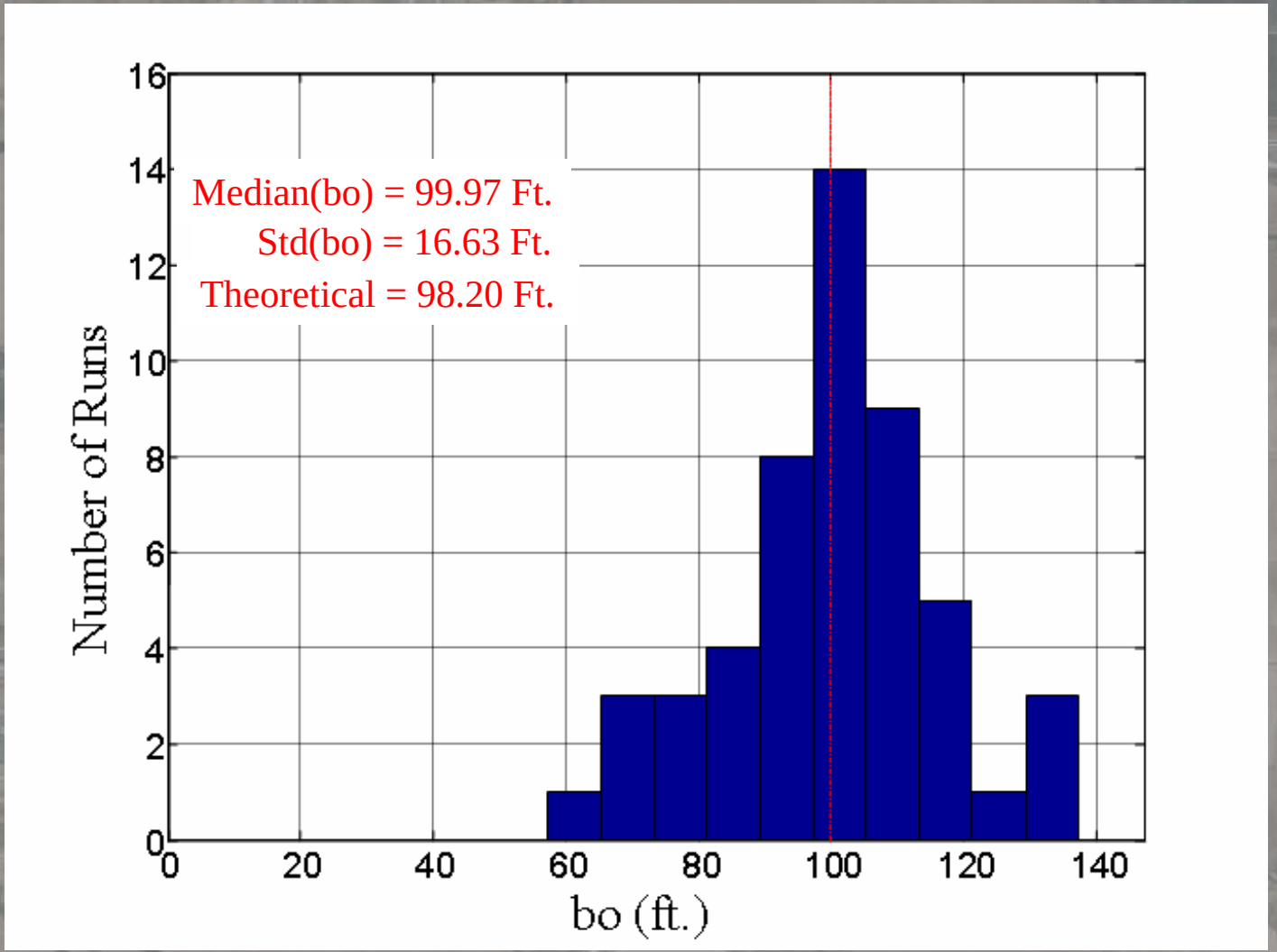


Pulsed Lidar and Mic. Array Comparison

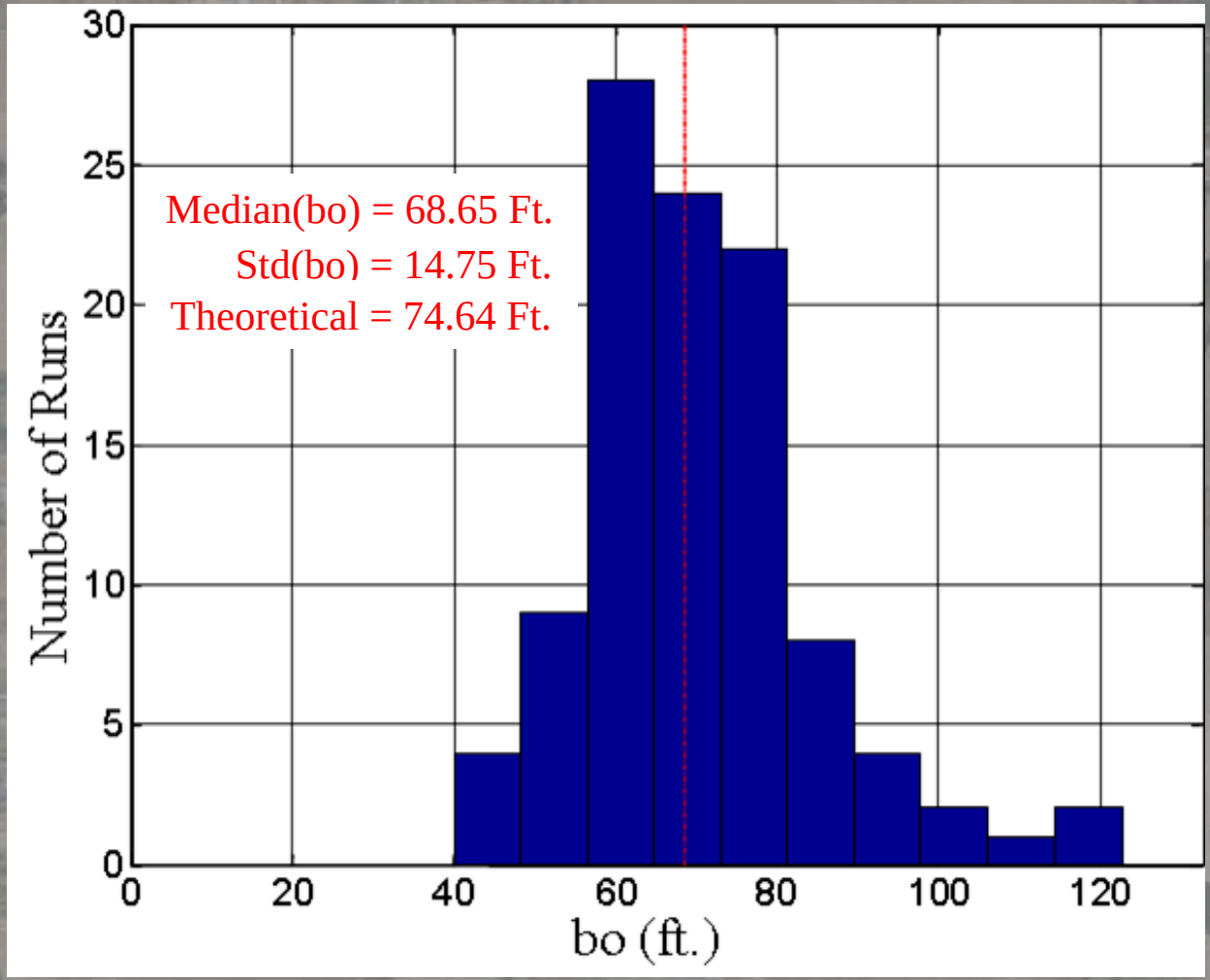




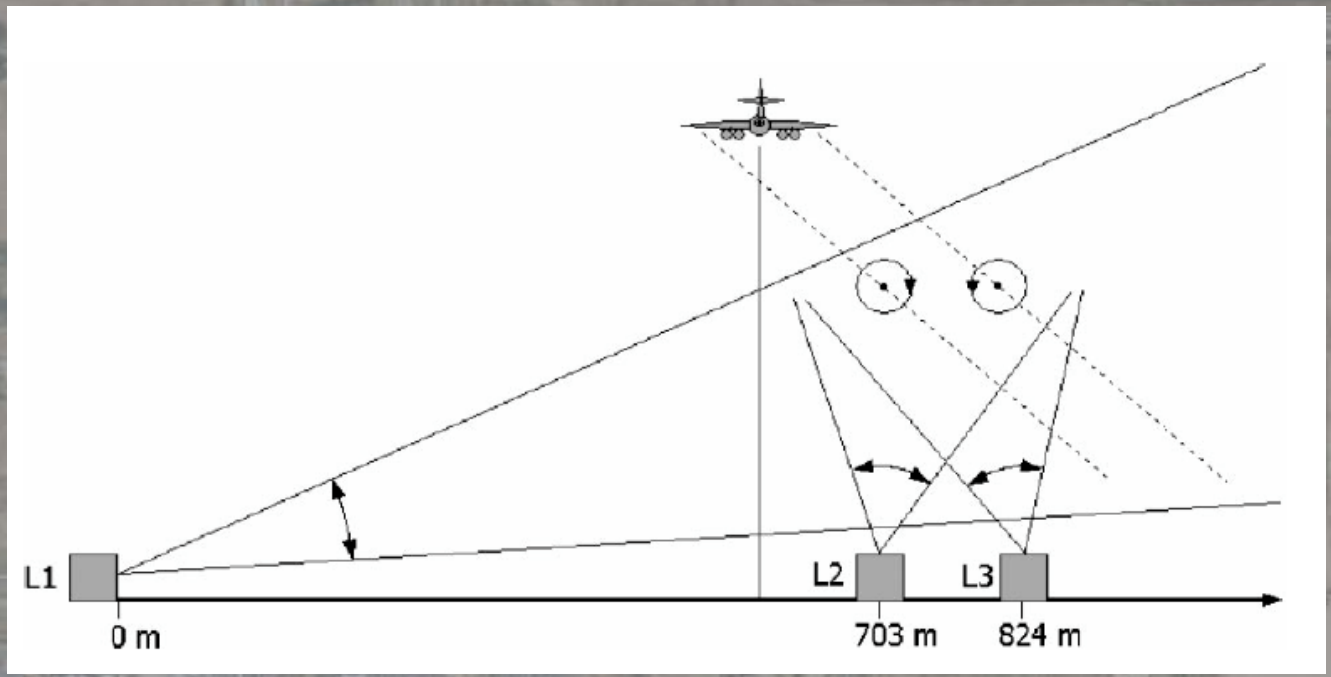
B752 bo Distribution (Upto 22 Sec. Age)



