Wind Decision Support for UAS Operations

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Air Traffic Control Systems Group

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LINCOLN LABORATORY
Massachusetts Institute of Technology
Outline

- Operational needs
- Current capability for low altitude (below 500 ft AGL) winds information
  1. Forecasts (e.g., HRRR) plus ASOS
  2. FAA Weather Systems
     - Integrated Terminal Weather System (ITWS) for 34 major metropolitan areas
       Gridded winds analysis
       Wind shear phenomena (microbursts, gust fronts)
     - NextGen Weather Processor and CSS-Wx product distribution
- Experience with low altitude strategic (multi-hour lead time) wind forecasts for airport AAR decision support
- Suggestions for next steps
Assumptions about UTM

- Traffic Management System for small UAVs (e.g., under 50 lb)
  - Class G airspace: Up to 500 feet AGL
  - Fixed wing and rotor
  - Winds of concern for rotor and small foam fixed wing are 10-20 knots
- Weather conditions for “routine” operation is an important factor
  - Package/medical delivery, fire/police usage are likely to consider operation when precipitation is in the area (not necessarily on flight path)

<table>
<thead>
<tr>
<th>Element</th>
<th>Operational Decisions</th>
<th>Available Data Sources</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wind @ launch altitude</td>
<td>Launch control</td>
<td>ASOS (10 m)</td>
</tr>
<tr>
<td>Wind @ cruise altitude (up to 500 feet)</td>
<td>Flight/trajectory control&lt;br&gt;Avoid wind phenomena of concern to vehicle (gust fronts, microbursts)&lt;br&gt;Planning for operations (e.g., trajectories, go- no go)</td>
<td>Radar (TDWR, WSR-88D, ASR), Rawinsonde, Aircraft (MDCRS), LLWAS, UAS(???)&lt;br&gt;Numerical forecasts (HRRR, RUC, RAP, etc)</td>
</tr>
<tr>
<td>Precipitation</td>
<td>Flight control; vehicle damage; interference with communication and/or mission objectives</td>
<td>Weather and Surveillance Radars; Integrated Weather Systems (CIWS, CoSPA, NWP); numerical forecasts</td>
</tr>
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• Suggestions for next steps
HRRR model as a Baseline Decision Support System

- NASA / Lincoln Lab consensus to use as a baseline forecast
  - Provides a readily available generalized “solution”
    - Leverages numerical weather prediction R&D that has evolved for decades
    - Provides forecasts of nearly all relevant UTM weather elements
    - Coverage over entire CONUS

- Observed shortcomings (see next slides)
  - Skill diminishes at local scale, which may be a factor for UTM ops
    - Spatial scale of physics
    - Inherent “smoothing” of analysis field (observations) and forecast fields
  - Does not fully exploit high resolution information from recent observations in its shorter horizon forecasts (~ under 3 hours)
Forecast bias observed at 10 m

SFO observed 10-m wind (ASOS) versus forecast wind, all forecast horizons

9 AM forecast target

3 PM forecast target

HRRR substantially under-forecasting observed 10 m ASOS wind
• There is a diurnal cycle in observed winds
• At 10m AGL: HRRR captures cycle, underestimates magnitude
• At 80m AGL: HRRR misses cycle, overestimates magnitude

Comparison of Observations and HRRR at 10 m and 80 m

40 day period:

5 days period:

80 m obs made using LIDAR

Blue – obs
Red - HRRR
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Integrated Terminal Weather System (ITWS) Locations

- **Western Region**: SFO, OAK, SJU, NV, RNO, SLC, CA, AZ, PHX, DIA, CO, NCT
- **Central Region**: IAH, HOU, FSM, OKC, TUL, DFW, DAL, IAH, AFW, LIT, MEM, JAN, BN, CLT, ATL, PDK, TIA, PIS, DCA, IAD, BWI, JAX, RDU, LGA, LHD, CVG, CVG, MCI, MKC, SFO, ATL, LGA, LAX, SFO, MCO, LAX, SFO, MCO, LAX, SFO
- **Eastern Region**: PVD, BOS, PHL, N90, JFK, LGA, LAX, CVG, DCA, IAD, BWI, TEB, NRT, HND, JFK, LGA, LAX, CVG, DCA, IAD, BWI, TEB, NRT, HND, JFK, LGA, LAX, CVG, DCA, IAD, BWI, TEB, NRT, HND, JFK, LGA, LAX, CVG, DCA, IAD, BWI, TEB, NRT, HND

