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**ATC-351**

# Redeployment of the New York TDWR: Technical Analysis of Candidate Sites and Alternative Wind Shear Sensors

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16. Abstract

The John F. Kennedy International Airport (JFK) and LaGuardia Airport (LGA) are protected from wind shear exposure by the New York Terminal Doppler Weather Radar (TDWR), which is currently located at Floyd Bennett Field, New York. Because of a September 1999 agreement between the Department of the Interior and the Department of Transportation, this location is required to be vacated not later than January 2023. Therefore, a study based on model simulation of wind shear detection probability was conducted to support future siting selection and alternative technologies. A total of 18 candidate sites were selected for the analysis, including leaving the radar where it is. (The FAA will explore the feasibility of the latter alternative; it is included in this study only for technical analysis.) The 18 sites are: Six candidate sites that were identified in the initial New York TDWR site-survey studies in the 1990s (one of which is the current TDWR site), a site on Staten Island, two Manhattan skyscrapers, the current location of the WCBS Doppler weather radar in Twombly Landing, New Jersey, and eight local airports including JFK and LGA themselves. Results clearly show that for a single TDWR system, all six previously surveyed sites are suitable for future housing of the TDWR. Unfortunately, land acquisition of these sites will be at least as challenging as it was in the 1990s due to further urban development and likely negative reaction from neighboring residents. Evaluation results of the on-airport siting of the TDWR (either at JFK or at LGA) indicate that this option is feasible if data from the Newark TDWR are simultaneously used. This on-airport option would require software modification such as integration of data from the two radar systems and implementation of "overhead" feature detection. The radars on the Manhattan skyscrapers are not an acceptable alternative due to severe ground clutter. The Staten Island site and most other candidate airports are also not acceptable due to distance and/or beam blockage. The existing Airport Surveillance Radar (ASR-9) Weather Systems Processor (WSP) at JFK and the Brookhaven (OKX) Weather Surveillance Radar 1988-Doppler (WSR-88D, commonly known as NEXRAD) on Long Island cannot provide sufficient wind shear protection mainly due to limited wind shear detection capability and/or distance

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# ABSTRACT

The John F. Kennedy International Airport (JFK) and LaGuardia Airport (LGA) are protected from wind shear exposure by the New York Terminal Doppler Weather Radar (TDWR), which is currently located at Floyd Bennett Field, New York. Because of a September 1999 agreement between the Department of the Interior and the Department of Transportation, this location is required to be vacated not later than January 2023. Therefore, a study based on model simulation of wind shear detection probability was conducted to support future siting selection and alternative technologies. A total of 18 candidate sites were selected for the analysis, including leaving the radar where it is. (The FAA will explore the feasibility of the latter alternative; it is included in this study only for technical analysis.) The 18 sites are: Six candidate sites that were identified in the initial New York TDWR site-survey studies in the 1990s (one of which is the current TDWR site), a site on Staten Island, two Manhattan skyscrapers, the current location of the WCBS Doppler weather radar in Twombly Landing, New Jersey, and eight local airports including JFK and LGA themselves. Results clearly show that for a single TDWR system, all six previously surveyed sites are suitable for future housing of the TDWR. Unfortunately, land acquisition of these sites will be at least as challenging as it was in the 1990s due to further urban development and likely negative reaction from neighboring residents. Evaluation results of the on-airport siting of the TDWR (either at JFK or at LGA) indicate that this option is feasible if data from the Newark TDWR are simultaneously used. This on-airport option would require software modification such as integration of data from the two radar systems and implementation of "overhead" feature detection. The radars on the Manhattan skyscrapers are not an acceptable alternative due to severe ground clutter. The Staten Island site and most other candidate airports are also not acceptable due to distance and/or beam blockage. The existing Airport Surveillance Radar (ASR-9) Weather Systems Processor (WSP) at JFK and the Brookhaven (OKX) Weather Surveillance Radar 1988-Doppler (WSR-88D, commonly known as NEXRAD) on Long Island cannot provide sufficient wind shear protection mainly due to limited wind shear detection capability and/or distance.

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# 1. INTRODUCTION

The Terminal Doppler Weather Radar (TDWR) is a radar system specifically designed to reduce wind shear related accidents in airport terminal areas (Michelson et al., 1990; FAA, 1996; Cho et al., 2008). The TDWR scans terminal operational areas and airspace aloft for the location, intensity, and movement of low-altitude hazardous wind shear phenomena, primarily microbursts (the most hazardous form of wind shear), gust fronts, and other severe weather conditions to provide warnings to approaching and departing aircraft. The TDWR also provides early warning up to 20 minutes of imminent shifts in wind direction and strength due to the approach of gust fronts, which aids the efficient management of runway use configuration. A total of 45 TDWRs are deployed operationally in the USA today. Information on wind shear phenomena and other weather conditions from the TDWR is used by air traffic control supervisors, air traffic management specialists, and pilots. Weather information collected with the TDWR is also used by the broader meteorological community such as the National Weather Service and research institutes. Due to deployment of the TDWRs, the safety and efficiency of airport operation have greatly improved, resulting in significant economic benefits (Hallowell et al., 2009).

While the deployment of the TDWRs has successfully reduced wind shear related aviation accidents, the fact that the TDWRs are sited off the airport properties creates land acquisition problems for some sites (Dune, 1994). The siting of the New York (NY) TDWR is an extreme case. Due to the urban environment, sensitive residents, and political agenda, it took the FAA a decade and a fatal wind shear accident, the crash of USAir Flight 1016 at Charlotte, North Carolina, on July 2, 1994, to finally deploy one New York TDWR for wind shear protection of both John F. Kennedy International Airport (JFK) and LaGuardia Airport (LGA).

The siting of the New York (or JFK) TDWR is not without issues, because the current site, the former US Coast Guard Station at Floyd Bennett Field in Brooklyn, NY, is within the Gateway National Recreation Area. According to the agreement between the FAA and the Department of the Interior, the TDWR can only remain at its present site until 2023, and the FAA is to make the removal of the TDWR from its current site their highest priority. Since the TDWR is currently the single best sensor for wind shear detection and protection, a future site must be found for this TDWR with equivalent or better coverage of both JFK and LGA.

Lincoln Laboratory was heavily involved in the TDWR design and deployment project. The Laboratory developed critical wind shear detection and prediction algorithms for the TDWR, tested the algorithms in the field, and transferred the technology to Raytheon, the manufacturer of the TDWRs. The Laboratory continues to be committed to improving the performance and sustainability of the TDWR through a service life extension program. Due, in part, to this long-standing technical expertise with the TDWR, the Laboratory was commissioned by the FAA to take on the challenge of determining acceptable alternatives to the current Floyd Bennett Field location of the New York TDWR.

We assessed the technical viability of various alternatives for providing wind shear detection services to JFK and LGA in this study. Questions we addressed are: (1) What will be the wind shear detection coverage for these airports if we decommission the current TDWR without adding new sensors to the system? (2) How does the wind shear detection performance of a relocated TDWR compare to the performance of the TDWR at its current site? (3) Can we mount a commercial off-the-shelf (COTS) Doppler weather radar such as those used by TV stations on top of a Manhattan skyscraper and obtain sufficient wind shear detection coverage? (4) Can acceptable wind shear detection capability obtained with a TDWR or a COTS radar of similar performance installed on the airport properties of JFK and/or LGA? (5) Can other sensors such as the Airport Surveillance Radar (ASR-9) Weather Systems Processor (WSP), Weather Surveillance Radar 1988-Doppler (WSR-88D, commonly known as NEXRAD), Low Level Wind Shear Alert System (LLWAS), or Doppler light detection and ranging (lidar) system provide an equivalent level of wind shear detection if the current TDWR is decommissioned?

We quantitatively examined the suitability of the candidate sites for wind shear protection of JFK and LGA. The types of candidate sites included the ground-based sites identified in the initial site-survey documents, a landfill on Staten Island, two Manhattan skyscrapers, and the airport properties of JFK and LGA as well as other nearby municipal airports. The technical criteria used to evaluate the sites included detection probability of microbursts and gust fronts from a model, radar coverage of the targeted airspace, and angular relationship of the candidate site to the runways at JFK and LGA. All siting and sensor options were thoroughly examined, and the on-airport siting option was intensively explored.

# 2. METHOD

## 2.1 STUDY SITES

A total of 18 sites were identified to have potential for the TDWR redeployment study (Table 1). Among these sites, we included the six ground-based candidates surveyed and documented in the initial TDWR siting effort. They are Floyd Bennett Field (the current site), Bellmore (a former US Army Reserve Center), Roslyn (a former Air National Guard Station), Fort Tilden (a former US Army Reserve Center), Beach 169$^{th}$ Street (a private parcel by the roadside), and Hart Island (a former Nike missile facility). The two off-shore sites included in the initial search for suitable TDWR locations, Ambrose Lighthouse site and Ocean site, were excluded from this study because they are not economically feasible. As documented in the earlier studies, they would be extremely expensive (estimated to be then-current $25 million to $68 million more than the land-based TDWR) and provide poor availability due to unique factors like seawater corrosion and inaccessibility (FAA, 1996; SRI, 1998).

In addition to the old candidate sites, we investigated six nearby airports and current TDWR sites, namely the Newark TDWR site (EWR), Teterboro (TEB), White Plains (HPN), Linden (LDJ), Farmingdale (FRG), Caldwell (CDW), and JFK and LGA themselves with the hope that land acquisition may be less difficult compared to those off-airport sites. Furthermore, a Staten Island landfill site, Fresh Kill Dump, was considered for potential siting of the TDWR on Staten Island.

Other than the sites mentioned above, we also examined the possibility of using COTS C-band Doppler weather radars and/or piggy-backing on existing TV station weather radars on Manhattan skyscrapers. Three TV stations in New York City, WNBC, WCBS, and FOX5, have their own weather radars. WNBC's Super Doppler 4000 (Enterprise Electronics Corporation (EEC), 350 kW power, model DWSR-90CTV) is installed on the General Electric (GE) Building at 30 Rockefeller Center. WCBS's Live Doppler (Baron Services, Inc., 1 MW power, model VHDD-1000C), is located in Twombly Landing, NJ, which is 38 km from JFK and 21 km from LGA. The third radar, FOX5's Sky Guardian Baron 1 MW Dual Polarimetric and Livestream Radar, is located in Martinsville, NJ, which is too far from JFK and LGA to be considered as a possible candidate. For this exercise, we included the GE Building and the Empire State Building as representatives of Manhattan skyscraper sites. (For the latter case, where no radar is now present, we selected a COTS radar with the highest performance for wind shear detection in a clutter-dominated environment, the 850-kW klystron-powered system, EEC DWSR-8501C/K.) The results should answer important questions such as the severity of ground clutter and the detection sufficiency of wind shear phenomena from a Manhattan skyscraper. Since the current WCBS weather radar site, the Twombly site, is within reasonable distance from JFK and LGA, we also included this location.

The location and elevation for the current JFK and EWR TDWRs are based on global positioning system (GPS) measurements conducted by the TDWR Program Support Facility (PSF). For the candidate airports, the TDWR is assumed to be located at the latitude and longitude listed in AIRNAV (see Bibliography section) for those airports. For candidate sites in the initial site-survey documents, the Roslyn and Bellmore sites have detailed location and elevation information. No such information was provided for the Ft. Tilden, Beach, and Hart Island sites, so the latitude, longitude, and elevation of these sites were estimated to our best knowledge from Google Earth. The location and elevation of the Fresh Kill site is also an approximation. WNBC's Super Doppler 4000 on the GE Building and WCBS's Live Doppler at Twombly Landing, NJ, are visible from Google Earth, so the information of the radar locations gathered from Google Earth should be quite accurate. For the Empire State Building, the latitude and longitude is for the broadcast tower on top of the building.

**TABLE 1**

**Candidate sites for New York TDWR redeployment**

| Site | Site Info | Latitude (deg) | Longitude (deg) | Elevation (m) | Distance to Airport (km) | |
|---|---|---|---|---|---|---|
| | | | | | JFK | LGA |
| Floyd[1] | Floyd Bennett Field Site, New York, NY | 40.589 | 73.880 | 5 | 10 | 21 |
| Bellmore | Bellmore US Army Reserve Center Site, New York, NY | 40.688 | 73.531 | 12 | 22 | 30 |
| Roslyn | Roslyn Former Air National Guard Station Site, New York, NY | 40.797 | 73.631 | 96 | 21 | 21 |
| Ft. Tilden | Fort Tilden Site, New York, NY | 40.563 | 73.889 | 2 | 13 | 24 |
| Beach | South Beach 169th Street Site, New York, NY | 40.565 | 73.881 | 2 | 12 | 24 |
| Hart Island | Hart Island Site, New York, NY | 40.858 | 73.771 | 12 | 24 | 12 |
| JFK | John F. Kennedy International Airport, New York, NY | 40.640 | 73.779 | 4 | 0 | 17 |
| LGA | LaGuardia Airport, New York, NY | 40.777 | 73.873 | 7 | 17 | 0 |
| EWR[2] | Newark TDWR, NJ | 40.594 | 74.270 | 17 | 42 | 39 |
| TEB | Teterboro Airport, Teterboro, NJ | 40.850 | 74.061 | 3 | 33 | 18 |
| HPN | Westchester County Airport, White Plains, NY | 41.067 | 73.708 | 134 | 48 | 35 |
| LDJ | Linden Airport, Linden, NJ | 40.617 | 74.245 | 7 | 39 | 36 |
| FRG | Republic Airport, Farmingdale, NY | 40.729 | 73.413 | 25 | 32 | 39 |
| CDW | Essex County Airport, Caldwell, NY | 40.875 | 74.281 | 53 | 50 | 36 |
| Fresh Kill | Fresh Kill Dump Site, Staten Island, NY | 40.576 | 74.191 | 11 | 36 | 35 |
| GE[3] | GE Building, New York, NY | 40.758 | 73.979 | 259 | 21 | 9 |
| EMPIRE[4] | Empire State Building, New York, NY | 40.749 | 73.987 | 381 | 21 | 10 |
| Twombly[5] | Twombly Landing, NJ | 40.961 | 73.923 | 158 | 38 | 21 |

[1] Current New York TDWR location
[2] Newark TDWR location
[3] Current location of WNBC's EEC DWSR-90CTV
[4] Examined using EEC 850 kW Doppler weather radar (DWSR-8501C/K) specifications
[5] Current location of WCBS's Baron VHDD-1000C

Figure 1 is a map included for reference from an initial siting document showing the location of the current TDWR site (Floyd Bennett Field), JFK, and LGA (FAA, 1995). The geographical location of all candidate sites, three nearby ASR-9s (Newark, JFK, and Islip), and a nearby NEXRAD located in Upton, NY on Long Island (OKX), are shown in Figure 2. The Islip ASR-9 is excluded from this study due to the excessive distance to JFK and LGA. The GE Building with the EEC DWSR-90CTV, the Empire State Building with the broadcast tower, and the Baron VHDD-1000C in Twombly are shown in Figure 3.

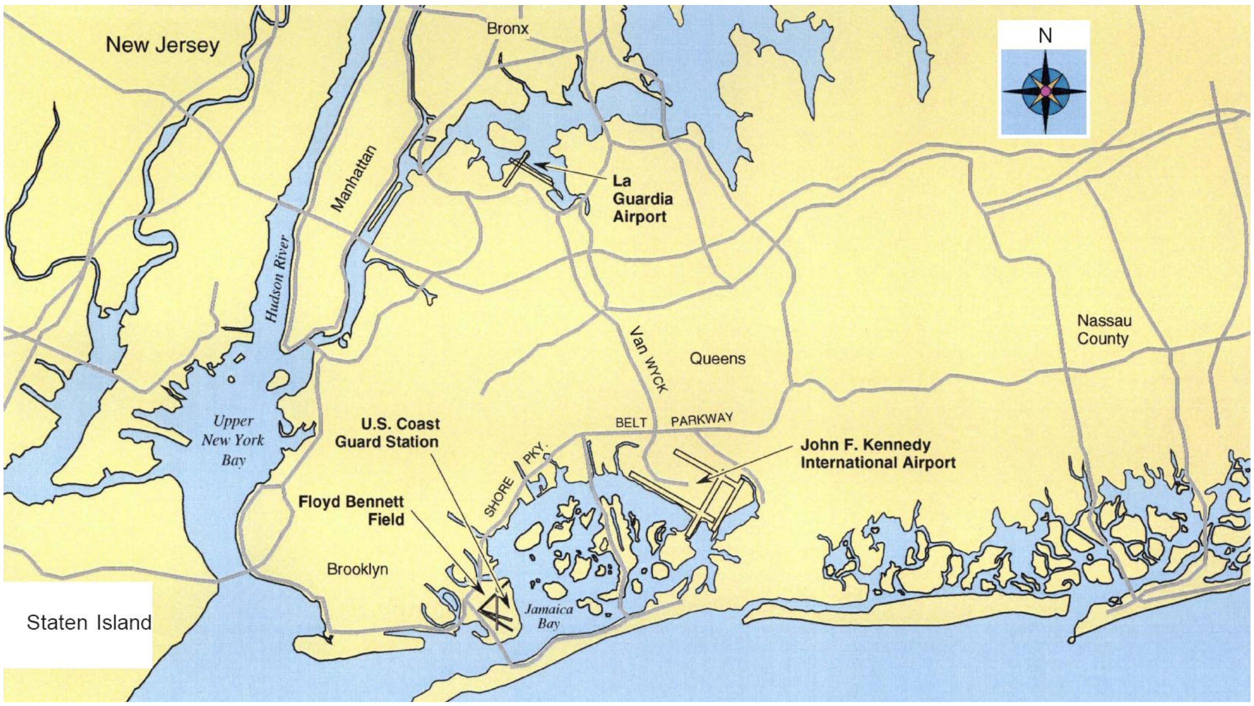


*Figure 1. The geographical location of the current TDWR site (Floyd Bennett Field), JFK, and LGA (FAA, 1995).*

## 2.2 QUANTITATIVE EVALUATION OF CANDIDATE SITES

The general conditions of an ideal TDWR site as specified by the original site selection study can be summarized as follows. It should be sited around 15–23 km (i.e., 8–12.5 nmi) from the airport. The radar location should be such that the approaching storm can be tracked when it passes over the airport runways. The angle between the site and the centerline of the runway most commonly used during adverse weather conditions, so called inclement weather runways, should be small to ensure accurate wind velocity measurement for winds parallel to the runways. Finally, the radar site should be free of terrain and structural blockage (Sterling, 1993; Burns et al., 1996; SRI, 1998).


*Figure 2. The geographical locations of the candidate sites (the yellow pins and yellow balloons), as well as the nearby ASR-9s (New York, Newark, Islip) and NEXRAD (OKX) (the red balloons) (Google Earth). Note that OKX is 81 km from JFK and 85 km from LGA, and the Islip ASR-9 is 61 km from JFK and 66 km from LGA.*

The following procedures were used by others a decade ago to determine the suitable candidate sites in the initial site survey effort. First the regions of interest were identified based on the optimal distance between the TDWR and the airport and the desired aspect angle between the TDWR and inclement weather runways at the airport. Then candidate sites were selected with considerations for land ownership and availability. Finally, clutter and terrain blockage of the candidate sites were estimated based on field radar data and panorama photos collected from an instrumented survey van equipped with an X-band radar, considering different levels of severity of rain attenuation (e.g., Sterling, 1993; Burns et al., 1996). Detection of wind shear phenomena was estimated based on the expected performance of the TDWR.

In contrast, we approach the problem of candidate site performance evaluation primarily by using a high quality wind shear detection probability model. In addition to the modeled detection probability of microbursts and gust fronts, we also examined volumetric coverage of the radar, and angular relationship between the TDWR and airport runways for each site. The rest of this section gives detailed explanations of these quantities.

