NASA's Wake Acoustics Research

Presentation by NASA and DOT-Volpe Center

4th NASA Integrated CNS Conference and Workshop
Fairfax, VA, April 26-30, 2004

Denver Wake Acoustics Test – Introduction

- NASA Conducted an Extensive Measurement Campaign at DIA on the Phenomenon of Acoustic Emission of Wake Vortices.
- August 18 to September 26, 2003.
- Recorded About 1200 Flybys (Mostly for Aircraft in Landing Configuration).

NASA's Interest in Wake Sensors

- **NASA Developed an Active Wake Vortex Predictor for the Terminal Area (AVOSS - Aircraft VOrtex Spacing System) which was Demonstrated at DFW in July 2000.**
- **Under the Joint NASA-FAA Wake Turbulence Research Management Plan (RMP), NASA Will Focus on Developing Mid- and Long-Term Products to Improve NAS Capacity without Compromising Safety.**

NASA's Interest in Wake Sensors

- NASA, as Part of Its Long-Term RMP Efforts, Continues to Mature the Predictor and Wake Sensor Components.
- NASA Has Been Exploring a Number of Technologies for the Wake Sensor Component of a Wake Vortex Advisory System.
- Examples Are Lidar, Windline, Sodar, Radar, RASS and More Recently…

NASA's Interest in Passive Wake Acoustics

- **Congress Directed NASA to Examine the Concept Behind SOCRATES (Sensor for Optically Characterizing Remote Atmospheric Turbulence Emanating Sound) - A Laser Based Passive Wake Acoustics Sensor Under Development.**

Objectives of the Denver Wake Acoustics Test

- ✓ *1*: **Scientific Investigation of the Acoustic Properties of Aircraft Wake Vortices and Ambient Noise Characterization Using a NASA-DOT Phased Microphone Array.**
- ✓ *2*: **Assess Improvements in SOCRATES Instrumentation.**
- ✓ *3*: **Benchmark NASA-DOT Microphone Array Using DLR Array.**

Denver International Airport

- ✓ **Desirable Acoustic Environment**
- ✓ **Diverse Traffic Mix, Abundance of *Large* and *Heavy* Aircraft**

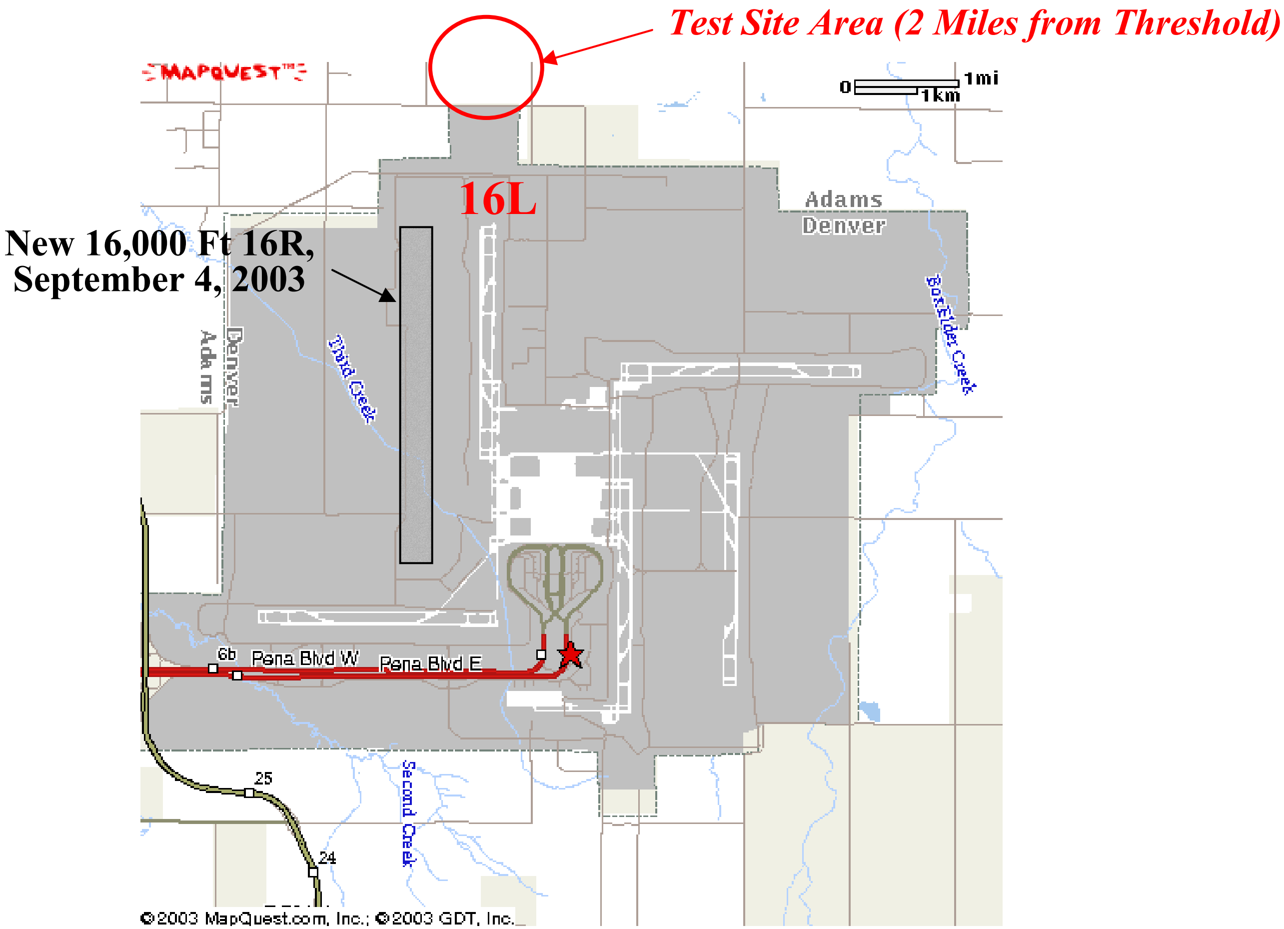
Participating and Supporting Organizations

