NASA/CP—2002-210964

Turbulence Lidar Development Status

Weather Accident Prevention (WxAP)
Annual Project Review

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Cleveland, OH, Hilton South
June 5-7, 2001

Overview

Aviation Safety Program

- **Background information**
- **Technical accomplishments to date**
  - **ground and flight test activities**
- **Plans**
  - **flight test activities**
  - **algorithm development and performance simulation**

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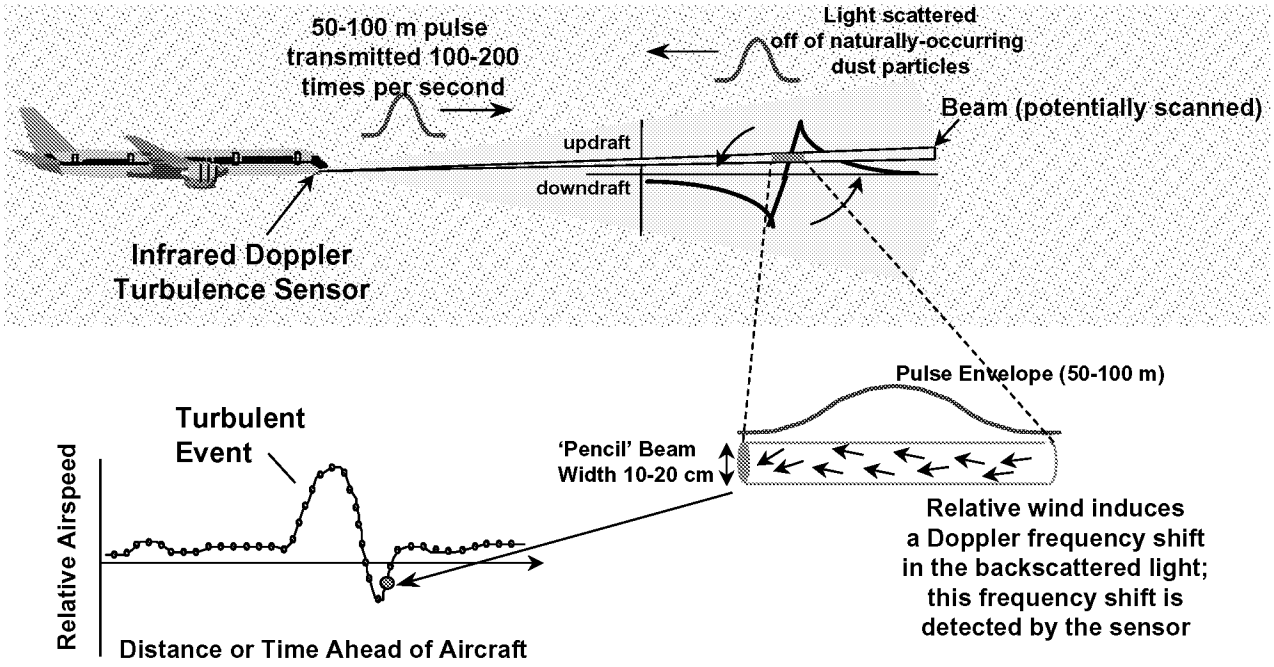
General Principle of Infrared Doppler Radar (Lidar) Turbulence Measurement

Aviation Safety Program



Turbulence Product Development Team Objective

Aviation Safety Program

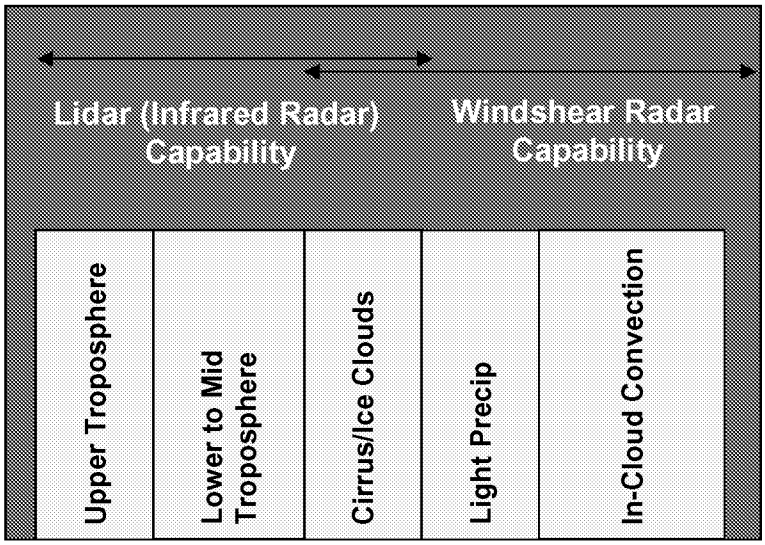
- **Develop a robust detection capability that spans the full range of turbulence environments**
  - **Provide Timely Reliable Tactical Warning to:**
    - **Deviate,**
    - **Institute Cabin Safety Measures, and/or**
    - **Institute Mitigation Measures**
  - **Provide Real-Time Alerts to AWIN Network**

Complete Detection Capability Provided through Dual Wavelength Radar

Aviation Safety Program

TDAM Objective: Develop a robust detection capability that spans the full range of turbulence environments

- Convective Storms (within and as far as 40 miles away from visible clouds in clear air)
- Jet Stream (at confluence of multiple streams and near boundaries)
- Mountain Wave (upward propagating from disturbances near the surface)