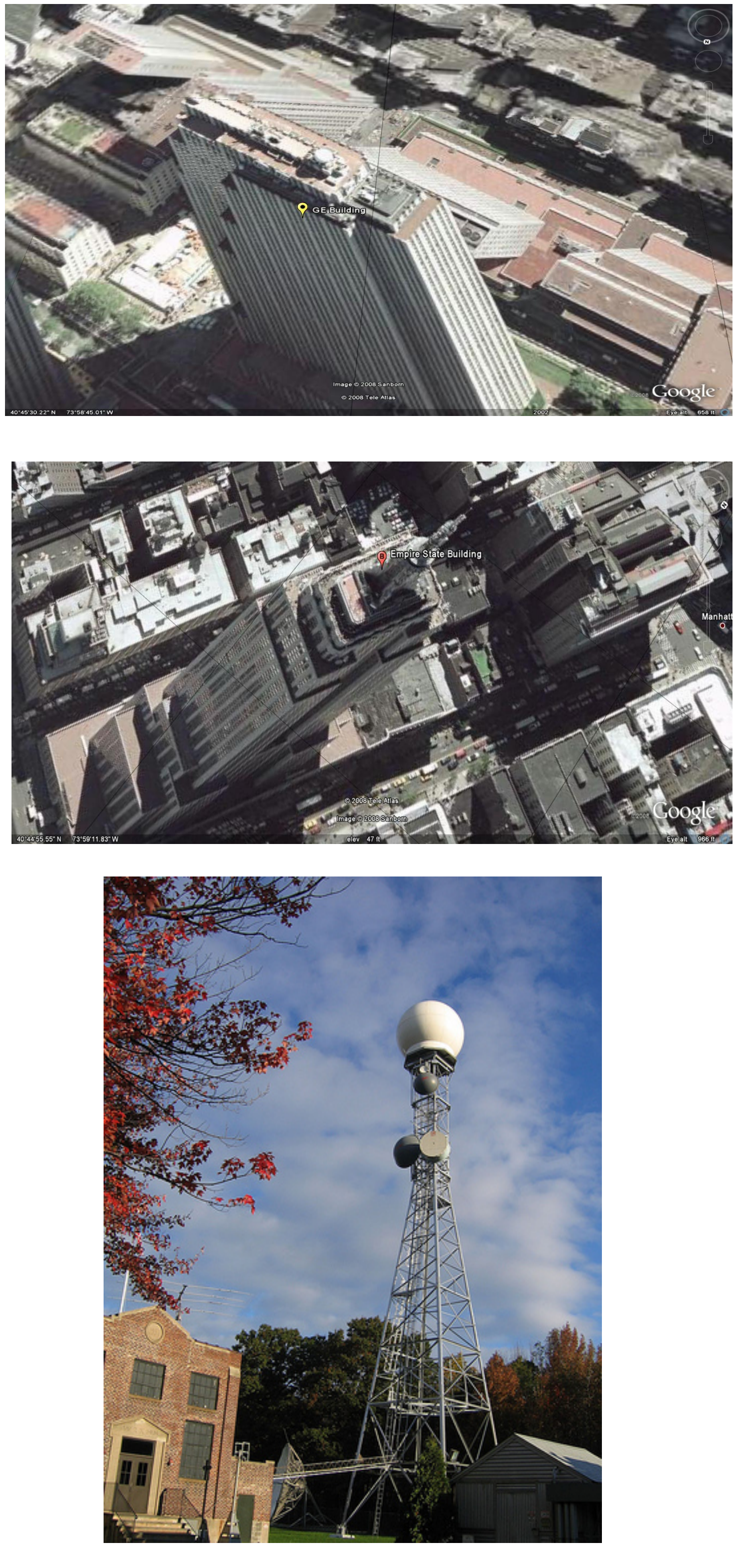


*Figure 3. Top. WNBC's EEC DWSR-90CTV weather radar on the GE Building at Rockefeller Plaza. Middle. The Empire State Building (Google Earth). Bottom. WCBS's Baron VHDD-1000C weather radar in Twombly, NJ (http:/flickr.com/photos/afschu/57523315).*

### 2.2.1 Wind shear detection probability model

We used a wind shear detection probability model to quantitatively evaluate the candidate sites and various wind shear sensor options based on the fact that the effects of wind shear morphology statistics, sensor characteristics, terrain blockage, and ground clutter for a certain site on wind shear detection can be physically modeled. In other words, a meaningful probability estimate can be achieved, provided that accurate information of these input quantities is available (Cho and Hallowell, 2008).

The model uses more accurate information about terrain blockage and ground clutter, such as digitally archived elevation and feature data in the region, which was not available in the previous studies. Also, the mobile X-band radar that was used in the previous studies had significantly different characteristics from a TDWR. Therefore, our results are likely more accurate compared to the initial field survey. The model produces the estimated probability of detections (PODs) of microbursts and gust fronts, yielding an objective metric for site evaluation. In contrast, the initial siting studies were not able to provide such a metric for the evaluation of sites. Another merit of this model is that it can account for different sensor characteristics, even for lidars. As a result, this model enables us to study different candidate sites and different wind shear sensors in a rapid, quantitative, and objective fashion.

The wind shear detection probability model quantifies the line-of-sight radar POD for microbursts over the Areas Noted for Attention (ARENAs) and for gust fronts over an 18-km-radius circle around the airport (Cho et al. 2008; Cho and Hallowell, 2008). The flow diagram of the wind shear detection model is shown in Figure 4. The model is site-specific and sensor-specific. Data on terrain blockage and manmade features (e.g., roads and buildings) for each candidate site are used to generate the clutter map for the area of interest. Microburst and gust front outflow height distributions and the reflectivity distributions of these wind shear phenomena are used for each target airport (Cho and Hallowell, 2008; Hallowell et al., 2009). Each wind shear sensor's characteristics are considered in computing the wind shear detection probability. Other general factors that affect a weather radar system's sensitivity to detect microbursts and gust fronts, such as atmospheric attenuation due to precipitation, partial beam filling, and range alias contamination, are all considered in the model. The quantitative nature and the capability of evaluation of different sites and sensors make this model well-suited for the TDWR resiting study.

Compared to the study by Cho and Hallowell (2008), adjustments were made to accommodate the urban environment of the New York City region in this study. Although the Digital Terrain Elevation Data (DTED) and Digital Feature Analysis Data (DFAD) had been used in the model to generate clutter maps, this combination was not able to accurately represent the uniquely tall building features of Manhattan. Thus, instead of DTED, we utilized data from the Shuttle Radar Topography Mission (SRTM) that give the elevations of the tops of all ground-based features. However, even this data set failed over the heart of Manhattan, because shadowing artifacts from the tallest buildings rendered the accurate retrievals of height impossible. To compensate for this, we filled in the gaps in the SRTM data with airborne laser radar (ladar) data gathered by the Active Optical Systems Group at MIT Lincoln Laboratory (Cho, 2008).

The comparison of the DTED-only elevation map of the New York City area to the SRTM plus ladar map clearly shows the better resolution of the latter in the Manhattan region (Figure 5).

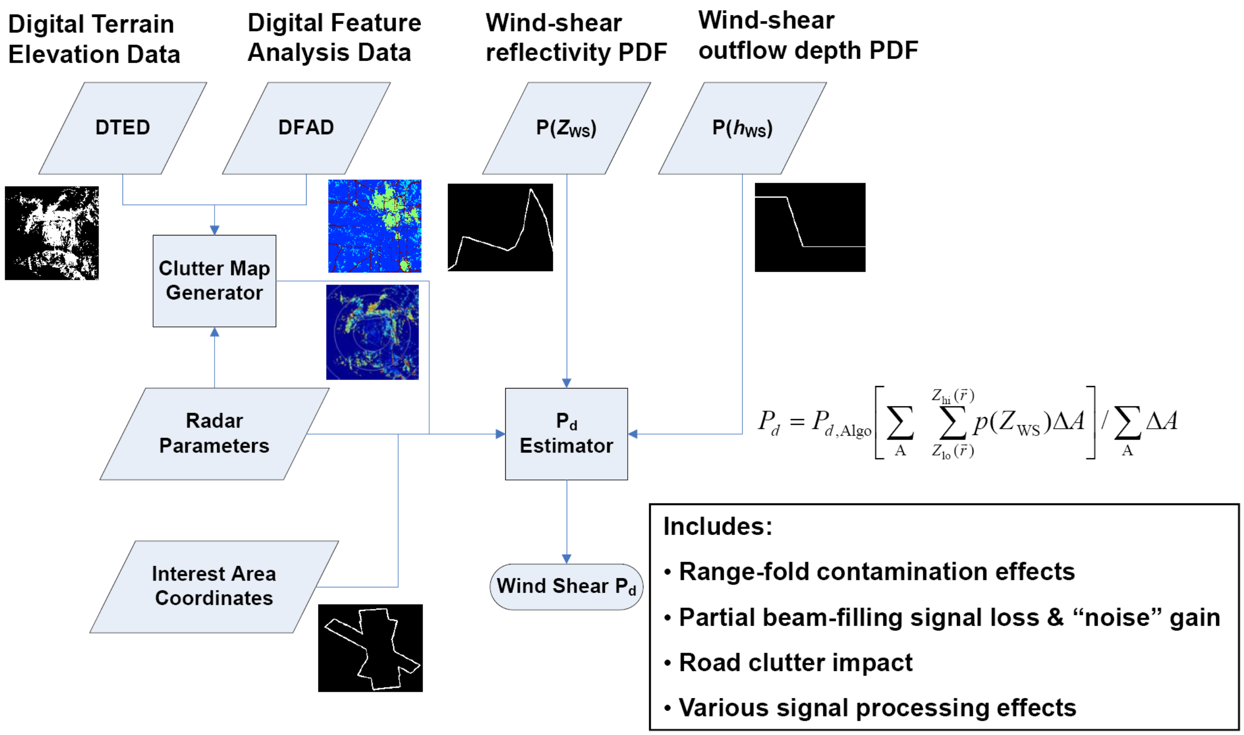


*Figure 4. Flow chart of the wind shear detection probability model (Cho et al., 2008).*

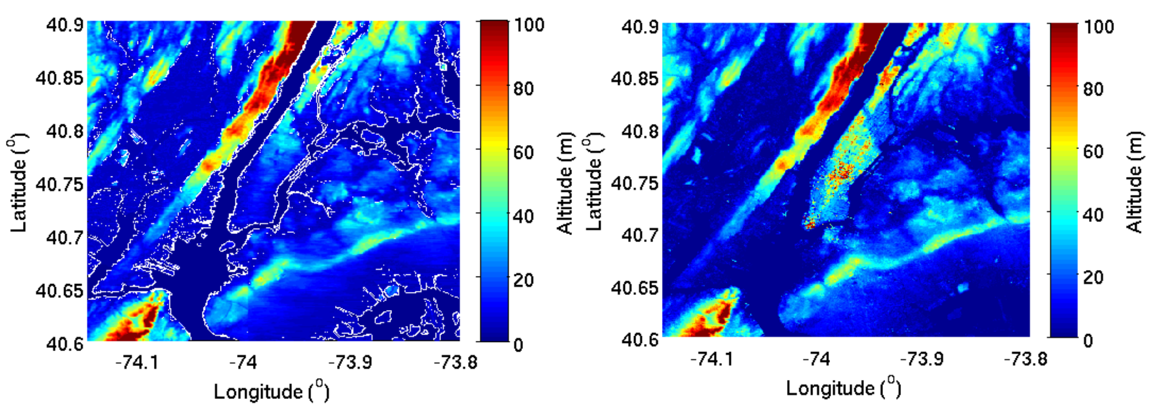


*Figure 5. Altitude above mean sea level using DTED (left) and SRTM plus airborne ladar data (right). The map on the right was used for this study since it carries more detailed information of tall buildings in Manhattan region (see middle of the maps).*

The microburst outflow height probability distribution is one factor that is crucial in estimating the microburst detection performance, and yet it is a quantity that has been measured very sparsely. In fact, the definition of the outflow height itself is subject to debate. In the earlier cost-benefit study that utilized our wind shear detection performance model the definition used was the height at which the microburst outflow velocity decreased to 50% of the maximum value, which is usually observed close to the surface (Cho and Hallowell, 2008). The reason for using this definition was that the outflow measurements recorded at both wet and dry sites used this criterion (Biron and Isaminger, 1991).

Upon further study, however, including a sensitivity analysis of the microburst outflow height distribution on detection probability estimates (Appendix A), we decided to adopt a more conservative definition of the outflow height as the altitude at which the velocity falls to 80% of the maximum. This new definition also dovetails nicely with the TDWR system requirement to measure wind shear with an accuracy of ±20%.

Direct measurements of both the 50%-maximum and 80%-maximum outflow heights were available only at one site (Denver, CO) with the latter heights being approximately half of the former (Biron and Isaminger, 1991). Therefore, we scaled the microburst outflow height distributions from the earlier study by a factor of 0.5 for this study. (The gust front height distributions were not affected, since their measurements were based on the highest altitude at which the gust front reflectivity was visible, not on the velocity profile.)

These microburst outflow height distributions were objectively interpolated to the New York airports from statistics previously collected in Huntsville, AL and Denver, CO, using various relevant meteorological variables (Hallowell et al., 2009). Clearly, the ideal approach would have been to collect an extensive database of outflow heights using the New York TDWR. Since this was beyond the scope of this study, we examined microburst statistics during one severe weather event in the New York City area using archived TDWR data. This exercise confirmed that the microburst outflow height distribution, as defined by the highest altitude at which the microburst signature was observed, is between the 50%-maximum and 80%-maximum outflow height distributions, in turn demonstrating the conservative nature of our currently used distribution (Appendix A).

The wind shear detection algorithms use data from the lowest elevation scan angle. We assumed the default TDWR surface scan angle of 0.3° (essentially half the antenna beamwidth) for all ground-based sites except for Roslyn and HPN, which were located significantly higher in altitude than the airports. For those two sites we used the elevation angles optimized for best performance. For the COTS radar at Twombly we used half the antenna beamwidth (0.5°) for the elevation angle, which lets the beam just graze above the surface when the altitudes of the site and ARENAs are similar. The two skyscraper cases require very negative elevation angles and their results are discussed separately.

The antenna height of the TDWR and COTS radars was set to 25 m above ground level for all the candidate sites other than the existing New York and Newark TDWR, for which the actual antenna height values were used. The currently existing TDWRs have antenna heights ranging from 10 m to 35 m, with an arithmetic mean of 28 m. Our model results showed that the predicted PODs are not very sensitive to the antenna height. When the antenna height changes from 10–35 m, the PODs for microbursts for the candidate sites within 30 km range vary by only 0.03; the PODs for gust fronts are constant (Appendix B). For radars on top of the Manhattan skyscrapers, we assumed they would be optimally mounted for viewing over the airport ARENAs of JFK and LGA.

One caveat about the radar and lidar wind shear detection probability model is that it does not explicitly predict false alarm probability. It is implicitly included in that, based on empirical statistics, maximum achievable PODs are set to 98% and 95% for the microburst and gust front cases, respectively, for a constant false alarm rate of 10% (Cho and Hallowell, 2008). There are, however, particular local conditions that can push the false alarm rate beyond the threshold of 10%, which is the FAA requirement. For example, studies have shown that bats or birds flying outward from a single location appear very much like a microburst in radar data. Both JFK and LGA are located adjacent to seawater and within the Atlantic Flyway for migrating seabirds. The Jamaica Bay Wildlife Refuge and Dubos Point Wildlife Sanctuary, which host many species of seabirds, is located just across the water from JFK (essentially in between the airport and the current TDWR at Floyd Bennett Field) and the double bird strike on January 15, 2009 that brought down US Airways Flight 1549 departing LGA shows that the density of birds in the air can be quite high in this area. Therefore, although a specific study regarding false alarms due to birds have not been conducted for the New York TDWR, it is likely that such a problem may manifest itself from time to time. However, for the purposes of this study, the exact location of the radar is not expected to have much impact on the degree of bird clutter—what matters is the location of the birds and that is not dependent on the radar. Also, Lincoln Laboratory is currently developing a technique to filter out much of the bird clutter in the range-Doppler domain, which, we hope, will mitigate this problem in the future.

Another possible source of false alarms (as well as degradation to the POD) is radio frequency interference (RFI). Since 2003, when the Federal Communications Commission (FCC) began allowing unlicensed national information infrastructure (U-NII) devices to operate in the same frequency band as the TDWRs, RFI has steadily increased. At the time of this writing, 22 sites are experiencing at least intermittent RFI, and the severity of interference to the New York TDWR is second only to the San Juan TDWR. Efforts are underway by the FAA to combat this national problem. Although RFI is affected by the exact location of the TDWR, we did not include this factor in our study, because this is a dynamic phenomenon that is constantly changing, and we do not know what the situation will be like in 2023.

The wind shear sensors compared in this study include the TDWR, ASR-9 WSP, NEXRAD, LLWAS, the Lockheed Martin Coherent Technologies (LMCT) Doppler lidar, TV station weather radars (EEC DWSR-90CTV and Baron VHDD-1000C), and COTS C-band radar EEC DWSR-8501C/K. This last system was chosen for the generic COTS radar, because its klystron transmitter yields significantly better phase stability, which leads to better clutter suppression than magnetron radars. Thus, even with lower power (850 kW klystron vs. 1 MW magnetron) the low-altitude wind shear detection performance is better in a ground clutter dominated environment such as the New York metropolitan area. (This statement was validated by our model results.)

For model computation of alternative wind shear sensors, we assumed that no new ASR-9s and NEXRADs would be introduced in the region. This leaves the COTS radar, lidar, and LLWAS as the only new sensors allowed to be deployed on the airports (Cho et al., 2008; Hallowell et al., 2009). Currently there is an ASR-9 at JFK and none at LGA. The JFK ASR-9 is not equipped with a WSP because of the current TDWR coverage. To study the effect of decommissioning the TDWR, we let the JFK ASR-9 be equipped with a WSP. The NEXRAD closest to the airports is the Brookhaven NEXRAD (OKX), which is located on Long Island in Upton, New York.

For multiple radar/lidar systems, the model integrates the data of multiple sensors at the pixel level. This level of data integration requires more software development, but, in principle, provides better performance than integration at the alert message level. For the radar-LLWAS combination, the detections of the wind shear by the radar and by the LLWAS are independent processes. Thus, the joint probability of detection is simply the union of the detection probabilities of the radar system(s) and the LLWAS (Cho and Hallowell, 2008):

$$POD_{joint} = 1 - (1 - POD_{radar})(1 - POD_{LLWAS})$$

The radar system parameters used in the model are listed in Table 2. Note that the TDWR, NEXRAD, and ASR-9 are either undergoing or have planned upgrades (to be completed before the 2023 relocation deadline) that will increase the maximum clutter suppression capability to about 60 dB (Cho et al., 2005; Chrisman and Ray, 2005; M. Ball, private communication); therefore, we used that value in our model computations. Information about the TV station radars was obtained via personal communications with TV station and manufacturer personnel (J. Huff, K. Vickers, and W. Walker). For the hypothetical COTS weather radar on the Empire State Building and on-airport sites, we used the specifications of the EEC DWSR-8501C/K for reasons explained above.

For the LMCT Doppler lidar, the average transmitted power is 2 W, and the wavelength is 1.6 μm. The diameter of the laser beam is 10 cm, and the maximum scan rate is 20° $s^{-1}$. The range resolution of the lidar is 30–50 m. The sampling range of the lidar is assumed to be 18 km (Cho and Hallowell, 2008 and references therein). We assume that the lidar is not affected by ground clutter but is affected by terrain blockage. The lidar's PODs of microbursts and gust fronts were computed at a beam elevation angle of 0.7° at a 7-m emitter height at the center of the union of the ARENAs for each airport, JFK and LGA. There are eight anemometers for the LLWAS-NE++ system at LGA. For a hypothetical LLWAS at JFK, the national average PODs of microbursts and gust fronts are used (Cho and Hallowell, 2008). To achieve these average PODs we estimate that approximately 11 anemometers would need to be installed at JFK (see Section 3.6).

**TABLE 2**
**Radar system parameters used in the model**

| Parameter | TDWR | ASR-9 WSP | NEXRAD | COTS Doppler Weather Radar |
|---|---|---|---|---|
| Peak Power (kW) | 250 | 1,120 | 750 | 250[1]/850[2]/1,000[3] |
| Pulse Length (µs) | 1.1 | 1 | 1.6 | 0.8 |
| Antenna Gain (dB) | 50 | 34 | 45.5 | 46[1,2]/45[3] |
| Beamwidth (AZ x EL) | 0.55°x0.55° | 1.4°x4.8° | 0.925°x0.925° | 1°x1° |
| Beam Elevation Angle | 0.3° | 2° | 0.5° | 0.5° |
| Wavelength (cm) | 5.4 | 11 | 10.5 | 5 |
| Max. Clutter Suppression (dB) | 60 | 60 | 60 | 30[1]/55[2]/45[3] |
| Rotation Rate (°/s) | ~20 | 75 | ~20 | ~20 |
| Pulse Repetition Freq. (Hz) | ~1600 | ~1100 | ~1000 | ~1600 |
| Min. Detectable dBZ @ 50 km | -11 | 7 | -10 | -5[1]/-10[2,3] |

[1] EEC DWSR-90CTV (GE Building).
[2] EEC DWSR-8501C/K (Empire State Building, on airports).
[3] Baron VHDD-1000C (Twombly)

### 2.2.2 Volumetric coverage

If a radar cannot scan all the way up to zenith, then there will be a "cone of silence" above it that it cannot observe. TDWR can only scan up to 60° elevation angle, so it has a (30° x 2 =) 60°-wide "cone of silence" directly above the radar, centered on the zenith angle.

In the initial site-survey documents, the radar coverage of the required airspace over airport ARENAs was calculated based on the distance of the site to the airport and coarsely estimated terrain blockage. By utilizing the detailed terrain and structure elevation map in the New York City region, we are able to produce more accurate results about the volumetric coverage of the required airspace from a radar at a candidate site.

A quantity called volume visibility is thus constructed to quantify the collective effects of the radar "cone of silence," terrain blockage, and Earth's curvature. Volume visibility measures the vertically integrated radar coverage of the airport ARENAs up to 6 km aloft. The maximum height of 6 km is based on the observation that microburst precursor signatures can be seen up to this level. A volume visibility of unity would mean that the whole volume is observable by the radar. In addition to volume visibility, we also computed the ARENAs visibility cross section, or areal visibility, to obtain more detailed horizontal coverage information at a certain altitude. Digital data used for the wind shear probability detection model again is used for volume/areal visibility computation.

### 2.2.3 Angular relationship between radar and airport runways

The aspect angle between the radar and the runway orientation affects the measurement accuracy of the wind component parallel to the runway. It is defined as the angle between the runway orientation and the radar line-of-sight to a point along the runway centerline.

The aspect angle varies depending on the location of the radar and the point over the runway where the measurement takes place. For a radar site that is far from the airport, the value of the angle will vary little once the site is chosen, because the runway is "short" compared to the radar-airport distance. For a radar site that is close to the airport, especially on the airport property, the value of the angle will change by a large amount depending on both radar location and the point of measurement.