**Legend**:
- ▲ ITWS PGs (34) – Commissioned/Operational
- ▲ 16 Secondary Reliever Airports (SRAs)
- ▲ Associated ATCT to Designated PG
- ▲ Support Systems (3)

**Notes**:
1. All sites are commissioned
2. All ARTCC have ITWS except ZAN and ZSE
Integrated Terminal Weather System (ITWS)

- ASR-9/11
- TDWR
- NEXRAD
- ATCSCC
- LLWAS
- Lightning (NLDS)
- Aircraft (MDCRS)
- RAP
- ITWS PG (Product Generator)
- Microburst
- Gust Front
- Storm Location & Motion
- Storm Cell Information
- Terminal Winds
- Tornado
- External Users
  - Airlines
  - Other non-FAA Users
- TRACON / ATCT / ARTCC
  - TMU
  - Supervisors
  - Controllers
  - ARTCC CWSU
- Pilots (TWIP)
- Integrated Terminal Weather System (ITWS) PG (Product Generator)
- Ribbon Display (RBDT)
Terminal Winds Analysis

Output: Several ‘layers’ of horizontal winds on 2 different grids

TDWR scans and detects wind shear 360° in azimuth

Updates every 5 minutes
Example—DFW Terminal Winds

Areas of fine grid winds

<table>
<thead>
<tr>
<th>TRACON</th>
<th>Area (x 1000 sq km)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dallas</td>
<td>23</td>
</tr>
<tr>
<td>New York</td>
<td>40</td>
</tr>
<tr>
<td>Orlando</td>
<td>104</td>
</tr>
<tr>
<td>Washington Baltimore</td>
<td>112</td>
</tr>
<tr>
<td>Northern California</td>
<td>112</td>
</tr>
</tbody>
</table>
Gust Front Product (ITWS, NEXRAD)

- **Solid purple line** indicates the current location of the gust front. Dashed purple lines indicate estimated location of the gust front 10 and 20 minutes in the future. **Purple arrow and number** indicate direction and speed of wind behind the gust front.

- If a gust front is strong enough, it can generate a wind shear with a gain alert on the ribbon displays and the alerted runways and/or runway extensions are purple.

- **Gust Front Impact Timer** indicates when the most imminent gust front is expected to arrive at the airport. A purple timer without a number indicates a gust front is on the airport.

- The range of coverage for gust fronts is 60 km from the radar.

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**Microbursts** are detected by both TDWR and NEXRAD - range of coverage is 35 km from radar.

- **Microbursts can create very strong winds** a considerable distance from the rain core – see the backup information slide #1.
Accessing Terminal Winds, Wind Shear and Precipitation Products with NextGen

- NWP will be generating the ITWS wind products described earlier as well as providing significantly improved precipitation products
- CSS-Wx provides access to all of the NWP products via SWIM
- Current ITWS/CIWS/CoSPA user displays will be replaced by Aviation Weather Display (AWD)
## CSS-Wx/NWP Milestones (as of spring 2016)

<table>
<thead>
<tr>
<th>Milestone</th>
<th>CSS-Wx</th>
<th>NWP</th>
</tr>
</thead>
<tbody>
<tr>
<td>Final Investment Decision (FID)</td>
<td>March 2015</td>
<td>March 2015</td>
</tr>
<tr>
<td>Contract Award*</td>
<td>June 2015</td>
<td>June 2015</td>
</tr>
<tr>
<td>Factory Acceptance Test (FAT) Completed</td>
<td>March 2018</td>
<td>February 2019</td>
</tr>
<tr>
<td>Operational Test (OT) Completed</td>
<td>November 2018</td>
<td>May 2020</td>
</tr>
<tr>
<td>Key Site Initial Operational Capability (IOC)</td>
<td>January 2019</td>
<td>August 2020</td>
</tr>
<tr>
<td>In Service Decision</td>
<td>September 2019</td>
<td>April 2021</td>
</tr>
<tr>
<td>First Site Operational Readiness Date (ORD)</td>
<td>October 2019</td>
<td>May 2021</td>
</tr>
<tr>
<td>Last Site ORD</td>
<td>August 2022</td>
<td>August 2022</td>
</tr>
</tbody>
</table>

