New Meteorological and Lightning Instrumentation at Pad 39B
Kennedy Space Center, Florida

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- Data
Background

LC 39B Lightning Protection System Construction, 2009
Background

Atlantis and Endeavour, 2009
Background

STS-125, Atlantis, May 11 2009
Background

ARES I-X Test Rocket, October 28 2009
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### Meteorological Instrumentation

<table>
<thead>
<tr>
<th>Measurement</th>
<th>Range</th>
<th>Accuracy</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wind Speed</td>
<td>0.0 to 60 m/s</td>
<td>± 2% up to 25 m/s</td>
</tr>
<tr>
<td>Wind Direction</td>
<td>0 to 359 degrees</td>
<td>± 2 degrees</td>
</tr>
<tr>
<td>Air Temperature</td>
<td>-10 to 50 deg Celsius</td>
<td>0.1 deg Celsius (NIST traceable)</td>
</tr>
<tr>
<td>Relative Humidity</td>
<td>0 to 100 %</td>
<td>3% (from 10 to 90% RH)</td>
</tr>
<tr>
<td>Rain Rate</td>
<td>0 to 19.685 inches/hour</td>
<td>5% Accumulation</td>
</tr>
<tr>
<td>Rain Precipitation Accumulation</td>
<td>0 to 39.37 inches</td>
<td>5% Accumulation</td>
</tr>
</tbody>
</table>
Meteorological Instrumentation

- Meteorological stations (CS CR1000):
  - Battery backed up
  - GILL Instruments HS WindObserver
    - 0-75 m/s (0-168 mph)
    - 0.01 m/s resolution
    - 0-12 m/s +/- 1%; 12-25 m/s +/- 2%; 25-45 m/s +/- 3%; 45-65 m/s +/- 4%; 65-80 m/s +/- 6%
    - Resolution of 1° and accuracy of +/- 2° @ 12 m/s, no dead band
  - R.M. Young 41372VC/VF with aspirated shield
    - Temperature range -10 to 60°C, accuracy +/- 0.1°
    - RH range 0-100%, accuracy 3%
  - Optical Rain Gauge OSI ORG-815-DS
    - Range 0.1 to 500 mm/hr, resolution 0.001 mm, accuracy 5% accumulation,
Meteorological Instrumentation
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Lightning 101

• What is a flash? What is a stroke?
Lightning 101

Diagram of lightning processes:
- Cloud charge distribution
- Preliminary breakdown
- Stepped leader
- Attachment process
- First return stroke
- Dart leader
- Second return stroke

Timelines:
- 1.00 ms
- 1.10 ms
- 1.25 ms
- 19.00 ms
- 23.00 ms
- 20.0 ms
- 20.20 ms
- 40.00 ms
- 63.00 ms
- 61.00 ms
- 62.05 ms
How many different types of lightning?

- **Upper Atmosphere**, or TLE:
  - blue jets, gigantic jets, sprites, sprite halo, elves, etc.
- **Lower Atmosphere**:
  - cloud to cloud, cloud to ground, ground to cloud, upward, downward, ball, spider, triggered, positive, negative, volcanic, etc.
Lightning 101

• Can lightning strike more than one location simultaneously?
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Lightning Instrumentation Requirements

• Immune to lightning strikes
• High detection efficiency $\approx 100\%$, no dead time
• Highly Accurate:
  • $\approx 95\%$, error $< 2$ meters (High Speed Cameras)
  • $\approx 5\%$, error $< 5 - 10$ meters (Ddot & Hdot Sensors)
• Commercial Off-The-Shelf (COTS),
  • Transient Recorders*,
  • Digitizers*,
  • Current Sensors
• Bdot and Ddot Sensors*,
• High Speed Cameras*,
• Custom made,
  • Power conditioning: racks and enclosures,
  • High Speed Camera Trigger Chassis
Lightning Instrumentation

Genesis Transient Recorder, HBM (Nicolet)

- FIFO, computer data transfer,
- Segmented Memory, no dead time
- 100 Megasamples/sec,
- Single mode fiber interface with time propagation delay compensation,
- Comprehensive triggering capabilities:
  - stretch trigger option,
- Master/Slave (shared trigger bus),
- Automated waveform exports,
- 60 channels/chassis x 8 chassis, 10 ns
Perception
Digitizer

Ruggedized 7600 Digitizer, HBM (Nicolet)