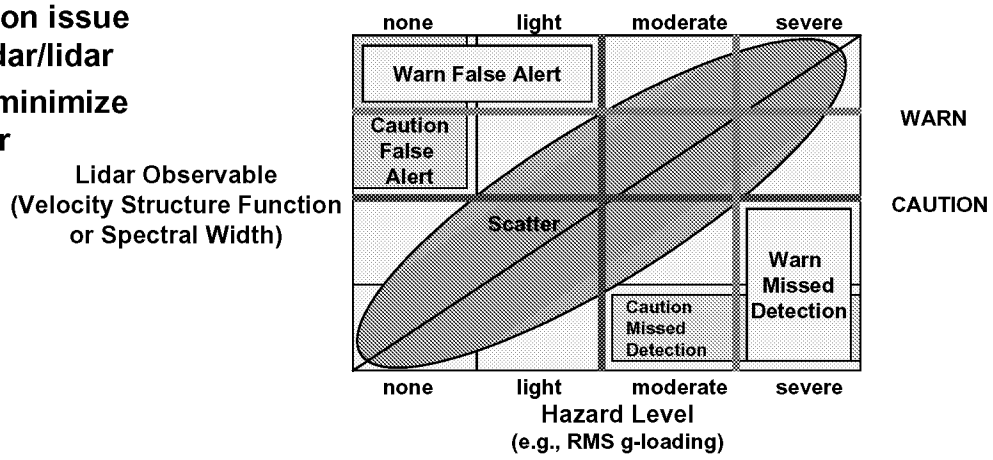
Technology Readiness Development Needs

- **Lidar needs are similar to those for microwave radar and include:**
  - **definition and characterization of hazard**
  - **hazard algorithm for quantifying the threat**
  - **validated algorithm(s) for using the IR radar to detect, discriminate, and quantify the threat**
  - **simulation test case development**
  - **validated system performance with properly designed field tests**

Detection Issues

Aviation Safety Program

- **Detection/False Alert must consider the random nature of turbulence**
  - multiple turbulence warning levels
  - multiple turbulence classes/types
  - viewing longitudinal velocity behavior and inferring the vertical
- **Definition of errors required (not just Type I and Type II)**
  - common issue for radar/lidar
  - must minimize scatter



Flight Testing: Objectives and Needs

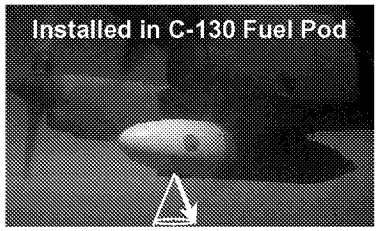
Aviation Safety Program

- **More flight hours at cruise altitudes**
  - identified as a major gap
  - measuring turbulence levels requires a large number of flight hours
- **More flight hours in moderate or stronger turbulence**
  - mid-level altitudes with focus on convective (storm) and breaking wave turbulence
  - performance envelope for onboard radar and lidar
- **Extended data sets for aerosol/turbulence correlation modeling**
- **Scanning versus single line of sight configuration**
  - scanning will enable better characterization of turbulent events
    - more direct comparison with radar for joint tests
  - include a mixture of both modes

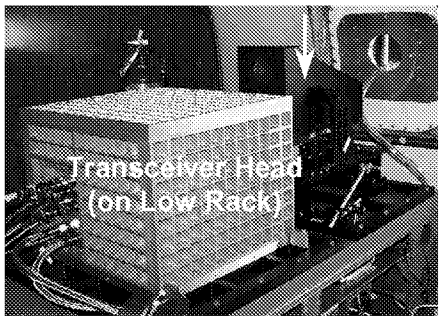
Program Assets and Resources:
Government Agency and Industry

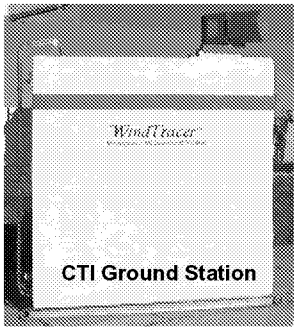
Aviation Safety Program

AFRL System for Precision Air Drop

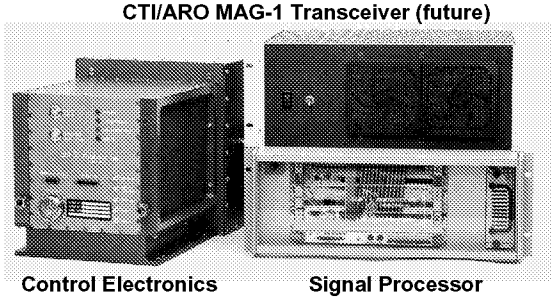


NASA/ACLAIM System

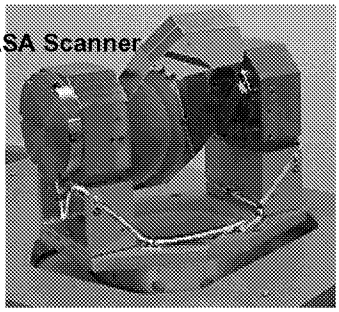




CTI/ARO MAG-1 Transceiver (future)