- **Contract awarded April 2015***

**Key:**  
- **Complete**  
- **On Track**
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Key Factors in Airport Arrival Rate Setting for GDP Planning

### EWR Airport Acceptance Rate Worksheet

<table>
<thead>
<tr>
<th>Time</th>
<th>ARR Runways</th>
<th>Forecast Weather/Winds</th>
<th>Available Overflow</th>
<th>Scheduled Arrivals</th>
<th>Airport Arrival Rate</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Primary</td>
<td>Primary Runway MIT</td>
<td>Overflow</td>
<td>20KT Max Tailwind Component</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Final</td>
<td>Final Approach Winds</td>
<td>Winds aloft</td>
<td>Jet and Prop Arrival Fixes</td>
<td>Winds aloft</td>
</tr>
<tr>
<td></td>
<td>Winds</td>
<td>Field Conditions</td>
<td></td>
<td>'NO OVERFLOW' Check Box</td>
<td></td>
</tr>
<tr>
<td></td>
<td>10KT Max Tailwind Component</td>
<td>20KT Max Tailwind Component</td>
<td>'NO OVERFLOW' Check Box</td>
<td>Heavy Jets</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Primary Runway</td>
<td>20KT Max Tailwind Component</td>
<td>Heavy Jets</td>
<td>B757's</td>
<td>'Compression'</td>
</tr>
<tr>
<td></td>
<td>Final Approach Speed</td>
<td>20KT Max Tailwind Component</td>
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<td>Scheduled Arrivals</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Wind Direction</td>
<td>20KT Max Tailwind Component</td>
<td>B757's</td>
<td>Primary Runway AAR</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Wind Velocity</td>
<td>20KT Max Tailwind Component</td>
<td>B757's</td>
<td>Secondary Runway AAR</td>
<td></td>
</tr>
<tr>
<td></td>
<td>10KT Max Tailwind Component</td>
<td>20KT Max Tailwind Component</td>
<td>B757's</td>
<td>Hourly Total AAR</td>
<td></td>
</tr>
</tbody>
</table>

Variables Utilized in Determining Airport Arrival and Departure Rates

April 6, 2011

Federal Aviation Administration

Lincoln Laboratory
Massachusetts Institute of Technology
A study of numerical model and TAF wind forecast accuracy for purposes of GDP decision support was conducted for the FAA (Lincoln Laboratory Project Report ATC-414). Accuracy for various numerical models (RUC, RAP, HRRR) was similar to the TAF. Probability of infeasible runway selection was low (<1%), but probability of non-optimal runway selection was about 50%. Timing of significant changes was not assessed — this is a very important issue.

**Wind Forecast Accuracy for GDP Decision Support**

- **2 hour**
  - Observed headwind (knots)
  - Forecast headwind (knots)
  - Key:
    - Perfect forecast
    - Forecast selection correct
    - Forecast selection within tolerance
    - Forecast selection infeasible

- **8 hour**
  - Observed headwind (knots)
  - Forecast headwind (knots)
  - Key:
    - Perfect forecast
    - Forecast selection correct
    - Forecast selection within tolerance
    - Forecast selection infeasible
Display Concept – Surface Winds Forecasts With Real Time Forecast Accuracy Verification

Verification using observations from outlying locations

NOAA Front Forecast

ORD 0-2 Hr Forecast Winds
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Suggested Future Work