B737 bo Distribution (Upto 22 Sec. Age)



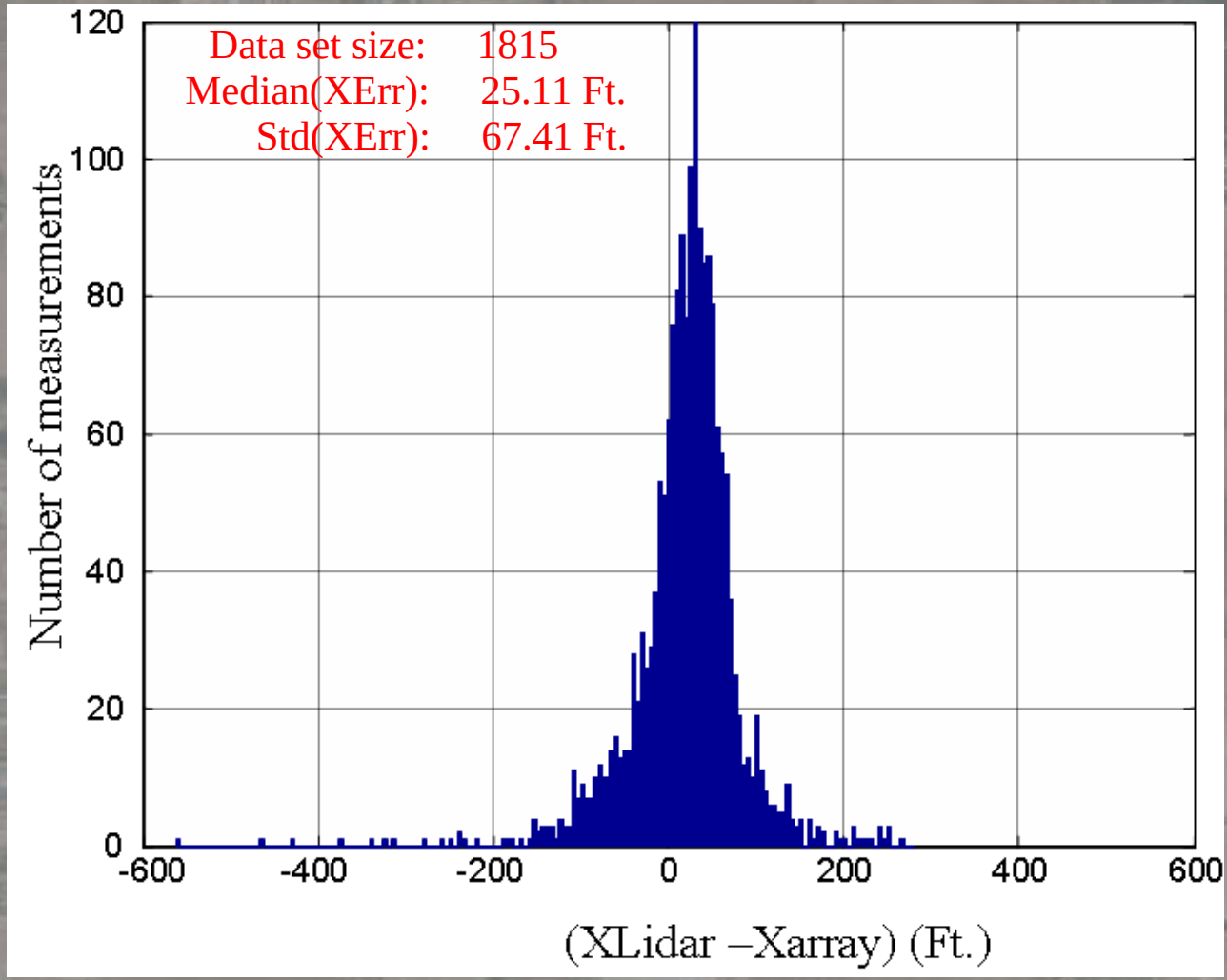
Alternative Approach



Köpp, F., Rahm, S., Smalikho, I., "Characterization of Aircraft Wake Vortices by 2-μm Pulsed Doppler Lidar," JAOT, Vol. 21, 2004, pp.194-206.