- NASA LaRC
- DOT Volpe Center
- Titan
- OptiNav
- Microstar Laboratories
- CTI
- MIT LL
- AeroVironment
- WLR Research
- FST
- Lockheed Martin
- DLR - Berlin
- Anteon
- FAU
- United Airlines
- DIA Airport
- Local Denver FAA

General Test Configurations

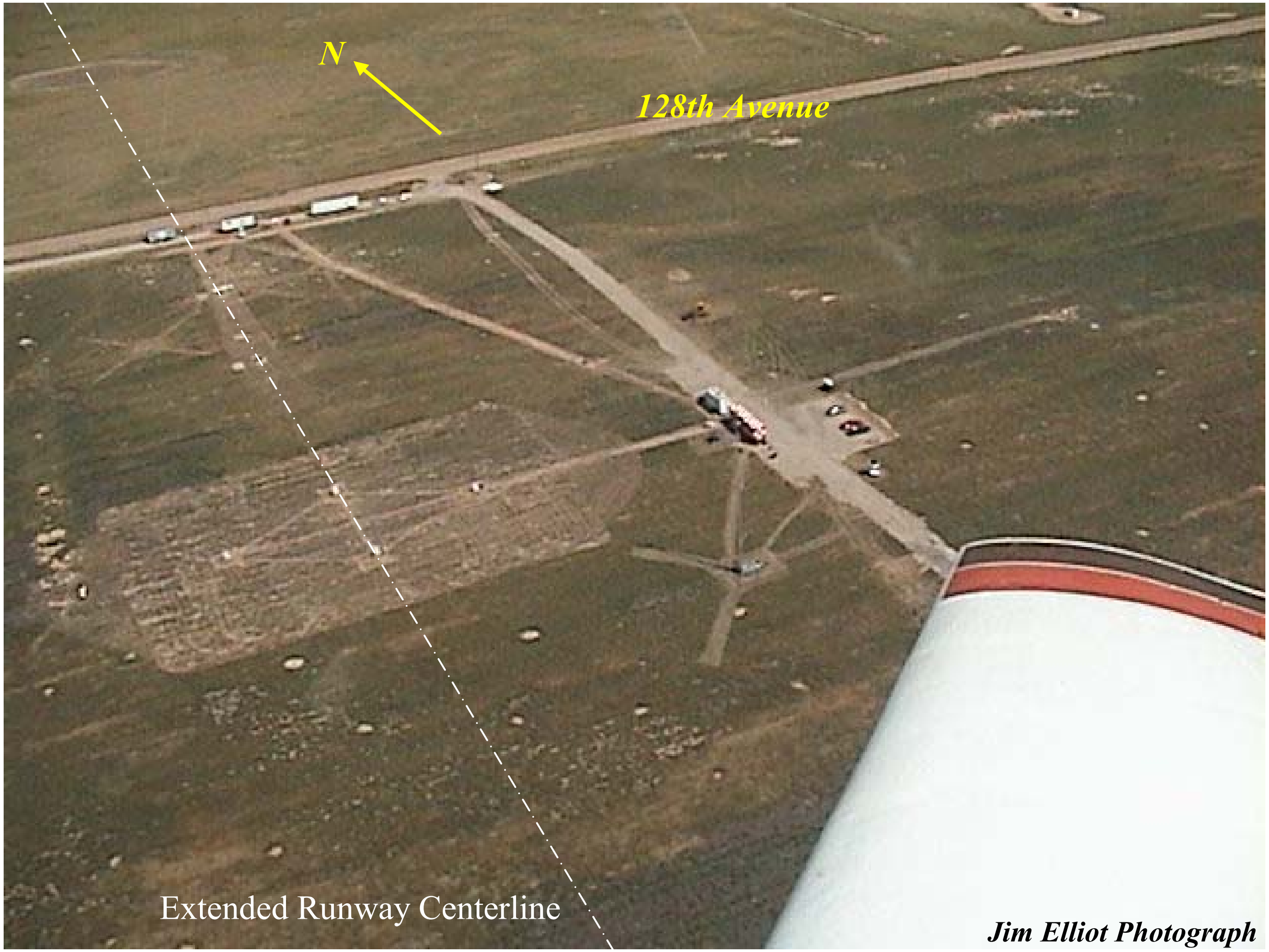
- **Landing Configuration.**
- **Vortices Generated from Nominally 700 Feet Altitude.**
- **Acoustic Data from Government Microphone Array.**
- **Lidars Providing Ground-Truth Wake Track and Strength Data.**
- **Metrological Sensors Characterizing State of the Atmosphere.**
- **Aircraft Identification and Flight Tracks from ARTS.**