NASA Scanner



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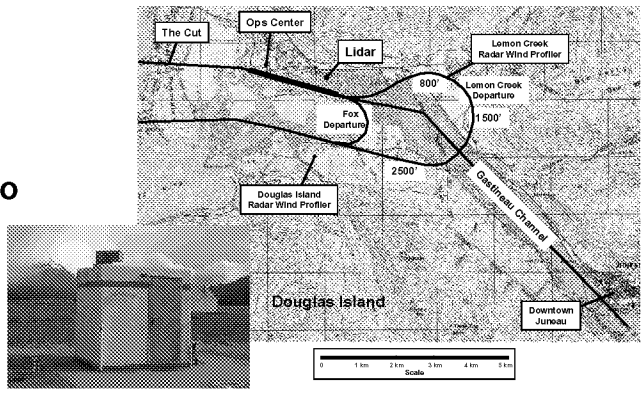
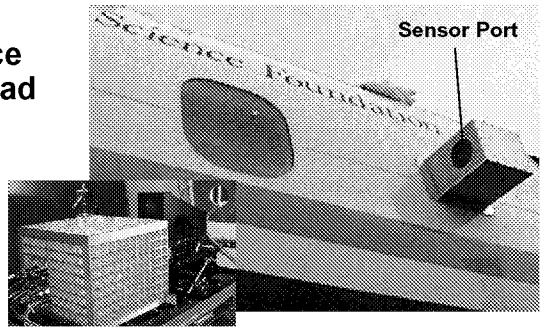
TDAM 1998 Accomplishments: Lidar

Aviation Safety Program

- **Juneau lidar deployment**
  - characterization of low altitude wind shear and turbulence
  - generated validated data sets to support development of lidar turbulence and wind shear detection algorithms

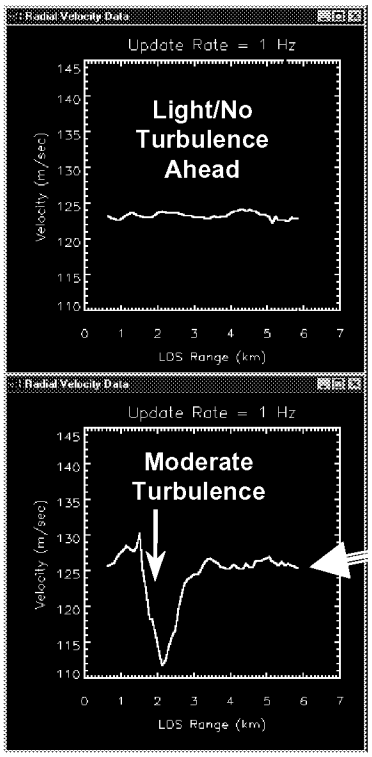


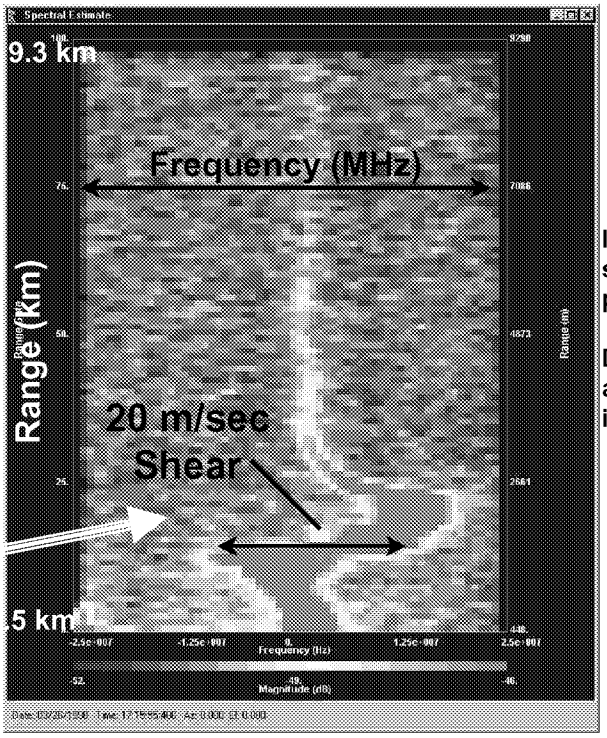
- **ACLAIM/Electra flights**
  - Detected light to moderate turbulence at ranges between 3 and 6 miles ahead
  - Penetrated turbulence to verify
  - Operated 15 hours in a variety of conditions from ground to 25kft



Sample Doppler Spectrum from ACLAIM/Electra

Aviation Safety Program





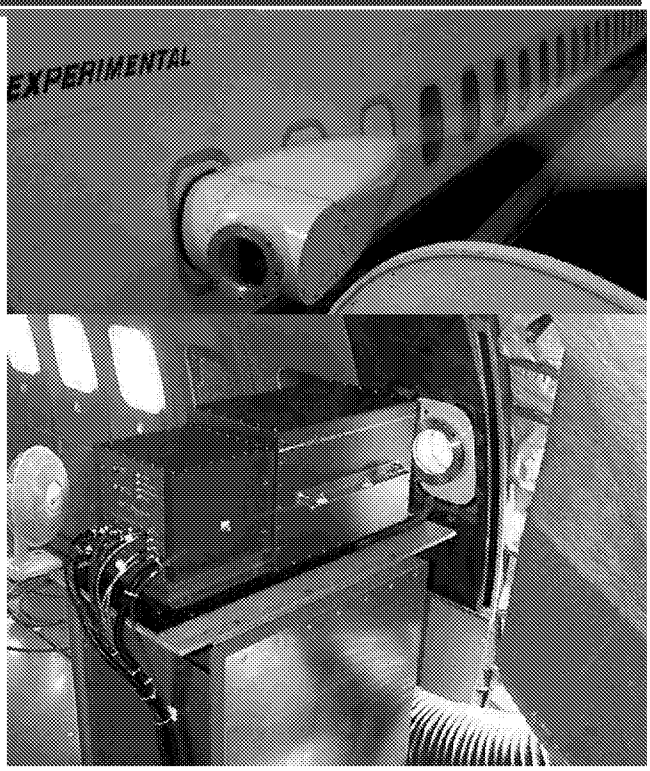
Isolated moderate to severe turbulence patch ahead

