LED Airport Lighting Behavior in Real-World Conditions

Data Collected Between April 2019 and January 2020

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Special Thanks

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  - Matt Harmon
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  - Leo Jacobs

Background and Site Overview

Background

- LED lamps are more energy-efficient and have a much longer service life, so are attractive options for airport lighting
  - However, they are relatively new and have different spectral characteristics to existing incandescents
- A data collection effort was conducted to assess the characteristics of LED and incandescent lamps under real-world adverse weather conditions
  - Particular focus on severe adverse weather conditions, where lights are most important

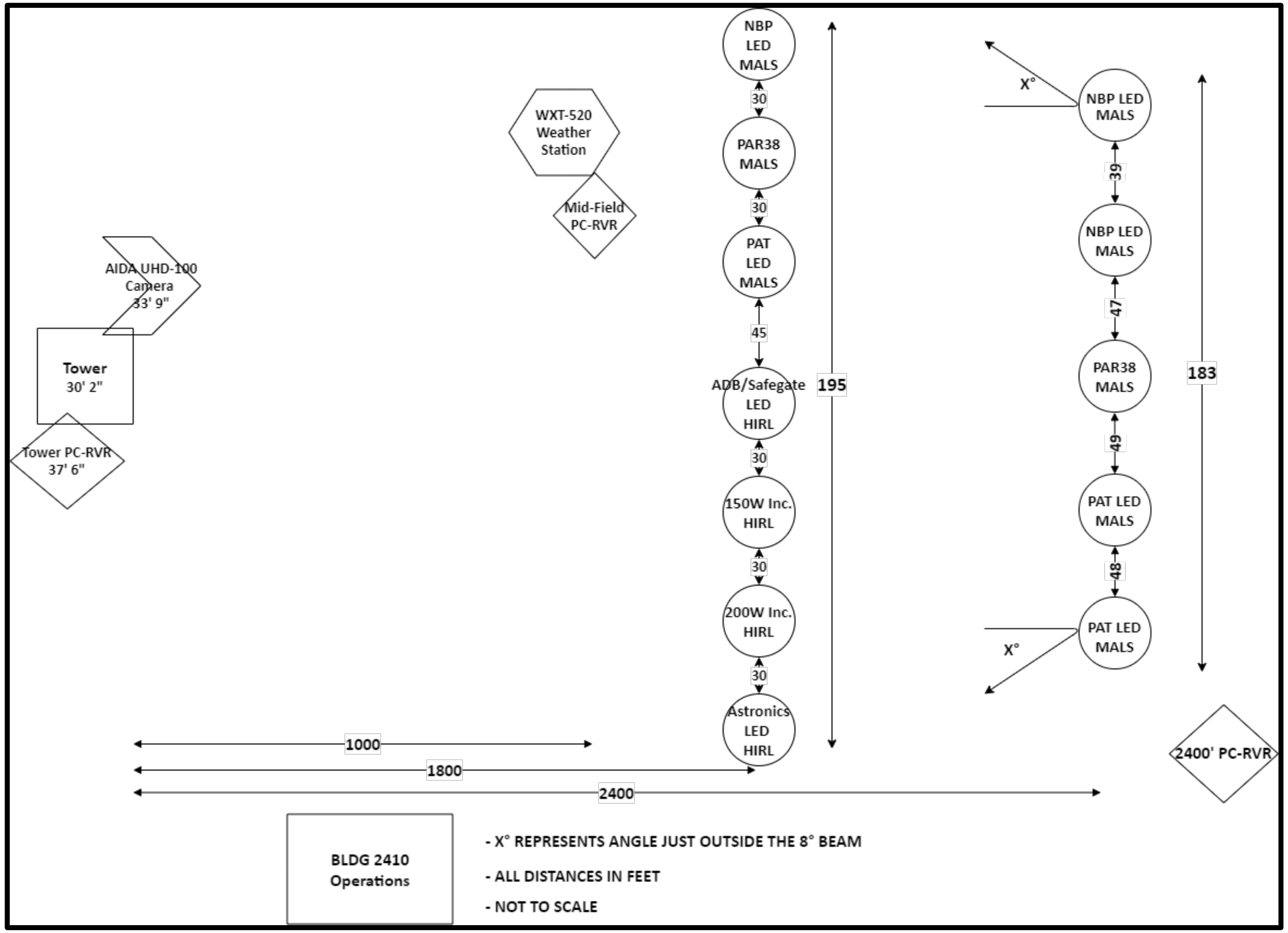
Brand Name Disclaimer

- The purpose of this analysis was not to compare specific manufacturers' products, but to evaluate LED and incandescent airport lighting as groups
- The United States Government does not endorse products or manufacturers. Trade or manufacturers' names appear herein solely because they are considered essential to the objective of this presentation.