DIA Test Site

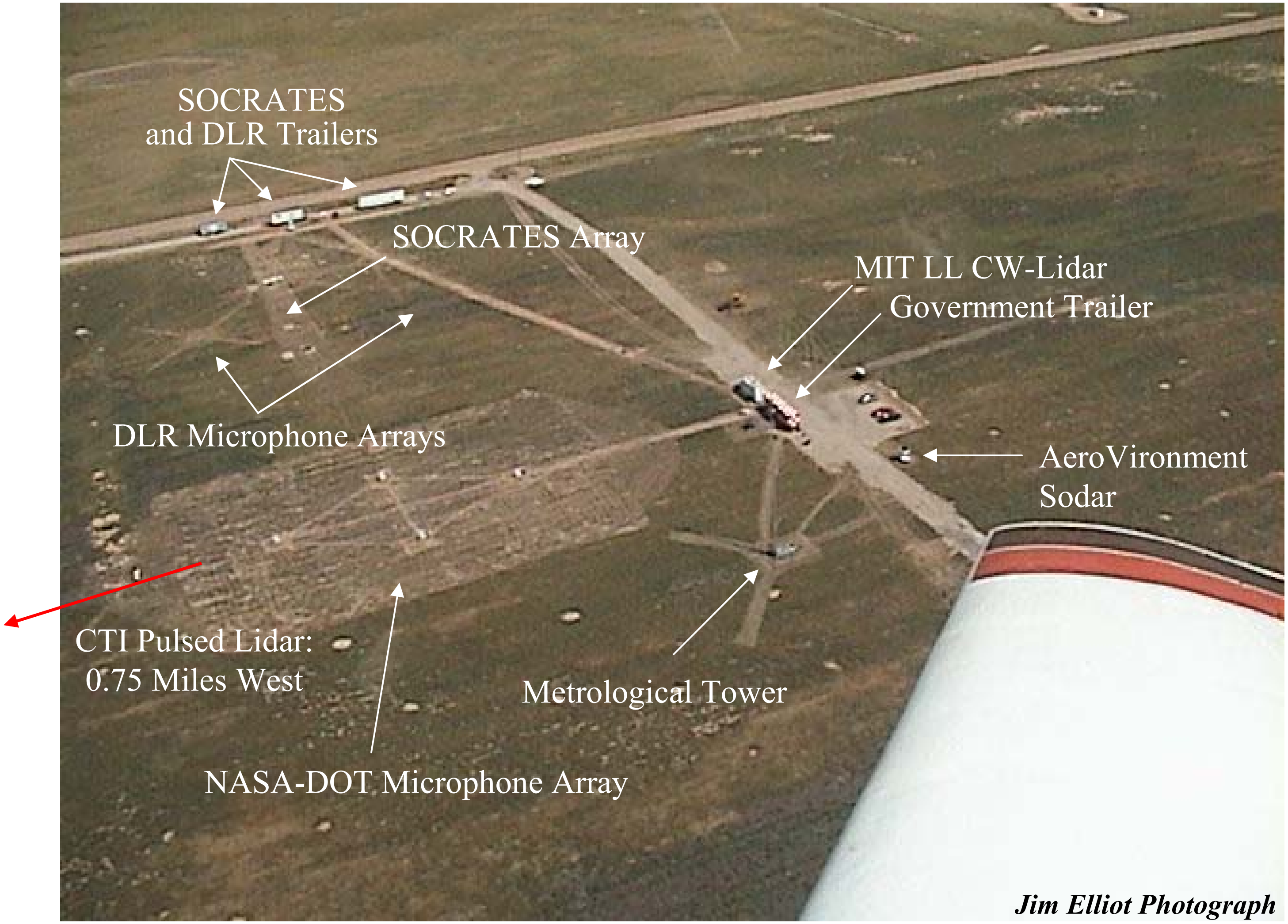


The first operation on 16R/34L was a United Airlines 777 departure, flight 244 to Chicago at 10:38AM local time.

Test Site Aerial Photograph



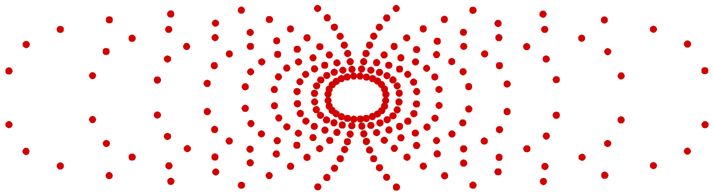
Test Site Aerial Photograph



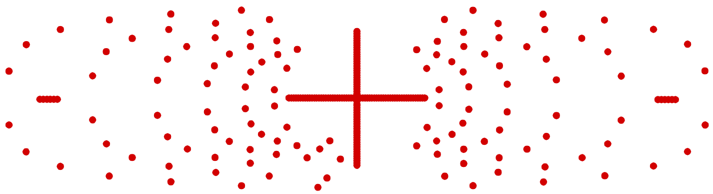
Primary Acoustic Sensor - NASA-DOT Array

- **Two Configurations Deployed.**
- **Configuration 1 – 8/28 to 9/19 (20 – 1000 Hz).**
- **Configuration 2 – 9/22 to 9/23 (10 – 2000 Hz).**