To account for these variations, we computed the aspect angles between the radar and each of ten evenly spread points on the runway axis extending 3 nmi from both ends of the runway to approximate the ARENAs of JFK and LGA (Figure 6). Each airport runway was dealt with separately. For off-airport candidate sites, the aspect angles for each runway were computed for one radar location vs. different points on the axis of the runway and its "extension." For on-airport siting options, endpoints of each runway and the central location of the airport are chosen for the possible TDWR locations. Thus, for the case of LGA as a candidate site, angles of (2x2+1=) 5 radar locations vs. each of the 20 different measurement points were computed. For the case of JFK, angles of (4x2+1=) 9 radar locations vs. each of the 40 points on the runways and "extensions" were computed. Multiple radar locations were employed, because the actual radar site could be anywhere on the airport.

Contradictory information was found about which runways are the "inclement weather" runways at JFK and LGA. According to some initial site-survey documents, the most frequently used runways during severe weather events are 4R/22L and 4L/22R for JFK and 4/22 for LGA (FAA, 1991; Burns et al., 1996; SRI 1998). However, other documents pointed out that the most frequently used runways in all weather are 13R/31L and 13L/31R for JFK and 13/31 for LGA (Burns et al., 1993; Sterling, 1993; FAA, 2004). Runway use (take-off and landing) at JFK is 18%, 15%, 27%, and 40% on 4L/22R, 4R/22L, 13L/31R, and 13R/31L, respectively (Burns et al., 1993). At LGA, the runway use figures for 13/31 and 4/22 are 53% and 47%, respectively (Sterling, 1993). Since TDWR is designed to protect the whole airport ARENAs, we consider all six runways listed above (Figure 6).

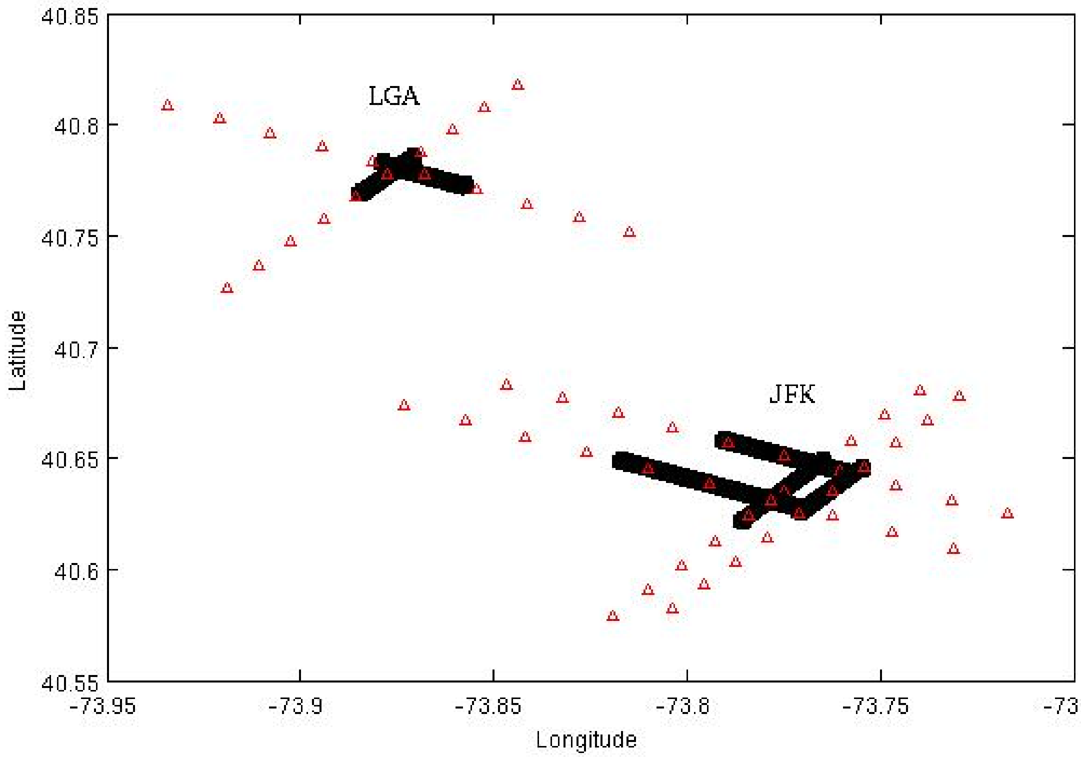


*Figure 6. Illustration of runways (the thick solid lines) at JFK and LGA, and the points (the triangles) where the aspect angles are calculated, extended to 3 nmi beyond each end of the runway.*

## 2.3 VALIDATION OF THE WIND SHEAR DETECTION PROBABILITY MODEL

Performance statistics of the TDWR can be used to verify the results generated from the model. For TDWR performance evaluations, typically the archived NEXRAD and TDWR base data are analyzed by experienced meteorologists for the number, location, and strength of the wind shear events. These "truths" are compared with the results or products from the TDWR microburst or gust front detection algorithms to give the detection probabilities of the TDWR over the airport ARENAs.

For airports outside the New York City region, Cho and Hallowell (2008) compared the model PODs of microbursts with TDWR performance analyses in Atlanta, GA (ATL), Washington, D.C. (DCA), Denver, CO (DEN), Houston, TX (IAH), Orlando, FL (MCO), and Memphis, TN (MEM). The POD differences between the model results and actual TDWR performance were within 3% in all cases.

For the three New York City airports JFK, LGA, and EWR, Allan et al. (1999) evaluated the performance of the TDWR during a severe weather event. A total of 58 divergence-related "wind shear" (WS) and "microburst" (MB) events were "truthed," of which 51 events were detected using the TDWR microburst detection algorithm, i.e., the POD was 0.88. A wind shear event in the microburst detection algorithm is defined as a wind velocity loss between 15–30 kt (7.5–15 m/s) over a distance of 4 km. A microburst event is defined as a wind velocity loss of 30 kt (15 m/s) or greater over the same distance. The combined POD of WS and MB should be equivalent to the model POD, because the microburst outflow height distribution was based on minimum velocity threshold of 10 m/s (Biron and Isaminger, 1991). It is clear that the TDWR performance POD is comparable to our model results of the legacy system (0.87–0.89) (Table 3). The legacy system performance is lower than the upgraded system performance used in the rest of this study, due to the lack of range-aliasing protection and slightly worse clutter suppression.

In this study, more TDWR performance analysis in the New York City region was conducted to compare with the model results of the legacy TDWR system (Table 3). Seven severe weather events during 2002–2003 were analyzed for the TDWR performance at JFK, LGA, and EWR. A total of archived 357 "wind shear" and "microburst" events were observed, and the TDWR measurement PODs for each airport were obtained. For JFK, the model underestimated the POD value by 0.04 (-4%). For LGA, the model overestimated the POD by 0.03 (+3%). For EWR, the model underestimated the POD by 0.07 (-7%). The overall TDWR performance in the New York City region was 0.91, which is ~3% higher than the averaged POD of JFK, LGA, and EWR of the legacy system from our model (0.88). Given the small number (seven) of weather events sampled, the agreement is reasonable.

**TABLE 3**

**Comparison of the model microburst POD with the performance of the TDWR Microburst Detection Algorithm in the New York City Region**

| Airport | Event Type | True Events | Detected Events | TDWR Performance (POD) | Model POD |
|---|---|---|---|---|---|
| | WS[1] | 66 | 60 | 0.91 | |
| | MB[2] | 0 | 0 | - | |
| JFK | ***WS + MB*** | ***66*** | ***60*** | ***0.91*** | ***0.87*** |
| | WS | 106 | 90 | 0.85 | |
| | MB | 10 | 10 | 1.00 | |
| LGA | ***WS + MB*** | ***116*** | ***100*** | ***0.86*** | ***0.89*** |
| | WS | 169 | 159 | 0.94 | |
| | MB | 6 | 6 | 1.00 | |
| EWR | ***WS + MB*** | ***175*** | ***165*** | ***0.94*** | ***0.87*** |

[1] Wind shear event
[2] Microburst event

No evaluation about the model gust front PODs was made due to the different definitions of the region of interest in the model and in the various gust front detection performance studies in the past (Cho and Hallowell, 2008).

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# 3. RESULTS AND DISCUSSION

## 3.1 AVAILABILITY OF THE SIX CANDIDATE SITES STUDIED EARLIER BY OTHERS

The extreme difficulty in finding a site for the New York TDWR was well-recorded in the initial siting documents and newspaper articles. Since the New York City airports were on the FAA's priority list for TDWR installation, initial site survey efforts started quite early, in 1991. By 1993, several sites were identified and most of them were federal land. Among these sites, two were selected for the siting of two TDWRs: the Bellmore site for the JFK TDWR and the Roslyn site for the LGA TDWR. These two sites, however, were blocked at the Congressional level due to local residents' fear of radiation and the political response by their representatives. The public interest in deployment of the TDWR for JFK and LGA was later renewed after a wind shear related fatal accident (USAir Flight 1016 at Charlotte, NC in July 1994). Ironically, this accident could have been avoided because a TDWR was scheduled to be in service for the Charlotte airport before then, but the installation was delayed due to a land acquisition problem (Dune, 1994; Beck, 1995; New York Times, 1999). Finally in late 1999 the Department of the Interior agreed that the FAA could use the US Coast Guard Station at Floyd Bennett Field for the TDWR site for 20 years (Burns et al., 1993; FAA, 1995; SRI, 1998; New York Times, 1999). The TDWR was finally in service in 2003 after 12 years of siting effort. Because the current TDWR location was judged to be not ideal for LGA according to the original siting criteria, an LLWAS system was installed at LGA for further protection.

The technical assessment in the initial site survey documents can be summarized as follows. The Bellmore site was the preferred site for the JFK TDWR. The TDWR was planned to be installed on the foundation of an old water tower inside the Bellmore (former) US Army Reserve Center, Nassau County (Burns et al., 1993; SRI, 1998). The Roslyn site was initially selected for siting the LGA TDWR. It is a high ground in the Roslyn (former) US Air National Guard Station, Nassau County. Both Roslyn and Bellmore sites were blocked by Congress. The current TDWR site, Floyd Bennett Field, is located on a parcel of a former U.S. Department of Transportation property in the former US Coast Guard Air Station, Brooklyn, and is within the National Park Service's Jamaica Bay Jurisdiction. The current site was considered to be too close to JFK (~5 nmi) according to initial siting criteria (Burns et al., 1993).

Two other sites considered are the Ft. Tilden site and the Beach 169$^{th}$ Street site. Both of them are close to the Floyd Bennett Field site. Ft. Tilden is a former US Army Reserve Center. The initial reasons for dismissal of this site were: The TDWR tower would stand out from the surrounding low structures and be visible to both Ft. Tilden and Jacob Riis Park (an aesthetic objection); it would be technically unsuitable due to the radar blockage caused by the Marine Parkway Bridge. The Beach site was described in the initial siting documents as a privately owned parcel in an open sand dune area on the side of a road adjacent to the Ft. Tilden US Army Reserve Center. The reasons for dismissal of this site were possible negative ecosystem effects and potential aesthetic impacts due to the direct view of the site from all of the Jacob Riis Park shoreline. It appears that both Ft. Tilden and Beach sites were not being seriously considered, because the exact locations for the TDWR foundation were not proposed in the initial site-survey documents.

The Hart Island site is a former Nike missile facility that was operated by the Department of Defense on Hart Island. Located in western Long Island Sound, the island is administered by the New York City Department of Correction and is used as a city cemetery. At the time when the survey was conducted, there were no residential buildings on the island. Ferry was the only means of transportation for authorized personnel. The reasons for dismissal of this site were comparatively high installation costs ($9 million as compared to the then-current $6 million plus additional operating costs), access difficulty, poor coverage for JFK because of distance, beam blockage when scanning JFK, and less operational time due to relative inaccessibility. The Hart Island site was ranked second, next to Floyd Bennett Field, the current TDWR site (SRI, 1998).

Figure 7 gives the current satellite views of the Roslyn, Bellmore, Ft. Tilden, Beach, and Hart Island sites. It appears that the property of the Roslyn (former) US Air National Guard Station has been fully developed (Figure 7a). Further research about the Roslyn site indicates that the former federal land was sold to the local community. The property has been developed into a recreational park, which was opened to local residents in 2006 with many facilities such as "the largest leisure municipal pool on Long Island" (New York Times, 2000; http://en.wikipedia.org/wiki/East_Hills,_New_York). The land of the Bellmore (former) Army Reserve Center appears demolished but undeveloped (Figure 7b). The water tower inside the Army Reserve Center that was planned to be replaced with the TDWR has been removed, but its foundation is not currently occupied. Information gathered from the Internet indicates that the Bellmore Army Reserve Center was decommissioned in 1996 and demolished ten years later, currently being developed for senior citizen housing (http://wikimapia.org/4643230/Former-Site-of-US-Army-Bellmore-Logistics-Activity-Center). Ft. Tilden appears deserted according to pictures posted on the Internet. According to Arlington Economic Development, it was also opened for redevelopment (http://www.arlingtonvirginiausa.com/index.cfm/13495). Later news mentioned that Ft. Tilden is now run by the National Park Service (Crewdson and Mittelbath, 2001) (Figure 7c). No detailed information is available for the Beach site mentioned in initial site-survey documents, so we are not able to locate the exact surveyed location and contact information. Nevertheless, Ft. Tilden and Beach sites are within the Gateway National Recreation Area, the same park that the TDWR is supposed to vacate. The Hart Island site appears undeveloped, too, and it is still owned by the City of New York (Figure 7d).

The contact information of the five candidate sites in the initial site-survey documents are listed in Appendix C. The detailed report of a follow-up survey about the availability of these lands is included in Appendix D.


*Figure 7a. Roslyn (former) US Air National Guard Center. The initially proposed TDWR location (for LGA) is marked with a yellow pin.*


*Figure 7b. Bellmore (former) US Army Reserve Center. The initially proposed TDWR location (for JFK) is marked with a yellow pin.*


*Figure7c. Previously identified TDWR sites at Ft. Tilden (former) US Army Reserve Center and on the road side of Beach 169th Street.*


*Figure 7d. Hart Island. The likely initially proposed TDWR location, a former Nike missile range foundation, is marked with a yellow pin.*

### 3.2 MICROBURST AND GUST FRONT DETECTION RESULTS FOR CANDIDATE SITES

Terrain blockage, ground clutter, Earth's curvature, and microburst/gust front outflow height distributions can all affect the radar detection of wind shear events. Of these factors, only the effect of Earth's curvature is directly related to the radar-airport distance. When the radar is located far from the airport, curvature of the Earth can cause the radar to miss the detection of low altitude events over the airport ARENAs. In the comparisons that follow, we sort the candidate sites based on their distances to the airports.

Model PODs of microbursts and gust fronts for JFK and LGA are listed for the ground-based candidate sites (Table 4). To help visually inspect the results, the PODs with POD≥0.90 are shaded in green color, those with PODs of 0.81–0.89 are shaded in yellow color, and those with POD<0.81 are shaded in red color. Note that a POD of equal or better than 0.90 is the FAA requirement for microburst detection. For gust fronts, however, there is no official POD requirement.

**TABLE 4**

**Radar probability of detection (POD) of microbursts and gust fronts for (a) JFK and (b) LGA airports at candidate sites, excluding the two Manhattan skyscraper sites, sorted by the distance to the airport. Those with POD ≥ 0.90 are shaded in green, those with PODs of 0.81 – 0.89 are shaded in yellow, and those with POD < 0.81 are shaded in red.**

**4a. Detection probabilities for JFK**

| Site | Beam Elevation Angle (deg) | Radar-Airport Distance (km) | Microburst POD | Gust Front POD |
|---|---|---|---|---|
| JFK | 0.3 | 0 | 0.93 | 0.88 |
| Floyd[1] | 0.3 | 10 | 0.93 | 0.89 |
| Beach | 0.3 | 12 | 0.94 | 0.89 |
| Ft. Tilden | 0.3 | 13 | 0.93 | 0.89 |
| LGA | 0.3 | 17 | 0.97 | 0.93 |
| Roslyn | 0 | 21 | 0.96 | 0.94 |
| Bellmore | 0.3 | 22 | 0.95 | 0.92 |
| Hart Island | 0.3 | 24 | 0.94 | 0.93 |
| FRG | 0.3 | 32 | 0.84 | 0.94 |
| TEB | 0.3 | 33 | 0.00 | 0.68 |
| Fresh Kill | 0.3 | 36 | 0.01 | 0.57 |
| Twombly[2] | 0.5 | 38 | 0.48 | 0.93 |
| LDJ | 0.3 | 39 | 0.16 | 0.89 |
| EWR[3] | 0.3 | 42 | 0.03 | 0.94 |
| HPN | -0.1 | 48 | 0.86 | 0.91 |
| CDW | 0.3 | 50 | 0.00 | 0.00 |

**Table 4 (continued)**

**4b. Detection probabilities for LGA**

| Site | Beam Elevation Angle (deg) | Radar-Airport Distance (km) | Microburst POD | Gust Front POD |
|---|---|---|---|---|
| LGA | 0.3 | 0 | 0.93 | 0.88 |
| Hart Island | 0.3 | 12 | 0.95 | 0.89 |
| JFK | 0.3 | 17 | 0.97 | 0.91 |
| TEB | 0.3 | 18 | 0.13 | 0.69 |
| Roslyn | 0 | 21 | 0.96 | 0.93 |
| Twombly[2] | 0.5 | 21 | 0.71 | 0.91 |
| Floyd[1] | 0.3 | 21 | 0.96 | 0.91 |
| Beach | 0.3 | 24 | 0.95 | 0.91 |
| Ft. Tilden | 0.3 | 24 | 0.95 | 0.91 |
| Bellmore | 0.3 | 30 | 0.89 | 0.94 |
| Fresh Kill | 0.3 | 35 | 0.44 | 0.68 |
| HPN | -0.1 | 35 | 0.89 | 0.88 |
| LDJ | 0.3 | 36 | 0.80 | 0.94 |
| CDW | 0.3 | 36 | 0.00 | 0.00 |
| FRG | 0.3 | 39 | 0.76 | 0.95 |
| EWR[3] | 0.3 | 39 | 0.76 | 0.94 |

[1] Current New York TDWR location

[2] Baron VHDD-1000C

[3] Newark TDWR location

For both JFK and LGA, all sites investigated in the initial TDWR siting studies have good overall PODs for microbursts and gust fronts (Table 4). While Bellmore has a microburst detection probability of 0.89 for LGA, this value is not significantly different from the FAA POD requirement considering the model uncertainty and antenna height sensitivity (Section 2.2.1). Siting the TDWR at either JFK or LGA shows excellent microburst and gust front detection. The excellent detection predicted for these prescreened candidate sites is consistent with the initial site survey results.

The Newark TDWR shows very favorable detection probabilities of gust fronts for both JFK and LGA, although the microburst detection performance is unacceptable at both airports. The option of on-airport siting is discussed in detail in Section 3.5.

About 30 km from the airports, the Staten Island site, Fresh Kill, has low wind shear detection for both JFK and LGA, caused by terrain and building blockage. Thus, this Staten Island site is not an acceptable choice for siting the TDWR.

Compared to the sites in the initial site-survey documents, the municipal airport sites other than JFK and LGA are considerably farther from both airports. The exceptions are FRG (32 km from JFK) and TEB (18 km from LGA). Model results show that siting the TDWR at TEB would not provide good microburst or gust front performance, while siting the TDWR at FRG would provide sufficient detection for gust fronts but not for microbursts. So, these airports are not acceptable for TDWR relocation without additional sensors. In addition to FRG, airport sites that show good PODs for gust fronts are HPN and LDJ. Further study shows that HPN is a promising location for the TDWR, provided that additional sensors are installed on the airports (Section 3.5).

The idea of using a C-band COTS Doppler weather radar on top of a Manhattan skyscraper to provide wind shear protection at JFK and LGA is not new. The EEC DWSR-90CTV radar of WNBC has been qualitatively investigated in the initial siting documents (SRI, 1998). The investigators concluded that while the radar could provide general weather information, it did not have the capability of detecting and reporting wind shear phenomena. Even if that capability were added, it would still be less accurate and less effective than the TDWR due to the wider beam width, lower pulse repetition frequency, lower duty cycle and sensitivity, and inferior clutter suppression capabilities (SRI, 1998). Another concern was that the skyscraper is nearly perpendicular (85°) to runways 4R/22L and 4L/22R at JFK and 4/22 at LGA so the radar may not measure winds parallel to these runways accurately (SRI, 1998). Moreover, a radar on the skyscraper is likely to encounter stronger ground clutter than a radar at a ground site due to negative scan angles, which would not only reduce the detection sensitivity but also increase the false alarm rate (SRI, 1998). In fact, severe ground clutter was the main reason for the National Weather Service to abandon their weather radar site on top of the GE Building after 30 years of service: The skyscraper station is now substituted with a ground station 45 miles from Manhattan (New York Times, 1990). As a result, the idea of using the WNBC radar for the TDWR substitution was promptly rejected by the authors of the prior siting studies.

We reanalyzed the option of using the TV station radars or any similar COTS Doppler weather radar mounted on top of a Manhattan skyscraper for wind shear protection at the airports. Unsurprisingly, our results support the arguments in the initial siting documents.