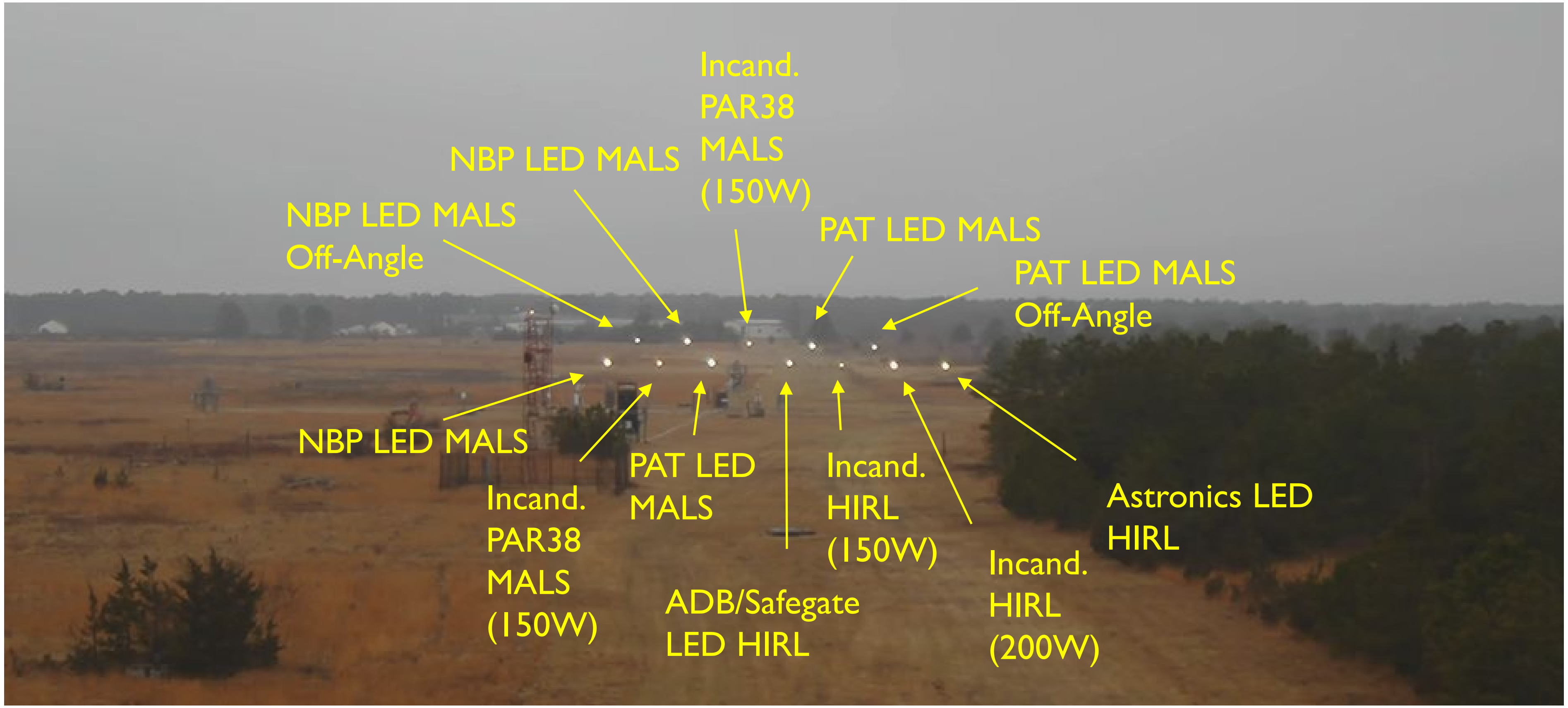
Test Design/Setup

- Data collected at the Volpe Aviation Weather Research Facility (AWRF)
- Designed a "simulated runway"
  - Unobstructed cleared region about 200 feet wide and 2400+ feet long
  - Array of 12 lights, in two rows at 1800' and 2400' from the tower
  - One row of 7 lights (3 MALS, 4 HIRLs), 1800' from the tower
  - One row of 5 lights (all MALS), 2400' from the tower
  - Light arrangement was staggered to ensure visual separation between lamps
- Observation point was a 30-foot tower with mounted visible-spectrum camera, PC-RVR visibility sensor, and data acquisition equipment
- All lamps were tested at maximum intensity to assess performance under severely reduced visibility

Site and Lighting Layout - Schematic



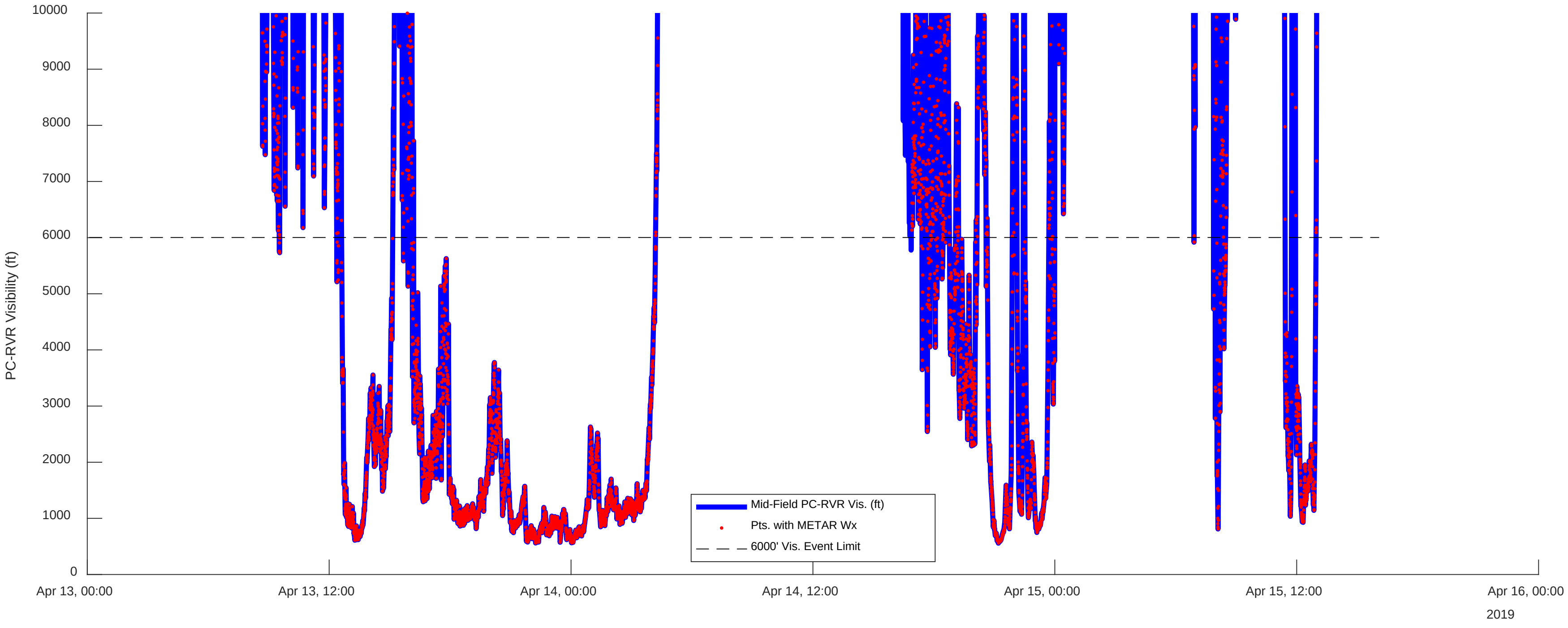
Site Layout – Camera View



Data Collection Overview

- Data collection period ~9 months: April 2019 to January 2020
- METARs reports from KFMH (approx. 1.5 miles away) used to identify weather for low-visibility events
- Site Sensors/Instrumentation
  - **Visible-spectrum camera**
  - **3 PC-RVRs (located tower, mid-field, and next to the 2400’ row of lights)**
  - FM-120 Fog Spectrometer
  - WXT-520 Weather Station
  - OTT Parsivel² Disdrometer/Present Weather Sensor
- **Bold** = focus of this assessment