Array Layout



Configuration 1



Configuration 2

Aerodynamic Sensors

- **CTI Pulsed Lidar**
- **MIT LL CW Lidar**

Metrological Sensors

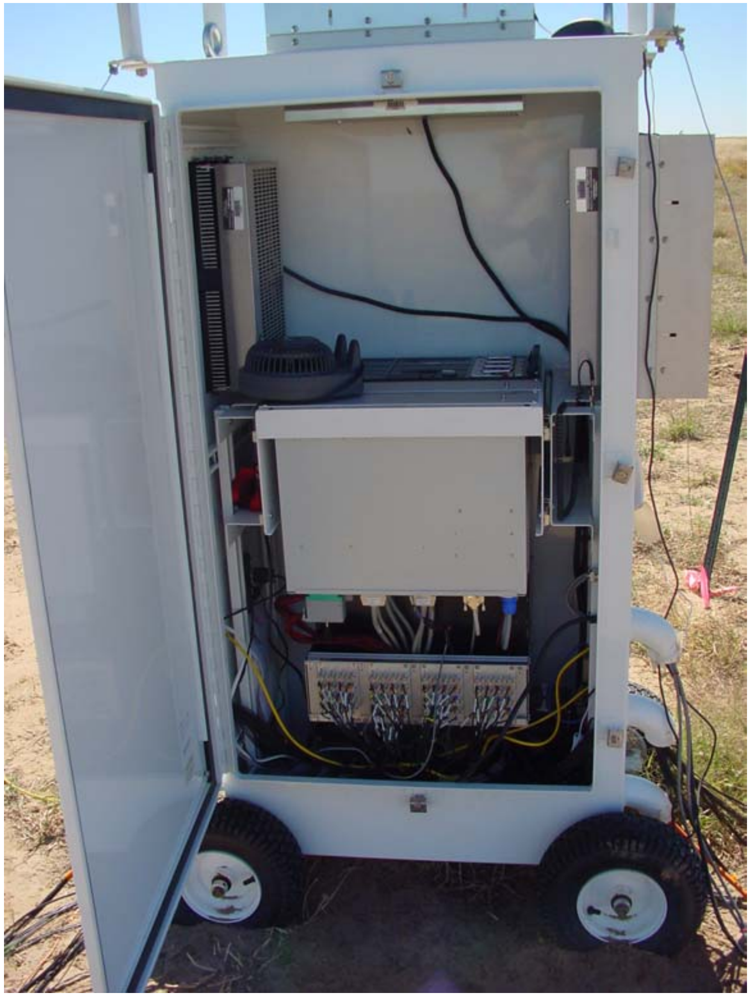
- AeroVironment Wind Sodar
- 107 Ft Tower with R. M. Young Propeller Anemometers at Three Heights
- Vaisala Temperature and Relative Humidity Sensor at Mid-Height of Tower
- Kipp & Zonen Microwave Radiometer Temperature Profiler
- METEK Ultrasonic Anemometer