Detected turbulence and later penetrated it for confirmation

B-720 Compact Lidar Flight Tests

Aviation Safety Program

- **Collected lidar data to demonstrate CAT IR product capability at cruise altitudes**
  - **data consistent with performance model predictions**
  - **justified parametric system scaling for compact next-generation system**
- **Flights aboard Honeywell-owned B-720**
- **Conducted October, 2000**
  - **focus on cruise altitude operation**
  - **no significant turbulence encountered**



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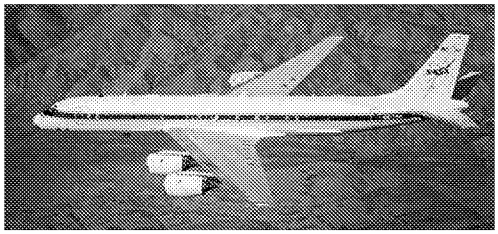
- Plans
  - flight test activities
  - algorithm development and performance simulation

FY01/02 Lidar Flight Tests

- **DC-8 flight tests**
  - lidar operates in a piggy-back fashion
  - joint data for post-flight correlation with
    - in-situ
    - aerosol particle measurements
  - support lidar performance scaling and algorithm development efforts

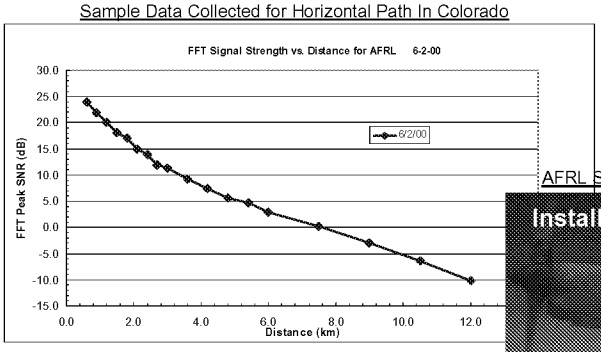


- **B-757 flight tests**
  - joint with other WxAP tests
  - primarily focus on convective turbulence
  - joint data for post-flight correlation with
    - in-situ
    - radar measurements
  - support lidar performance scaling and algorithm development efforts
  - investigate scan strategy tradeoffs

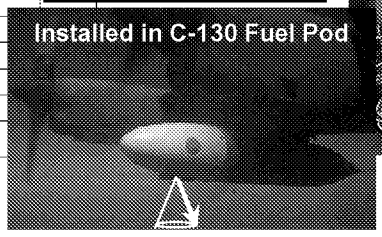
Transceiver Status

- **AFRL hardware delivered in March 2000**
  - **Specs after tune-up at CTI**
    - **2.0125 μm wavelength**
    - **9.3 mJ (out of telescope), 440 nsec pulse duration, 100 Hz PRF**
    - **8 cm beam diameter, 10 cm aperture, internal telescope focused at 1.5-2.5 km**
    - **20% small beam efficiency measured in June**
    - **horizontal path data show range performance to 10-12 km (Colorado data)**

Sample Data Collected for Horizontal Path In Colorado



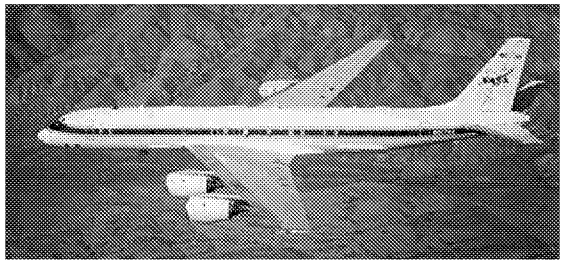
AFRL System for Precision Air Drop

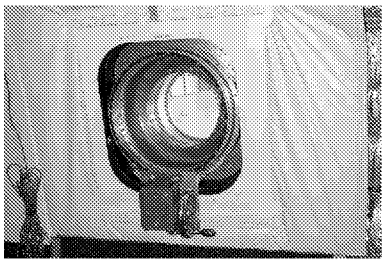


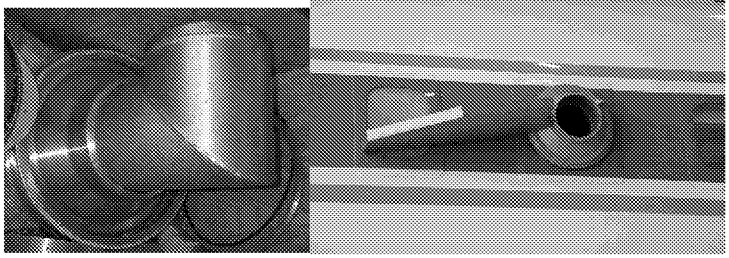
NASA/ACLAIM System

DC-8 Flight Test Status

- **DC-8 volcanic ash encounter**
  - engine replacement required
- **Initial flight window (FY00) dropped**
  - Air-Sci program cancelled
- **CAMEX DC-8 flights scheduled for August-September**
  - piggyback status
  - ~100 flight hours total