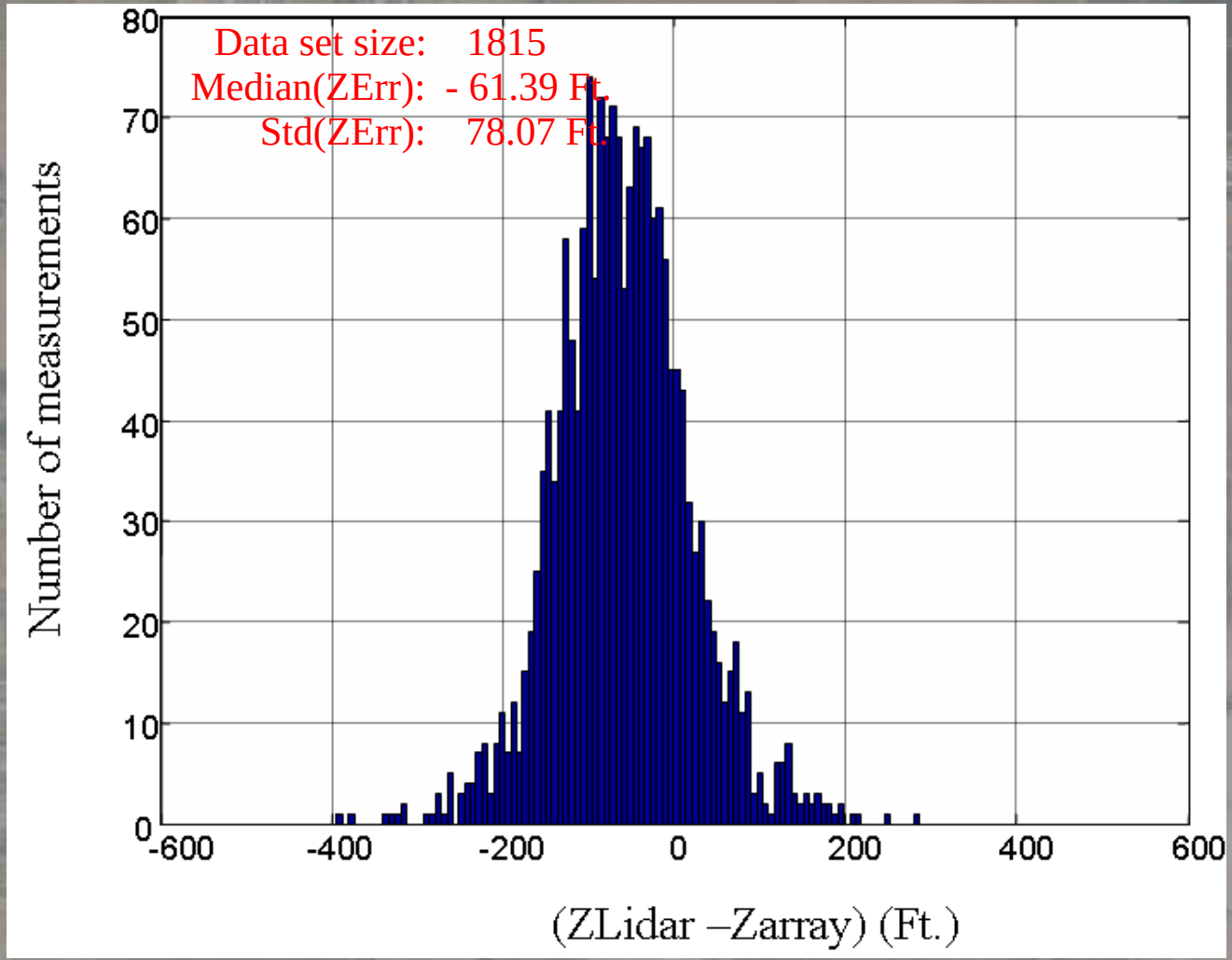
Lateral Position Difference

PLidar Indicating Wakes are Further East than Array Tracks



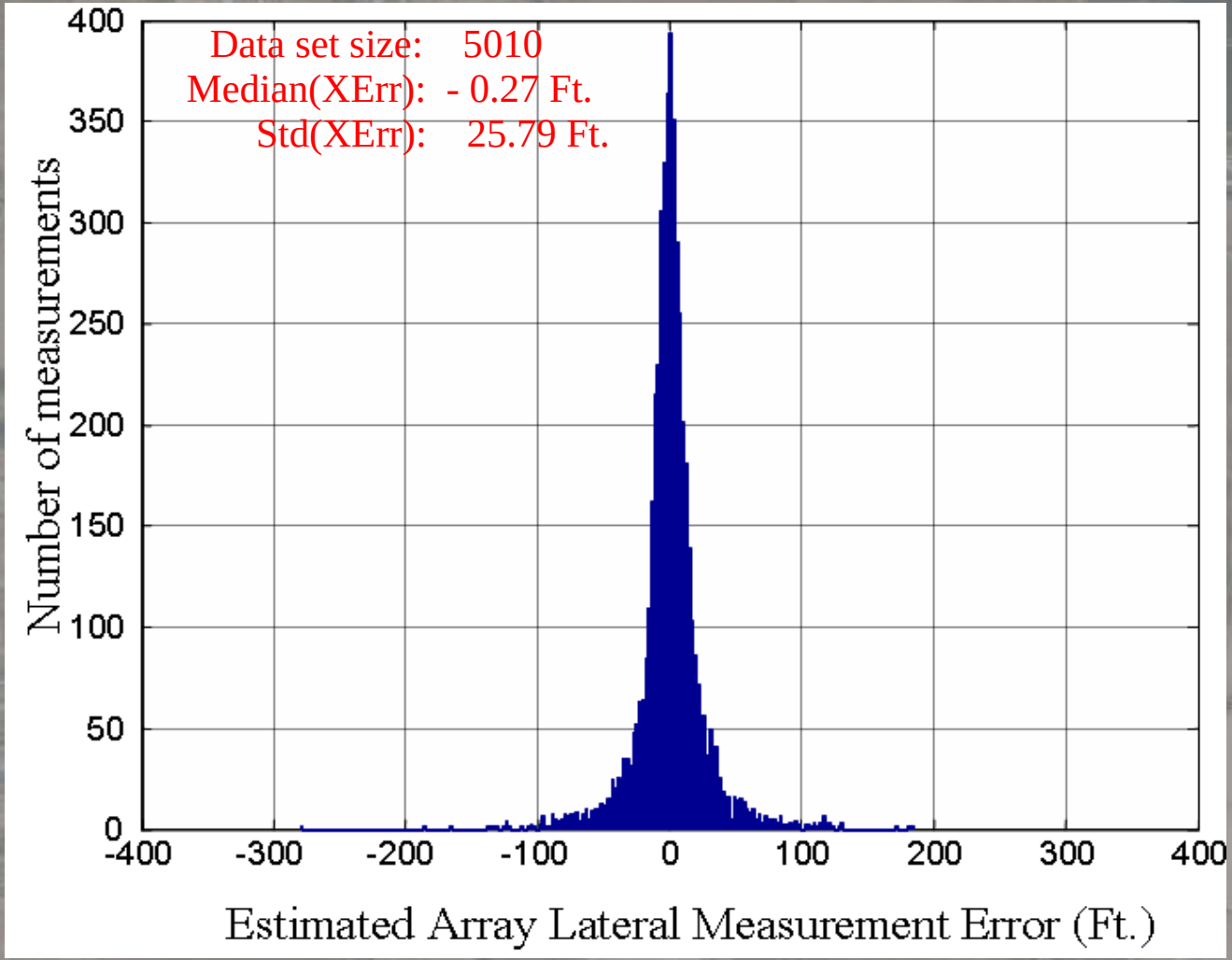