A radar mounted on a tall skyscraper needs a negative elevation angle in order to be able to see wind shears near the surface. Larger negative angles, however, lead to increased ground clutter and decreased effective range. In order to determine the optimal angle for each site and airport, we ran our model for various beam elevation angles (Figure 8). Based on these results, the FAA microburst detection probability requirement of greater than or equal to 0.90 over the airport ARENAs would be impossible to meet with a C-band COTS Doppler weather radar mounted on top of a Manhattan skyscraper. The problem would be even more difficult if we take into account the additional adverse issues such as finding the right mounting spot so that the radar would not be blocked by other skyscrapers and the undesirable large angles to certain runways (Section 3.4). Hence, we can easily rule out the option of mounting a radar of similar type to protect JFK and LGA from wind shear exposure.

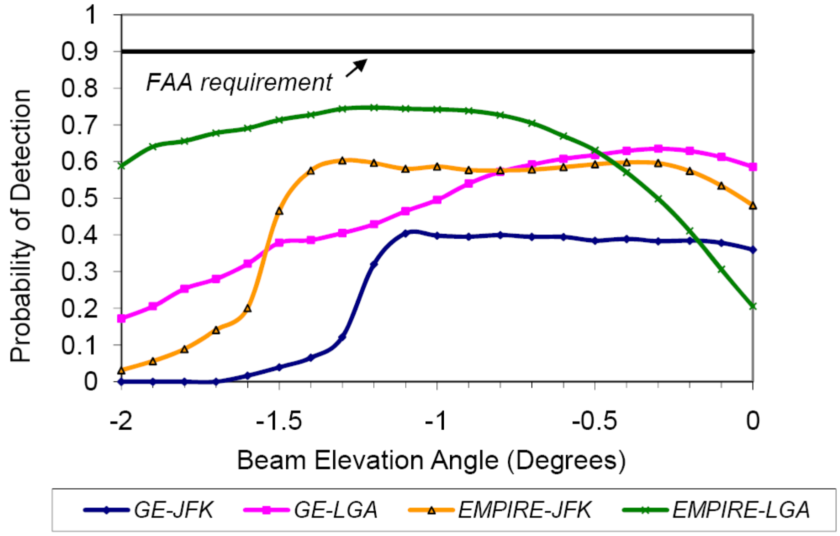


*Figure 8. Change in microburst PODs with various beam elevation angles for C-band COTS radars scanning JFK and LGA, respectively, at microburst outflow height scale of 0.5.*

## 3.3 RADAR COVERAGE: AREAL AND VOLUME VISIBILITY

In addition to the near-surface detection capability, the coverage of airspace aloft is another importation consideration for TDWR siting. As a result, we computed volume visibility as well as areal visibility at various altitudes for all candidate sites including the Manhattan skyscrapers (Table 5). The results show that if the TDWR were deployed at the airport, the volume coverage of the TDWR would decrease by 40%–50%. This poor coverage clearly is a result of the radar "cone-of-silence" effect due to the limited elevation scan angles of the TDWR (≤60°). This limitation results in poor radar visibility at altitudes higher than ~1 km over the ARENAs (Table 5).

This "cone-of-silence" issue is a factor that works against siting a radar close to or on the airport. Although the most hazardous forms of wind shear phenomena to terminal operations, such as microbursts and gust fronts, occur at low altitudes, observing weather aloft is also important. By keeping track of precursor signatures in a thunderstorm aloft, microbursts can be predicted 1–2 min in advance before wind shear (divergence) is actually observed over terminal areas. This early prediction feeds into the microburst detection algorithm and improves the POD by 1%–2% compared to wind shear observation alone (R. Hallowell, unpublished work on review of the Integrated Terminal Weather System (ITWS) operational data). Furthermore, verification of an overhead storm cell reduces false alarms of microburst detection. For the TDWR microburst detection algorithm, a microburst alert is issued only when the reflectivity above the observed microburst exceeds a certain threshold. Keeping in mind the importance of observing weather features aloft the terminal areas, we need to modify the TDWR wind shear detection algorithm if the TDWR is sited on the airport, and if the accompanying decrease in performance is deemed to be unacceptable. Specifically, "feature aloft" detection will need to be facilitated via integration of data obtained from an off-airport radar.

**TABLE 5**

**Areal visibility at different altitudes and volume visibility over the ARENAs viewed from the TDWR candidate sites, as well as the two skyscrapers, sorted by the distance to the airport. Those with visibility ≥ 0.90 are shaded in green, those with visibilities of 0.81–0.89 are shaded in yellow, and those with visibility < 0.81 are shaded in red.**

**5a. Areal Visibility for JFK airport**

| Site | Radar Type | Radar-Airport Distance (km) | Areal Visibility 100 m | 150 m | 200 m | 300 m | 900 m | 1500 m | 3000 m | 4500 m | 6000 m | Volume Visibility |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| JFK | TDWR | 0 | 1 | 1 | 1 | 1 | 0.93 | 0.93 | 0.61 | 0.29 | 0.13 | 0.60 |
| Floyd[1] | TDWR | 10 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0.98 | 0.95 | 0.99 |
| Beach | TDWR | 12 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0.97 | 1 |
| Ft. Tilden | TDWR | 13 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0.99 | 1 |
| LGA | TDWR | 17 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| EMPIRE | EEC DWSR-8501C/K | 21 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| GE | EEC DWSR-90CTV | 21 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| Roslyn | TDWR | 21 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| Bellmore | TDWR | 22 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| Hart Island | TDWR | 24 | 0.96 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| FRG | TDWR | 32 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| TEB | TDWR | 33 | 0 | 0 | 0 | 0.36 | 1 | 1 | 1 | 1 | 1 | 0.96 |
| Fresh Kill | TDWR | 36 | 0 | 0 | 0 | 0.03 | 1 | 1 | 1 | 1 | 1 | 0.93 |
| Twombly | VHDD-1000C | 37 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| LDJ | TDWR | 39 | 0 | 0.03 | 0.18 | 0.47 | 1 | 1 | 1 | 1 | 1 | 0.96 |
| EWR[2] | TDWR | 42 | 0 | 0 | 0.03 | 0.41 | 1 | 1 | 1 | 1 | 1 | 0.96 |
| HPN | TDWR | 48 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| CDW | TDWR | 50 | 0 | 0 | 0 | 0 | 0 | 0.42 | 1 | 1 | 1 | 0.74 |

While on-airport sites suffer from the "cone-of-silence" deficit, some off-airport sites have areal and volume visibility problems as well, at altitudes ≤1500 m (Table 5). This is caused by the effects of terrain blockage and the curvature of the Earth. For off-airport sites within 30 km, only TEB (and Bellmore at an altitude of ~100 m) shows low altitude blockage when viewing LGA. For farther sites such as CDW, the radar airspace visibility below 1500 m is ≤40% for both airports.

**TABLE 5 (continued)**

**5b. Areal Visibility for LGA airport**

| Site | Radar Type | Radar-Airport Distance (km) | Areal Visibility 100 m | 150 m | 200 m | 300 m | 900 m | 1500 m | 3000 m | 4500 m | 6000 m | Volume Visibility |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| LGA | TDWR | 0 | 1 | 1 | 1 | 1 | 0.86 | 0.86 | 0.52 | 0.19 | 0.02 | 0.52 |
| GE | EEC DWSR-90CTV | 9 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| EMPIRE | EEC DWSR-8501C/K | 10 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| Hart Island | TDWR | 12 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| JFK | TDWR | 17 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| TEB | TDWR | 18 | 0 | 0.16 | 0.52 | 1 | 1 | 1 | 1 | 1 | 1 | 0.98 |
| Roslyn | TDWR | 21 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| Twombly | VHDD-1000C | 21 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| Floyd[1] | TDWR | 21 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| Beach | TDWR | 24 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| Ft. Tilden | TDWR | 24 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| Bellmore | TDWR | 30 | 0.70 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| Fresh Kill | TDWR | 35 | 0.14 | 0.26 | 0.63 | 0.85 | 1 | 1 | 1 | 1 | 1 | 0.98 |
| HPN | TDWR | 35 | 0.84 | 0.90 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| LDJ | TDWR | 36 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| CDW | TDWR | 36 | 0 | 0 | 0 | 0 | 0 | 0.40 | 1 | 1 | 1 | 0.76 |
| FRG | TDWR | 39 | 0.44 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0.99 |
| EWR[2] | TDWR | 39 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |

[1] Current New York TDWR location
[2] Newark TDWR location

To investigate the possibility of on-airport siting option discussed in Section 3.5, we further computed the areal and volume visibility for dual radar systems that combine on-airport TDWRs and the existing EWR TDWR, COTS 1 MW weather radar at the Twombly site, JFK ASR-9, and OKX NEXRAD (Table 6). The results clearly show that the "cone-of-silence" region for on-airport TDWRs can be covered by these existing off-airport radar systems, with the caveat that the spatial resolution of the data will be reduced due to the distance. Thus, the on-airport siting option is feasible provided that data integration of two sensor systems is implemented.

In general, the results of volume and areal visibilities support the initial distance requirement for TDWR siting.

**TABLE 6**

**Areal and volume visibilities of dual sensor system for combinations of on-airport TDWRs and existing radar systems. The color coding follows the same convention of Table 4.**

**6a. Dual-radar visibilities for JFK airport**

| Location 1 (Radar Type) | Location 2 (Radar Type) | Areal Visibility 100 m | 150 m | 200 m | 300 m | 900 m | 1500 m | 3000 m | 4500 m | 6000 m | Volume Visibility |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Floyd (TDWR)[1] | JFK (TDWR) | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0.96 | 1.00 |
| Floyd (TDWR)[1] | LGA (TDWR) | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| Floyd (TDWR)[1] | EWR (TDWR)[2] | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| Floyd (TDWR)[1] | Twombly (COTS)[3] | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| Floyd (TDWR)[1] | JFK (ASR9) | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0.98 | 0.95 | 0.99 |
| Floyd (TDWR)[1] | OKX (NEXRAD) | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| JFK (TDWR) | LGA (TDWR) | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| JFK (TDWR) | EWR (TDWR)[2] | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| JFK (TDWR) | Twombly (COTS)[3] | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| JFK (TDWR) | JFK (ASR9) | 1 | 1 | 1 | 1 | 0.93 | 0.93 | 0.61 | 0.29 | 0.13 | 0.60 |
| JFK (TDWR) | OKX (NEXRAD) | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| LGA (TDWR) | EWR (TDWR)[2] | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| LGA (TDWR) | Twombly (COTS)[3] | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| LGA (TDWR) | JFK (ASR9) | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| LGA (TDWR) | OKX (NEXRAD) | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| EWR (TDWR)[2] | Twombly (COTS)[3] | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| EWR (TDWR)[2] | JFK (ASR9) | 0.99 | 0.98 | 0.97 | 0.96 | 1 | 1 | 1 | 1 | 1 | 1.00 |
| EWR (TDWR)[2] | OKX (NEXRAD) | 0 | 0 | 0.03 | 0.41 | 1 | 1 | 1 | 1 | 1 | 0.96 |
| Twombly (COTS)[3] | JFK (ASR9) | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| Twombly (COTS)[3] | OKX (NEXRAD) | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| JFK (ASR9) | OKX (NEXRAD) | 0.98 | 0.98 | 0.97 | 0.92 | 1 | 1 | 1 | 1 | 1 | 1.00 |

## 3.4 ASPECT ANGLES BETWEEN AIRPORT RUNWAYS AND CANDIDATE SITES

The arithmetic mean aspect angles between the candidate sites and the runways, sorted by the distance to the airports, are shown in Figure 9. Both JFK and LGA possess two sets of (parallel) runways that are perpendicular to each other (Figure 6). It is the general understanding that the airports would try to use both sets of the runways as much as possible. So, for the cases of JFK and LGA, the aspect angle becomes a less critical measure in terms of site comparison. For off-airport candidate sites, a site that is favorable for one set of the runways is less favorable for the other set of the runways at the same airport. For example, the Roslyn site is good for runways 4R/22L and 4L/22R at JFK but not optimal for runways 13R/31L and 13L/31R. Another expected result is that the aspect angle of a site that is far from the airport is less variable than that of a nearby site, and the on-airport siting produces the largest variation of aspect angles. The most interesting finding is that on-airport siting results in small mean aspect angles for both sets of the runways at the housing airport. This is because the radar is close to all runways at the airport.

Therefore, from the viewpoint of the aspect angle, on-airport siting is superior to off-airport siting for the housing airport.

**TABLE 6 (continued)**

**6b. Dual-radar visibilities for LGA airport**

| Location 1 (Radar Type) | Location 2 (Radar Type) | Areal Visibility 100 m | 150 m | 200 m | 300 m | 900 m | 1500 m | 3000 m | 4500 m | 6000 m | Volume Visibility |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Floyd (TDWR)[1] | JFK (TDWR) | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| Floyd (TDWR)[1] | LGA (TDWR) | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| Floyd (TDWR)[1] | EWR (TDWR)[2] | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| Floyd (TDWR)[1] | Twombly (COTS)[3] | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| Floyd (TDWR)[1] | JFK (ASR9) | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| Floyd (TDWR)[1] | OKX (NEXRAD) | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| JFK (TDWR) | LGA (TDWR) | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| JFK (TDWR) | EWR (TDWR)[2] | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| JFK (TDWR) | Twombly (COTS)[3] | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| JFK (TDWR) | JFK (ASR9) | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| JFK (TDWR) | OKX (NEXRAD) | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| LGA (TDWR) | EWR (TDWR)[2] | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| LGA (TDWR) | Twombly (COTS)[3] | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| LGA (TDWR) | JFK (ASR9) | 1 | 1 | 1 | 1 | 1 | 1 | 0.97 | 0.19 | 0.02 | 0.66 |
| LGA (TDWR) | OKX (NEXRAD) | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| EWR (TDWR)[2] | Twombly (COTS)[3] | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| EWR (TDWR)[2] | JFK (ASR9) | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| EWR (TDWR)[2] | OKX (NEXRAD) | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| Twombly (COTS)[3] | JFK (ASR9) | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| Twombly (COTS)[3] | OKX (NEXRAD) | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| JFK (ASR9) | OKX (NEXRAD) | 0.96 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1.00 |

[1] Current New York TDWR location
[2] Newark TDWR location
[3] Baron VHDD-1000C

A study by Hallowell (1993) provides an upper bound on the uncertainty of microburst strength estimation due to different aspect angles. It reveals that when the microburst is asymmetric, or aspect angle dependent, the radar could underestimate as much as 25% of its strength depending on the viewing angle of the radar. The consequence of this underestimation to the TDWR microburst detection algorithm is that some "microburst" alerts (issued when wind velocity loss is 15 m/s or 30 kt and over) may be reported as "wind shear" alerts (issued with 7.5–15 m/s or 15–30 kt velocity loss), and some "wind shear" events may not be detected.

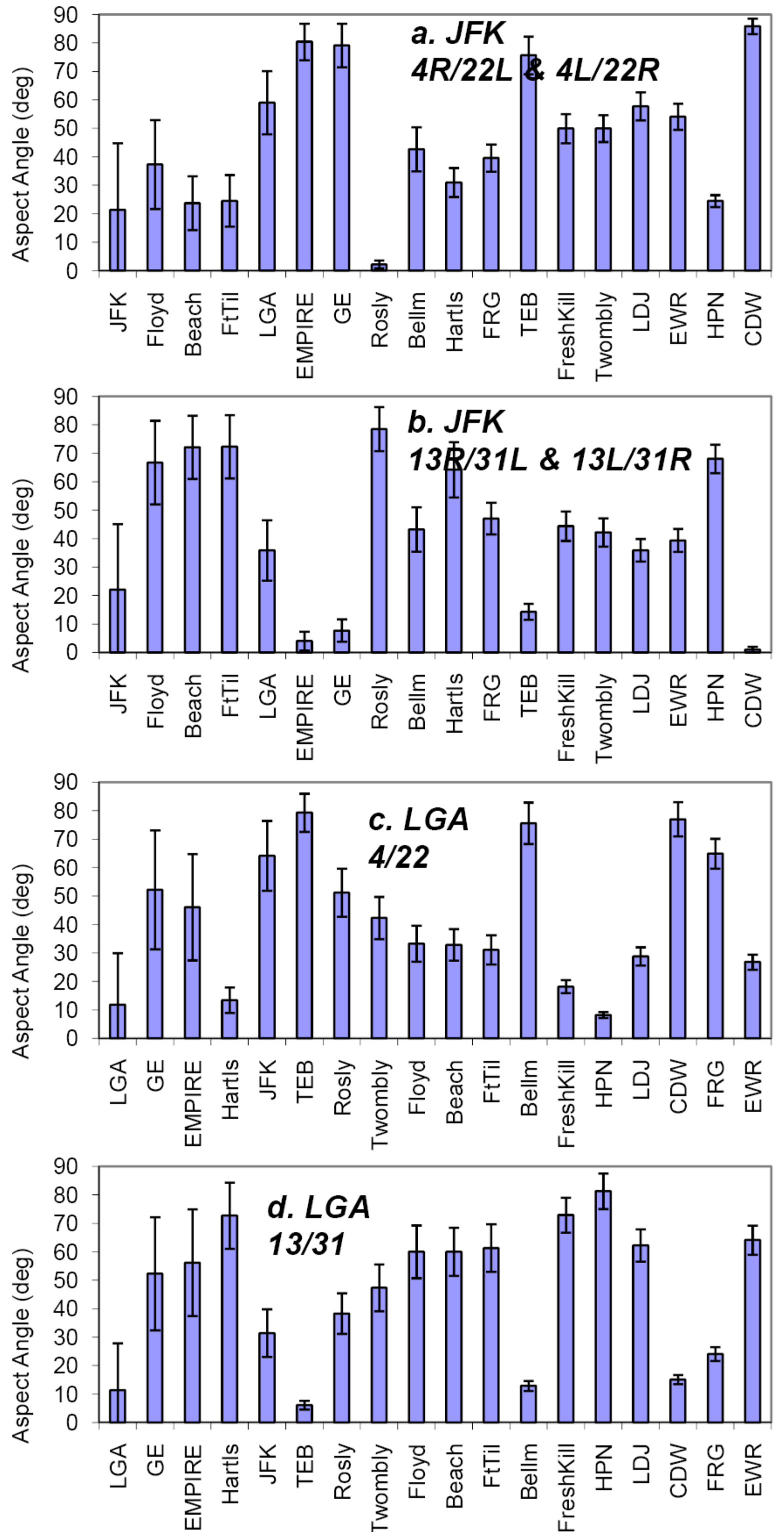


*Figure 9. Arithmetic mean aspect angles to runways for candidate sites sorted by the distance increasing to the right. The error bars are one sample standard deviation (s.d.). a. JFK: runways 4R/22L and 4L/22R. b. JFK: runways 13R/31L and 13L/31R. c. LGA: runway 4/22. d. LGA: runway 13/31.*

## 3.5 COMPARISON OF CANDIDATE SITES AND SITING ASSESSMENT

To compare the strengths and weaknesses of each candidate site, we compiled the results of the probability of detection for microbursts, the volume visibility, and the aspect angles (Table 7). Color is again introduced in the table to help with the comparison. The green shading is applied to a POD or volume visibility of 0.90 or greater, or an aspect angle that overlaps 45° considering 1 standard deviation (*s.d.)* of variation. The yellow shading is used when the value is off but is still within 10% of 0.90 for POD and volume visibility, or within the 2 *s.d.* range of 45° aspect angle. The red shading indicates that it is beyond the 10% margin of 0.90 POD or volume visibility, or 2 *s.d.* of 45° aspect angle. In other words, green is "good," yellow is "marginal," and red is "undesirable". Note that only the microburst POD has a hard FAA requirement of 0.90. So, the gust front PODs, volume visibilities, and aspect angles are shown for intercomparison purposes only.

### 3.5.1 Comparison of off-airport options

For JFK protection, the sites in the initial siting documents and LGA show either all green shading or at most one yellow shading (for gust fronts) ignoring the aspect angle columns. These are candidate sites that meet the FAA microburst detection requirement and do not have volumetric coverage problems (Table 7a**).** The TDWR located on the JFK property would produce good wind shear detection and good overall aspect angles but would not have good volumetric coverage over airspace above the airport ARENAs, so the "cone-of-silence" issue would need to be resolved for siting consideration. The TDWR sited on the LGA property would provide good wind shear protection for JFK with a slight sacrifice of velocity measurement accuracy of wind parallel to runways 4R/22L and 4L/22R.

The EWR TDWR is far in terms of distance so its microburst detection probability at JFK is next to nothing, i.e., it cannot serve JFK alone. However, this TDWR has excellent detection of gust fronts around JFK. Further computation shows it can serve as a supplementary radar to cover the airspace aloft the airport ARENAs if JFK is equipped with an on-airport TDWR (Table 6a and Table 8). Similar to the EWR TDWR, the COTS 1 MW radar at the Twombly site cannot serve the airports alone but can be used for supplementary "overhead" coverage if it is possible to obtain the data from that radar.

FRG and HPN could provide JFK with ~5% lower microburst detection than the required 0.90 POD level yet 2%–5% higher gust front detection than the current level. They also are good candidate sites for a complementary TDWR in addition to an on-airport TDWR at JFK. The Manhattan skyscraper sites and the rest of the sites show poor microburst detection at JFK so they are unsuitable for relocating the New York TDWR.