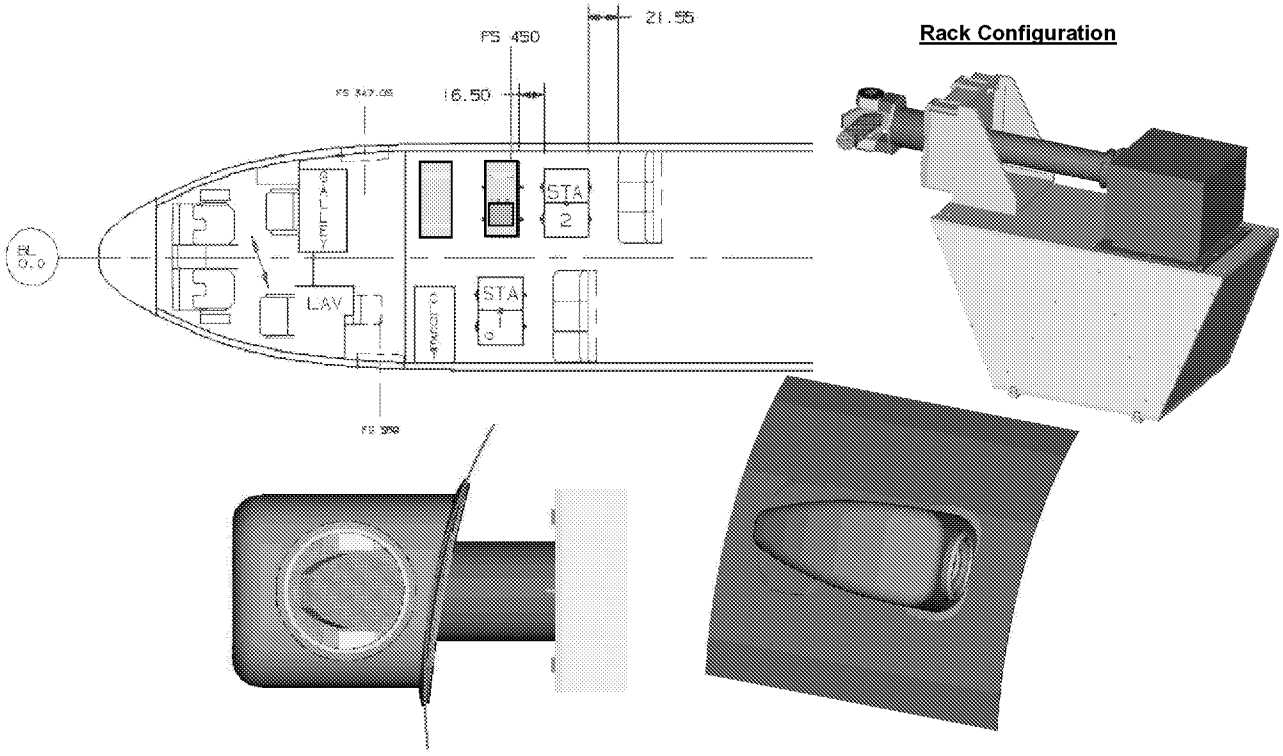


DC-8 Lidar Flight Test Status/Plans

- Forward-looking periscope installed at FS1015
- Integrated AFRL / NASA Lidar system undergoing ground testing at LaRC
- Instrument upload scheduled for July
- Flights anticipated in August-September
  - piggyback on CAMEX includes in-situ turbulence and aerosol
- Research focused on:
  - cruise-condition flight data
  - correlation with atmospheric aerosols
  - correlation of wind shear measurements with other CAMEX measurements

B-757 LIDAR Instrument Layout

Aviation Safety Program



B-757 LIDAR Instrument Layout

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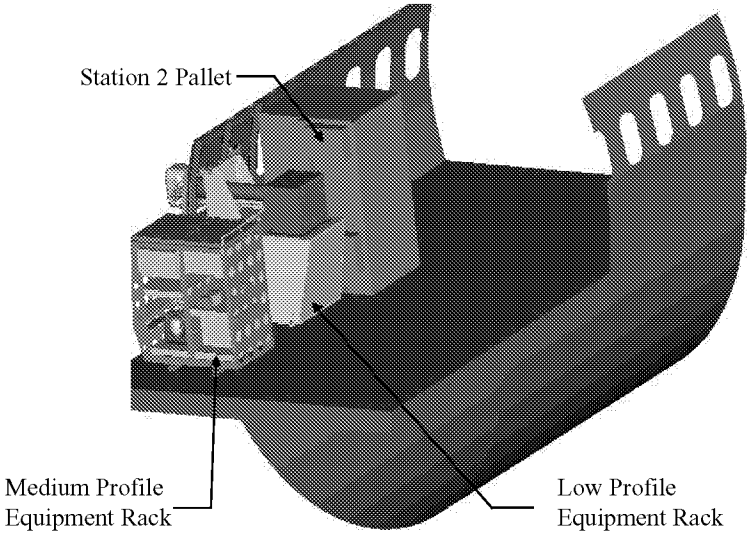


B-757 Lidar Flight Test Status/Plans

- NASA Critical Design Review held in May 2001
- Design for forward-looking scanner installation approved for FS450
- Integrated AFRL / NASA scanning Lidar system undergoing ground testing at LaRC
- Flights anticipated in early CY02
  - joint with Turbulence Radar and Turbulence In-Situ
- Research focused on:
  - scanning effects and strategies
  - synergism with radar
  - convectively-induced turbulence

Lidar Algorithm Development Objective

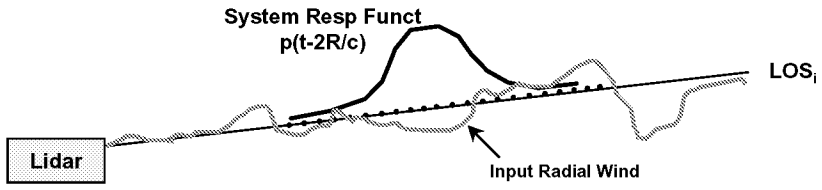
Aviation Safety Program

- **Develop reliable detection and discrimination algorithms for Doppler lidar prediction of turbulence hazard**
  - **exploit understanding of unique aspects of lidar phenomenology**
  - **incorporate common aspects of radar developments**