Vertical Position Difference

PLidar Indicating Wakes are Lower than Array Tracks



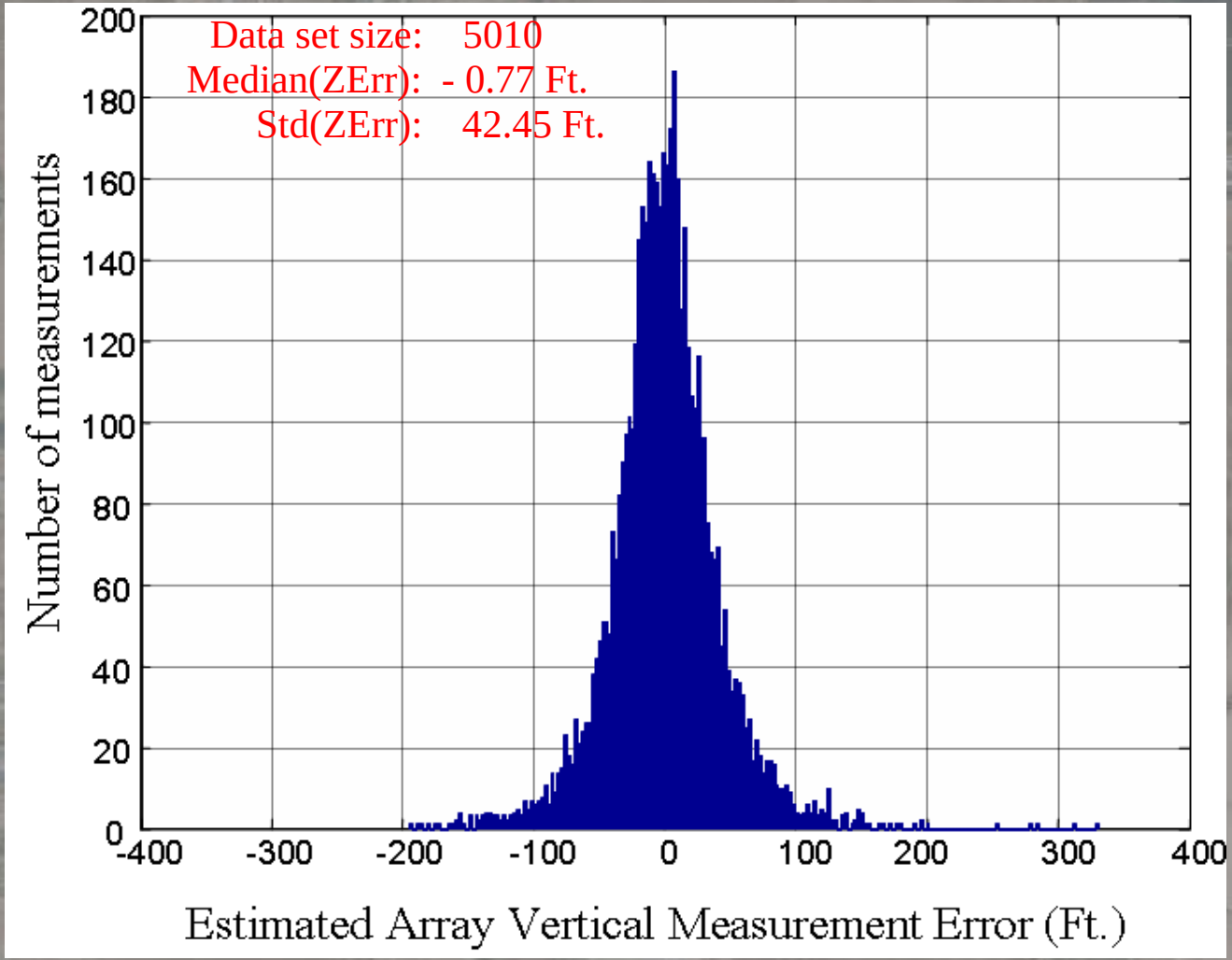
Lateral Position Error Estimates - Array