Results similar to JFK can be seen for LGA wind shear protection (Table 7b). Most sites in the initial siting documents are good candidates except for the Bellmore Site, which was initially suggested for siting the JFK TDWR. It has a marginal microburst POD (0.89). However this POD is not statistically significantly different from 0.90 (the FAA requirement) taking into account the model uncertainty and antenna height sensitivity (Section 2.2.1). The TDWR, if located on the JFK property, can protect LGA from wind shear. The TDWR, if deployed on LGA itself, again needs coverage aloft the airport ARENAs. Again this coverage can be provided by the EWR TDWR or a COTS 1 MW radar at the Twombly site. HPN once again shows only slightly less optimal wind shear detection even at long distance, POD of 0.89 for microbursts and 0.88 for gust fronts; however, the decreased azimuthal and vertical resolution at this distance (not accounted for in the model) would likely result in worse performance. This deficit may be compensated by additional sensors (Section 3.6).

**TABLE 7**

**Summary comparison of candidate sites. The POD and volume visibility values are color-coded as in Tables 4 and 5. For aspect angles, those with values ≤45°+1 *s.d.* are shaded in green, those with values between 45°+1 *s.d.* and 45°+2 *s.d.* are shaded in yellow, and those with values >45°+2 *s.d.* are shaded in red.**

**7a. Single-site comparisons for JFK airport**

| Site | Radar - Airport Distance (km) | POD (>=0.90) | | Volume Visibility (>=0.90) | Aspect Angle | |
|---|---|---|---|---|---|---|
| | | Microburst | Gustfront | | 13R/31L & 13L/31R[6] | 4R/22L & 4L/22R[7] |
| JFK | 0 | 0.93 | 0.88 | 0.60 | 22 | 21 |
| Floyd[1] | 10 | 0.93 | 0.89 | 0.99 | 67 | 37 |
| Beach | 12 | 0.94 | 0.89 | 1 | 72 | 24 |
| Ft. Tilden | 13 | 0.93 | 0.89 | 1 | 72 | 25 |
| LGA | 17 | 0.97 | 0.93 | 1 | 36 | 59 |
| Roslyn | 21 | 0.96 | 0.94 | 1 | 79 | 2 |
| Bellmore | 22 | 0.95 | 0.92 | 1 | 43 | 43 |
| Hart Island | 24 | 0.94 | 0.93 | 1 | 64 | 31 |
| FRG | 32 | 0.84 | 0.94 | 1 | 47 | 40 |
| TEB | 33 | 0.00 | 0.68 | 0.96 | 14 | 76 |
| Fresh Kill | 36 | 0.01 | 0.57 | 0.93 | 44 | 50 |
| Twombly[2] | 38 | 0.48 | 0.93 | 1.00 | 42 | 50 |
| LDJ | 39 | 0.16 | 0.89 | 0.96 | 36 | 58 |
| EWR[3] | 42 | 0.03 | 0.94 | 0.96 | 39 | 54 |
| HPN | 48 | 0.86 | 0.91 | 1 | 68 | 24 |
| CDW | 50 | 0.00 | 0.00 | 0.74 | 1 | 86 |
| EMPIRE[4] | 21 | 0.59 | 0.47 | 1 | 4 | 80 |
| GE[5] | 21 | 0.40 | 0.28 | 1 | 8 | 79 |

As is shown in both Table 7 and Figure 8, the detection of microbursts from the Manhattan skyscrapers is unacceptable at any beam elevation angle. Therefore, these skyscraper sites with COTS radars should not be considered as alternative options for wind shear protection of JFK and LGA.

Other sites, including TEB (18 km away) and the Staten Island Site, show poor microburst detection so they are unacceptable as a new site for the New York TDWR. Considering JFK and LGA as a whole, the qualified candidate sites are still the six sites identified in the initial site-survey documents. It is also of interest to note that the only candidate sites with green shading across the board are Bellmore for JFK and Roslyn for LGA, which were the originally recommended sites before political opposition placed the TDWR at Floyd Bennett Field.

**TABLE 7 (continued)**

**7b. Single-site comparisons for LGA airport**

| Site | Radar - Airport Distance (km) | POD (>=0.90) | | Volume Visibility (>=0.90) | Aspect Angle | |
|---|---|---|---|---|---|---|
| | | Microburst | Gustfront | | 13/31 | 4/22 |
| LGA | 0 | 0.93 | 0.88 | 0.52 | 11 | 12 |
| Hart Island | 12 | 0.96 | 0.89 | 1 | 73 | 13 |
| JFK | 17 | 0.96 | 0.92 | 1 | 31 | 64 |
| TEB | 18 | 0.13 | 0.69 | 0.98 | 38 | 79 |
| Roslyn | 21 | 0.96 | 0.93 | 1 | 31 | 51 |
| Twombly[2] | 21 | 0.71 | 0.91 | 1 | 47 | 42 |
| Floyd[1] | 21 | 0.96 | 0.91 | 1 | 60 | 33 |
| Beach | 24 | 0.95 | 0.91 | 1 | 60 | 33 |
| Ft. Tilden | 24 | 0.95 | 0.91 | 1 | 61 | 31 |
| Bellmore | 30 | 0.89 | 0.94 | 1 | 13 | 76 |
| Fresh Kill | 35 | 0.43 | 0.68 | 0.98 | 73 | 18 |
| HPN | 35 | 0.89 | 0.88 | 1 | 81 | 8 |
| LDJ | 36 | 0.79 | 0.94 | 1 | 62 | 29 |
| CDW | 36 | 0.00 | 0.00 | 0.76 | 15 | 77 |
| FRG | 39 | 0.75 | 0.95 | 0.99 | 24 | 65 |
| EWR[3] | 39 | 0.75 | 0.94 | 1 | 64 | 27 |
| GE[5] | 9 | 0.50 | 0.41 | 1 | 52 | 52 |
| EMPIRE[4] | 10 | 0.74 | 0.55 | 1 | 56 | 46 |

[1] Current New York TDWR location
[2] Baron VHDD-1000C with beam elevation angle of 0.5°
[3] Newark TDWR location
[4] EEC DWSR-90CTV with beam elevation angle of -1°
[5] EEC DWSR-8501C/K with beam elevation angle of -1°
[6] Arithmetic mean of runways 13R/31L and 13L/31R
[7] Arithmetic mean of runways 4R/22L and 4L/22R

### 3.5.2 Comparison of on-airport options

Deployment of on-airport TDWR or a C-band COTS Doppler weather radar deserves special attention. The merits of this arrangement are multifold. There will presumably be minimal land acquisition costs. The TDWR will be easy to access for maintenance so its downtime will be reduced. There will be minimal communication problems between the TDWR and air traffic management systems. It has low environmental impact. Finally, the siting is not as likely to be affected by unforeseen political hurdles in the future.

On the other hand, critical technical issues need to be addressed for the on-airport siting scheme. For example, weather features right above the TDWR cannot be observed by the radar itself due to the “cone-of-silence” limitation. Further, the radial velocity distribution shape of a microburst that occurs at the radar location will look different from a microburst that is distant from the radar. Moreover, since the radar is located on the airport, it will occasionally have detection difficulty when a gust front becomes radially aligned with the radar as it passes over the airport.

To investigate whether the microburst detection algorithm can resolve the shape distortion problem, we did some model simulations of both the Integrated Terminal Weather System Microburst Detection Algorithm (ITWS-MDA, currently used where ITWS products are available, such as JFK and LGA) and ASR-9 Microburst Detection Algorithm (AMDA). Preliminary results show that wind divergence caused by a microburst that occurs where the TDWR or ASR-9 WSP is located can be properly tracked if a sufficient quantity of precipitation is present at the time of the event. In other words, existing detection algorithms can detect on-site microbursts based on wind divergence. Furthermore, the radially-aligned gust front problem can be alleviated by “coasting” the gust front using past locations. This kind of gust front detector and tracker was already used in the ASR-9 WSP systems (which are located on airports) and proved successful. In short, it is possible to adopt the ASR-9 WSP microburst and gust front detection algorithm to enhance the performance of on-airport TDWRs.

The “cone-of-silence” issue cannot be resolved with a single TDWR system. Since the early warning part of the algorithm relies solely on observing the overhead microburst precursor, thunderstorms (Section 3.3), the consequence of not being able to observe weather aloft is that the radar (or the detection algorithm more precisely) will lose part of its early microburst prediction capabilities. Additionally, the unavailability of overhead storm observation means that the false alarm reduction algorithm using this information would have to be bypassed.

We can address all of the above concerns without reducing the wind shear performance of the TDWR by constructing a radar network, i.e., making detections and predictions based on observational data from multiple radars. (The current ITWS MDA uses single TDWR data only.) In other words, we can integrate data of an on-airport TDWR and an off-airport TDWR at the ITWS level and then produce wind shear detection for individual airports.

In light of the above discussion, we formulated siting schemes involving two TDWRs or COTS C-band radars of similar detection capabilities in addition to simply siting the New York TDWR on one of the candidate sites. The first scheme is the JFK (LGA)-EWR TDWRs solution. That is, move the TDWR from Floyd Bennett Field to the property of JFK (or LGA). The second scheme is the JFK-LGA TDWRs solution, i.e., (re)deploy two TDWRs, one on each airport. The third scheme is the TDWR-COTS C-band weather radar solution, i.e., install one TDWR on one airport property and COTS radar on the other airport property.

To assess the feasibility of on-airport siting of a TDWR or a C-band COTS radar for wind shear protection, we computed the probability of detection for an on-airport TDWR or a COTS radar only, and two-radar systems of their combination. In addition, we included two existing off-airport radars at their current sites, the Newark TDWR at its current location and the radar at the Twombly site (Table 8). The purpose of including the latter in this study is to investigate the detection performance using a similar commercial radar at nearby locations.

The results in Table 8 are intriguing in the following context. The dual radar systems have better detection capabilities for both microbursts and gust fronts than single on-airport radar. While the EWR TDWR is too far for microburst detection for both JFK and LGA, it is sufficient for detecting gust fronts at both airports with an improved detection probability compared to the current level. Further, including the EWR TDWR can resolve weather features aloft and the gust fronts that are radially aligned with the on-airport radar (Table 6). Thus, the EWR TDWR can act as a supplementary radar to improve the wind shear detection of both JFK and LGA if one of them is sited with a TDWR. Therefore, if relocation of the New York TDWR becomes inevitable, the most efficient way would be to move it to the airport property of either JFK or LGA and integrate the Newark TDWR for wind shear protection. (This proposition needs to be validated with a thorough cost-benefit analysis.) The only technical prerequisite to implementation would be to develop a detection algorithm for data combined from two radars. Note that such an algorithm (GFMosaic) has already been developed for gust fronts (Shaw et al., 2000), but not for microbursts. A description of the software modifications necessary to generate microburst and gust front alerts using data integrated from both TDWRs is included in Appendix F. In theory, the radar at Twombly site can also be used as a supplementary radar. However, the current radar there is not FAA owned, so that data may not be available to the FAA, and the radar scan strategy may not be optimized for wind shear detection at the airports. As such, this option is not thought to be viable.

**TABLE 8**

**Probability of detection (POD) for microbursts (MB) and gust fronts (GF) for TDWR, a C-band COTS Doppler weather radar, and their combinations. The radars are assumed to be located at the center of the individual airport, except that the Newark TDWR (EWR) and the EEC radar at Twombly are for their current locations. The values are color-coded as in Table 4.**

| Location 1 (Radar) | Location 2 (Radar) | JFK POD | | LGA POD | |
|---|---|---|---|---|---|
| | | MB | GF | MB | GF |
| JFK (TDWR) | none | 0.93 | 0.88 | 0.97 | 0.93 |
| LGA (TDWR) | none | 0.97 | 0.91 | 0.93 | 0.88 |
| EWR (TDWR) | none | 0.03 | 0.94 | 0.75 | 0.94 |
| JFK (COTS) [1] | none | 0.89 | 0.85 | 0.95 | 0.90 |
| LGA (COTS) [1] | none | 0.94 | 0.92 | 0.90 | 0.88 |
| Twombly (COTS) [2] | none | 0.48 | 0.93 | 0.71 | 0.91 |
| JFK (TDWR) | LGA (TDWR) | 0.98 | 0.95 | 0.98 | 0.95 |
| JFK (TDWR) | EWR (TDWR) | 0.96 | 0.95 | 0.97 | 0.95 |
| LGA (TDWR) | EWR (TDWR) | 0.97 | 0.95 | 0.97 | 0.95 |
| JFK (TDWR) | Twombly (COTS) [2] | 0.94 | 0.95 | 0.97 | 0.95 |
| LGA (TDWR) | Twombly (COTS) [2] | 0.97 | 0.95 | 0.94 | 0.94 |
| JFK (TDWR) | LGA (COTS) [1] | 0.98 | 0.95 | 0.98 | 0.95 |
| LGA (TDWR) | JFK (COTS) [1] | 0.98 | 0.95 | 0.98 | 0.95 |
| JFK (COTS) [1] | LGA (COTS) [1] | 0.97 | 0.95 | 0.97 | 0.95 |
| JFK (COTS) [1] | EWR (TDWR) | 0.95 | 0.95 | 0.95 | 0.95 |
| JFK (COTS) [1] | Twombly (COTS) [2] | 0.91 | 0.95 | 0.95 | 0.95 |
| LGA (COTS) [1] | EWR (TDWR) | 0.96 | 0.95 | 0.96 | 0.95 |
| LGA (COTS) [1] | Twombly (COTS) [2] | 0.94 | 0.95 | 0.93 | 0.94 |

[1] EEC DWSR-8501C/K

[2] Baron VHDD-1000C

In addition to dual radar systems involving the EWR TDWR, the dual systems involving two on-airport radars are also viable. The detection probability would be greatly improved when data from the two on-airport radars are integrated. Most importantly, the dual radar system can overcome the "cone-of-silence" problem encountered by single on-airport TDWR.

Since the COTS C-band radar can scan all the way up to zenith, they do not have a "cone of silence" (at least for reflectivity—horizontal velocity cannot be measured directly overhead). Based on the model, the wind shear coverage of JFK and LGA can be accomplished by siting a COTS radar of similar wind shear detection capability on one of the airports. The downsides are that we would need to adapt and test the wind shear detection algorithms for the COTS radar data, the wind shear protection (at least for LGA) would be slightly worse than the current level, and it would be expensive to purchase a new COTS C-band radar plus a maintenance contract or to develop in-house capabilities for maintaining it.

Another concern about on-airport siting is that the measurement accuracy of wind velocity parallel to the runways is highly variable depending on the location of the wind shear event. Hence, the TDWR would need to be located such that the parallel wind measurement accuracy is optimized. Locating the TDWR at LGA may be more difficult than at JFK because of the small size of the airport property, the presence of radio emitters, tall buildings and other structures, and hills in Northern Queens (SRI, 1998). Also, the presence of an LLWAS at LGA helps mitigate the nonideal viewing angle of a JFK-sited TDWR for near-surface wind shear detections at LGA.

The exact location of the TDWR on the airport property would also be determined by the need to avoid significant blockage by nearby buildings and other structures, and by the desire to minimize the overlap between the ARENAs and the close-in blind zone of the radar. All monostatic pulsed radars have a minimum observation range limitation, because of the inability of the system to switch instantaneously from transmit to (clean) receive mode. The required minimum observation range for the TDWR is 500 m, although individual TDWRs have been seen to generate valid data at even shorter ranges. To be conservative, we used the 500-m value in the wind shear detection probability model. Thus, if the model predicts a 90% microburst detection probability for an on-airport TDWR, part of that missed 10% is due to the overlap of the 500-m radius circle with the ARENAs where the radar data has an observation hole. This overlap, therefore, should be minimized when siting the radar; furthermore, it would be prudent to fill in any remaining gap by deploying LLWAS anemometers. Since the gap region will be very small (less than 0.8 $km^2$ even if the entire blind zone is in the ARENAs), the minimum number of anemometers for proper LLWAS operation (one triangle, i.e. three anemometers) would be sufficient. The alerts produced would then be integrated with the TDWR alerts using the existing algorithm. LGA already has an LLWAS system covering the inner ARENAs, so a radar located there will not be left with a near-range coverage gap. A radar deployed at JFK, however, would have a near-range gap without a second radar at LGA, so LLWAS sensors should be added (the EWR TDWR is too far to provide complementary microburst coverage over JFK).

### 3.6 ALTERNATIVE WIND SHEAR SYSTEMS

Some non-TDWR radars were investigated in the initial siting documents (SRI 1998). Those studies stated that the ASR-9 at JFK may be modified to provide wind shear coverage. As a matter of fact, WSP has since been developed for the ASR-9 to provide wind shear detection. However, the JFK ASR-9 was not equipped with a WSP because of the current TDWR coverage. LGA is not equipped with an ASR-9 and there are no plans for future installation of one. One disadvantage mentioned in the 1998 study regarding using the ASR-9 was the "cone-of-silence" issue, since the ASR-9 does not cover high elevation angles. Another shortcoming was that ASR-9 has lower wind shear detection performance than the TDWR.

The idea of using ASR-9 as well as other sensor alternatives was (re)examined using our wind shear probability detection model. The alternative wind shear sensors considered here are the ASR-9 WSP, NEXRAD, on-airport COTS Doppler weather radar, lidar, and LLWAS. We first consider a TDWR on a candidate site with complementary alternative wind shear systems ("TDWR+Others") (Table 9), then we consider options without the TDWR ("Others") (Table 10).

All candidate sites are evaluated for the "TDWR+Others" solutions (Table 9). The results are consistent with those shown in Table 4. The major implication is that if the TDWR is located far from the target airport, these alternative sensors, even supplemented with another, would not be enough to bring the wind shear protection of both airports up to their current level. The only exception is HPN, which has microburst detection probabilities close to the FAA requirement (0.86 for JFK and 0.89 for LGA). If the TDWR is placed at HPN, the deficits in its detections caused by its great distance from JFK and slightly lesser distance from LGA can be made up using combinations of TDWR with on-airport lidar, TDWR with on-airport LLWAS, TDWR with JFK ASR-9/WSP and on-airport LLWAS, or TDWR with on-airport LLWAS and NEXRAD. However, reduced azimuthal and vertical resolution, an effect not included in the model, could be a problem at such a distance. Algorithms that optimally combine data from all relevant sensors would also need to be developed and tested or existing algorithms adapted, such as have been developed for TDWR and LLWAS (Cole and Todd, 1993).

For non-TDWR sensors, the lidar has a better capability of detecting gust fronts at JFK than LLWAS but with a slightly lower level of microburst detection (Table 10). Installation of a lidar and an LLWAS system at the airport is likely to detect ~70% of the microbursts and gust fronts, which is much lower than the current level of ~90%. A Doppler lidar is an excellent complement to radars in detecting wind shear in dry environments, but their detection range is drastically shortened in precipitating conditions due to attenuation (Cho and Hallowell, 2008).

The areal coverage (roughly equal to POD) provided by LLWAS is mainly dependent on the number of anemometers deployed. A study of the airports that are currently equipped with LLWAS NE++ shows that on average each anemometer covers 3.8 $km^2$ (*s.d.* 1.2 $km^2$) of the airport ARENA area. Thus, with the size of JFK, which has 84 $km^2$ of ARENA area, it would need an LLWAS with 22±7 (mean±1*s.d.*) sensors to cover the whole ARENA area, 17±5 sensors for 75% coverage, and 11±4 sensors for 50% coverage. With an urban environment on one side and seawater on the other, it would be very difficult to install many anemometers outside of the airport itself. It is, of course, an unreasonable proposition to attempt to provide gust front coverage throughout the 18-km radius circle around the airport with an LLWAS system.

For non-TDWR systems, only an on-airport COTS radar along with a lidar shows sufficient detection capability (Table 10). The ASR-9 WSP plus NEXRAD at their current locations, even if configured properly for wind shear detection, can detect only 73% of microbursts at JFK. A similar detection level at LGA would be expected if an ASR-9 WSP were installed at the airport. This combination also produces a gust front detection lower than the current level. However, the gust front detection can be accomplished by using the Newark TDWR instead (Table 4). Thus, decommissioning the New York TDWR would put JFK and LGA at the risk of microburst, but not gust front, exposure because the gust front events at both airports could be sufficiently detected by the Newark TDWR.