Lidar Algorithm and Simulation: FY00-02 Approach and Plans

Aviation Safety Program

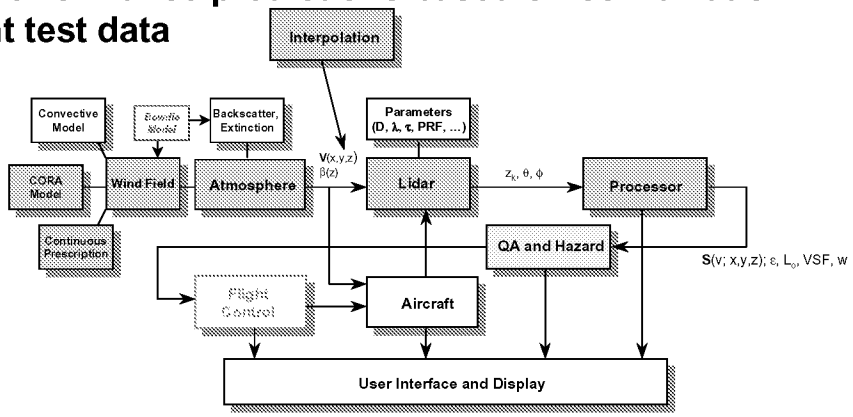
- Maintain synergy with radar algorithm development
- Establish SNR requirements and averaging/resolution/performance trades for spectral width and structure function algorithms
- Establish link to hazard metric algorithm(s)
- Incorporate test cases in more sophisticated simulation
- Test on additional data sets (joint lidar/radar test data)
- Produce more robust performance predictions and feed back into algorithm development
  - false alarm mitigation



Lidar Algorithm Development and Simulation: FY01/02 Activities

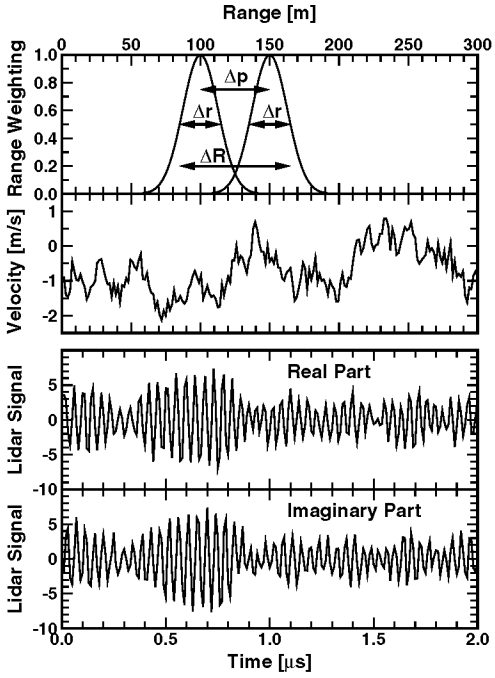
Aviation Safety Program

- Focus on single line of sight algorithms/analyses and leverage existing tools
- Pursue structure function and spectral-width-based algorithms
  - small SNR regime: long range (longer warning times)
  - large SNR regime: correlation of vertical loading with longitudinal observations
  - investigate scan strategy impacts
- Develop preliminary performance predictions based on combination of simulated and flight test data
- Truth metrics initially limited (simulation using 2DOF a/c)



Lidar Algorithm Development and Simulation: Leveraging

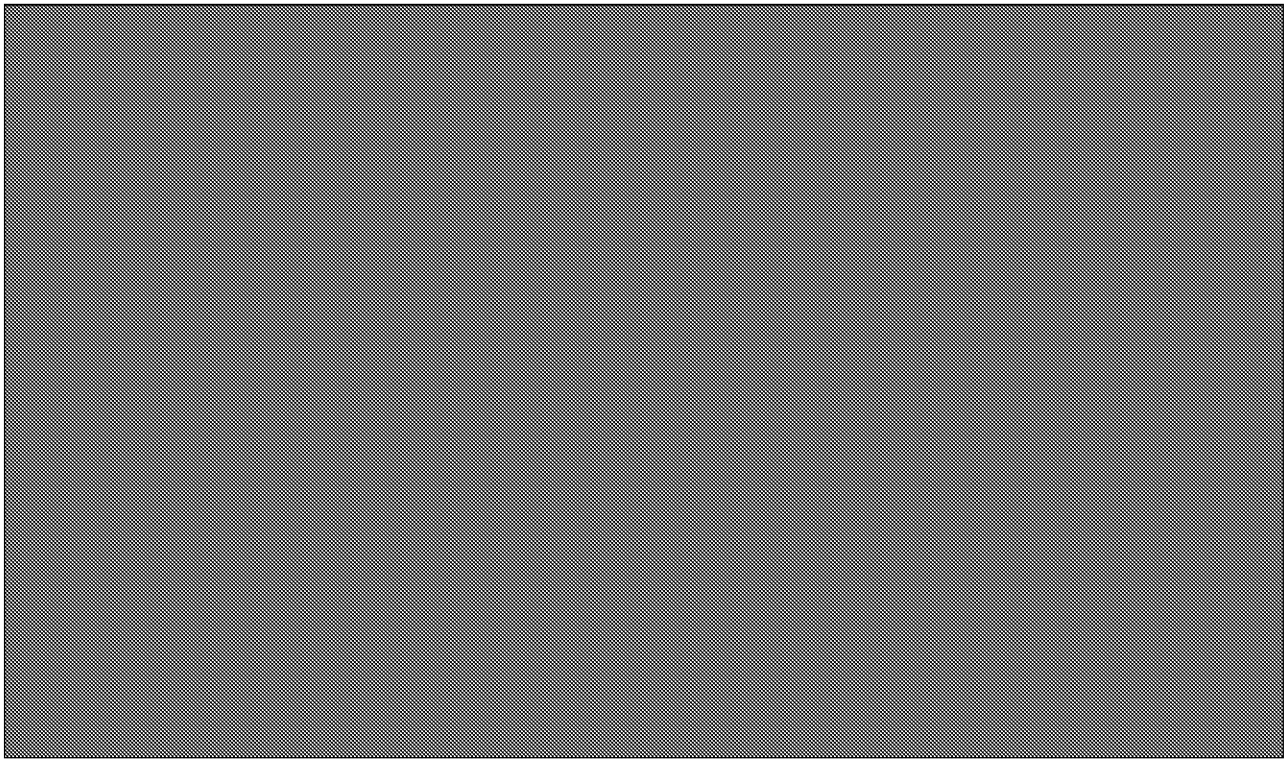
- **CIRES/NCAR:**
  - Space Lidar for NASA (SPARCLE)
  - extending detailed simulations
- **CTI**
  - simulation for wake vortex detection
  - existing real-time algorithms
- **Synergy with radar**
  - NCAR and RTI developments
- **Results in cost-effective development with near-term results**