- 12 VDC ± 20% 550 mA maximum
- 100 MS/sec, 25 MHz @ -3 dB, sync sampling
- Coupling AC/DC/GND/Reference
- ± 20 mV to ± 100 V Full Scale in 1, 2, 5 steps, 14 bits
- Temperature range: -10 °C to +70 °C
- Max Error: 1% DC to 5 MHz throughout Temp range
- Prototyped and tested at the ICLRT during the 2009, 2010, and 2011 campaigns
- (A) single-ended, isolated common input; (B) LC Duplex, 1310 nm, 4 km typ, 12 km max; (C) Power input; and (D) control output.
Digitizer

Ruggedized 7600 Digitizer, LDS Instrumentation (Nicolet), HBM
Digitizer

Ruggedized 7600 Digitizer, LDS Instrumentation (Nicolet), HBM
• Pearson Electronics 1330
• Usable rise-time: 250 ns
• 0.9 Hz to 1.5 MHz
• Maximum peak current 100 kA
• Current time product 65 A-s
• 23 MHz anti-aliasing filters
Downconductors
Why Downconductor Measurements?
Why Downconductor Measurements?

- $I_{max}$
- $I_1$
- 90%
- 10%
- $t_r$

Graphs showing current and timing measurements.
Bdot Field Stations

Four Stations with 3 Axis Bdot Sensors Each

- EG&G MGL-2 Bdot free field sensors,
- 100 Ω, differential twinaxial output, ≈ 300 MHz @ -3dB
- Balun to convert 100 Ω differential to 50 Ω, single mode,
- 23 MHz anti-aliasing filters,
- $A_{eq} = 1 \times 10^{-2} \text{ m}^2$ ($V_{out} = A_{eq} \times \text{dB/dt}$),
- Max field change of $2 \times 10^5$ Tesla/sec,
- Protected by a fiberglass dome,
Why Bdot Sensors?

- Estimate Peak Current and Rate of Change of Peak Currents for nearby events, - Ampere’s Law
- Locate Lightning Strikes, 2 stations with 3 axis allows for 3D location
Ddot Field Stations

Five Stations with 2 Ddot Sensors Each

- EG&G? Prodyne?
- 100 Ω, differential twinaxial output, ≈ 1 GHz @ -3dB
- Balun to convert 100 Ω differential to 50 Ω single mode,
- 23 MHz anti-aliasing filters,
- \( A_{eq} = 1 \times 10^{-2} \text{ m}^2 \) (\( V_{out} = R \times A_{eq} \times \frac{dD}{dt} \)),

\( R \) is the resistance, \( A_{eq} \) is the equivalent area, \( V_{out} \) is the output voltage, \( dD/dt \) is the rate of change of displacement.
Ddot Field Stations
Why Ddot Sensors?

- Locate Lightning Strikes, time difference of arrival, correlation,
- Four unknowns, \((x,y,z)\) and \(t\)
- More than four stations to have an over-determined system of linear equations

\[
\begin{align*}
\Delta t_{21} &= (R_2 - R_1)/c \\
t_1 &= R_1/c \\
t_2 &= R_2/c
\end{align*}
\]
Instrumentation

High Speed Cameras, Vision Research v310

- Two cameras per tower, level E,
- 1280x800 @ 3,200 fps, 8 GB, Color, HD-SDI Video Output to a HD recorder,
- Segmented memory, (12 @ 140 ms)
- 50% pre-trigger,
- Continuous recording,
- Restart after recording, FIFO,
- Triggered by the Genesis Transient Recorder, IRIG-B Synch
- 20-36 VDC, 70 W, Battery Backup Power with EMI filters and SPD
- Weatherproof enclosures with redundant AC units, and
- Stand alone temperature, humidity, power controller
- Dead-time of about 30 ms between segments (non deterministic)
High Speed Camera
Camp Blanding Tests
High Speed Cameras

Tower 1 High Speed Cameras Field of View

Bottom Camera: Tower 2

Top Camera: Catenary (DC7) Pad A background
High Speed Cameras

Tower 2 High Speed Cameras Field of View

Bottom Camera: Tower 3 (VAB background)

Top Camera: Tower 1
High Speed Cameras

Tower 3 High Speed Cameras Field of View

Bottom Camera: Catenary (DC3 & DC4)

Top Camera: Tower 2
High Speed Camera

LCC High Speed Camera Field of View

LC39B  LC39A
How far can the high speed cameras see?
How far can the high speed cameras see?
How far can the high speed cameras see?
How far can the high speed cameras see?
How far can the high speed cameras see?
How far can the high speed cameras see?
How far can the high speed cameras see?
How can we determine the strike location (1)?
How can we determine the strike location (2)?
How can we determine the strike location (2)?
How can we determine the strike location (2)?
How can we determine the strike location (2)?
WX Subsystem LC39B Deployment, 2011