## TABLE 9

**Probability of detection of microbursts (MB) and gust fronts (GF) for TDWR plus alternative wind shear systems at candidate sites sorted by the distance to the airport. The values are color-coded as in Table 4.**

**9a. JFK**

| site | Radar - Airport Distance (km) | TDWR + LIDAR | | TDWR + LLWAS | | TDWR + ASR9/WSP | | TDWR + NEXRAD | | TDWR + LIDAR + LLWAS | | TDWR + ASR9/WSP + LLWAS | | TDWR + NEXRAD + LLWAS | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | MB | GF | MB | GF | MB | GF | MB | GF | MB | GF | MB | GF | MB | GF |
| JFK | 0 | 0.97 | 0.94 | 0.96 | 0.88 | 0.94 | 0.91 | 0.94 | 0.94 | 0.98 | 0.94 | 0.97 | 0.92 | 0.97 | 0.94 |
| Floyd[1] | 10 | 0.97 | 0.94 | 0.96 | 0.89 | 0.93 | 0.91 | 0.93 | 0.93 | 0.98 | 0.94 | 0.97 | 0.91 | 0.96 | 0.94 |
| Beach | 12 | 0.97 | 0.94 | 0.97 | 0.89 | 0.94 | 0.91 | 0.94 | 0.93 | 0.99 | 0.94 | 0.97 | 0.91 | 0.97 | 0.94 |
| Ft.Tilden | 13 | 0.97 | 0.94 | 0.97 | 0.89 | 0.94 | 0.91 | 0.93 | 0.93 | 0.99 | 0.94 | 0.97 | 0.91 | 0.97 | 0.94 |
| LGA | 17 | 0.98 | 0.94 | 0.98 | 0.93 | 0.97 | 0.93 | 0.97 | 0.95 | 0.99 | 0.94 | 0.98 | 0.94 | 0.98 | 0.95 |
| Roslyn | 21 | 0.98 | 0.95 | 0.98 | 0.94 | 0.96 | 0.94 | 0.96 | 0.95 | 0.99 | 0.95 | 0.98 | 0.94 | 0.98 | 0.95 |
| Bellmore | 22 | 0.98 | 0.94 | 0.97 | 0.92 | 0.95 | 0.93 | 0.95 | 0.95 | 0.99 | 0.94 | 0.97 | 0.93 | 0.97 | 0.95 |
| Hart Island | 24 | 0.98 | 0.94 | 0.97 | 0.93 | 0.94 | 0.94 | 0.94 | 0.95 | 0.99 | 0.94 | 0.97 | 0.94 | 0.97 | 0.95 |
| FRG | 32 | 0.98 | 0.95 | 0.92 | 0.94 | 0.84 | 0.94 | 0.84 | 0.95 | 0.99 | 0.95 | 0.92 | 0.95 | 0.92 | 0.95 |
| TEB | 33 | 0.40 | 0.88 | 0.49 | 0.68 | 0.30 | 0.83 | 0.25 | 0.86 | 0.69 | 0.88 | 0.64 | 0.83 | 0.62 | 0.86 |
| Fresh Kill | 36 | 0.41 | 0.87 | 0.49 | 0.57 | 0.27 | 0.71 | 0.17 | 0.77 | 0.70 | 0.88 | 0.62 | 0.71 | 0.57 | 0.78 |
| Twombly[2] | 38 | 0.86 | 0.94 | 0.73 | 0.93 | 0.49 | 0.93 | 0.48 | 0.94 | 0.93 | 0.95 | 0.74 | 0.94 | 0.73 | 0.94 |
| LDJ | 39 | 0.54 | 0.93 | 0.57 | 0.89 | 0.36 | 0.92 | 0.21 | 0.89 | 0.77 | 0.93 | 0.67 | 0.92 | 0.60 | 0.89 |
| EWR[3] | 42 | 0.43 | 0.95 | 0.50 | 0.94 | 0.21 | 0.94 | 0.10 | 0.94 | 0.71 | 0.95 | 0.59 | 0.94 | 0.54 | 0.94 |
| HPN | 48 | 0.98 | 0.94 | 0.93 | 0.92 | 0.86 | 0.92 | 0.86 | 0.93 | 0.99 | 0.94 | 0.93 | 0.92 | 0.93 | 0.93 |
| CDW | 50 | 0.40 | 0.70 | 0.49 | 0.01 | 0.13 | 0.32 | 0.14 | 0.12 | 0.69 | 0.70 | 0.56 | 0.33 | 0.56 | 0.13 |

**9b. LGA**

| site | Radar - Airport Distance (km) | TDWR + LIDAR | | TDWR + LLWAS | | TDWR + ASR9/WSP | | TDWR + NEXRAD | | TDWR + LIDAR + LLWAS | | TDWR + ASR9/WSP + LLWAS | | TDWR + NEXRAD + LLWAS | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | MB | GF | MB | GF | MB | GF | MB | GF | MB | GF | MB | GF | MB | GF |
| LGA | 0 | 0.97 | 0.88 | 0.96 | 0.89 | 0.93 | 0.89 | 0.94 | 0.94 | 0.98 | 0.89 | 0.96 | 0.89 | 0.96 | 0.94 |
| Hart Island | 12 | 0.98 | 0.89 | 0.97 | 0.89 | 0.96 | 0.90 | 0.96 | 0.94 | 0.99 | 0.89 | 0.97 | 0.91 | 0.97 | 0.94 |
| JFK | 17 | 0.98 | 0.92 | 0.98 | 0.92 | 0.97 | 0.92 | 0.97 | 0.94 | 0.99 | 0.92 | 0.98 | 0.92 | 0.98 | 0.94 |
| TEB | 18 | 0.51 | 0.69 | 0.48 | 0.69 | 0.13 | 0.76 | 0.46 | 0.90 | 0.71 | 0.70 | 0.48 | 0.77 | 0.68 | 0.90 |
| Roslyn | 21 | 0.98 | 0.93 | 0.98 | 0.93 | 0.96 | 0.93 | 0.96 | 0.94 | 0.99 | 0.93 | 0.98 | 0.94 | 0.98 | 0.94 |
| Twombly[2] | 21 | 0.96 | 0.91 | 0.82 | 0.91 | 0.71 | 0.91 | 0.71 | 0.93 | 0.98 | 0.91 | 0.82 | 0.91 | 0.83 | 0.94 |
| Floyd[1] | 21 | 0.98 | 0.91 | 0.98 | 0.91 | 0.96 | 0.92 | 0.96 | 0.94 | 0.99 | 0.91 | 0.98 | 0.92 | 0.98 | 0.94 |
| Beach | 24 | 0.98 | 0.91 | 0.97 | 0.91 | 0.95 | 0.92 | 0.95 | 0.94 | 0.99 | 0.91 | 0.97 | 0.92 | 0.97 | 0.94 |
| Ft.Tilden | 24 | 0.98 | 0.91 | 0.97 | 0.91 | 0.95 | 0.92 | 0.95 | 0.94 | 0.99 | 0.91 | 0.97 | 0.92 | 0.97 | 0.94 |
| Bellmore | 30 | 0.98 | 0.94 | 0.93 | 0.94 | 0.89 | 0.94 | 0.89 | 0.95 | 0.99 | 0.94 | 0.94 | 0.94 | 0.94 | 0.95 |
| Fresh Kill | 35 | 0.72 | 0.68 | 0.66 | 0.68 | 0.44 | 0.75 | 0.56 | 0.83 | 0.83 | 0.69 | 0.67 | 0.75 | 0.74 | 0.84 |
| HPN | 35 | 0.96 | 0.88 | 0.93 | 0.89 | 0.89 | 0.89 | 0.89 | 0.92 | 0.98 | 0.89 | 0.93 | 0.89 | 0.94 | 0.92 |
| LDJ | 36 | 0.96 | 0.94 | 0.87 | 0.94 | 0.80 | 0.94 | 0.81 | 0.94 | 0.98 | 0.94 | 0.88 | 0.94 | 0.88 | 0.94 |
| CDW | 36 | 0.42 | 0.67 | 0.40 | 0.02 | 0.00 | 0.07 | 0.15 | 0.24 | 0.66 | 0.67 | 0.40 | 0.09 | 0.50 | 0.25 |
| FRG | 39 | 0.98 | 0.95 | 0.85 | 0.95 | 0.76 | 0.95 | 0.76 | 0.95 | 0.99 | 0.95 | 0.85 | 0.95 | 0.85 | 0.95 |
| EWR[3] | 39 | 0.98 | 0.94 | 0.85 | 0.94 | 0.76 | 0.94 | 0.76 | 0.94 | 0.99 | 0.94 | 0.86 | 0.94 | 0.86 | 0.94 |

[1]Current New York TDWR location

[2]Baron VHDD-1000C

[3]Newark TDWR location

**TABLE 10**

**Microburst and gust front probability of detection for alternative wind shear systems. WSP is the existing JFK ASR-9 with WSP upgrade. NEXRAD is the OKX NEXRAD. Values for COTS radar, lidar, and LLWAS are those when each airport is installed with such sensor(s). The values are color-coded as in Table 4.**

| Wind Shear System | JFK | | LGA | |
|---|---|---|---|---|
| | MB | GF | MB | GF |
| WSP | 0.70 | 0.80 | 0.06 | 0.80 |
| NEXRAD | 0.13 | 0.21 | 0.03 | 0.21 |
| COTS[1] | 0.89 | 0.85 | 0.90 | 0.88 |
| LIDAR | 0.40 | 0.70 | 0.42 | 0.67 |
| WSP + LIDAR | 0.89 | 0.92 | 0.47 | 0.80 |
| NEXRAD + LIDAR | 0.53 | 0.79 | 0.45 | 0.21 |
| COTS[1] + LIDAR | 0.94 | 0.93 | 0.95 | 0.88 |
| WSP + NEXRAD | 0.73 | 0.86 | 0.38 | 0.80 |
| WSP + NEXRAD + LIDAR | 0.93 | 0.94 | 0.80 | 0.80 |
| LLWAS | 0.49 | 0.01 | 0.41 | 0.02 |
| WSP + LLWAS | 0.85 | 0.80 | 0.44 | 0.80 |
| NEXRAD + LLWAS | 0.55 | 0.22 | 0.42 | 0.22 |
| COTS[1] + LLWAS | 0.94 | 0.85 | 0.94 | 0.88 |
| LIDAR + LLWAS | 0.69 | 0.70 | 0.66 | 0.67 |
| WSP + NEXRAD + LLWAS | 0.86 | 0.87 | 0.63 | 0.80 |

[1] EEC DWSR-8501C/K

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# 4. SUMMARY AND RECOMMENDATIONS

Our study shows that decommissioning the New York TDWR and relying solely on alternative sensors is practically a nonoption. In other words, the currently existing Newark TDWR, ASR-9 at JFK with WSP upgrade, the Brookhaven NEXRAD, and LGA LLWAS cannot provide adequate wind shear protection for the JFK and LGA airports. The only alternative not utilizing a TDWR that meets the FAA wind shear detection requirement is to install a COTS C-band Doppler weather radar (which has slightly lower performance than the TDWR) plus a lidar or an LLWAS system on each airport's property. Moreover, this option is likely to be much more expensive than redeployment of the New York TDWR.

About half of the candidate sites investigated do not meet the FAA microburst detection requirement so they should not be pursued further. These sites are the Manhattan skyscrapers, the Staten Island site, TEB, LDJ, FRG, CDW, and Twombly Landing, NJ.

Eleven top performing options including the current site, from a technical point of view, are listed item-by-item as a decision-making reference (Table 11). The alternatives follow in overall performance order, irrespective of cost or site availability. The sites not thought to be available to the FAA are shown in red color. The performance evaluation compared to the current site is explained in the "Pros" and "Cons" columns.

The problem of redeploying the New York TDWR can be approached in two different ways. The first solution is to move the TDWR to one of the locations investigated in the initial site-survey documents, namely the Roslyn, Hart Island, Bellmore, Ft. Tilden, Beach Sites, in order of preferred to less preferred. Locating the TDWR at one of these sites would provide wind shear protection similar to the current site, but is likely to experience extreme difficulty in land acquisition. (The Beach site has performance similar to the current TDWR site and Ft. Tilden site, but it is not included in Table 11 because the site cannot be located and the site is within the general area of the Gateway National Recreation Area.)

The second solution is to redeploy the TDWR on the airport property of JFK or LGA while using the Newark TDWR for supplementary coverage. This seems to be a more feasible solution, if the TDWR has to be relocated. Many of the land acquisition issues associated with off-airport siting would not be in play, radar service costs would be reduced, and no new sensors would need to be added except for the case of siting at JFK where three LLWAS anemometers would be added to cover the near-range blind zone of the TDWR. To integrate the two TDWRs for wind shear detection, the current wind shear detection algorithms will need to be modified (Appendix F). On-airport siting of the TDWR could also provide valuable field data for future on-airport siting studies of the multifunctional phased array radar (MPAR), a state-of-the-art radar concept for simultaneous aircraft and weather surveillance, which could eventually replace the TDWRs and ASRs (Weber et al., 2007).

Other more expensive yet equally effective solutions include siting two TDWRs, one TDWR and one C-band COTS Doppler weather radar, one on each of the airports, or one on-airport COTS radar integrated with the Newark TDWR. The two radars also need to be integrated into the ITWS network to provide wind shear detection for both airports. The on-airport radar location would need to be carefully selected to optimize the angular relationship between the radar and the runways and to minimize building blockage at both airports.

Note that since the cost analysis of the options that were analyzed in this report is beyond the scope of this study, the references to cost in this section are gross, subjective, and intuitive in nature. They are not intended to be used for anything other than as an aid in understanding the comparisons that we provide.

Based on the time length from the initial siting investigation to the final selection in the 1990s, we recommend performance of a detailed cost-benefit analysis immediately and the commencement of the land acquisition process, if needed, at least ten years in advance before the lease expiration date of the current TDWR.

Since a significant fraction of TDWR sites are not owned by the FAA, the method developed in this study, i.e., rapid assessment of a TDWR site and wind shear sensors of various types, can be applied to other TDWR sites should a land lease become an issue. Of the 45 operational TDWR sites, 22 are owned by the FAA, eight are permitted or leased from a government agency to the FAA, 14 are leased by the FAA from private owners, and one (the New York TDWR) is permitted by the Department of the Interior and must be vacated by January 2023. The current TDWR site land ownership status is included in Appendix G (T. Weyrauch, personal communication).

**TABLE 11**

**Top eleven siting options in likely overall performance order including the current site. The performance of the alternative sites is evaluated and compared to the current site. The sites not thought to be available to the FAA are shown in red color. The radar is TDWR unless otherwise specified.**

| Order | Siting Description | POD (JFK) | | POD (LGA) | | Performance Evaluation | |
|---|---|---|---|---|---|---|---|
| | | MB | GF | MB | GF | Pros | Cons |
| 1 | JFK plus LGA | 0.98 | 0.95 | 0.98 | 0.95 | better overall wind shear detection for both airports | need software development in order to utilize data collected from two TDWRs; need careful location selection to minimize aspect angle variation |
| 2 | JFK plus LGA (COTS[1]) or vice versa | 0.98 | 0.95 | 0.98 | 0.95 | better overall wind shear detection for both airports | need software development in order to utilize data collected from both TDWR and commercial radar; need careful location selection to minimize aspect angle variation |
| 3 | JFK (integrated with EWR TDWR) | 0.96 | 0.95 | 0.97 | 0.95 | better overall wind shear detection for both airports; presence of LLWAS at LGA for extra wind shear coverage there | need software development in order to utilize data collected from two TDWRs; need careful location selection to minimize aspect angle variation; need small LLWAS system to cover minimum radar range gap |
| 4 | LGA (integrated with EWR TDWR) | 0.97 | 0.95 | 0.97 | 0.95 | better overall wind shear detection for both airports | need software development in order to utilize data collected from two TDWRs; need careful location selection to minimize aspect angle variation; small size of the airport property; presence of radio emitters, tall buildings, structures, and hills |
| 5 | JFK (COTS[1]) (integrated with EWR TDWR) | 0.95 | 0.95 | 0.95 | 0.95 | better overall wind shear detection for both airports; presence of LLWAS at LGA for extra wind shear coverage there | need software development in order to utilize data collected from both TDWR and commercial radar; need careful location selection to minimize aspect angle variation; need small LLWAS system to cover minimum radar range gap |
| 6 | LGA (COTS[1]) (integrated with EWR TDWR) | 0.96 | 0.95 | 0.96 | 0.95 | better overall wind shear detection for both airports | need software development in order to utilize data collected from both TDWR and commercial radar; need careful location selection to minimize aspect angle variation; small size of the airport property; presence of radio emitters, tall buildings, structures, and hills |
| 7 | Roslyn[2] | 0.96 | 0.94 | 0.96 | 0.93 | better overall wind shear detection for both airports | None |
| 8 | Hart Island | 0.94 | 0.93 | 0.96 | 0.89 | better GF detection for JFK | slightly worse GF detection for LGA; difficult to access |
| 9 | Bellmore | 0.95 | 0.92 | 0.89 | 0.94 | better overall wind shear detection for JFK | slightly worse (but still acceptable) MB detection for LGA |
| 10 | Floyd Bennett Field[3] | 0.93 | 0.89 | 0.96 | 0.91 | Current (reference) level | |
| 11 | Ft. Tilden[4] | 0.93 | 0.89 | 0.95 | 0.91 | similar level of wind shear detection | |

[1] EEC DWSR-8501C/K
[2] In a community park
[3] Current TDWR site
[4] In the same national recreation area where the current TDWR is located

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# GLOSSARY

| | |
|---|---|
| AMDA | ASR-9 Microburst Detection Algorithm |
| ARENA | Area Noted for Attention |
| ASR-9 | Airport Surveillance Radar-9 |
| ATL | Hartsfield - Jackson Atlanta International Airport Atlanta, GA |
| BRAC | Base Relocation and Closure Commission |
| CDW | Essex County Airport, Caldwell, NY |
| COTS | Commercial Off-The-Shelf |
| DCA | Ronald Reagan Washington National Airport, Washington, DC |
| DEN | Denver International Airport, Denver, CO |
| DFAD | Digital Feature Analysis Data |
| DTED | Digital Terrain Elevation Data |
| EEC | Enterprise Electronics Corporation |
| EMPIRE | Empire State Building, New York, NY |
| EWR | Newark Liberty International Airport, Newark, NJ |
| FAA | Federal Aviation Administration |
| FCC | Federal Communications Commission |
| FRG | Republic Airport, Farmingdale, NY |
| GE | GE Building, 30 Rockefeller Center, New York, NY |
| GF | Gust Front |
| GF Mosaic | Gust Front Mosaic |
| GFTMAP | Gust Front TRACON Map |
| GFUP | Gust Front Update |
| GNRA | Gateway National Recreation Area |
| GPS | Global Positioning System |
| HPN | Westchester County Airport, White Plains, NY |
| IAH | George Bush Intercontinental/Houston Airport, Houston, TX |
| ITWS | Integrated Terminal Weather System |
| JFK | John F. Kennedy International Airport, New York, NY |
| Ladar | laser radar |
| LAMBDA | Lincoln Advanced Microburst Detection Algorithm |
| Lidar | Light detection and ranging |
| LGA | LaGuardia Airport, New York, NY |
| LDJ | Linden Airport, Linden, NJ |
| LLWAS | Low Level Wind Shear Alert System |
| LMCT | Lockheed Martin Coherent Technologies |
| MB | Microburst |

| | |
|---|---|
| MCO | Orlando International Airport, Orlando, FL |
| MDA | Microburst Detection Algorithm |
| MEM | Memphis International Airport, Memphis, TN |
| MIGFA | Machine Intelligent Gust Front Algorithm |
| MPAR | Multifunction Phased Array Radar |
| NEXRAD | Next Generation Weather Radar |
| OKX | Brookhaven NEXRAD, Upton, NY |
| PG | Product Generator |
| POD | Probability of Detection |
| PSF | Program Support Facility |
| RDA | Radar Data Acquisition |
| RFI | Radio Frequency Interference |
| RPG | Radar Product Generator |
| s.d. | Standard deviation |
| SJU | Luis Munoz Marin International Airport San Juan, Puerto Rico |
| SRTM | Shuttle Radar Topography Mission |
| TEB | Teterboro Airport, Teterboro, NJ |
| TRACON | Terminal Radar Approach Control |
| U-NII | Unlicensed National Information Infrastructure |
| VIL | Vertically Integrated Liquid Water |
| WS | Wind Shear |
| WSP | Weather Systems Processor |
| WSR-88D | Weather Surveillance Radar-1988 Doppler |

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# APPENDIX A
# WIND SHEAR DETECTION PROBABILITY MODEL SENSITIVITY TO MICROBURST OUTFLOW HEIGHT DISTRIBUTION

Two important variables affecting the radar detection of a wind shear event in the model are the probability distributions of the microburst and gust front outflow heights. For gust fronts, the measurement of the outflow height distribution were based on the maximum heights at which the fronts were observed, so it is a straightforward quantity (Klingle-Wilson and Donovan, 1991). It also does not vary greatly with location.

For microbursts, however, the outflow height is a definition based on the vertical velocity profile. For the measurements used in our earlier TDWR cost-benefit study, the microburst outflow height was defined to be the height at which the velocity decreased to half the maximum value (Biron and Isaminger, 1991). The few sites where the measurements were conducted include two wet microburst sites (Huntsville, AL, and Orlando, FL) and one dry microburst site (Denver, CO) (Biron and Isaminger, 1991). These measurement data were utilized, along with relevant climatological data, to generate microburst outflow height distributions at other airports for model use (Cho and Hallowell, 2008). The sparsity of the actual measured data, however, and the arbitrariness of the outflow height definition led us to perform a model sensitivity analysis.

To assess the impact of the microburst outflow height on model results, we scaled the distribution of the microburst outflow height by various amounts. A full scale microburst outflow height distribution and a half scale distribution (i.e., scaling factor of 0.5) are shown in Figure A-1 for JFK and LGA. The full scale distribution was derived from the measurement data at other sites and the NEXRAD data at JFK and LGA (Biron and Isaminger, 1991; Cho and Hallowell, 2008; Hallowell et al., 2009). The half-scale distribution is the same distribution squeezed down to half of the maximum outflow height. In this way we are able to investigate the effect of the microburst height distribution to the model detection probability of the microburst.

Change in PODs with the microburst outflow height for all the candidate sites, excluding the two skyscraper sites, is shown in Figure A-2, where the plots on the left of the plate are for JFK and the ones on the right are for LGA. The candidate sites in Figure A-2 are presented following the order of their distance (from near to far) to the airport. A scaling factor of 1 is equivalent to a maximum outflow height of 1.1 km. If radar detection were insensitive to the microburst outflow height, it would show a line with a constant POD. Yet, this is not the case as is shown in Figure A-2, where a microburst outflow height dependency is clear seen.