Distribution of “Residual” from Linear Fit



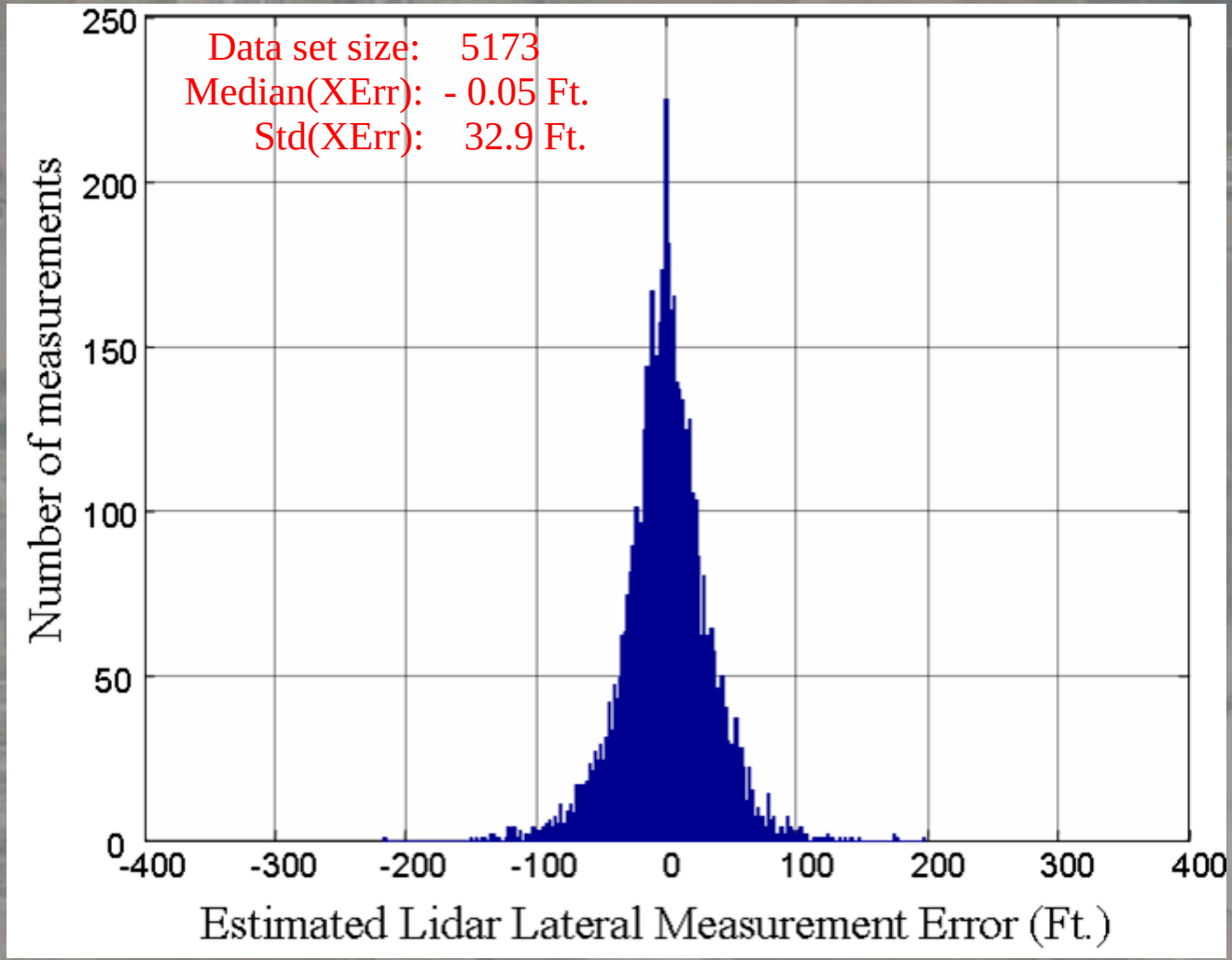
Vertical Position Error Estimates - Array

Distribution of “Residual” from Linear Fit



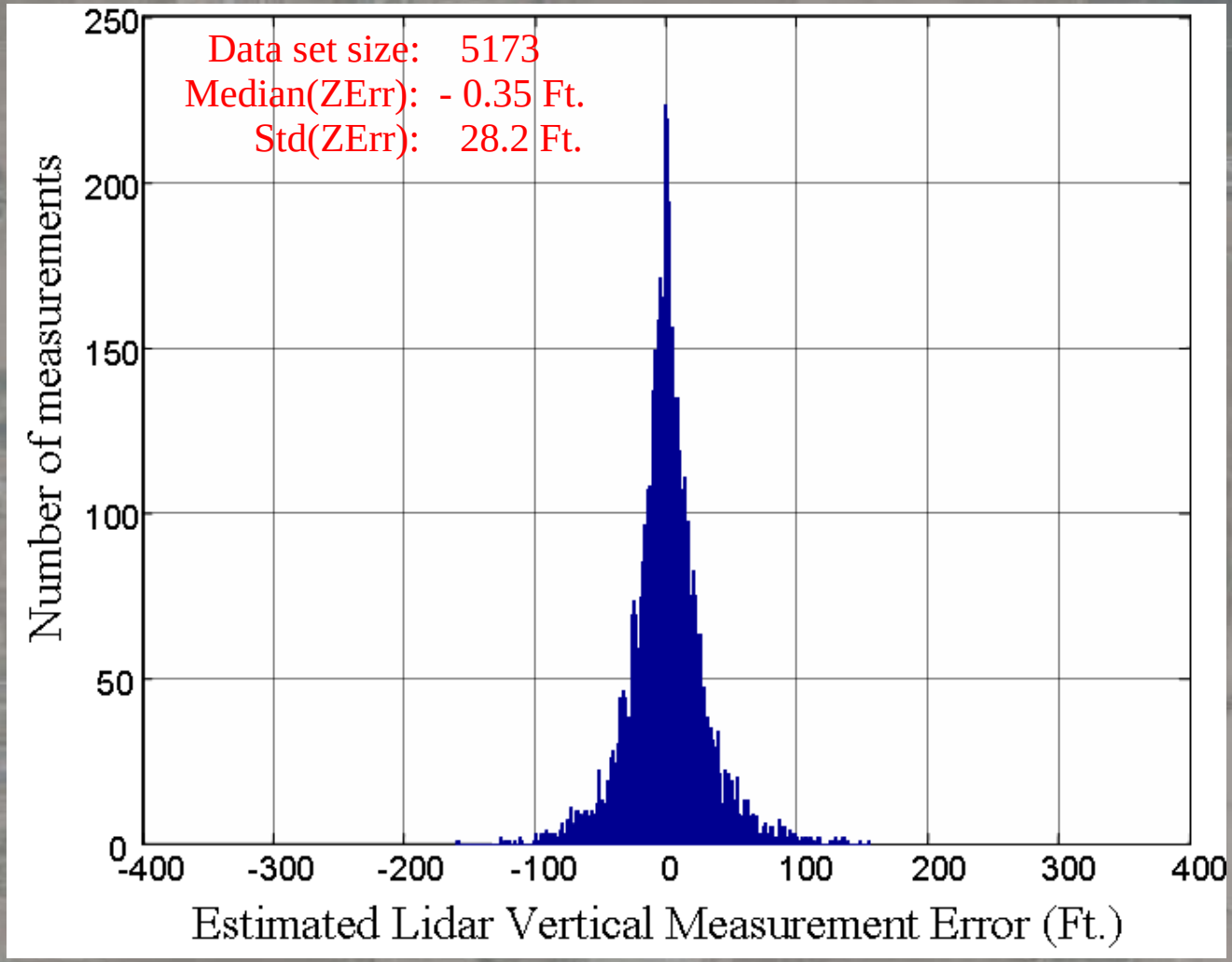
Lateral Position Error Estimates - PLidar