- WX Racks installation PTCR
- Tower One Meteorological Stations Active [MISS]
- Downconductors Instrumentation Active [LISS]
- Towers 2 & 3 Meteorological Stations Active [MISS]
- Two HS Cameras Active [LISS]
- Four HS Cameras Active [LISS]
- All Magnetic Field Measurements Active [LISS]
- All six HS Cameras Active [LISS]
- All Electric Field Measurements Active [LISS]
- LC39A Trigger Signal [LISS]
- LCC HS Camera Added [LISS]

Pending

MISS: installation of Rain Gauge Stations, 45th WS Serial Link

LISS: installation of VAB camera (remove LCC camera)

January | February | March | April | May | June | July | August

Equipment Deployment Only

First Lightning Strike Triggers DAQ
Partial DAQ Active

First Lightning Strike Triggers DAQ

Full DAQ Active
Meteorological Data Shown on OTV (ch. 1002)
## Direct Lightning Strikes LPS Pad B

<table>
<thead>
<tr>
<th>RS #</th>
<th>Date (2011)</th>
<th>Time (UTC)</th>
<th>Delta T [ms] (sub. RS)</th>
<th>Strike Location</th>
<th>Ipeak [kA]</th>
<th>$\Sigma_{bc}$</th>
<th>Rise Time [us] (10%-90%)</th>
<th>Detected</th>
<th># of sensors</th>
<th>Ipeak [kA]</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>3/31</td>
<td>14:50:49.887798</td>
<td>--</td>
<td>DC4</td>
<td>-28.8</td>
<td>2</td>
<td></td>
<td>No</td>
<td>--</td>
<td>--</td>
</tr>
<tr>
<td>2*</td>
<td>3/31</td>
<td>14:50:49.887798</td>
<td>180.445</td>
<td>Catenary (DC3)</td>
<td>-19.3</td>
<td>1.5</td>
<td></td>
<td>No</td>
<td>--</td>
<td>--</td>
</tr>
<tr>
<td>1</td>
<td>5/27</td>
<td>18:21:34.107026</td>
<td>--</td>
<td>Tower 2</td>
<td>-77.6</td>
<td>5.89</td>
<td></td>
<td>Yes</td>
<td>5</td>
<td>-57.0</td>
</tr>
<tr>
<td>1*</td>
<td>5/27</td>
<td>18:24:24.541573</td>
<td>--</td>
<td>DC8</td>
<td>-29.8</td>
<td>2.91</td>
<td></td>
<td>Yes</td>
<td>3</td>
<td>-18.2</td>
</tr>
<tr>
<td>1</td>
<td>5/27</td>
<td>18:25:47.633965</td>
<td>--</td>
<td>Tower 2 &amp; nearby</td>
<td>-26.4</td>
<td>4.37</td>
<td></td>
<td>No</td>
<td>--</td>
<td>--</td>
</tr>
<tr>
<td>1</td>
<td>6/15</td>
<td>00:20:55.637149</td>
<td>--</td>
<td>DC8</td>
<td>-29.4</td>
<td>2.46</td>
<td></td>
<td>No</td>
<td>--</td>
<td>--</td>
</tr>
<tr>
<td>1</td>
<td>7/07</td>
<td>16:29:45.843432</td>
<td>--</td>
<td>Tower 3</td>
<td>&gt; -174.3</td>
<td>5.41</td>
<td></td>
<td>Yes</td>
<td>5</td>
<td>-141.5</td>
</tr>
<tr>
<td>1</td>
<td>7/07</td>
<td>16:29:45.931982</td>
<td>--</td>
<td>Tower 2 &amp; nearby</td>
<td>-74.9</td>
<td>5.66</td>
<td></td>
<td>No</td>
<td>--</td>
<td>--</td>
</tr>
</tbody>
</table>

* No video available for this event.

Two downconductor currents show saturation.
## Direct Lightning Strikes LPS Pad B