Additional Measurements

- **SOCRATES Laser Array**
- **DLR Phased Microphone Arrays**

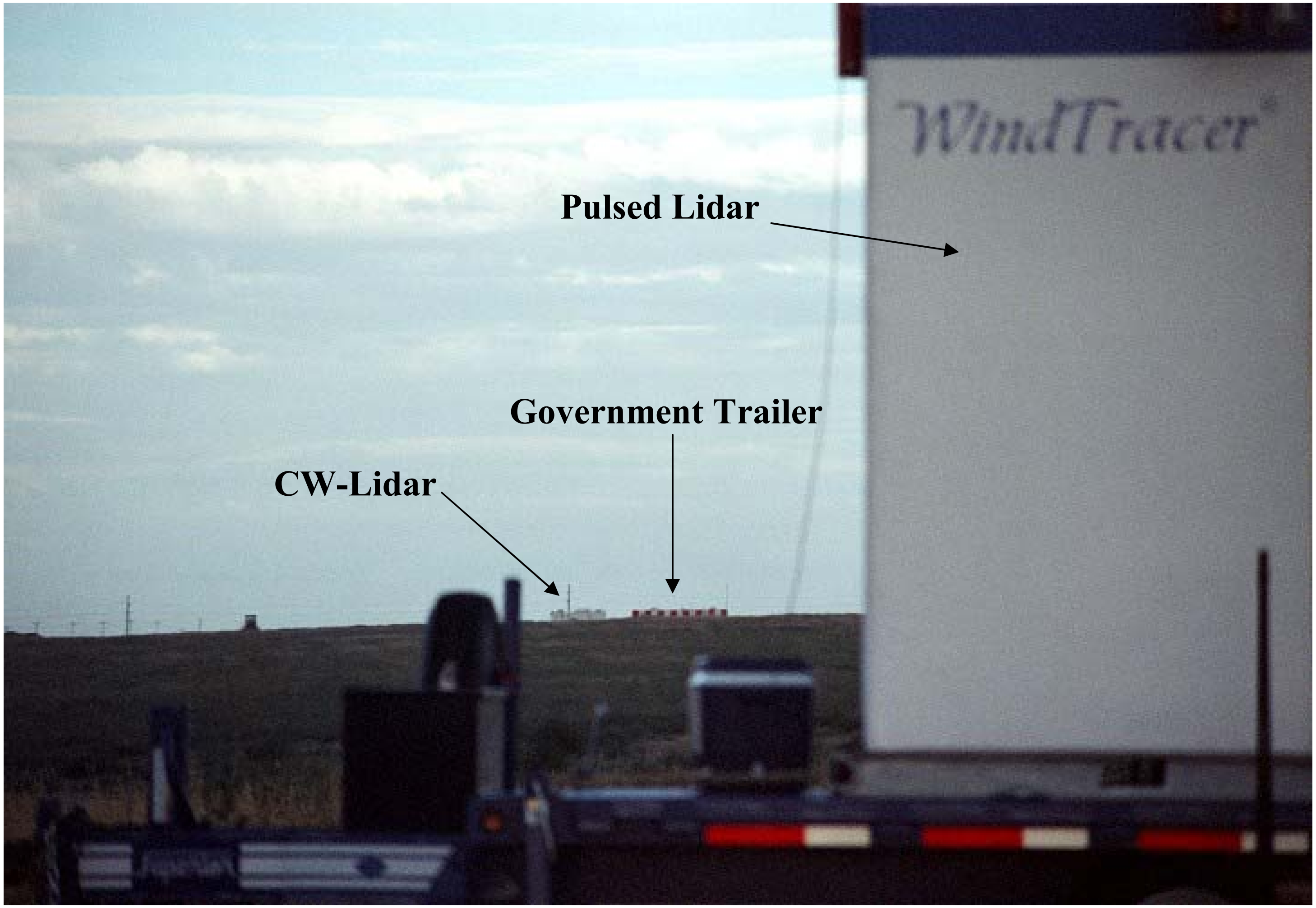
Looking South from the Government Array

Close-Up of the Array Components

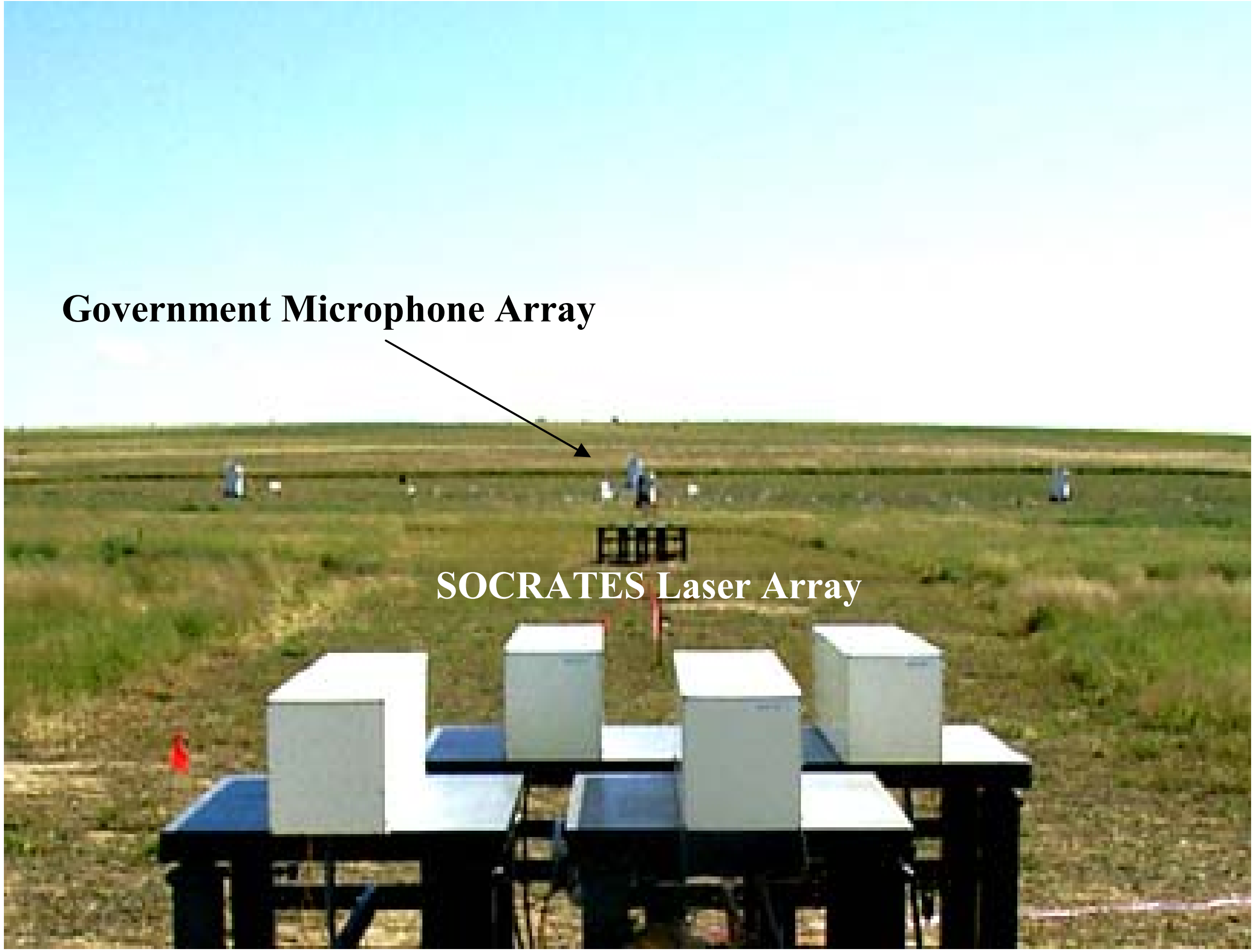


Looking West

Looking East from CTI Pulsed Lidar

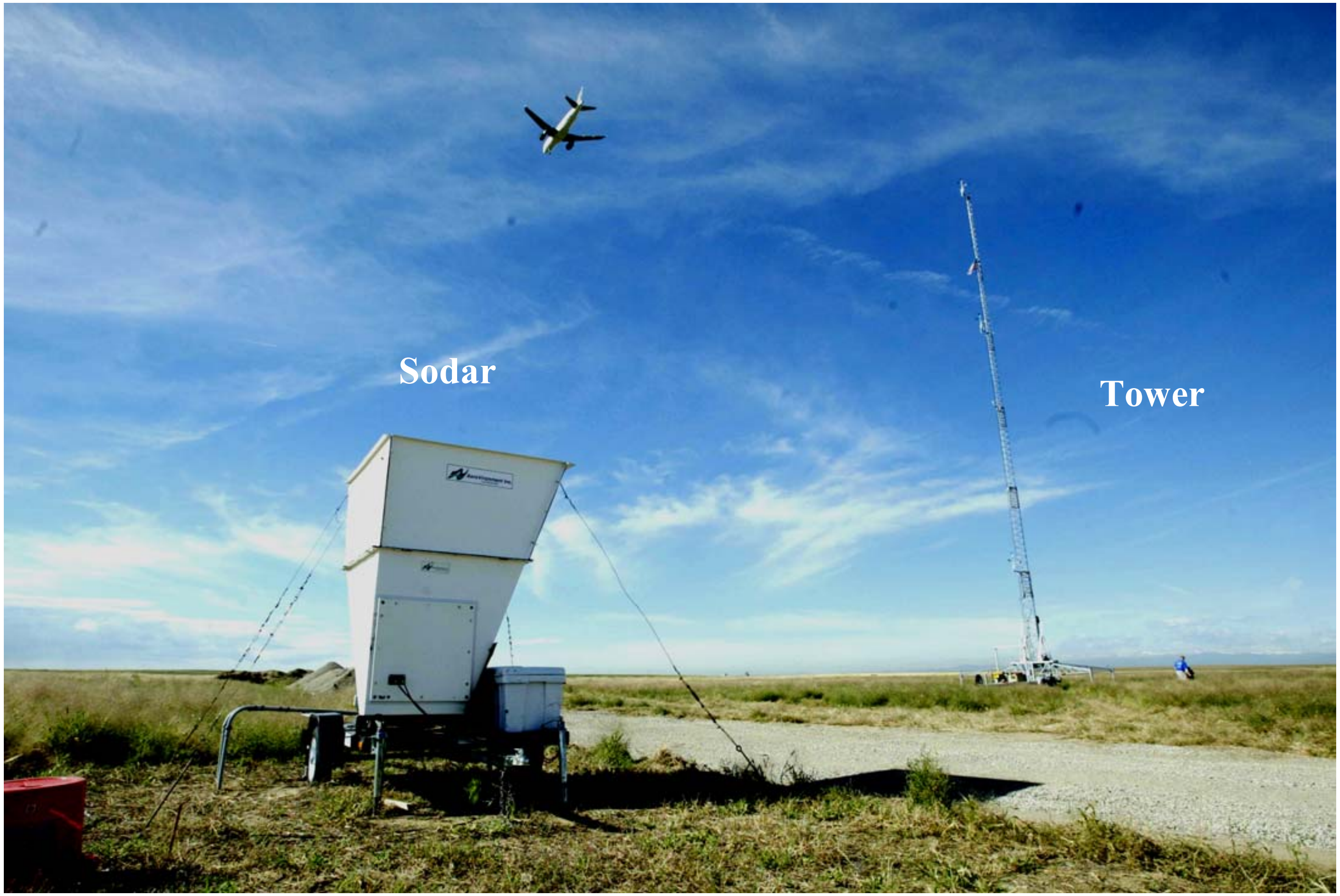