Distribution of “Residual” from Linear Fit

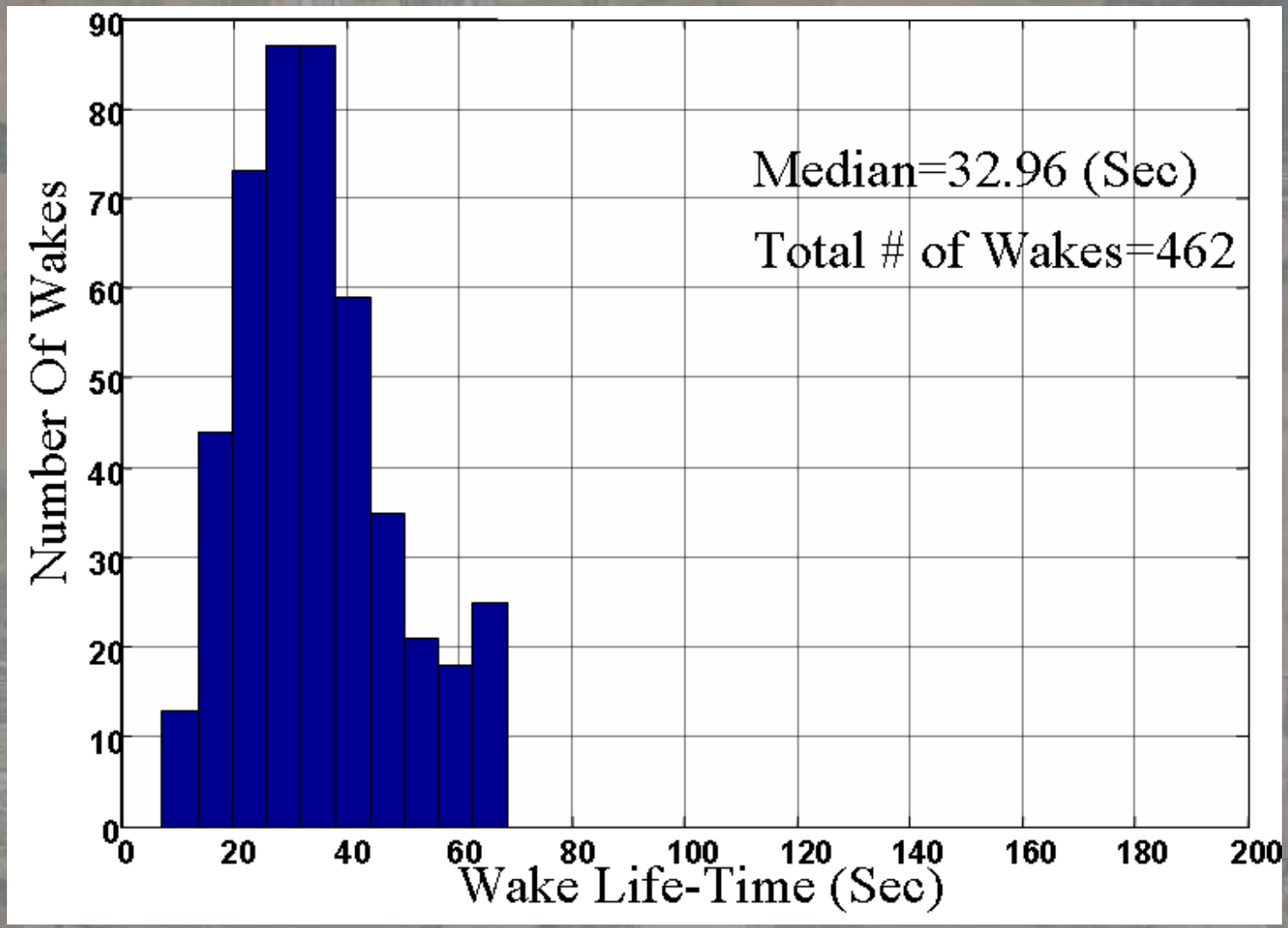


Vertical Position Error Estimates - PLidar

Distribution of “Residual” from Linear Fit

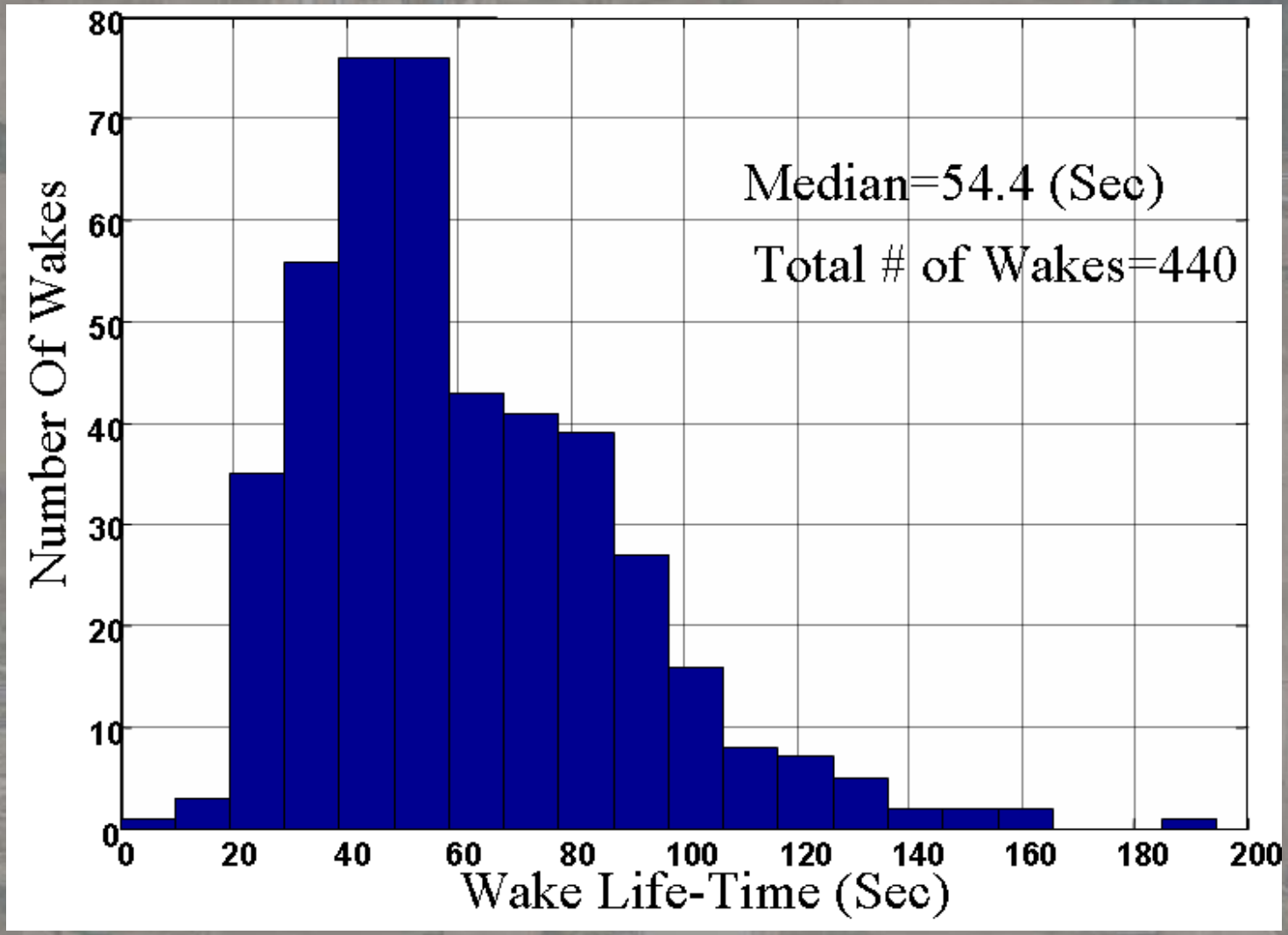


Wake Age Distribution in The Array Data



Array Data Collection : Max of 90 Sec.

Wake Age Distribution in The PLidar Data



Acoustics-Aerodynamics Correlation

Preliminary Effort

- Seeking a Power Law Relationship Between Acoustic Power (t) and Circulation (t).
- Acoustic Power Integrated (i) 0-400, (ii) “Narrow Band” (Most Consistent Portion of the Spectra).

Narrow Band Range
B752: 30-54 Hz
B737: 43-76 Hz

Spectral Data – 461 Tracks Generated

233 Common Tracks Between PLidar and Mic. Array

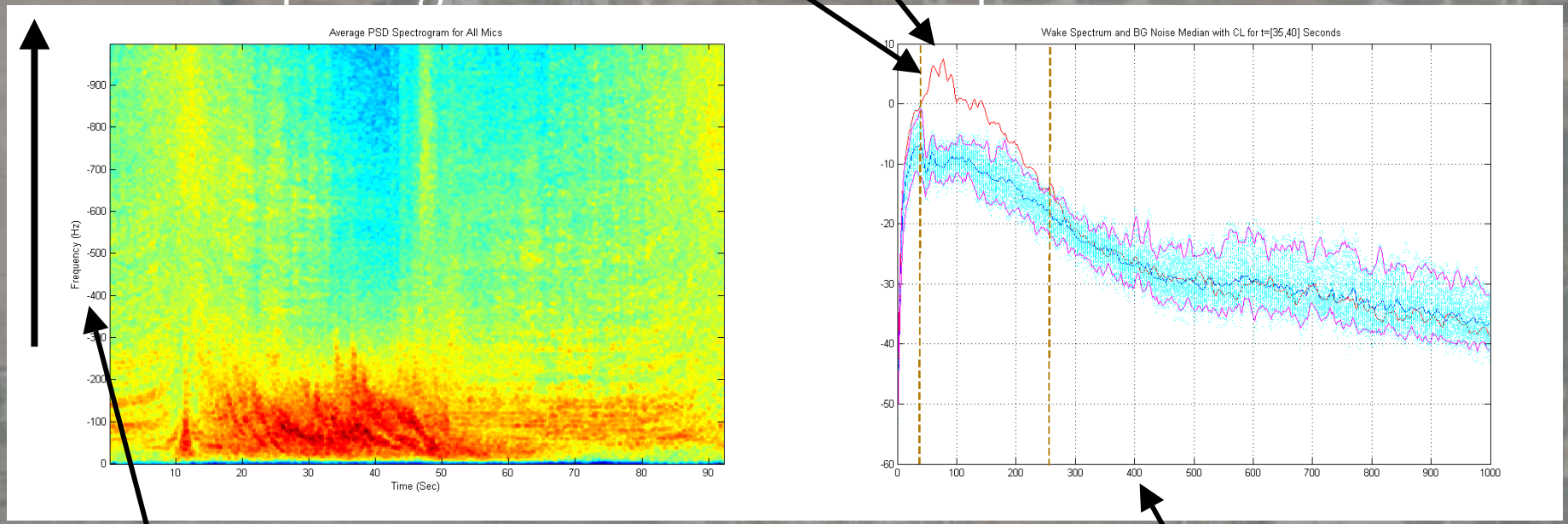
Max Power Spectral Density above background ~17dB

~75 Hz

Freq.

