Historical Review of CLR Wind Sensing

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Coherent Investments, LLC
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obtained, design values calculated
• Models developed, experiments conducted, data
• Strong shock interactions producing high temperatures
• Liquid Hydrogen-Oxygen Plumes
• Liquid Kerosene-Oxygen Plumes

RADIAITION DESIGN CRITERIA FOR SATURN VEHICLES •
• ALSO -- Tekkies
• Heat and Mass Loss from Re-Entry Vehicles
• Study of Heat Protection Materials
• Re-Entry Physics

NASA-MSC -- 1961

Sensing

Historical Review of CLR Wind
Sensing Historical Review of CLR Wind
Possible Atmospheric Wind Measurements Were Center Management Asked Whether Sensing Historical Review of CLR Wind
Historical Review of CLR Wind Sensing

- First Wake Vortex Velocity Measurements
- First Atmospheric Wind Comparisons Performed
Using A MOPA Design.
Utilized Except Smaller Optics And Short Pulse, But
Feasibility Study Conducted. FIPER Pond Lidar Design
Measurement Detection Of CAT.
Technology Could Be Extended To On-Board Aircraft
Turbulence Detection, The Center Asked Whether The
Happening. There Was Interest In Airborne Clear Air
Saturn Design Programs Were Ending, Flights Were
First Wake Vortex Velocity Measurements
First Atmospheric Wind Comparisons Performed
sensing

Historical review of CLR wing

FIG. 3

CAT RESEARCH INSTRUMENTATION

ON CY 990

MSFC-78-E-AERO-135-A

PULSED LASER BEAM

BACKSCATTERED LASER LIGHT

TURBULENCE
Vortex data, operating for several months, International Airport for obtaining operational wake focused CO2 systems were used at JFK.

Bi-static CO2 approach. System was designed but not implemented. Utilizing a 3-Dimensional wind system was understanding, A 3-Dimensional wind system was used extensively for ground based CO2 system was used extensively for.

Enough laser energy for adequate range but concluded that 10 MJ at CO2 wavelength was not demonstrated overall feasibility of detecting cat.

10 MJ Pulse CO2 system developed and flight tested.

Sensing

Historical Review of CLR Wind
Real-Time Processing of CLR Winds
Russell Targ, Lockheed, Palo Alto, USA
Sammy Henderson, CFI, USA
Bob Menzie, JPL, USA
Jim Bibo, NASA-MSFC
Wermer K Dahe, NASA-MSFC
Ove Steinvall, FOA, Sweden
Lars Ladning, RISO, Denmark
Mike Hardesty, NOAA, USA
Pierre Flamant, CNRS, France
Christian Wermer, DFLR, Germany
Michael Vaughan at RSRE, Malvern, England

Many Contributors to CLR Wind Sensing

Sensing

Historical Review of CLR Wind
- Can steer transmit and receive
- Fast, random, efficient, steering over wide angles
- Can couple with FSM, or other fine steering
- Need a stack of them, + or - 1 deg, + or - 2 deg, etc.
- Can steer to random large angles, high efficiency (>99% diffraction)

Polarization birefringent gratings will make inroads
- May require steering for an acquisition sensor
- Have to steer on transmit and receive

Non-Mechanical Laser Beam Steering
Rugged, compact assembly
- Minimum number of interconnects
- Digital addressing
- No steering or overshoot

Random-access steering
- \(2^N\) steering angles for \(N\) layers

Geometric resolution increase
- Visible, NIR, SWIR & MIR
- Small to large (>1 cm) apertures
- 0.25° to 20° deflection per layer
- Bandwidth (750 nm @ 1550 nm)
- >99% diffraction efficiency per layer
- 3 states per layer (+1, 0, -1)

over Large angles

Non-mechanical steer beams
- Non-mechanical steer beams
- control (e.g., liquid crystal (LC) switches)

Thin PGS with polarization

Wide-angle steering in discrete steps

Polarization grating (PG) beam deflectors
Applications

- Limited range resolution
- 3 ps pulse duration
- Atmospheric CO$_2$
- Lidar absorption by CO$_2$
- Operated on 10.59 pm CO$_2$
- Pulse variability
- (Limited by chirp and pulse to Moderate frequency stability
- Longer range -> 20-30 km
- Source
- Injection-seeded TEA-pulsed CO$_2$
- 1 joule per pulse, 20 Hz