Looking South from SOCRATES

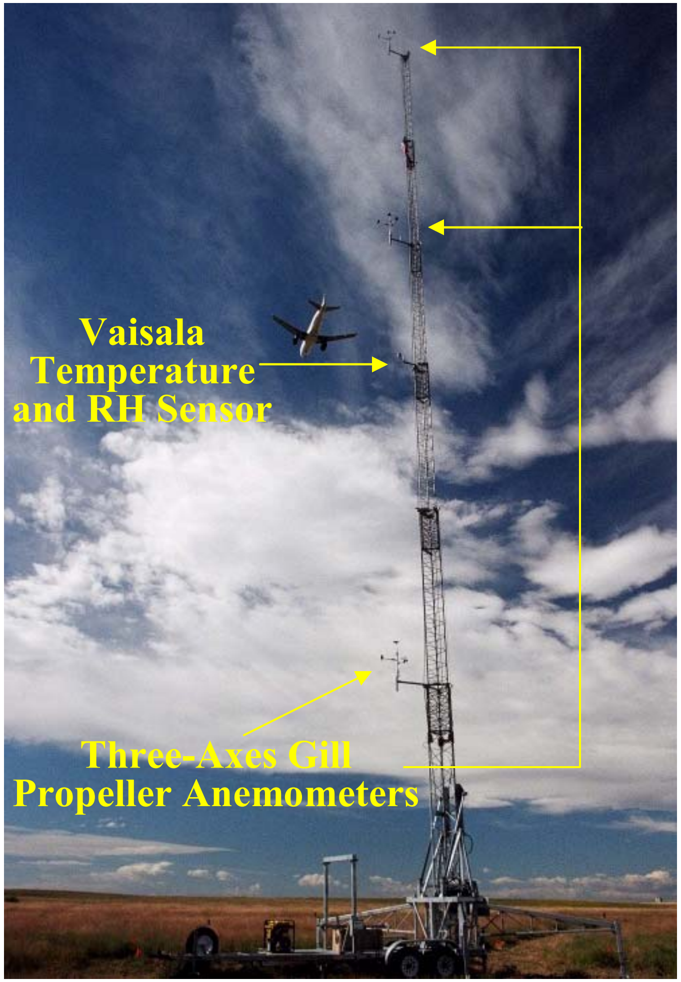


Lockheed-Martin Photograph

Meteorological Sensors



Tower – Metrological and Array Calibration



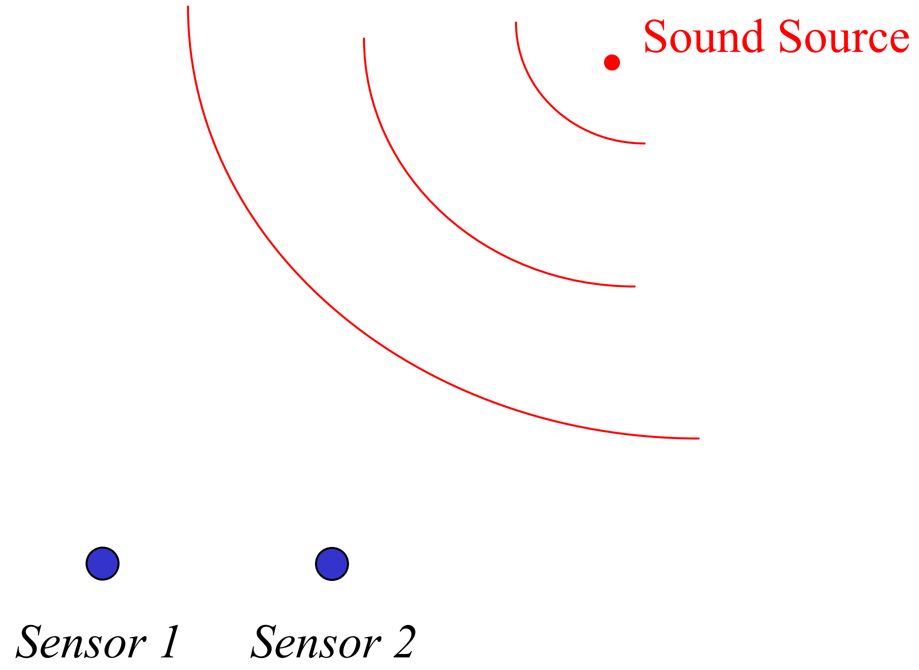
OptiNav Photograph

Meteorological Sensors

METEK Ultrasonic Anemometer

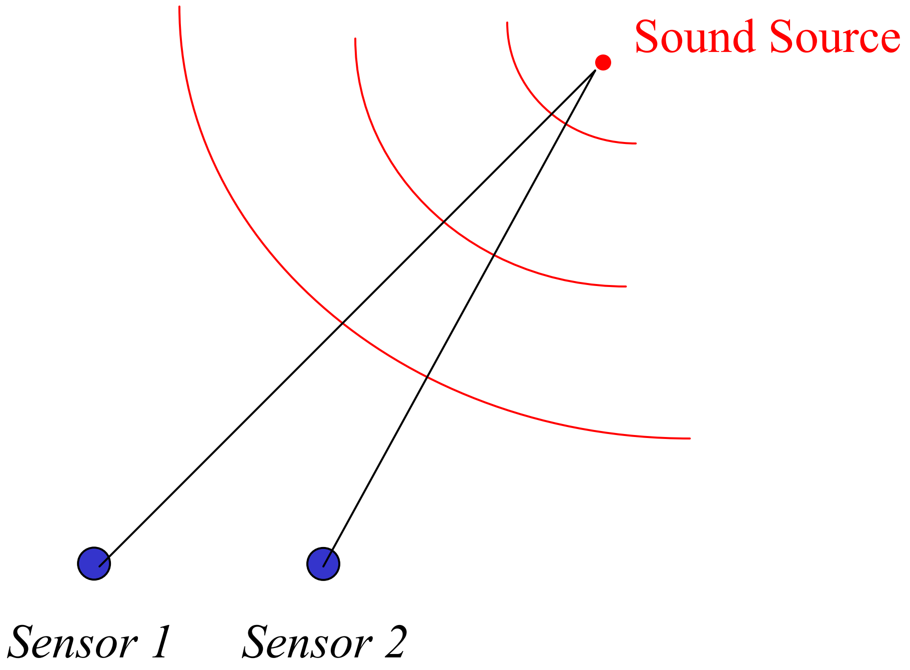