PC-RVR Visibility and METARs Adverse Weather

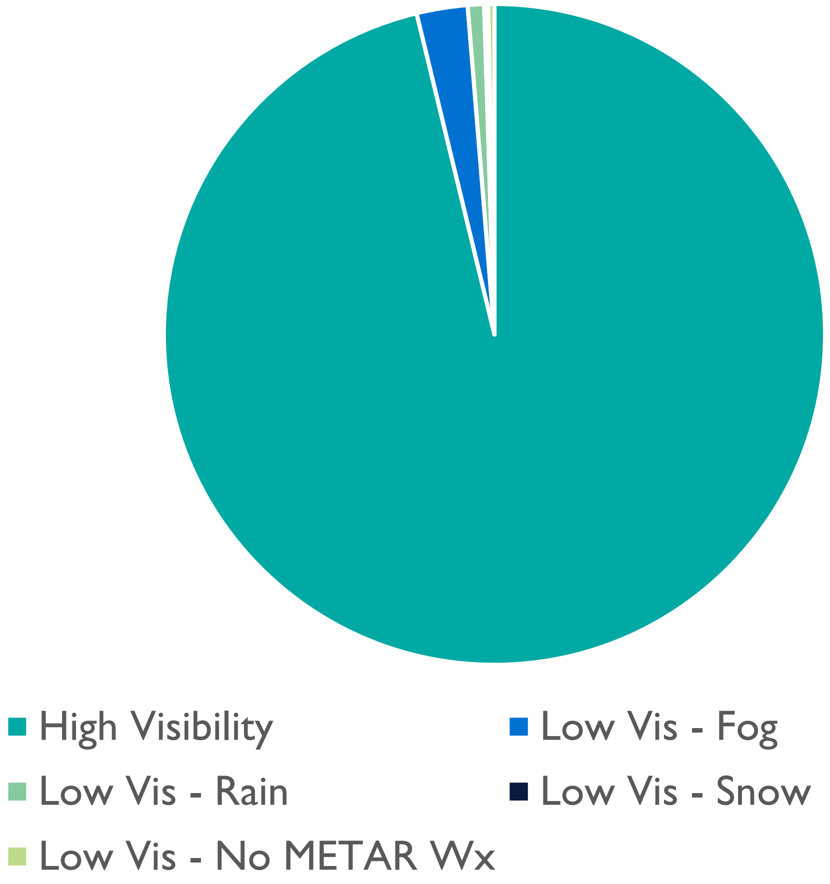


Precipitation/Obscuration Events

- Divided METAR precip./obs. codes into fog/rain/snow
- Resolution of METAR data is relatively low (20 min & 1 hour) so any wx that shows up during an event is saved
- Weather types are not exclusive (e.g. a fog event may also qualify as a rain event)
- A low-visibility event begins when visibility < 6000’ for at least 5 minutes
- A low-visibility event ends when visibility >= 6000’ for at least 5 minutes

Weather Statistics

- ~9 months (293 days) of data collection
- 304 low-visibility events (10 days of data / 3.4% of overall dataset):
  - 163 fog events (7.4 days or 2.5%)
  - 104 rain events (2.2 days or 0.8%)
  - 7 snow events (0.5 days or 0.2%)
  - Percentages add up to over 100% because weather types were not exclusive
  - Not all periods of reduced visibility were associated with adverse weather (1.0 days or 0.3% of low-visibility data without associated adverse weather)



Methodology

Assessment Strategy

- Previous lab-collected data and pilot reports have suggested that LED lamps are perceived as brighter than nominally equivalent incandescent lamps
- Volpe collected hundreds of hours of visible-spectrum video alongside PC-RVR visibility measurement in real-world adverse weather conditions
- Analysis methodology was developed to objectively and automatically use this large dataset to assess relative visibility of LED and incandescent lighting in adverse weather conditions

Key Metric: RMS Contrast Ratio (1/2)

- Differences in contrast are what allow humans to distinguish objects
- Contrast can be provided by color, luminance, or both, but human eyes are more sensitive to differences in luminance
- A contrast ratio (CR) can be defined to quantify the perceptual difference between an object and its background
- Several different CRs have been defined and used for previous studies (e.g. Weber contrast, *RMS contrast*)
- Depending on exact definition of contrast ratio used, 0.02 – 0.05 is generally held to be the threshold of "just visible"

Key Metric: RMS Contrast Ratio (2/2)

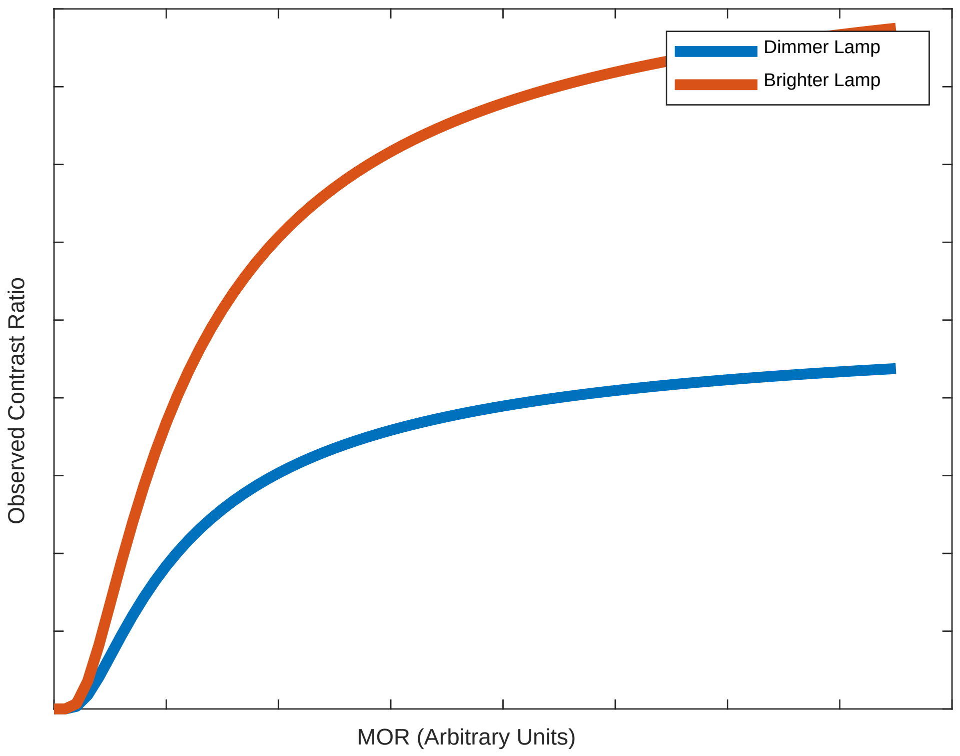
- This analysis uses RMS contrast ratio as the key metric, because:
  - Data analysis shows it tracks better with PC-RVR visibility than Weber contrast (which was also examined)
  - RMS contrast does not require an identification of the object vs. background, which is important because the apparent diameter of the lights changes based on weather conditions
  - RMS contrast "predicts human contrast detection thresholds…better than other common measures of contrast" ("Local luminance and contrast in natural images", Robert A. Frazor and Wilson S. Geisler, Vision Research 46 (2006) 1585–1598)