Lidar (1985 - 2000)

NOAA TEACO Extended Range Doppler
HRD observations of gravity waves and turbulence

<table>
<thead>
<tr>
<th>Precision</th>
<th>Scan rate</th>
<th>Beam rate</th>
<th>Range Res.</th>
<th>Max Range</th>
<th>PRF</th>
<th>Pulse Energy</th>
<th>Wavelength</th>
</tr>
</thead>
<tbody>
<tr>
<td>10 cm/s</td>
<td>Full Hemi</td>
<td>2 Hz</td>
<td>30 m</td>
<td>3-8 km</td>
<td>200 Hz</td>
<td>2 ms</td>
<td>2.02 micron</td>
</tr>
</tbody>
</table>

NOAA High Resolution Doppler Lidar (HRDL)
NOAA current wind research focus

Current NOAA efforts focused on boundary layer characterization for pollution studies, wind energy and greenhouse gas emission studies.

- Making extensive use of small, high resolution lidars potentially deployed in arrays for 3 dimensional characterization of winds.
- Studies of sampling error in vertical velocity measurements of Choukoukar et al., ILRC 27, 2014.
- Talks by Brewer, Bonin, Choukoukar, Hardesty, Pichugina at this conference.
CLAWS MOFA Ladar Architecture

Key Specs:
- ND: YAG at 1.06 μm
- Energy up to 1 J at 10 Hz
- "VAD" scanner mirror 20 cm off-axis telescope
- MOFA Architecture
- Variable Pulse Duration
- "VAD" Scanner Mirror

*Not for distribution*
Zig-Zag Slab Amplifier
- 1 pulse, 0.2-5.0 usec pulse duration (actively variable)

Nd:YAG Master Oscillator/Power Amplifier System
- See Applied Optics 32, 4577-4588 (1993)

CTI and Lockheed demonstrated a 1 J, 10 Hz, 1 m coherent laser radar in 1991

Coherent LIDAR Atmospheric Wind Sounder

CLAWS
Lidar and balloon borne rawinsonde data agreed well.

- Winds at Kennedy Space Center

- Accurately measured to 27 km Height
- Space-based winds for improved weather forecasting
- Boundary layer atmospheric research
- Wind energy survey and management
- Optimal air data
- Clear air turbulence (CAT) detection
- Aerosol plume detection and tracking
- Wake vortex detection for aviation efficiency
- Wind hazard alerting for aviation safety
- Precision airdrop and gunship ballistic winds

Areas

Key Lidar Wind Sensing Application
Technology

Evolution of CII Coherent Lidar
WindTracer® 2003 Product
Current Generation Product

<table>
<thead>
<tr>
<th>Specification</th>
<th>Details</th>
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<tbody>
<tr>
<td>Velocity Accuracy</td>
<td>~ 0.1 m/s</td>
</tr>
<tr>
<td>Typical Range</td>
<td>20 km (33 km max)</td>
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<tr>
<td>Wavelength</td>
<td>1.617 mm</td>
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<tr>
<td>Pulse Length (FWHM)</td>
<td>250 - 270 ns</td>
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<tr>
<td>Pulse Repetition Frequency</td>
<td>750 Hz</td>
</tr>
<tr>
<td>Pulse Energy</td>
<td>2.5 MJ ± 0.5 MJ</td>
</tr>
<tr>
<td>Average Power</td>
<td>2 W</td>
</tr>
</tbody>
</table>
Wake Measurements for Air Traffic Management

12 Years of Operational Wind Hazard Detection and WindTracer® Airport Installations
- Both Digital Holography / Spatial Heterodyne, and Temporal Heterodyne
  Coherent Laser has a strong future!
- Multi-aperture MIMO based coherent Laser will be explored for its benefits
  The ability to measure field will be a significant factor in future coherent
  Wavelengths will migrate longer as components develop
  Detector arrays are becoming larger and more sensitive
  Random access, non-mechanical, steering will gain traction
  In coherent Laser
  If laser diodes can solve coherence issues they will gain widespread usage
  Fiber based coherent Laser is becoming widespread
  Solid State Lasers became widespread in the 90's
  Strong LO to suppress noise
  CO2 Coherent Laser became widespread in the 70's and 80's using a

Talk at Barcelona Meeting
Summary from Paul McMammon