Spectrogram

Spectrum at 35 Seconds



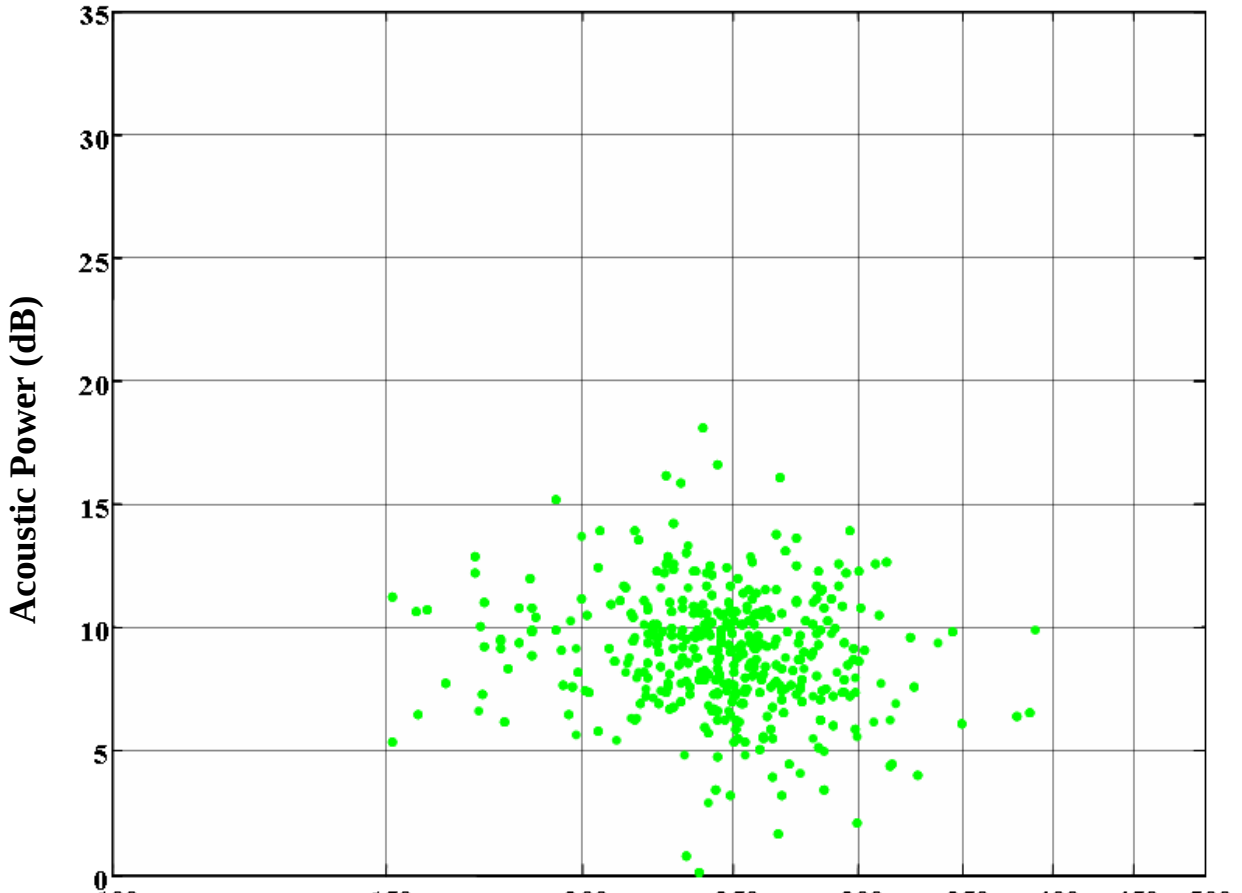
400 Hz

Time

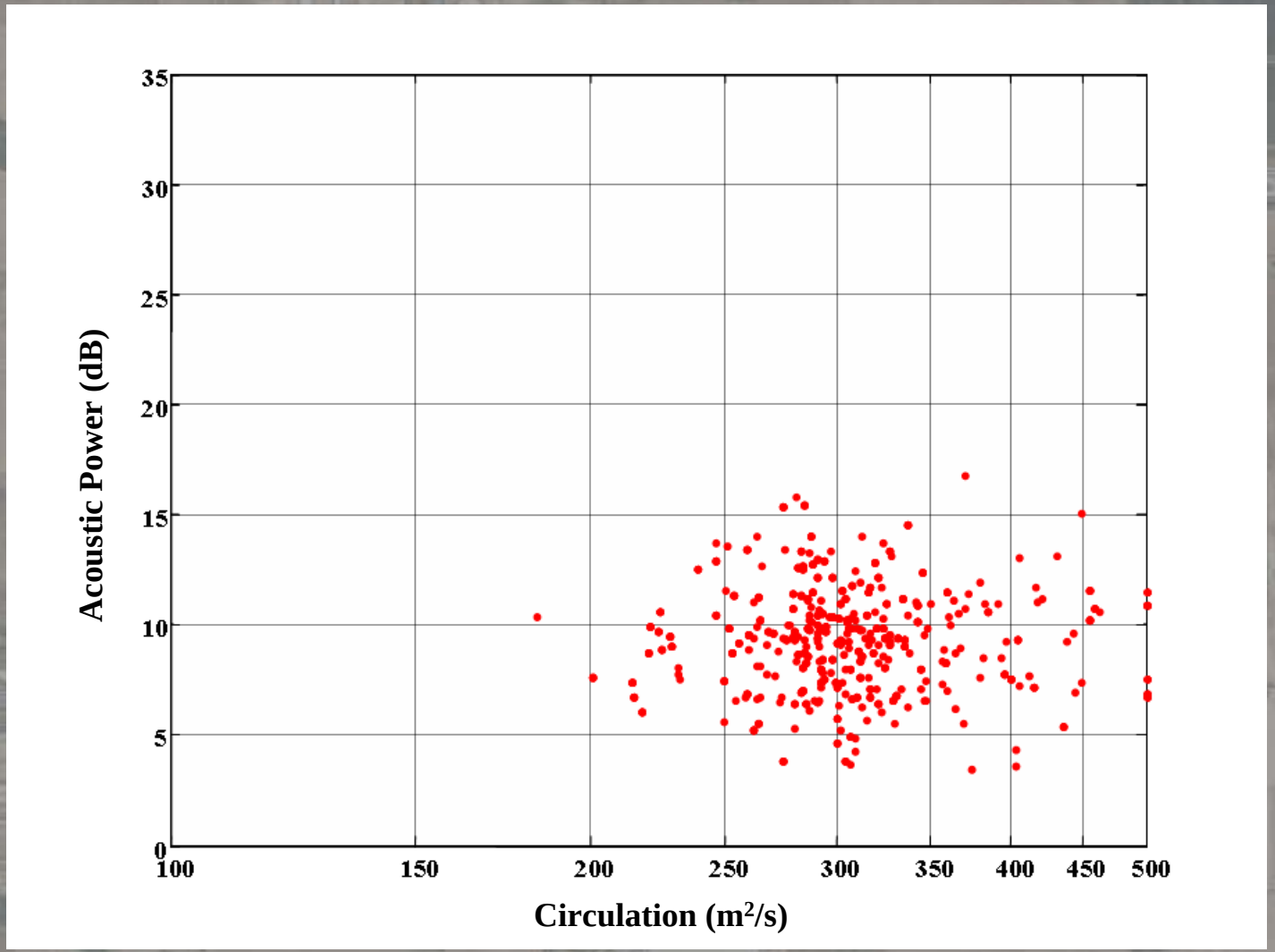
400 Hz

Event is a Boeing 737-500 on Sep 16, 2003 in the Early Afternoon Landing 16L

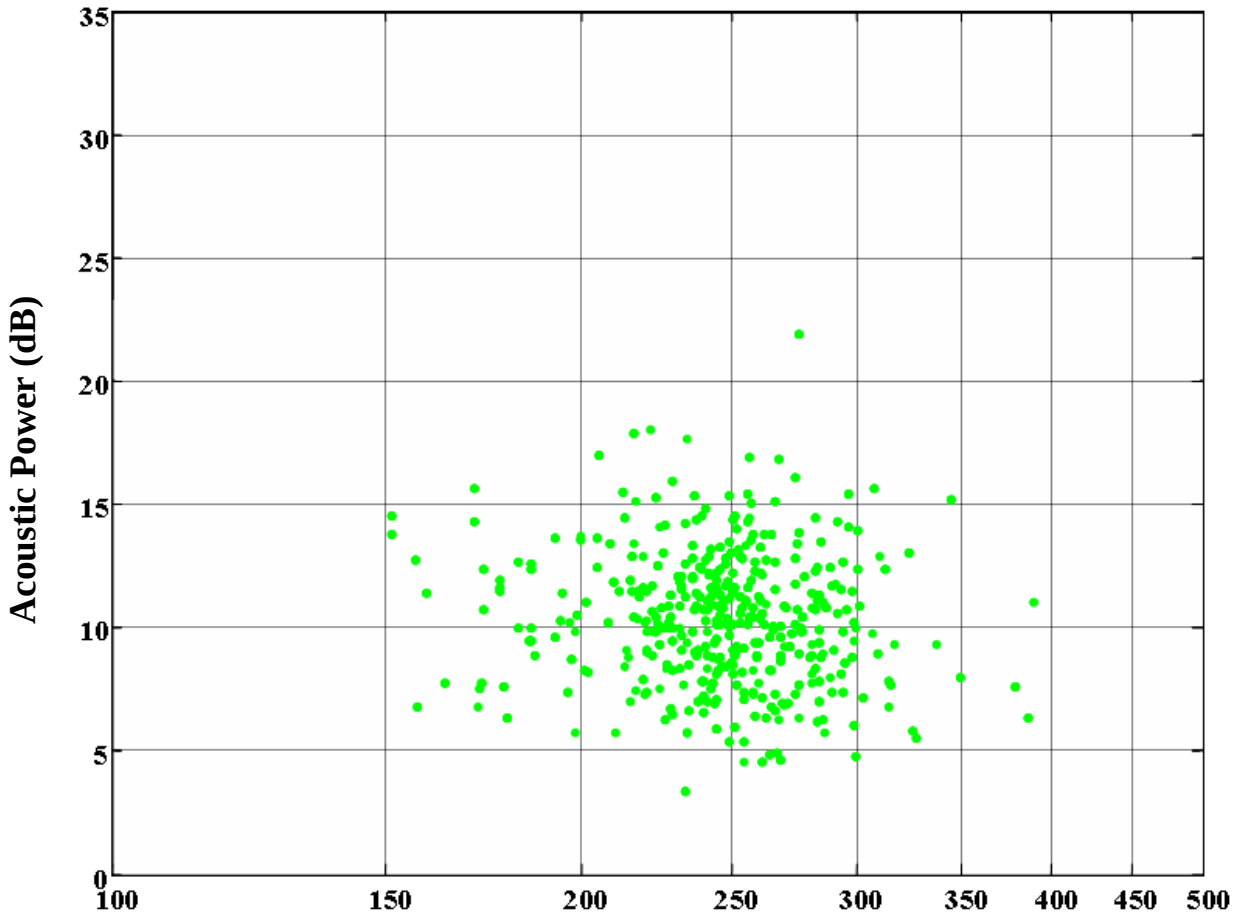
B737 (Broadband)