Connecting Contrast Ratio to Visibility (1/2)

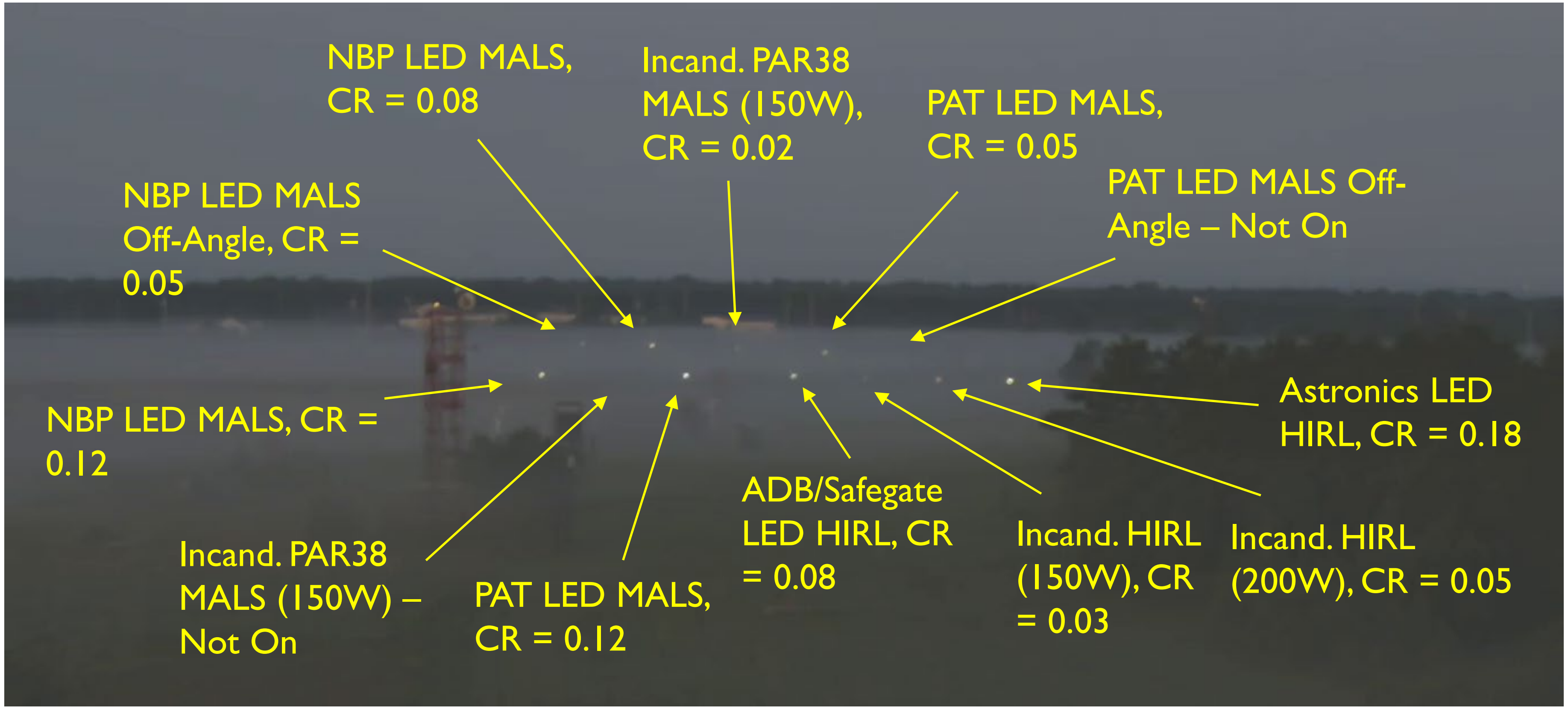
- As previously mentioned, differences in contrast allow us to distinguish objects
  - More contrast (larger CR) = easier to distinguish
- PC-RVRs provide us with an independent measurement of visibility / "meteorological optical range" (MOR)
- We can combine the independent measurement of visibility from the PC-RVRs with the video data showing the brightness of the lamps to gauge the appearance of the lamps at particular visibility ranges

Connecting Contrast Ratio to Visibility (2/2)

- If we are comparing lamps, and one lamp has a larger CR value than the other for a given PC-RVR-measured visibility, that lamp is brighter/easier to see at that visibility
- Based on Koschmieder's Law, we expect an inverse exponential relationship between visibility and CR, $CR \propto e^{-\frac{1}{V}}$ or $\frac{-1}{\ln(CR)} \propto V$ (schematic of relationship shown to right)



RMS Contrast Ratio – Example (inhomog. wx)



- Still from 6:41 AM on 7/10/19
- Visibility = about 1000 ft at lights; no meas. from tower PC-RVR but clearly much higher
- Wx = BR, BCFG (mist, patchy fog)
- All operating lights are visible (some barely)

Methodology Details (1/2)