Lidar Summary

- **Emphasis areas**
  - flight testing
  - algorithm development and associated performance analyses
- **Flight tests accomplished CY99-00**
  - NASA ACLAIM Electra flights
  - industry-funded B-720 flights
- **Flight tests planned for late CY01, early CY02**
  - DC-8 flights planned for August-September, piggy-back on CAMEX
  - B-757 flights in early CY02, joint with Turbulence Radar and In-Situ
- **Algorithm work highly leveraged**
  - NCAR and CTI developments
  - synergy with radar work (NCAR & RTI)
- **Parallel industry program to develop a clear air turbulence product**
  - focus is on cost reduction and reliability improvement

Turbulence Lidar Development Status

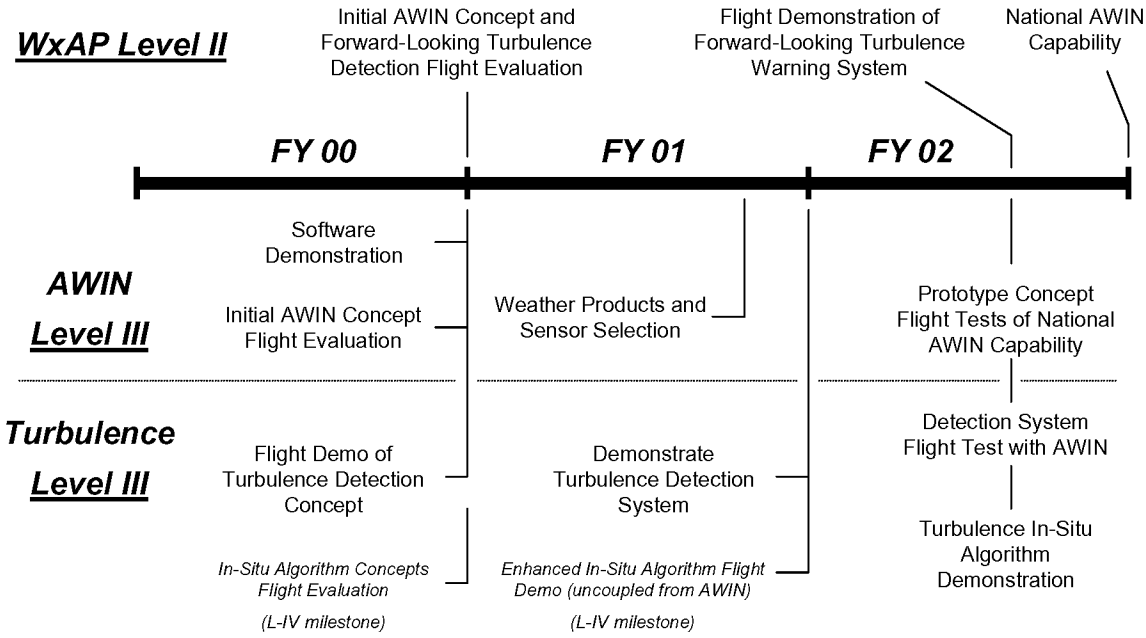


Reference Foils

SUPPORTED MILESTONES

(Through FY 02 only; Excludes WINCOMM)