- Better understand key UAS operator needs through use of wind products in actual operations with ongoing feedback from operational users
- Need to reexamine terminal winds accuracy in representative major metropolitan areas in the context of key UTM decisions (e.g., timing and magnitude of significant wind changes)
  - Key site testing of NWP implementation of ITWS functionality may offer an opportunity for pre 2020 real time usage
- Improve the 0-2 hour wind forecasts
- Develop wind forecast reliability metrics similar to what has been done for strategic traffic flow management in convective weather
- Look at downslope wind detection and forecasting for the Ames Nevada UTM test sites
- Consider use of non FAA metropolitan area wind sensors (e.g., air pollution wind profilers) as an input to ITWS terminal winds
- Develop training and guidelines for relating winds measured at surface (e.g., pole associated with delivery vehicle) to winds aloft at drone flight altitude (see: Siting Guidelines for Low Level Windshear Alert System (LLWAS) remote facilities," FAA Technical Order 6560.21A)
Summary

• Low altitude winds are important to operation of low altitude UAS
  – Significant horizontal and/or vertical shear will be a challenge for use of a single surface observation plus HRRR as the sole basis for UTM related wind decision support
  – Safety of the UAS is particularly important in major metropolitan areas

• Many of the UAS wind operational issues mirror longstanding issues for conventional aircraft operations
  – Low altitude wind shear and anticipation of wind changes at airports

• FAA terminal weather decision support systems provide high time/space resolution wind fields plus gust front and wind shear information at 34 major metropolitan areas
  – Product access for use in UTM will be significantly improved when the NextGen Weather Processor (NWP) is operational

• Ongoing work to improve FAA strategic and tactical management of wind impacts will often be applicable to UTM operations
Backup Information
Note that the surface winds spread out a long distance from the region of heavy rain at the surface (see the video at http://mashable.com/2016/07/19/striking-microburst-photo-phoenix/#ohTWSKDA2EqD )
CSS-Wx/NWP Implementation

Common Support Services—Weather (CSS-Wx)

- Current Wx Dissemination:
  - WARP WINS
  - CDDS
  - ITWS Web Server
  - CREWS

- Contract Award: April 2015

- Legacy Wx Dissemination:
  - WMSCR
  - ADAS
  - ALDARS
  - WIFS

- CSS-Wx Work Package 1

NextGen Weather Processor (NWP)

- Current Wx Processing:
  - WARP RAMP
  - CIWS
  - ITWS

- Contract Award: April 2015

- NWP Work Package 1

- Legacy Wx Processing:
  - IARD

- CSS-Wx Work Package 2

- IARD

- NWP Work Package 2

- NWP Work Package 3

- CY 2015 2020 2030 2040
### Key Acronyms

<table>
<thead>
<tr>
<th>Acronym</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>ADAS</td>
<td>Automated Weather Observing System (AWOS) Data Acquisition System</td>
</tr>
<tr>
<td>ALDARS</td>
<td>Automated Lightning Detection and Reporting System</td>
</tr>
<tr>
<td>CDDS</td>
<td>CIWS Data Distribution Service</td>
</tr>
<tr>
<td>CIWS</td>
<td>Corridor Integrated Weather System</td>
</tr>
<tr>
<td>CREWS</td>
<td>CTAS Remote Weather System</td>
</tr>
<tr>
<td>CSS-Wx</td>
<td>Common Support Services- Weather</td>
</tr>
<tr>
<td>IARD</td>
<td>Investment Analysis Readiness Decision</td>
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<td>IOC</td>
<td>Initial Operational Capability</td>
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<tr>
<td>ORD</td>
<td>Operational Readiness Date</td>
</tr>
<tr>
<td>RAMP</td>
<td>Radar Acquisition and Mosaic Processor</td>
</tr>
<tr>
<td>WARP</td>
<td>Weather and Radar Processor</td>
</tr>
<tr>
<td>WIFS</td>
<td>World Area Forecast System (WAFS) Internet File Service</td>
</tr>
<tr>
<td>WINS</td>
<td>Weather Information Network Server</td>
</tr>
<tr>
<td>WMSCR</td>
<td>Weather Message Switching Center Replacement</td>
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</table>