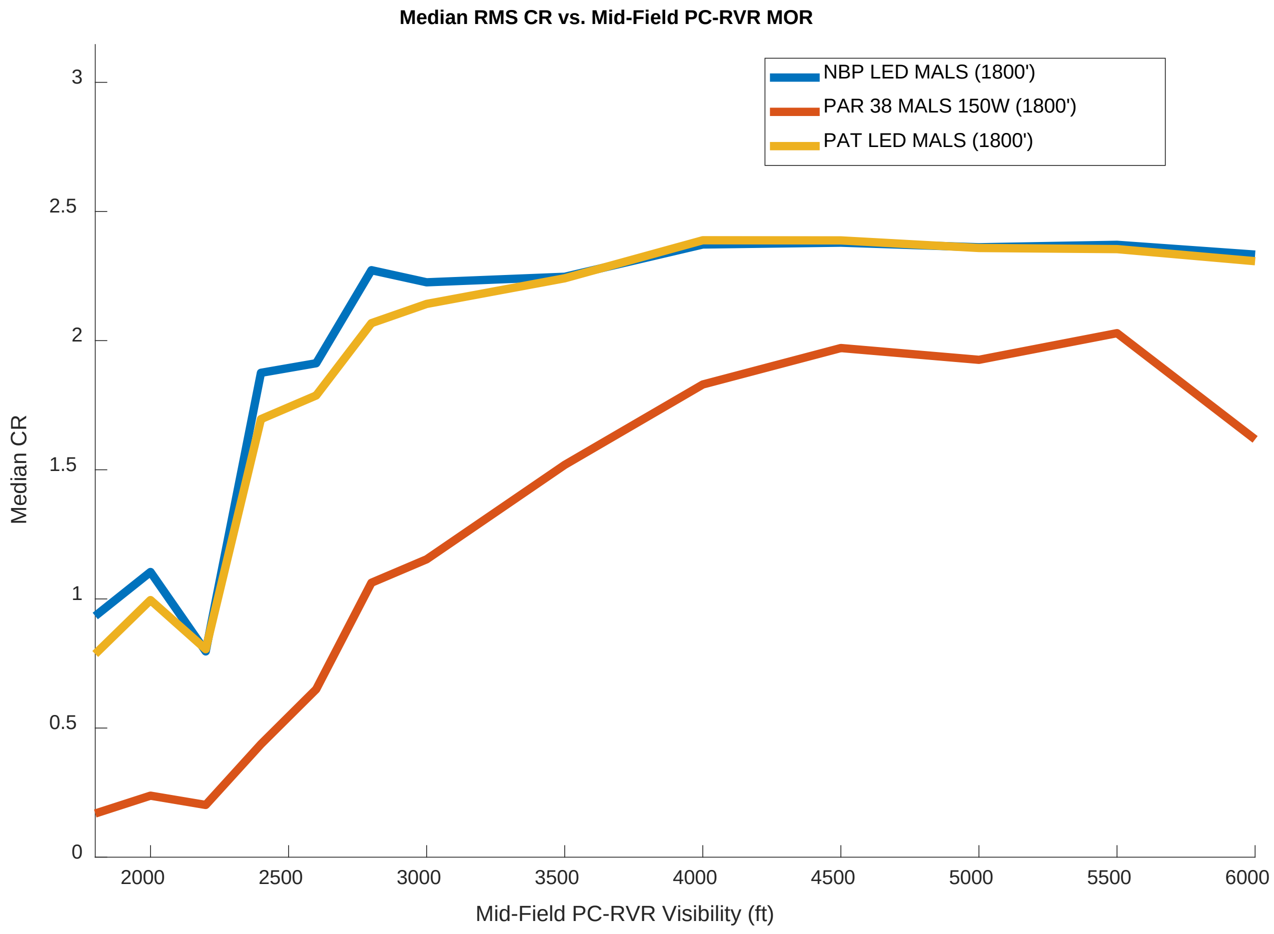
- Identify low-visibility events (vis <= 6000’ for at least 5 minutes)
- For each event:
  - Extract a frame from the video data every 15 seconds (update rate of PC-RVRs)
  - Match video frames to PC-RVR visibility
  - Draw a small box around each lamp containing the lamp and its immediate surroundings
  - Compute RMS contrast ratio for each lamp for every selected frame
  - Associate with METAR weather

Methodology Details (2/2)

- For selected weather conditions (all weather, fog, rain, snow), identify relevant low-visibility events
- Combine matched video-visibility data for relevant events
- Use PC-RVR visibility to separate relevant frames into bins using RVR reporting intervals
  - Reported values are1800 – 3000 ft in 200 ft increments; bins are centered on these values
  - Require at least 400 measurements (100 minutes of data) per bin
- Calculate median CR for each lamp in each PC-RVR bin and plot resulting visibility – CR curves