### WX Subsystem

<table>
<thead>
<tr>
<th>RS #</th>
<th>Date (2011)</th>
<th>Time (UTC)</th>
<th>Delta T [ms] (sub. RS)</th>
<th>Strike Location</th>
<th>Ipeak [kA]</th>
<th>Rise Time [us] (10%-90%)</th>
<th>Detected</th>
<th># of sensors</th>
<th>Ipeak [kA]</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>7/07</td>
<td>16:35:59.648752</td>
<td>--</td>
<td>Tower 2</td>
<td>-67.8</td>
<td>4.78</td>
<td>Yes</td>
<td>5</td>
<td>-40.0</td>
</tr>
<tr>
<td>2*</td>
<td>7/07</td>
<td>16:35:59.731152</td>
<td>82.2</td>
<td>Tower 1</td>
<td>-47.4</td>
<td>3.9</td>
<td>Yes</td>
<td>5</td>
<td>-26.3</td>
</tr>
<tr>
<td>3</td>
<td>7/07</td>
<td>16:35:59.773986</td>
<td>42.834</td>
<td>Tower 1</td>
<td>-37.4</td>
<td>1.46</td>
<td>Yes</td>
<td>5</td>
<td>-16.8</td>
</tr>
<tr>
<td>4</td>
<td>7/07</td>
<td>16:35:59.796866</td>
<td>22.88</td>
<td>Tower 1</td>
<td>-18.5</td>
<td>1.09</td>
<td>Yes</td>
<td>3</td>
<td>-10.4</td>
</tr>
<tr>
<td>5</td>
<td>7/07</td>
<td>16:35:59.946027</td>
<td>149.161</td>
<td>Tower 1</td>
<td>-38.1</td>
<td>1.16</td>
<td>Yes</td>
<td>5</td>
<td>-23.1</td>
</tr>
<tr>
<td>6</td>
<td>7/07</td>
<td>16:35:59.992795</td>
<td>46.768</td>
<td>Tower 1</td>
<td>-27.4</td>
<td>1.13</td>
<td>Yes</td>
<td>5</td>
<td>-16.6</td>
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<tr>
<td>7</td>
<td>7/07</td>
<td>16:36:00.079704</td>
<td>86.909</td>
<td>Tower 1</td>
<td>-32.4</td>
<td>1.11</td>
<td>Yes</td>
<td>5</td>
<td>-19.7</td>
</tr>
<tr>
<td>8</td>
<td>7/07</td>
<td>16:36:00.145245</td>
<td>65.541</td>
<td>Tower 1</td>
<td>-17.6</td>
<td>1.08</td>
<td>No</td>
<td>--</td>
<td>--</td>
</tr>
<tr>
<td>1</td>
<td>8/14</td>
<td>21:10:15.787065</td>
<td>--</td>
<td>Tower 1</td>
<td>-64.1</td>
<td>6.06</td>
<td>Yes</td>
<td>4</td>
<td>-34.1</td>
</tr>
<tr>
<td>2</td>
<td>8/14</td>
<td>21:10:15.849042</td>
<td>61.977</td>
<td>Tower 1</td>
<td>-17.1</td>
<td>1.4</td>
<td>No</td>
<td>--</td>
<td>--</td>
</tr>
<tr>
<td>3</td>
<td>8/14</td>
<td>21:10:15.941681</td>
<td>92.639</td>
<td>Tower 1</td>
<td>-24.1</td>
<td>1.07</td>
<td>Yes</td>
<td>2</td>
<td>-14.2</td>
</tr>
</tbody>
</table>
Between March and August:

- The Lightning DAQ has triggered on 11 different days.
- The lightning protection system has been struck directly by 9 lightning flashes (all towers are been struck):
  - 6 direct strikes to the towers
  - 3 direct strikes to catenary wires or downconductors
  - 6 single stroke flashes
  - 3 multi-stroke flashes (max. 8RS; min. 2RS)
- There have been 3 nearby lightning strikes within the LC39B perimeter:
  - 1 strike to the perimeter fence (multi-stroke flash)
  - 2 inside the perimeter (single-stroke flashes)
- How does the LC39B Lightning Instrumentation System compares to CGLSS II? \( \approx 63\% \)
Lightning Instrumentation and CGLSS
Lightning Instrumentation and CGLSS
Lightning Instrumentation and CGLSS

\[ y = 1.4x + 7.8 \]

- Peak Current [kA] - Direct Strikes from March to August 2011
- CGLSS Calculated Peak Current, kA
- LC39B/LPS Measured Peak Current, kA

Histogram of Estimation of CGLSS Peak currents compared to LC39B measurements, %
Selected Images

Direct Strike to Tower 2, 05/27/2011 18:21:34.107026 UTC.
Frame before 1\textsuperscript{st} RS

Following frame
Selected High Speed Camera Images
Selected High Speed Camera Images
Selected High Speed Camera Images
Selected High Speed Camera Images

LC39B WX SUBSYSTEM DATA
Selected High Speed Camera Images
Advantages of the LC39B Lightning Instrumentation System

• Very high detection efficiency, perhaps 100%,
• Very accurate system,
• Direct measurements, Ip and dl/dt,
• System will allow us to improve lightning protection systems by providing data to refine the striking distance method,
• System will provide ground-truth data to improve lightning detection system peak current estimation,
• Save significant amount of man hours in the future,
THANKS!!!

Questions?