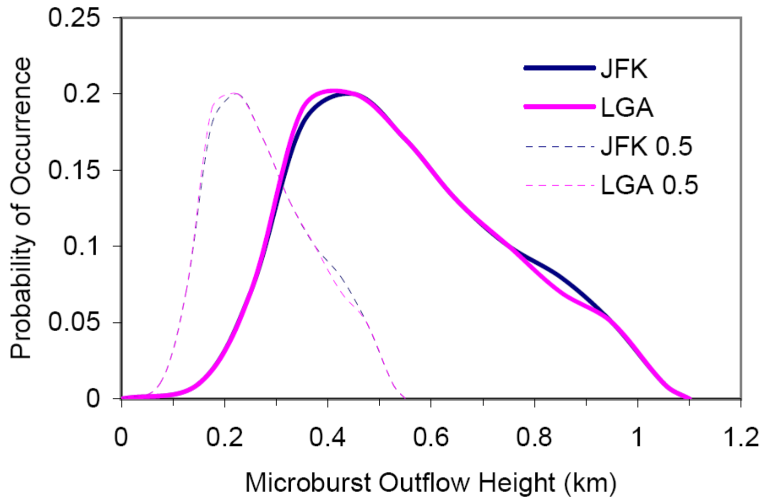


*Figure A-1. Microburst outflow height distributions for JFK and LGA (the solid lines). Distributions with a scaling factor of 0.5 are illustrated as the dashed lines.*

For candidate sites within 17 km of JFK (JFK itself, the current TDWR site and the nearby Ft. Tilden and Beach Sites, and LGA), the microburst detection is quite robust to change in the microburst outflow height until encountering outflow shallower than 200–300 m maximum (top left plot). For sites of intermediate distance (21–35 km, middle left plot and HPN in the bottom left plot), the microburst detection starts to deteriorate at an outflow height of 500–600 m. For farther distances, even a full-height microburst becomes difficult to detect (e.g., CDW). TEB and Fresh Kill show poor detection disproportionate to their distance to the airport, due to terrain blockage (Figure A-2).

Results similar to the JFK case are observed for the LGA case with a few exceptions. One exception is the Bellmore site, whose microburst detection seems vulnerable to events with outflow heights of 400 m or less. The poor detection is likely due to the blockage by the Mid Long Island Ridge. In fact, this ridge raised enough concern at the initial siting effort about LGA wind shear protection from the current TDWR site so that an LLWAS was installed at LGA to detect near-surface wind shear events. Another exception is TEB, which is near LGA but shows consistently poor detection. Terrain and building blockage is the culprit. Some distant airports (HPN, LDJ, FRG, and EWR) show satisfactory detection for outflow heights of 700 m or more. These sites may be considered for a supplementary radar to cover airspace at high altitude above the LGA ARENAs (see Section 3.4).

Due to the model sensitivity of the microburst detection to the microburst outflow height, the PODs of the half-scale microburst outflow height distribution (i.e., the PODs of the 80%-maximum velocity height as explained in Section 2.2) is used as a conservative measure for microburst detection in this study.

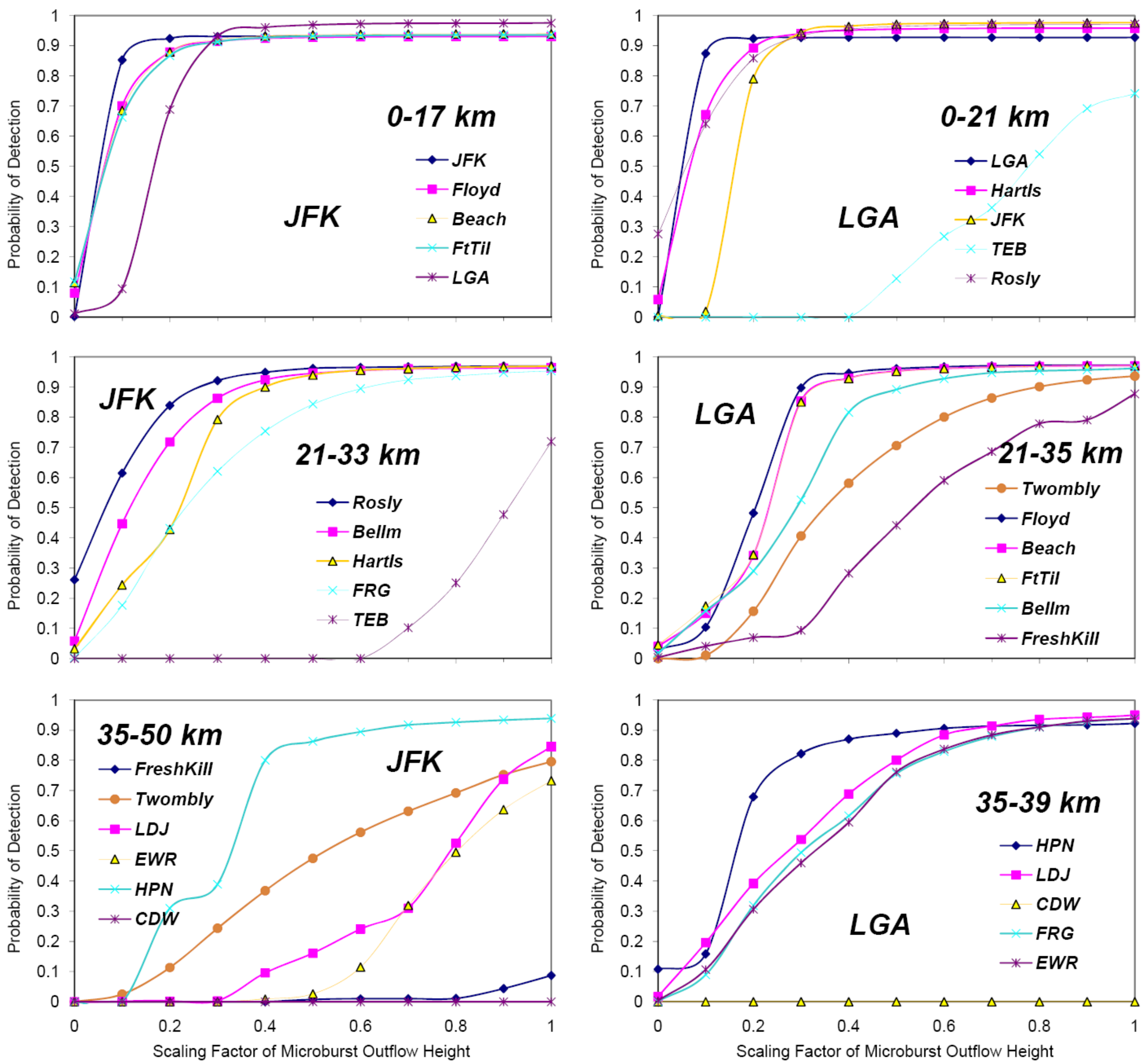


*Figure A-2. Effect of microburst outflow height distribution on microburst detection probability. The plots on the left are for JFK and the ones on the right are for LGA. The candidate sites are sorted by their distance to the airport. A scaling factor of 1 is equivalent to a maximum outflow height distribution of 1.1 km. All sites are for the TDWR except for Twombly, which is for the Baron VHDD-1000C.*

In order to gain confidence in the microburst outflow height distribution used, we ran a "spot check" for 29 microburst events that occurred on June 14, 2003 over JFK. They are multiple microbursts observed at different times and at continuous beam elevation angles. The histograms for the microburst outflow height and the velocity change ratio (or DV change ratio) are shown in Figure A-3. The outflow height is derived from the slant range and highest beam elevation angle of the TDWR at which the event was observed. The velocity change ratio is calculated as follows:

$$\text{DV Change ratio}=(DV_{Max.Ht} - DV_{0.5})/DV_{0.5}$$

where $DV_{Max.Ht}$ is the velocity loss at maximum beam elevation angle (or maximum height) at which the microburst can be observed and $DV_{0.5}$ is the velocity loss at the lowest beam elevation angle (0.5°).

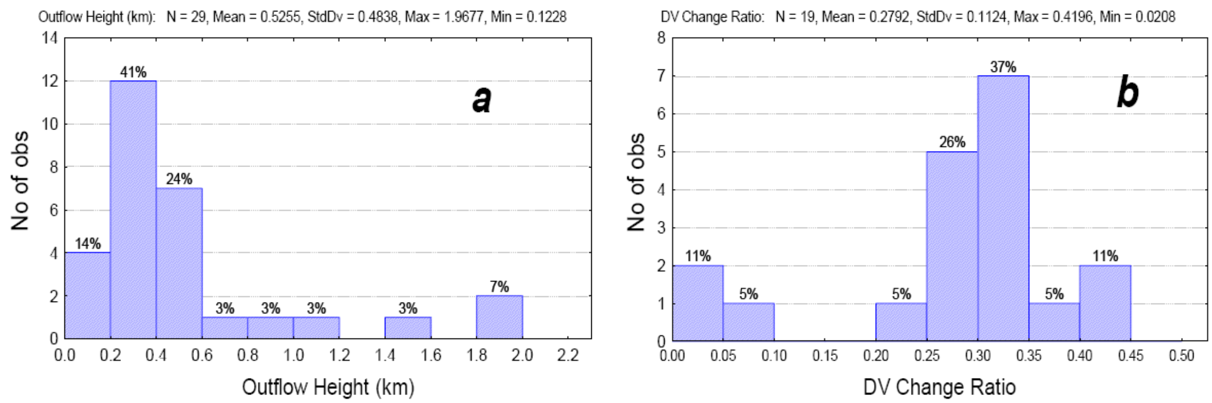


*Figure A-3. Histograms of outflow height (a) and velocity change ratio (or DV change ratio) (b) for microburst events observed on June 14, 2003 over JFK.*

The observed microburst outflow height distribution lies between the full- and half-scale derived distributions for JFK and LGA (Figure A-4). Therefore, the conservative nature of the microburst outflow height distributions used in this study is validated. The observed distribution of the velocity change ratio is also consistent with our definition of the microburst outflow height (i.e., at 80% maximum velocity): In 63% of the cases the observed velocity loss at maximum height was 25%–35% less than at the surface scan (Figure A-3b).

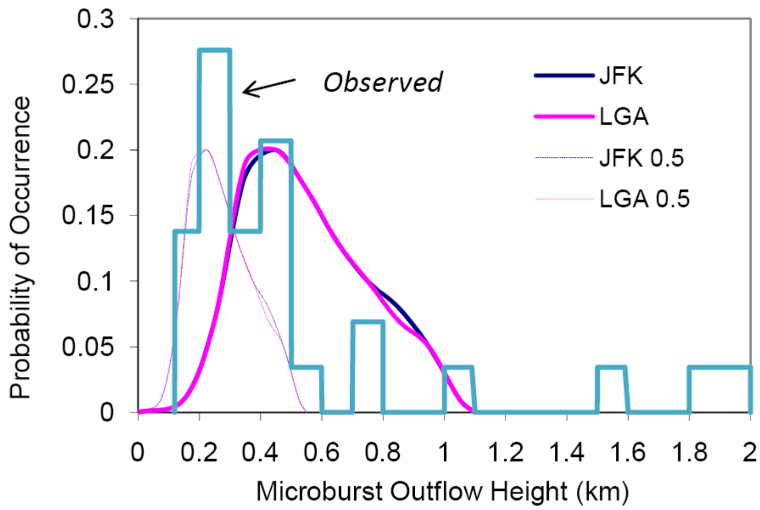


*Figure A-4. Figure A-3 overlaid with observed microburst outflow height distribution at JFK.*

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# APPENDIX B
# WIND SHEAR DETECTION PROBABILITY MODEL SENSITIVITY TO RADAR ANTENNA HEIGHT

In order to use the wind shear detection probability model for a radar located at a hypothetical location, the antenna height must be specified. The existing TDWRs have antenna heights above ground between 10 m and 35 m, with a mean of 28 m. The exact height that would be chosen for a given site is dependent on various local factors that are beyond the scope of this study. Therefore, an antenna height of 25 m was chosen for all ground-based hypothetical radar installations.

However, we also conducted a sensitivity study to check whether changing the antenna height would have a significant effect on the results. Table B-1 shows the median, minimum, and maximum wind shear detection probabilities as the antenna height was varied between 10 m and 35 m. Note that the results were essentially invariant for the “good” sites. The sites with a radar horizon and/or terrain blockage problem showed a slight variation, since these geometric issues are affected by the antenna height. We conclude that the single antenna height results are satisfactory for the purposes of this study.

**TABLE B-1**
**Median probability of detection of microbursts and gust fronts for the TDWR with 10–35 m antenna height. The minimum and maximum PODs are in parenthesis. The POD values are color-coded as in Table 4.**
**a. JFK**

| Site | Radar - Airport Distance (km) | POD | |
|---|---|---|---|
| | | Microburst | Gust front |
| JFK | 0 | 0.93 (0.93, 0.93) | 0.88 (0.88, 0.88) |
| Beach | 12 | 0.94 (0.94, 0.94) | 0.89 (0.89, 0.89) |
| Ft. Tilden | 13 | 0.93 (0.93, 0.93) | 0.89 (0.89, 0.89) |
| LGA | 17 | 0.97 (0.97, 0.97) | 0.93 (0.93, 0.93) |
| Roslyn | 21 | 0.96 (0.96, 0.96) | 0.94 (0.94, 0.94) |
| Bellmore | 22 | 0.95 (0.94, 0.95) | 0.92 (0.92, 0.92) |
| Hart Island | 24 | 0.94 (0.93, 0.95) | 0.93 (0.93, 0.93) |
| FRG | 32 | 0.84 (0.83, 0.86) | 0.94 (0.94, 0.94) |
| TEB | 33 | 0 (0, 0) | 0.68 (0.67, 0.69) |
| Fresh Kill | 36 | 0.01 (0, 0.01) | 0.57 (0.56, 0.58) |
| LDJ | 39 | 0.16 (0.14, 0.19) | 0.89 (0.89, 0.90) |
| HPN | 48 | 0.86 (0.85, 0.88) | 0.91 (0.91, 0.91) |
| CDW | 50 | 0 (0, 0) | 0 (0, 0) |

**Table B1. (continued)**
**b. LGA**

| Site | Radar - Airport Distance (km) | POD | |
|---|---|---|---|
| | | Microburst | Gust front |
| LGA | 0 | 0.93 (0.93, 0.93) | 0.88 (0.88, 0.88) |
| Hart Island | 12 | 0.95 (0.95, 0.96) | 0.89 (0.89, 0.89) |
| JFK | 17 | 0.97 (0.97, 0.97) | 0.91 (0.91, 0.91) |
| TEB | 18 | 0.13 (0.13, 0.17) | 0.69 (0.68, 0.71) |
| Roslyn | 21 | 0.96 (0.96, 0.97) | 0.93 (0.93, 0.93) |
| Beach | 24 | 0.95 (0.95, 0.96) | 0.91 (0.91, 0.91) |
| Ft. Tilden | 24 | 0.95 (0.95, 0.96) | 0.91 (0.91, 0.91) |
| Bellmore | 30 | 0.89 (0.89, 0.91) | 0.94 (0.94, 0.94) |
| Fresh Kill | 35 | 0.44 (0.42, 0.49) | 0.68 (0.68, 0.69) |
| HPN | 35 | 0.89 (0.89, 0.90) | 0.88 (0.88, 0.88) |
| LDJ | 36 | 0.80 (0.77, 0.82) | 0.94 (0.94, 0.94) |
| CDW | 36 | 0 (0, 0) | 0 (0, 0) |
| FRG | 39 | 0.76 (0.73, 0.78) | 0.95 (0.95, 0.95) |

## APPENDIX C
## CONTACT INFORMATION FOR THE CANDIDATE SITES IN THE INITIAL SITE-SURVEY DOCUMENTS

| Site | Best Contact Information (as of 3/20/2009) |
|---|---|
| Bellmore | BLF Associates of Woodbury<br>2755 Maple Avenue<br>North Bellmore, NY 11710-2433<br>Law firm representing BLF:<br>Rosenberg, Calica & Birney, LLP<br>Garden City, NJ<br>(516) 747-7400<br>Contact: Ms. Leslie Reardon |
| Roslyn | Village of East Hills<br>209 Harbor Hill Road<br>East Hills, NY 11576<br>Phone: (516) 621-5600<br>http://www/villageofeasthills.org/<br>(Source: http://www.safie.hq.af.mil/afrpa/legacybrac/formerroslyn.asp) |
| Ft. Tilden | Fort Tilden Redevelopment Authority<br>Irving Poy, Director, Planning and Development<br>Office of Queens Borough President<br>120-55 Queens Boulevard-Room 226<br>Kew Gardens, NY 11424<br>Phone: (718) 286-3000<br>(Source: http://www.arlingtonvirginiausa.com/index.cfm/13495) |
| Beach | Not available<br>This property is located within the<br>Gateway National Recreation Area (GNRA)<br>Public Affairs Office (718) 338-3988<br>210 New York Avenue<br>Staten Island, NY 10305 |
| Hart Island | City of New York<br>Department of Corrections<br>(212) 266-1500 |

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# APPENDIX D
# REPORT OF FOLLOW-UP SITE SURVEY

## Bellmore Site

The 17-acre Bellmore site, the former Bellmore US Army Reserve Center, was offered for sale to the city of Hempstead by the US government under the Federal Base Closure and Realignment Act of 1990. The town of Hempstead formed the North Bellmore Base Reuse Planning Group to develop a usage plan for the property. The town's reuse plan, after many public meetings, was issued in 1997 and contemplated the development of a limited number of mixed use single-family residences and senior housing. The town enacted zoning restrictions on the deed to specify the use that it wanted. However, the town never actually purchased the property.

In 2004 the Department of the Army sold the property for $10 million to a real estate developer: BLF Associates, LLC, which officially took ownership on November 30th, 2005. BLF seeks to develop 78 single-family residences which violate the zoning specified by the town. BLF sued to remove the deed restrictions and in May of 2007 the lower court ruling agreed with BLF that the restrictions should be removed. The town appealed the decision to the Appellate Court, which recently upheld the lower court decision (December, 2008, see Appendix E). The town has one level of appeal left and it is deliberating whether to proceed to that final appeal. Because the property is currently in litigation the site remains undeveloped. However, even if appeals fail and the zoning restriction were vacated, the vigorous law suit by the city and informal conversations with city officials shows that there is still strong political opposition to development of this property. Therefore, it is likely that installation of a radar on this site would meet stiff public opposition. However, a radar installation might limit the overall impact of the BLF development.

Court ruling on zoning restrictions: (see Appendix E)

www.courts.state.ny.us/courts/ad2/calendar/webcal/decisions/2008/D20405.pdf

Current Owners:

BLF Associates of Woodbury
2755 Maple Avenue
North Bellmore, NY 11710-2433
Law firm representing BLF:
Rosenberg, Calica & Birney, LLP
Garden City, NJ
(516) 747-7400
Contact: Ms. Leslie Reardon

Town of Hempstead:

Charles Kovitt (town attorney) (516) 489-5000
Law Firm representing the town's case:
Jaspen Schelsinger Hoffman, LLP
Garden City, NJ
(516) 746-8000
Contact: Ms. Lisa Cairo

## Roslyn Site

As a result of the 1995 Base Realignment and Closure Commission (BRAC), the Roslyn Air National Guard Station was closed in 2000. In 1999 the property was put on the market by the Air Force with a claim that the value was "as much as $22.4 million, or at least $14 million." Village officials from East Hills were concerned about the possible development such as low-income housing, a post office facility, and a drug rehabilitation center, so they moved quickly to purchase the facility for $3 million ($60,000 an acre). The site became the property of the Village of East Hills on December 9, 2000, and was voted by the residents to be developed into a signature park for the Village of East Hills in 2003 (http://www.mackyhistory.com/RoslynAirStation.htm and references thereinafter). Ground breaking for the park took place in September 2004, and it was opened for local residents in 2006 (New York Times, 2000; http://en.wikipedia.org/wiki/East_Hills,_New_York).

Figure D-1 shows the now completed park and the approximate location of the proposed TDWR site. The eastern half of the site has been fully developed with pools, ball fields, field houses and indoor athletic facilities. The western half (where the TDWR was proposed) was left largely undeveloped for use as walking and biking trails. A full brochure of the park can be found here: http://www.villageofeasthills.org/park.html. The extensive development of the site would seem to indicate that a radar installation would not be in keeping with the demeanor and aesthetics of the overall site.

On several dates (most recently March 13, 2009) a message was left for Mitchell Cohen (Special Counsel and Zoning) at (516) 621-5600 to verify whether the site would or would not be available for a proposed TDWR siting but received no reply. Office staff indicated informally that the site was fully developed and likely unavailable as a radar site. The Village Attorney is William, Burton, D'Amato & Lynch.