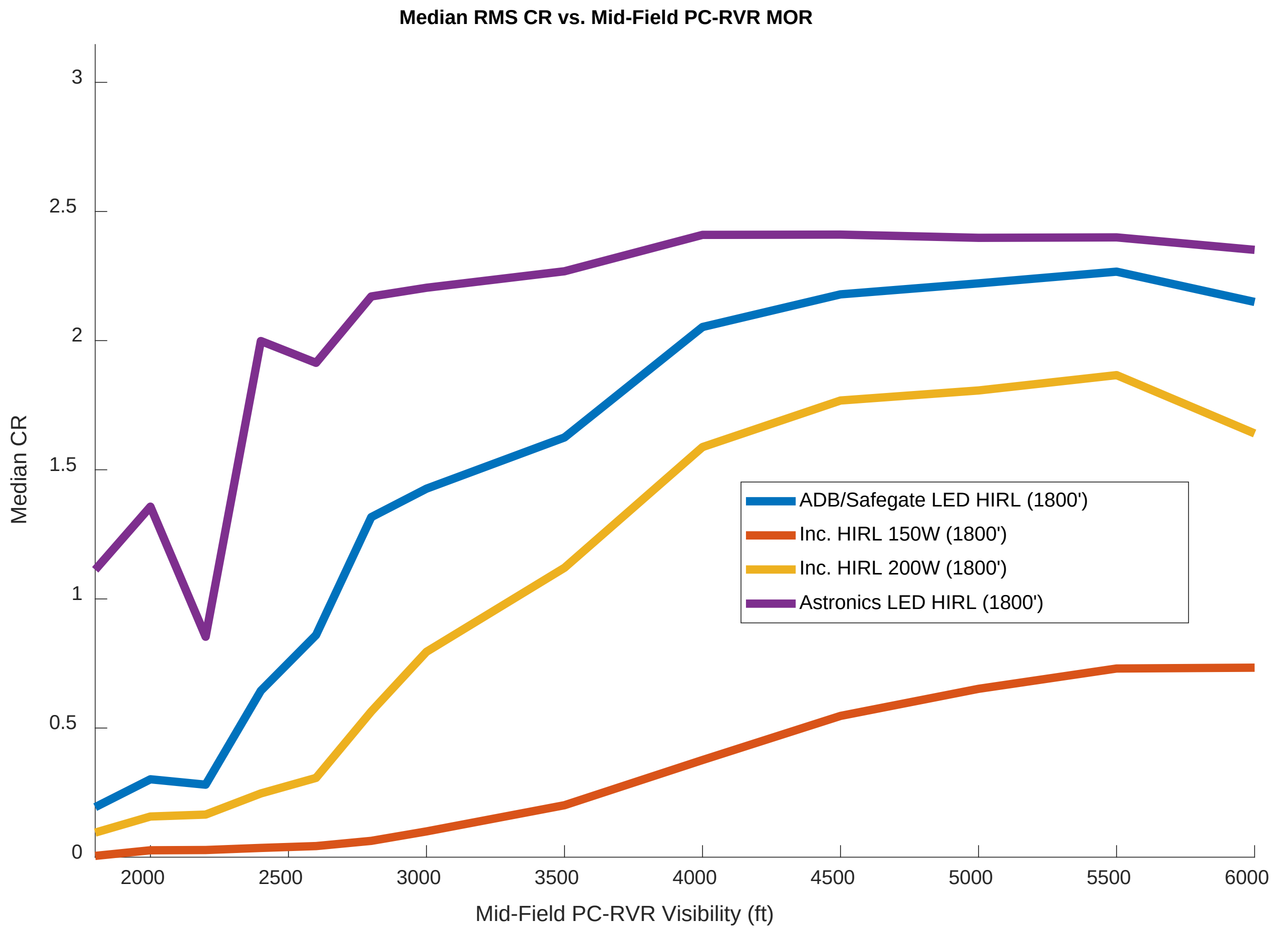
Results – All Weather

Results – 1800' MALS – All Weather



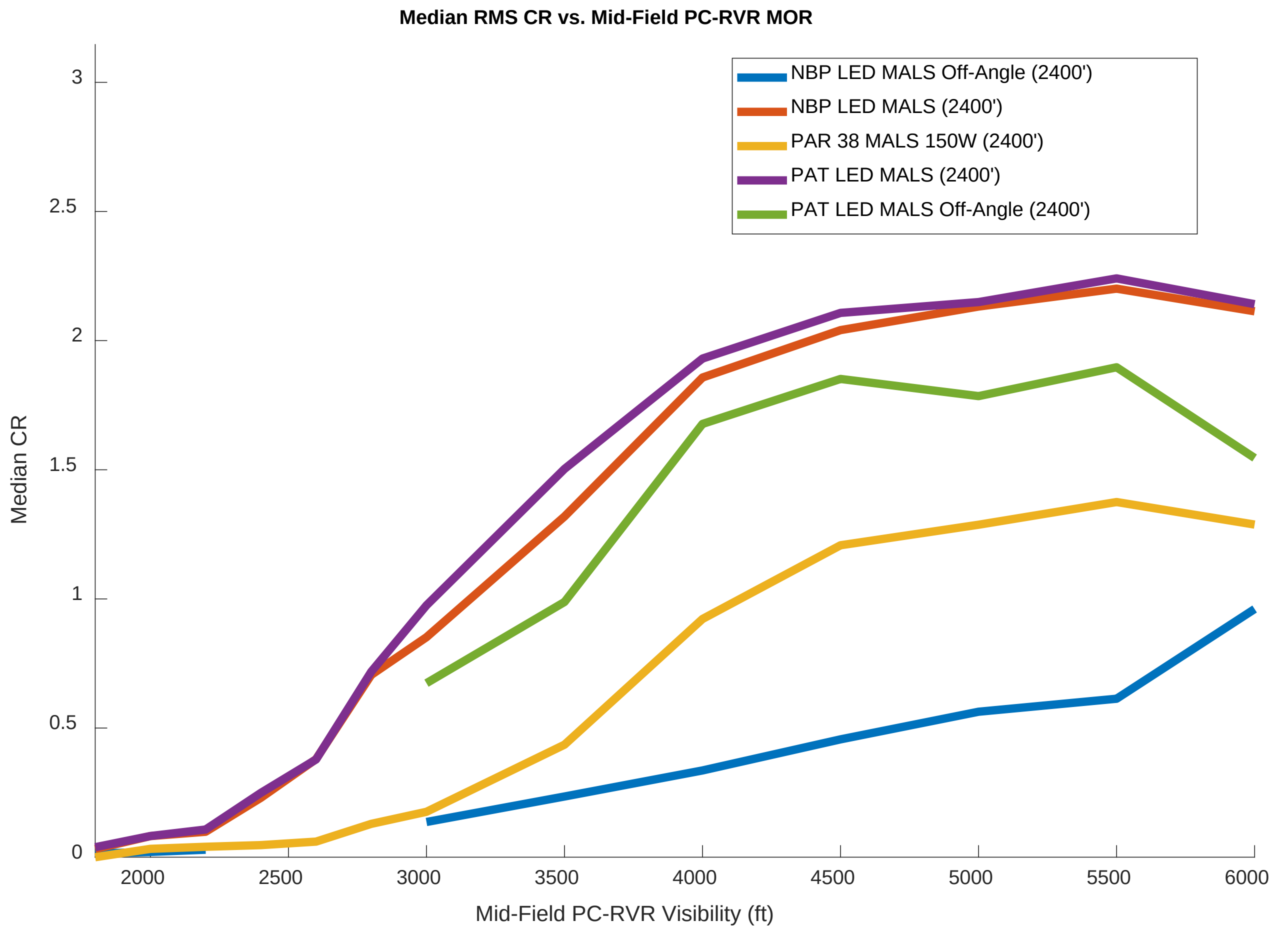
- Curves follow the expected shape
- Patriot and NBP LED lamps are essentially identical
- Both LED lamps are considerably brighter than the 150W PAR38 incandescent

Results – 1800' HIRLs – All Weather



- Curves follow the expected shape
- Astronics LED HIRL is the brightest lamp, with ADB/Safegate HIRL noticeably dimmer
- Both LED HIRLs are significantly brighter than either the 200W or 150W incandescent HIRLs

Results – 2400' MALS – All Weather



- Curves follow the expected shape
- Patriot and NBP LED MALS are very similar, with Patriot slightly brighter
- On-axis LED bulbs are considerably brighter than baseline 150W PAR38 lamp
- Differences in off-angle lamp brightness likely due to slight differences in position rather than lamps themselves