Aviation Safety Program



Background

- **Turbulence Initiators**
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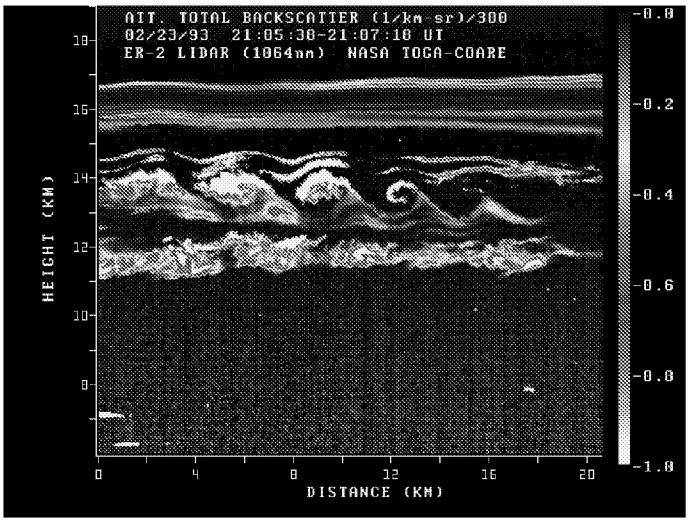
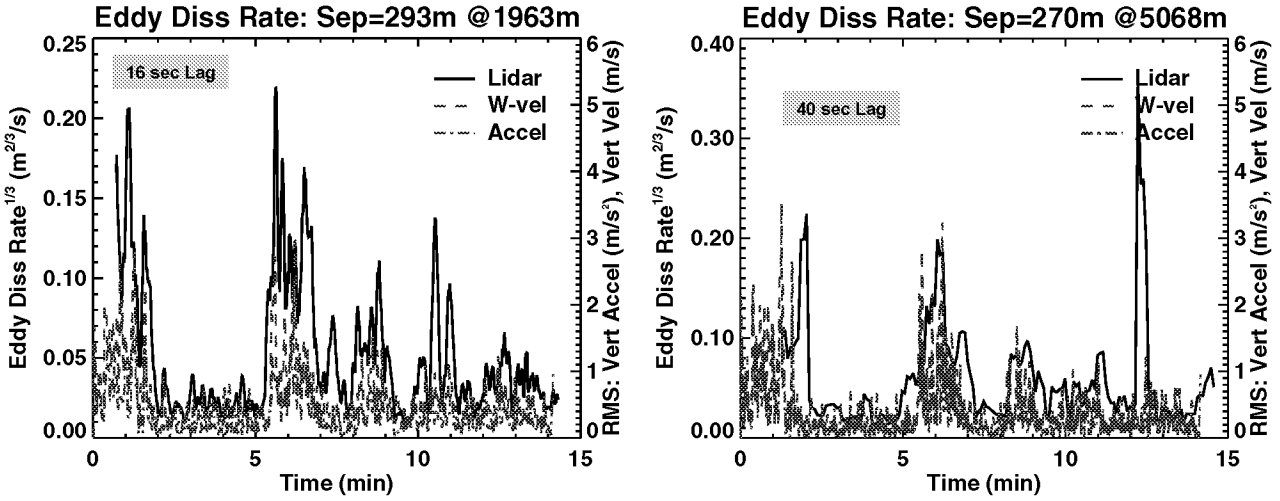


Localized "events" like these are extremely difficult to reliably forecast

Demonstration of Lidar Turbulence Detection

Good Correlation with Onboard Data out to 40 sec Lag (Flight 2)

Aviation Safety Program

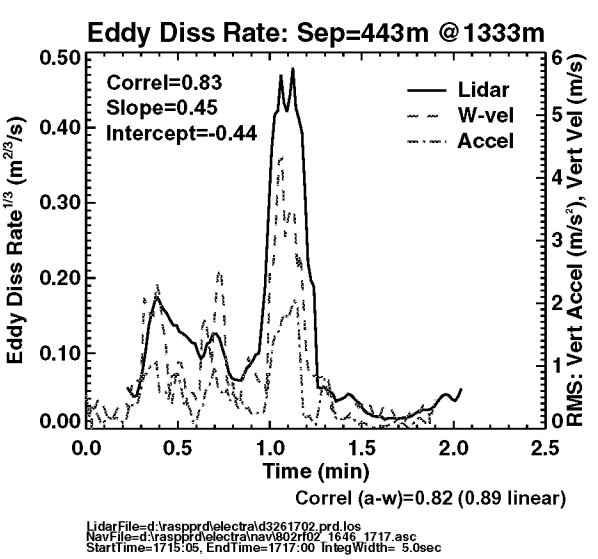


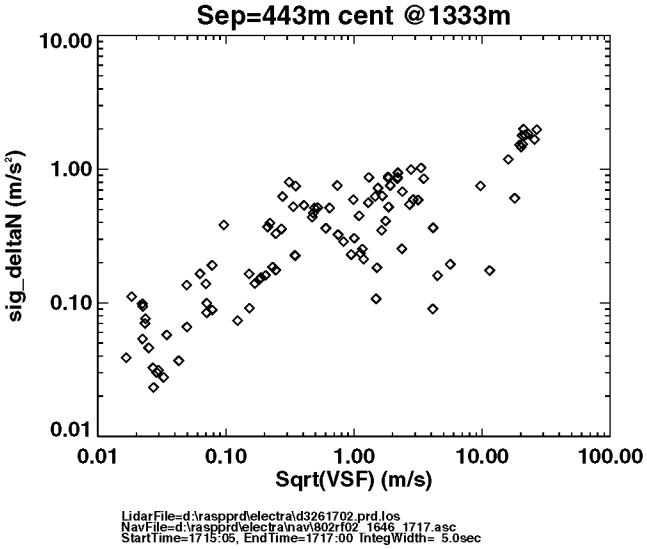
Time Evolution, Beam Pointing Jitter (A/C Pitch) Can Reduce Accuracy for Long Lags

Background: Demonstration of Lidar Turbulence Detection

Good Correlation with Onboard Data (Flight 2)

Aviation Safety Program





Correlation of 1.3 km lagged structure function about as good as that between rms acceleration and rms vertical velocity