Kipp & Zonen Microwave Radiometer

Array Signal Processing



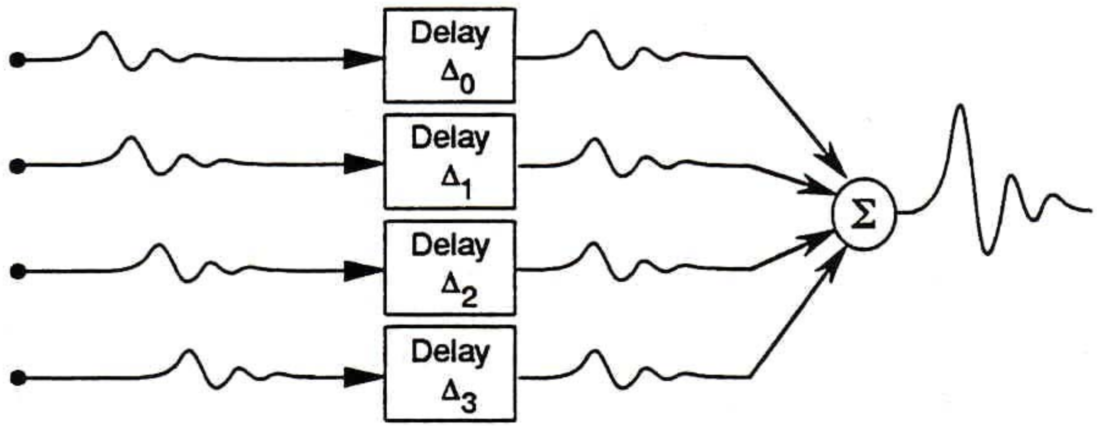
Sensor 2 Hears an Earlier Version of Sensor 1

Array Signal Processing



The Time Delay Sensor 1 Hears is Proportional to the Additional Distance the Same Sound Needs to Travel in Getting to Sensor 1