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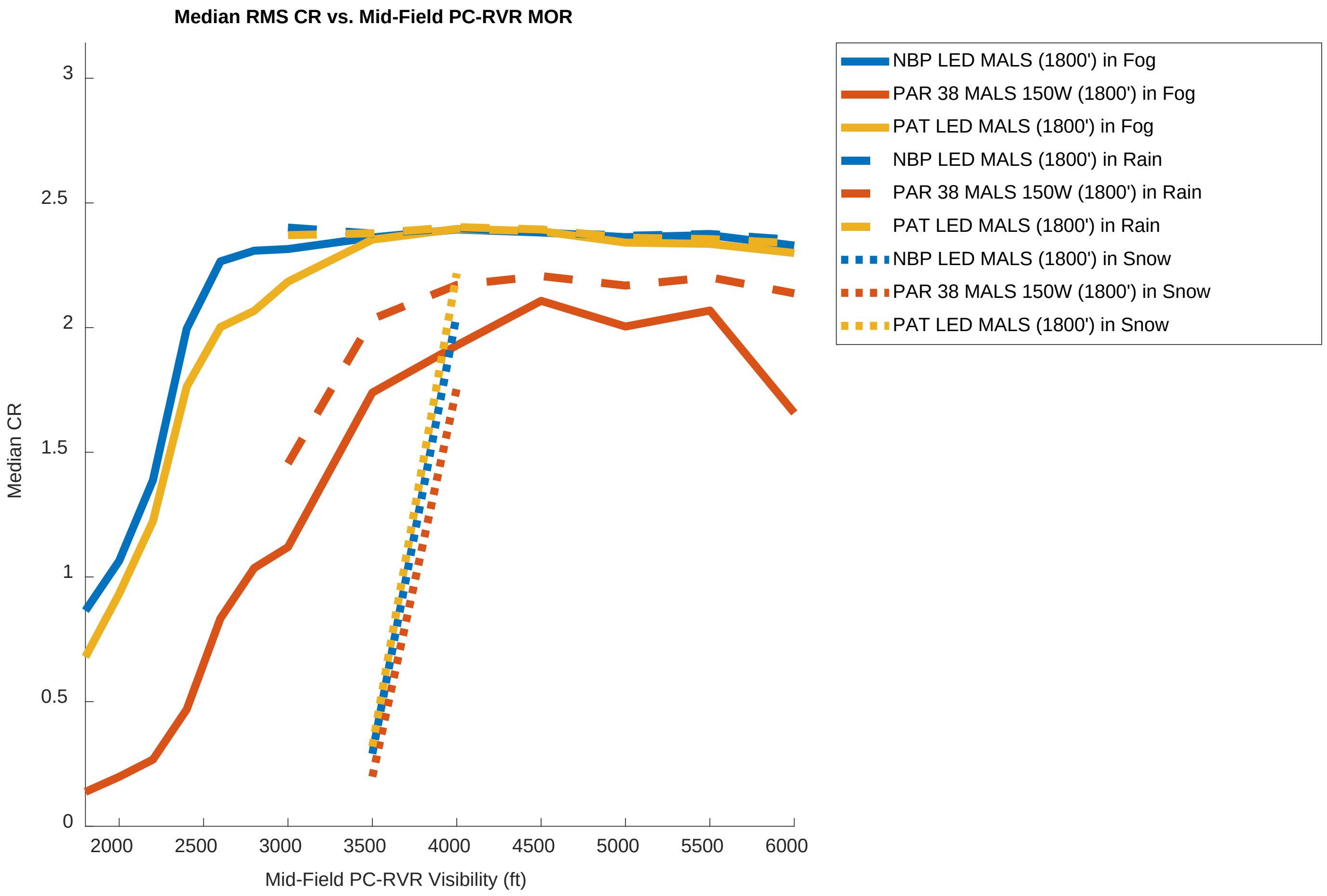
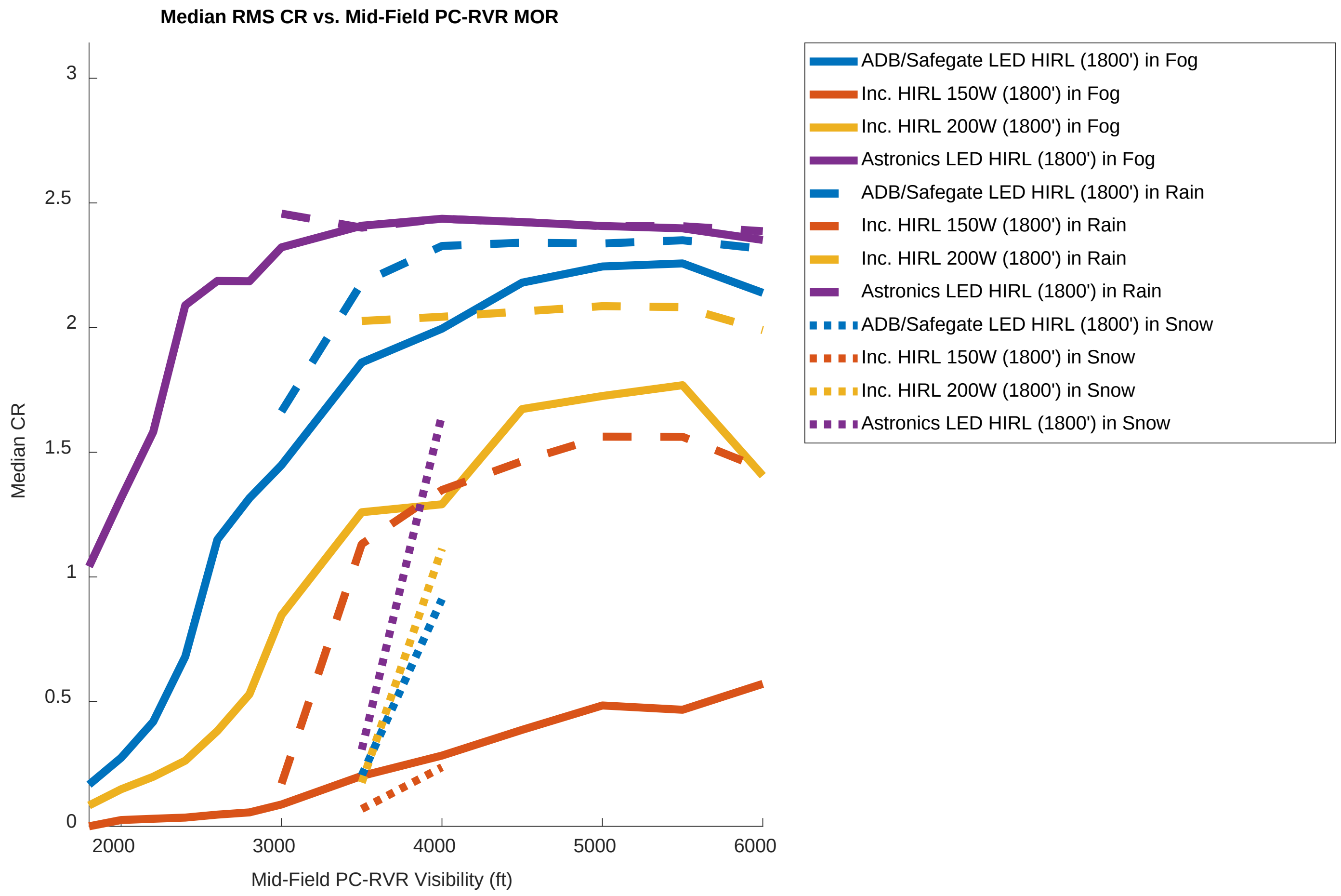
Results – Weather Effects