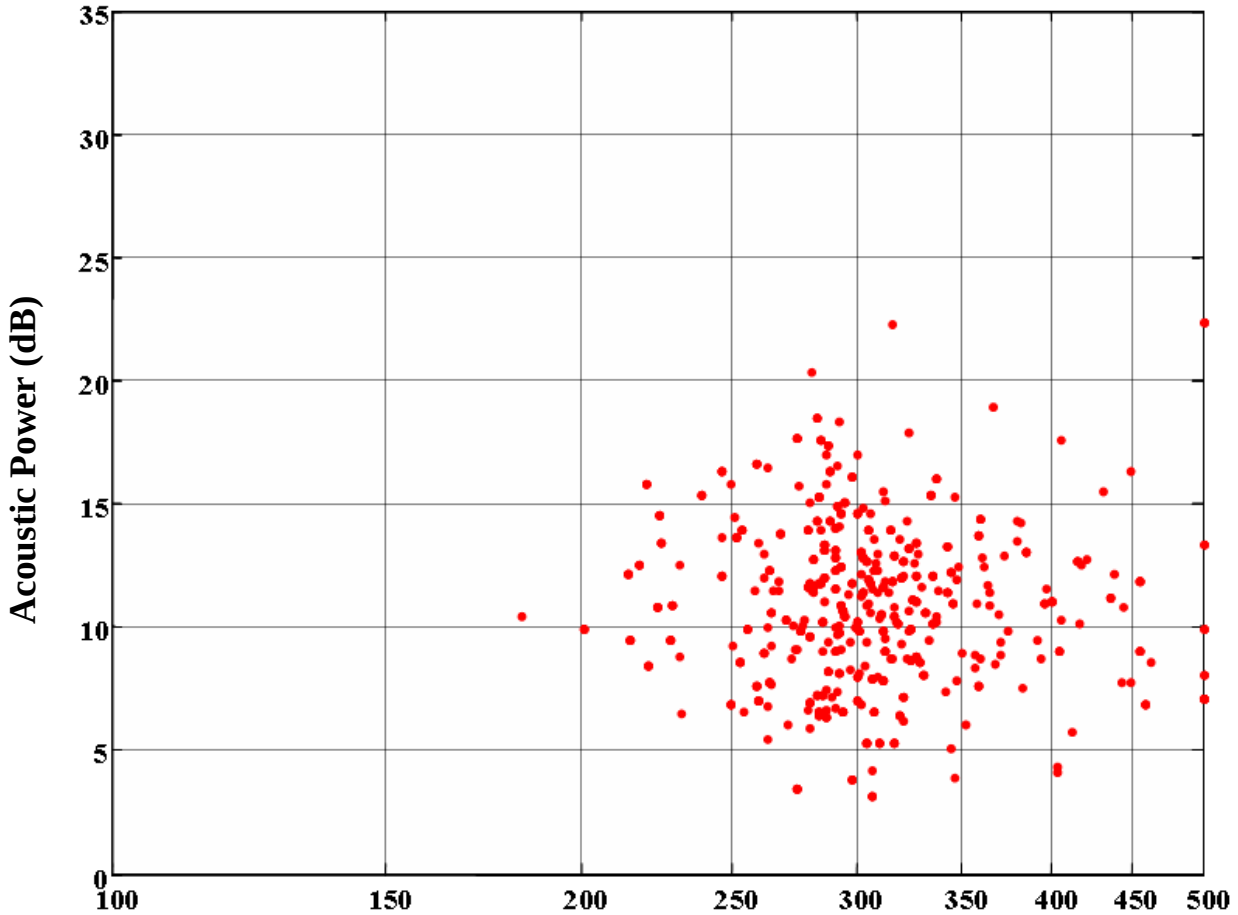
B752 (Broadband)



B737 (Narrowband)



B752 (Narrowband)



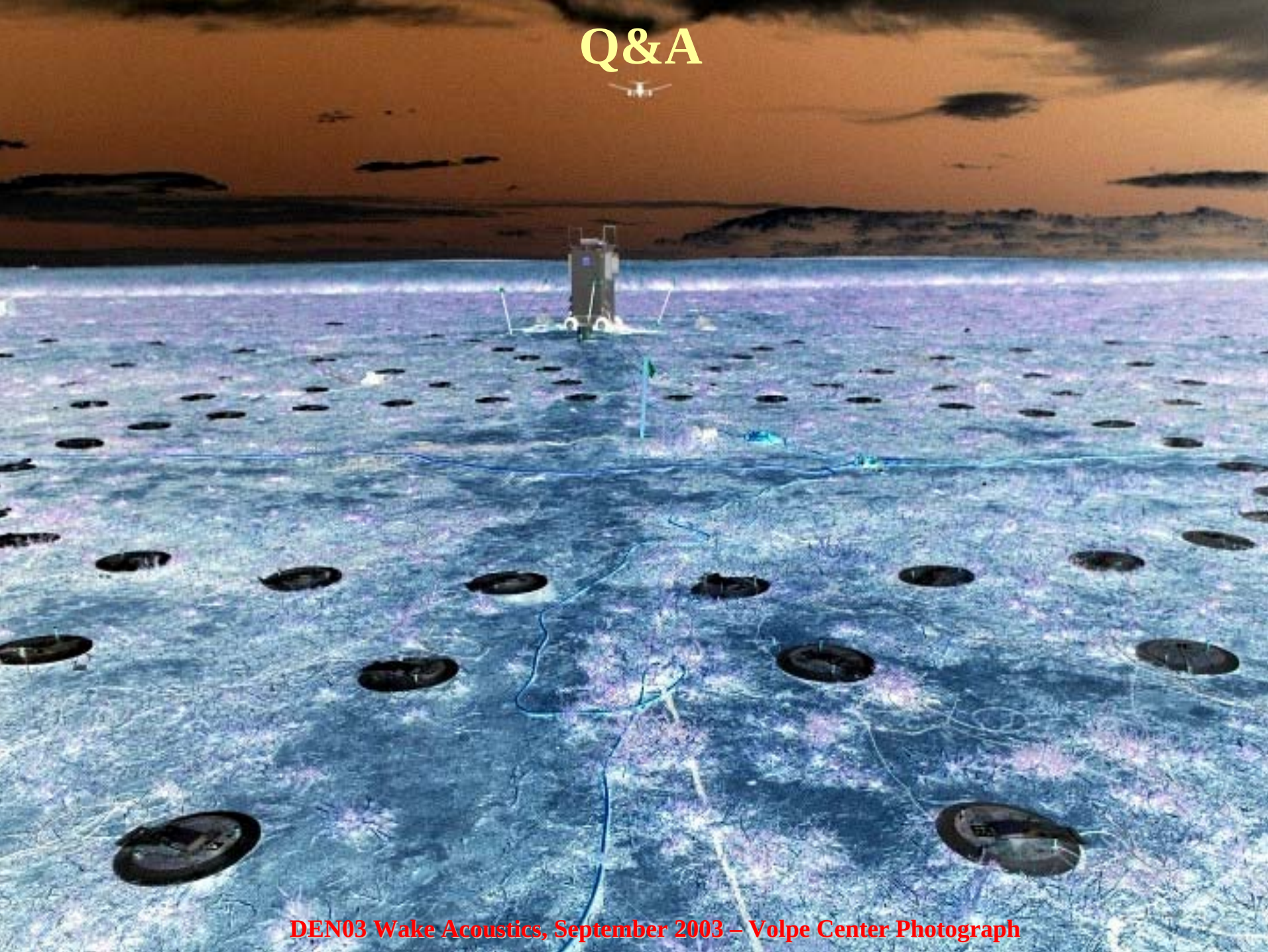
Perspectives

- Earlier Literature (FST/LM, Bedard, Rubin, Burnham, Hallock, DLR, etc.) – 1998 to 2001
- DLR Paper – June 2002
- DLR-Berlin Visit – April 2003
- 32 Mic. Subarray Bellevue Test – May 2003
- 64 Mic. Subarray Bellevue Test – June 2003
- 252 Mic. Denver Test – Aug/Sept. 2003
- AIAA Paper (Manchester) – May 2004
- Annual Data Review Meeting – Sept. 2004
- Additional Publications from Various Groups - 2005

Some Thoughts…

- **In One Year Plus (Result of the Mic Data), the Government Team Greatly Advanced the Wake Acoustics State of the Art.**
- **The Mic. Array Data Offers A Set of Unique Research Database.**
- **Believe to Have a Role as a Research Sensor (In the DEN03 Form, Has the Range of a CW Lidar).**

Q&A



DEN03 Wake Acoustics, September 2003 – Volpe Center Photograph

Documentation

- 149th Meeting of the Acoustical Society of America, May 2005.
- 23rd AIAA Applied Aerodynamics Conference, June 2005.
- Executive Summary Report, 2005.
- DEN03 Meteorological Data Report, 2005.