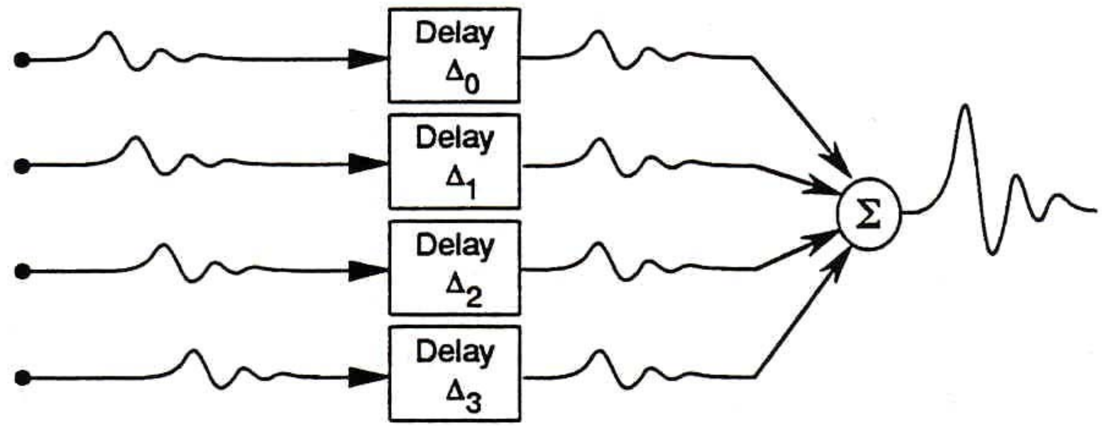
Delay and Sum Beamforming



- **If the Location of Sound Source Were Known, Appropriate Time Shifts in the Recorded Signals from Different Sensor Elements in the Array can be Applied in Software.**
- **Acoustic Signature from the Source of Interest is then added Constructively; Signal is Amplified from the Investigated Location.**

Figure Taken from Johnson, P. and Dudgeon, 1993

Delay and Sum Beamforming



- **Meanwhile, Sound From Other Locations Add Up Incoherently. The Result of Incoherent Summation Could be Shown as a Lower-Amplitude Wave ; Unwanted Noise is, in Effective, Rejected.**
- **Entire Array Acts as a Directional Acoustic Sensor (Hence, "Beamforming").**

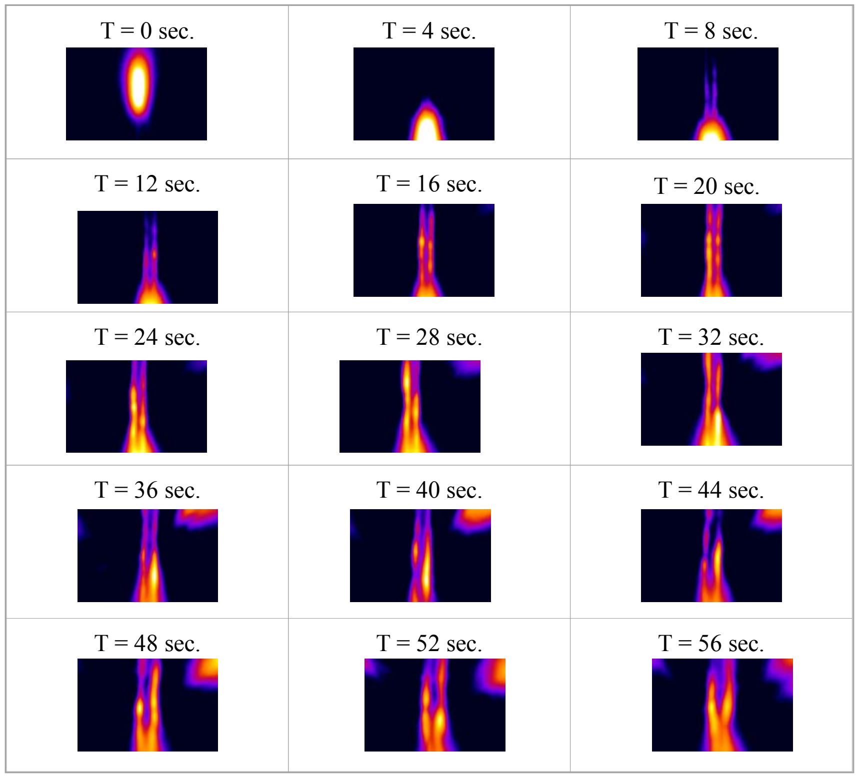
Figure Taken from Johnson, P. and Dudgeon, 1993

Delay and Sum Beamforming

- **Noise Source Location is Usually not Known - Need to Find it.**
- **Systematically Vary/Search Assumed Noise Source Locations.**
- **Apply the Appropriate Delays and then Sum Signals Based on Assumed Locations.**
- **Acoustic Pressure Level Computed at Each Searched Location (i.e., Grid Points).**
- **Results Can be Visualized as Contour Plots - Noise Source Localization Map ("Acoustic Imaging"; "Acoustic Camera").**

Sample Results - Microphone Array

- **Run 030903_194324 : September 3 at 7:43PM Local Time (B767).**
- **Beamforming at 500 Feet Altitude, 1000 Feet x 1500 Feet Coverage Area for a Horizontal Beamforming Planes (“Snapshots”).**
- **The Analysis Band is 200 Hz and Below.**



Data Analysis Needs to Address

- **Do Wake Vortices Generate a Unique Acoustic Signature?**
- **How Consistently do Wake Vortices Generate These Signature?**
- **What Are the Characteristics of these Signatures and Circumstances Under which they are Generated?**
- **What is the Frequency Range of these Acoustic Signals?**

Data Analysis Needs to Address

- **Can Vortex Strength be Reliably Inferred from Wake Acoustic Signatures? What is the Fundamental Scientific Principle?**
- **If the Answers to All of the Questions are Positive, Then Assess the Feasibility of an Acoustic-Based Sensor System Detecting, Identifying, Tracking Wake Vortices and Quantifying the Circulation in a High Ambient Noise Environment Typically Found in Major Airports.**

Questions?