Results – 1800' MALS – Weather Effects



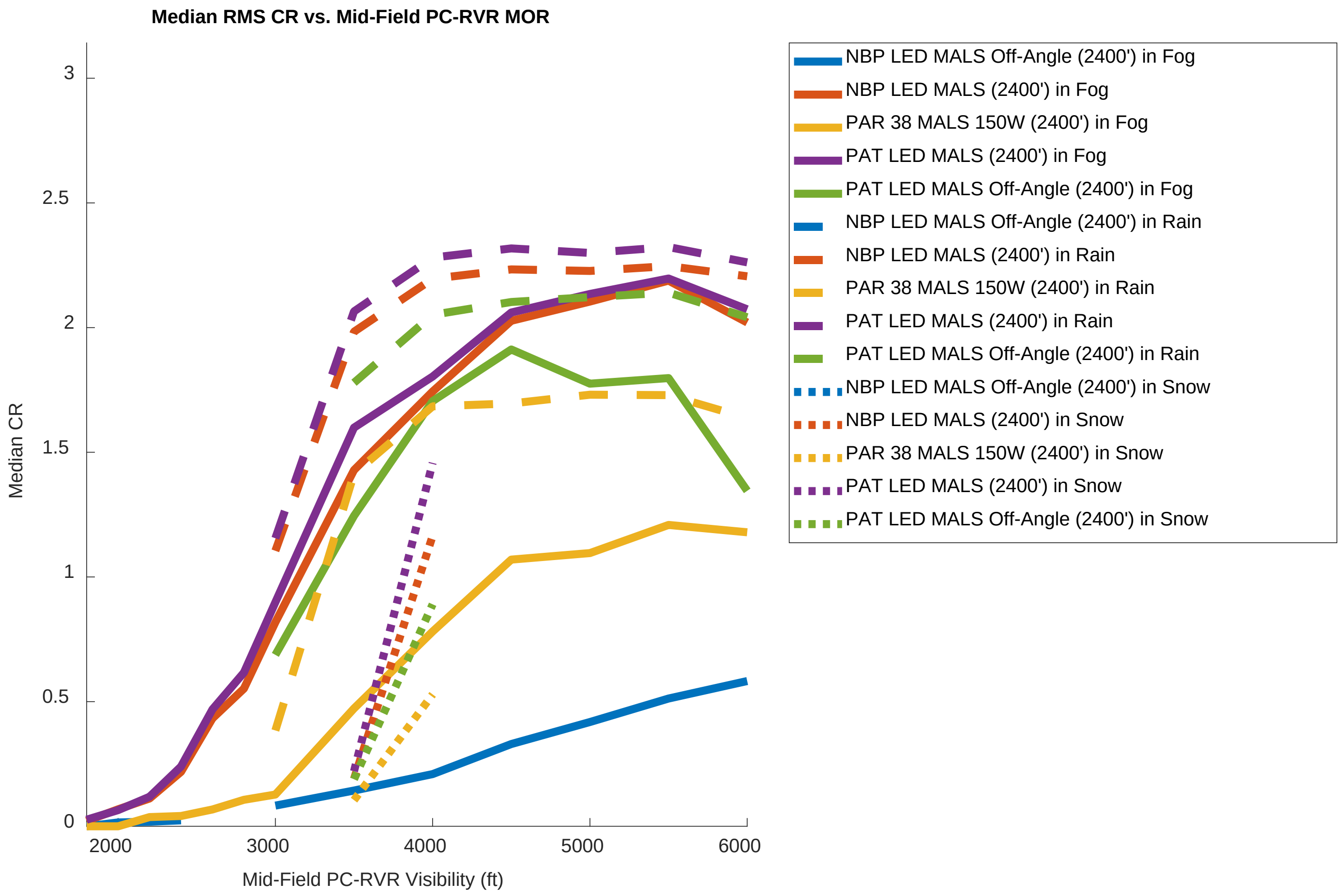
- Fog brightness ordering:
  - NBP LED
  - Patriot LED
  - 150W incandescent
- Rain brightness ordering:
  - Same as fog
- Snow brightness ordering:
  - Patriot LED
  - NBP LED
  - 150W incandescent

Results – 1800' HIRLs – Weather Effects



- Fog brightness ordering:
  - Astronics LED
  - ADB/Safegate LED
  - 200W incandescent
  - 150W incandescent
- Rain brightness ordering:
  - Same as fog
- Snow brightness ordering:
  - Astronics LED
  - 200W incandescent
  - ADB/Safegate LED
  - 150W incandescent

Results – 2400’ MALS – Weather Effects



- Fog brightness ordering:
  - Patriot LED
  - NBP LED
  - Off-angle Patriot LED
  - 150W incandescent
  - Off-angle NBP LED
- Rain brightness ordering:
  - Same as fog
- Snow brightness ordering:
  - Same as fog

Weather Effects - Observations

- Data requirement relaxed to 250 measurements to account for reduced data
  - Results have more uncertainty compared to all-weather results but are used to assess if there is a strong weather effect
- Overall, relative ordering of lamp brightness is not sensitive to weather condition
  - Some small changes for lamps that have very similar brightness using all-weather dataset are likely related to smaller data counts
- CR values are systematically higher in rain than in fog
  - Literature suggests forward scatter meters may underestimate visibility in rain
- CR values are systematically lower in snow than in fog
  - Manual review of some video shows that the lamps really are much more difficult to see with snowy background

Conclusions

Final Thoughts

- The LED lamps tested are brighter/easier to see than equivalent incandescent lamps when visibility is at its worst
  - NBP and Patriot MALS lamps tested are essentially equivalent to each other
  - Astronics HIRL tested was brighter than ADB/Safegate HIRL; but both are substantially brighter than incandescent lamps
- This conclusion is not sensitive to visibility range
- This conclusion is not sensitive to weather
- Results suggest there may be an opportunity to provide low-cost visibility measurements at airfields without PC-RVRs by using a camera looking at known light sources (e.g. existing airport/runway lights)
- Full report (DOT-VNTSC-FAA-21-04, "LED Airport Lighting Behavior in Real-World Conditions") will be published shortly

Questions?

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