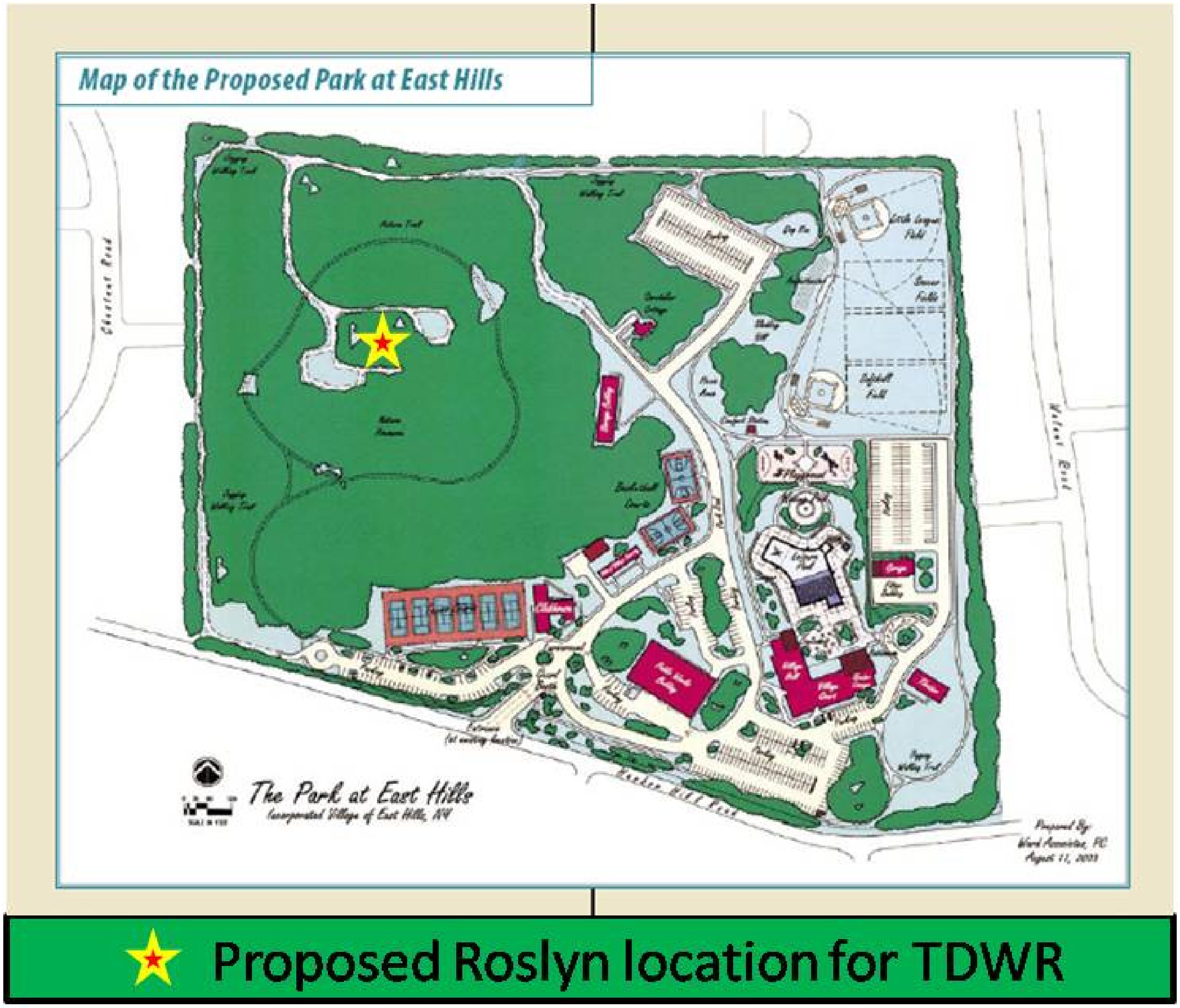


*Figure D-1. A map of the now completed Park at East Hills and the approximate location of the proposed TDWR site.*

## Fort Tilden Site

Former site of the Fort Tilden US Army Reserve Center (ARC), Nassau County.

*Installation Name*: Fort Tilden USARC / Fort Tilden Redevelopment Authority
*Point of Contact*: Irving Poy, Director, Planning and Development, Office of Queens Borough President
*Address*: 120-55 Queens Boulevard-Room 226, Kew Gardens, NY 11424
*Phone*: (718) 286-3000

Similar to many of the other former military sites this location is under the control of a local redevelopment authority. A phone conversation with Mr. Poy on November 13th, 2008 indicated that he had been informed that the site was being or had been taken as part of the Gateway National Recreation Area (GNRA) (http://www.nps.gov/gate/). A map of the GNRA indicates that Fort Tilden is now considered part of the GNRA (Figure D-2). This makes Fort Tilden part of the same park area that the existing TDWR is now located. Therefore, it seems questionable as to whether the National Park Service would be open to moving the radar within the GNRA.

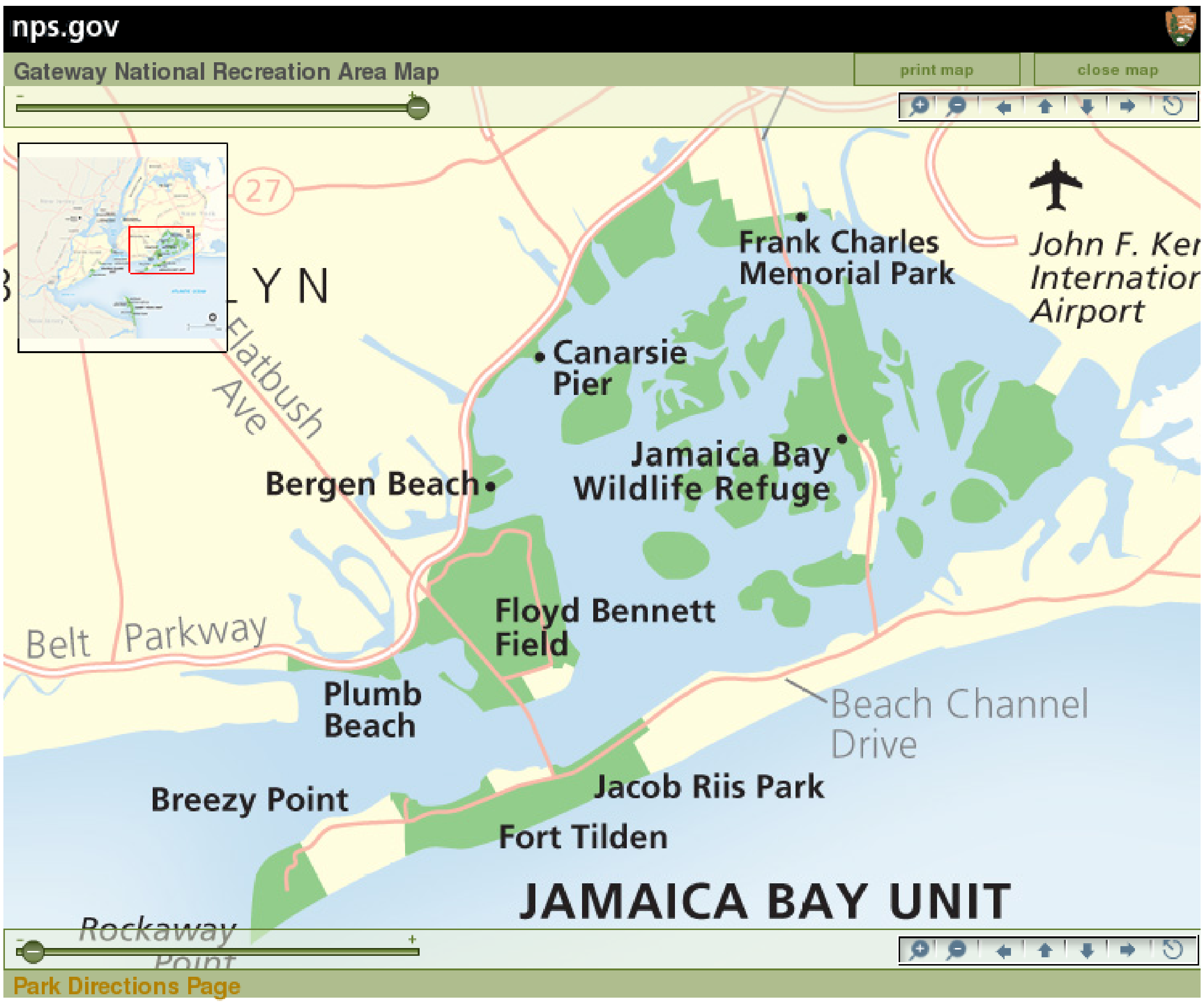


*Figure D-2. A map of the Gateway National Recreation Area.*

## Beach Site

While no specific parcel location could be found for this site in the initial siting documentation, it would appear to also be located within the Gateway National Recreation Area and, thus, likely unavailable as a radar site.

No official contact information could be found for this location, but as it is now within the GNRA they would be the best contact for access.

## Hart Island Site

The status of Hart Island as a cemetery site for unclaimed prisoners who have passed away appears to be unchanged. The concrete surface of the former Nike missile launching facility shown in initial site survey documents also seems unoccupied (Figure D-3) (http://www.correctionhistory.org/html/chronicl/hart/nike/hartnike2.htm). As such, it would appear this site would still be available for consideration.

*Figure D-3. The current picture of a former Nike missile launching facility at Hart Island. The foundation was proposed to be used as the TDWR foundation in initial site-survey documents. The Manhattan skyline is faintly visible in the background of the photo.*

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# APPENDIX E
# A RECENT COURT RULING DOCUMENT RELATED TO THE BELLMORE SITE

**Supreme Court of the State of New York**
**Appellate Division: Second Judicial Department**

D20405
C/hu

_____AD3d_____ Argued - May 9, 2008

WILLIAM F. MASTRO, J.P.
PETER B. SKELOS
ROBERT A. LIFSON
JOHN M. LEVENTHAL, JJ.

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2007-06330 OPINION & ORDER

BLF Associates, LLC, respondent, v Town of Hempstead, et al., appellants.

(Index No. 8342/06)

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APPEAL by the defendants, in an action, inter alia, for a judgment declaring that Article XXXVIII of the Building Zone Ordinance of the Town of Hempstead is ultra vires, void, and unconstitutional, from an order of the Supreme Court (Roy S. Mahon, J.), entered May 21, 2007, in Nassau County, which granted the plaintiff's motion for summary judgment on the complaint and denied their cross motion for summary judgment.

Jaspan Schlesinger Hoffman, LLP, Garden City, N.Y. (Laurel R. Kretzing, Lisa A. Cairo, and Seth A. Presser of counsel), for appellants.

Rosenberg Calica & Birney LLP, Garden City, N.Y. (Ronald J. Rosenberg and Lesley A. Reardon of counsel), for respondent.

LIFSON, J. This appeal involves the zoning of a 17-acre parcel of property (hereinafter the property) located in North Bellmore, in the Town of Hempstead. The property was previously owned by the United States of America and used as an Army Reserve facility by the Department of Defense. The property and the surrounding area was zoned as a "B Residence" district, which permits single-family detached housing or senior residences on 6,000 square foot lots with a minimum lot frontage of 55 feet. The B Residence zone also allows school, religious, "municipal recreational," and agricultural uses. In 1996 the United States of America closed the Army Reserve Facility and the property was made available for transfer, pursuant to the Federal Base Closure and Realignment Act of 1990. In accordance with that Act, the Town was afforded the first opportunity to acquire the property and redevelop it for a public purpose. In furtherance of its interest in acquiring the property, the Town formed the North Bellmore Base Reuse Planning Group as the Local Redevelopment Agency (hereinafter the LRA) to develop a usage plan for the property.

After a series of public meetings the LRA issued its Reuse Plan and Technical Report (hereinafter the Reuse Plan) in April 1997. The Reuse Plan contemplated a specific mixed-use development limited to 34 single-family homes with a price cap, 40 senior citizen semi-attached dwellings with a price cap, and a community recreational facility. The Town intended that the plan be incorporated as a deed restriction in the land sale documents promulgated by the United States Department of the Army (hereinafter the Department of the Army).

Ultimately, the Town chose not to purchase the property, and in 2004 the Department of the Army offered the property for sale through a competitive bidding process. The "Notice of Availability" for the sale of the property provided, inter alia, that the Town had a redevelopment plan for the property which included a mix of single-family and senior dwellings and a community recreational facility. In December 2004 the petitioner herein, BLF Associates, LLC (hereinafter BLF), which had been declared the successful bidder for the property, entered into an exchange agreement to purchase the property for the sum of $6,650,000 from the Department of the Army. The exchange agreement made no reference to the Reuse Plan.

In the meantime, the Town proposed enacting Article XXXVIII of the Town's Building Zone Ordinance to implement the Reuse Plan for the property. On November 16, 2004, a public hearing was held on the resolution, and a representative of BLF appeared in opposition to its enactment. On April 19, 2005, the Town passed a resolution approving the enactment of Article XXXVIII, which created the "North Bellmore Planned Residence District." Article XXXVIII provides, inter alia, that the property "may be used for any of the following purposes, and for no other:" no more than 34 single-family homes, no more than 40 senior citizen semi-attached dwellings, and a community recreational facility. The community recreational facility was required to be a 9,000-square foot center on no fewer than 1.25 acres of land, with a swimming pool, a picnic area, a minimum of two tennis courts, an exercise room, no fewer than two shuffleboard courts, a kitchen, an office, and a community room/lounge. Article XXXVIII also required the transfer of the 1.25-acre recreational facility to a homeowners' association. Additionally, Article XXXVIII sets various standards for matters such as the size and placement of yards, minimum lot area and width, and the height and area of buildings, and provides that no permits would be issued unless a site plan was first submitted to the LRA for review and recommendation, and then to the Town for approval.

On November 30, 2005, title to the property was transferred from the United States of America to BLF. Thereafter BLF commenced this action seeking a declaratory judgment that the Town's enactment of Article XXXVIII was ultra vires, void, and unconstitutional, a preliminary and permanent injunction enjoining the Town from imposing the Reuse Plan upon BLF, and compensatory and punitive damages. BLF moved for summary judgment on the complaint and the defendants cross-moved for summary judgment, and in an order entered May 21, 2007, the Supreme Court denied the defendants' cross motion and granted BLF's motion on the ground that the Town's enactment of Article XXXVIII was ultra vires and, therefore, void as a matter of law. We affirm.

"Towns and other municipal authorities have no inherent power to enact or enforce zoning or land use regulations. They exercise such authority solely by legislative grant and in the absence of legislative delegation of power, their actions are ultra vires and void" (*Matter of Kamhi v Planning Bd. of Town of Yorktown,* 59 NY2d 385, 389; *see Matter of Bayswater Realty & Capital Corp. v Planning Bd. of Town of Lewisboro,* 149 AD2d 49, 52). The enabling statutes applicable here are Town Law §§ 261 through 263. Section 261 confers upon the Town the broad authority to enact ordinances which, "[f]or the purpose of promoting the health, safety, morals or the general welfare of the community . . . regulate and restrict the height, number of stories and size of buildings and other structures, the percentage of the lot that may be occupied, the size of yards, courts and other open spaces, the density of population, and the location and use of buildings, structures and land." Section 262 states that the Town may create "districts of such number, shape and area as may be deemed best suited to carry out the purposes of this [enabling] act; and within such districts it may regulate and restrict the erection, construction, reconstruction, alteration or use of buildings, structures or land." Section 263 mandates that such zoning regulations enacted in accordance with the preceding statutes be "made in accordance with a comprehensive plan."

A comprehensive plan is a compilation of land use policies that may be found in any number of ordinances, resolutions, and policy statements of the town (*see Osiecki v Town of Huntington,* 170 AD2d 490). "Zoning legislation is tested not by whether it *defines* a well-considered plan, but by whether it *accords* with a well-considered plan for the community" (*Matter of Gernatt Asphalt Prods. v Town of Sardinia,* 87 NY2d 668, 685 [emphasis added]; *see Asian Am. for Equality v Koch,* 72 NY2d 121, 131; *Matter of Stone v Scarpato,* 285 AD2d 467, 469). The requirement that zoning decisions be made in accordance with a comprehensive plan for the community "operate[s] to impose mutual benefits and restrictions on the parties within the community" (*Matter of Village of Chestnut Ridge v Town of Ramapo,* 45 AD3d 74, 87).

The statement of legislative purpose in Article XXXVIII acknowledges that it was enacted in order to implement the Reuse Plan for the property. The re-zoning of property for implementation of a specific project which the Town had intended to construct if it acquired the property is not a consideration or purpose embodied in the enabling act (*see Mazzara v Town of Pittsford,* 34 AD2d 90, 92). Furthermore, while Town Law §§ 261 and 262 empower the Town to regulate and restrict lot sizes and permitted uses, there is nothing in these sections which empowers the Town to create a zoning ordinance that specifies the exact number and type of dwelling allowed.

Nor do the applicable enabling statutes purport to allow the enactment of a zoning ordinance that requires construction of a 9,000-square foot community recreational facility, with specified amenities, on no fewer than 1.25 acres of land. Zoning ordinances may go no further than determining what may or may not be built, and that Article XXXVIII is unnecessarily and excessively restrictive leads us to conclude that it was not enacted for legitimate zoning purposes (*see Vernon Park Realty, Inc. v City of Mount Vernon,* 307 NY 493; *Blitz v Town of New Castle,* 94 AD2d 92, 99). Moreover, and contrary to the Town's contention, the provisions of Article XXXVIII that require the recreational facility to be owned by a homeowners' association and that the senior citizen dwellings be cooperative units are clearly ultra vires and void. It is a "fundamental rule that zoning deals basically with land use and not with the person who owns or occupies it" (*Dexter v Town Bd. of Town of Gates,* 36 NY2d 102, 105; *see FGL & L Prop. Corp. v City of Rye,* 66 NY2d 111, 116).

While Article XXXVIII may define a well-considered plan in creating the "North

Bellmore Planned Residence District," the district and its specific form of mixed-usage development is inconsistent with the surrounding area of the Town, which is zoned B Residence. The Town itself, in its Reuse Plan, acknowledged that the Property was "surrounded by a totally developed, single-family neighborhood," that the Property was "surrounded by a densely populated single-family residential neighborhood," and that "the characteristic land use of the entire surrounding area" was B Residence.

Finally, regarding the Town's contention that BLF cannot be heard to complain because it knew about the Reuse Plan and Article XXXVIII before it closed title, the "[p]urchase of property with knowledge of [a] restriction does not bar the purchaser from testing the validity of the zoning ordinance [because] the zoning ordinance in the very nature of things has reference to land rather than to owner" (*Vernon Park Realty, Inc. v City of Mt. Vernon,* 307 NY at 500).

Accordingly, the Supreme Court properly denied the defendants' cross motion and granted BLF's motion for summary judgment on the ground that enactment of Article XXXVIII was ultra vires. Having determined that Article XXXVIII is invalid on such grounds, it is unnecessary to reach the constitutional issues raised by BLF (*see FGL & L Prop. Corp. v City of Rye,* 66 NY2d 111). Therefore, the order is affirmed, and the matter is remitted to the Supreme Court, Nassau County, for the entry of a judgment declaring that Article XXXVIII of the Building Zone Ordinance of the Town of Hempstead is ultra vires (*see Lanza v Wagner,* 11 NY2d 317, 334, *appeal dismissed* 371 US 74, *cert denied* 371 US 901).

MASTRO, J.P., SKELOS and LEVENTHAL, JJ., concur.

ORDERED that the order is affirmed, with costs, and the matter is remitted to the Supreme Court, Nassau County, for the entry of a judgment declaring that Article XXXVIII of the Building Zone Ordinance of the Town of Hempstead is ultra vires.

ENTER:

James Edward Pelzer
Clerk of the Court

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# APPENDIX F
# SOFTWARE INTEGRATION TO SUPPORT ON-AIRPORT SITING OF THE NEW YORK TDWR

All operational TDWRs are currently located 10 to 24 km from the associated airport(s). The primary reasons for choosing not to place TDWRs at the airport were the "cone-of-silence" problem and the poor viewing geometry to a gust front as it passes over the airport. If the New York TDWR is relocated onto an airport property (JFK or LGA) these issues would need to be addressed. In principle, data from the EWR TDWR could be used to supply the missing information directly above the on-airport TDWR and provide a complementary viewing angle for gust fronts passing through that airport. In order to accomplish this data integration, modifications to the existing software would be required. This appendix describes the necessary software modifications.

There are currently two sets of microburst and gust front detection products generated from TDWR base data. The first set is output by the TDWR radar product generator (RPG) and the second set is produced by the ITWS product generator (PG). At airports where ITWS is in operation, the ITWS wind shear products are the primary and the TDWR products are the back up. By the end of 2010 it is expected that all TDWR airports will have a commissioned ITWS. Therefore, our assumption here is that all TDWR airports will be using the ITWS wind shear products, with the TDWR products maintained as a back up in case the ITWS becomes temporarily unavailable.

Although there are differences in the wind shear detection algorithms employed by the ITWS PG and the TDWR RPG, all are expected to be impacted by the relocation of the source radar to an on-airport location. Review of the ITWS operational data indicates that losing the capability of overhead thunderstorm detection will reduce the POD of microbursts by 1%–2% (R. Hallowell, personal communication). Based on observations of site operators for the Newark and JFK TDWRs, from Nov. 2001 to Jul. 2003, radial alignment of gust fronts is estimated to have caused ~1% missed detection. False alarms can also increase for microburst detection if the overhead vertically integrated liquid water (VIL) threshold is not used to screen them out. For example, a study using the Denver ITWS microburst detection product showed an increase in false alarms from 9% to 14% when the VIL threshold was decreased from 0.5 to 0 kg/m$^2$ (M. Isaminger, past personal communication).

## F1. TDWR WIND SHEAR PRODUCTS

Since the TDWR was designed to only process its own data, modifying the Raytheon production code in the RPG to ingest base data from a second TDWR without the expertise of the original software architect would be a tricky and time consuming task. We propose, instead, a less invasive and more modular solution to this problem. That is, one could develop an ITWS-like system for the on-airport TDWR, which can be taken off line if the off-airport TDWR breaks down or the data link to it is lost (Figure F-1).

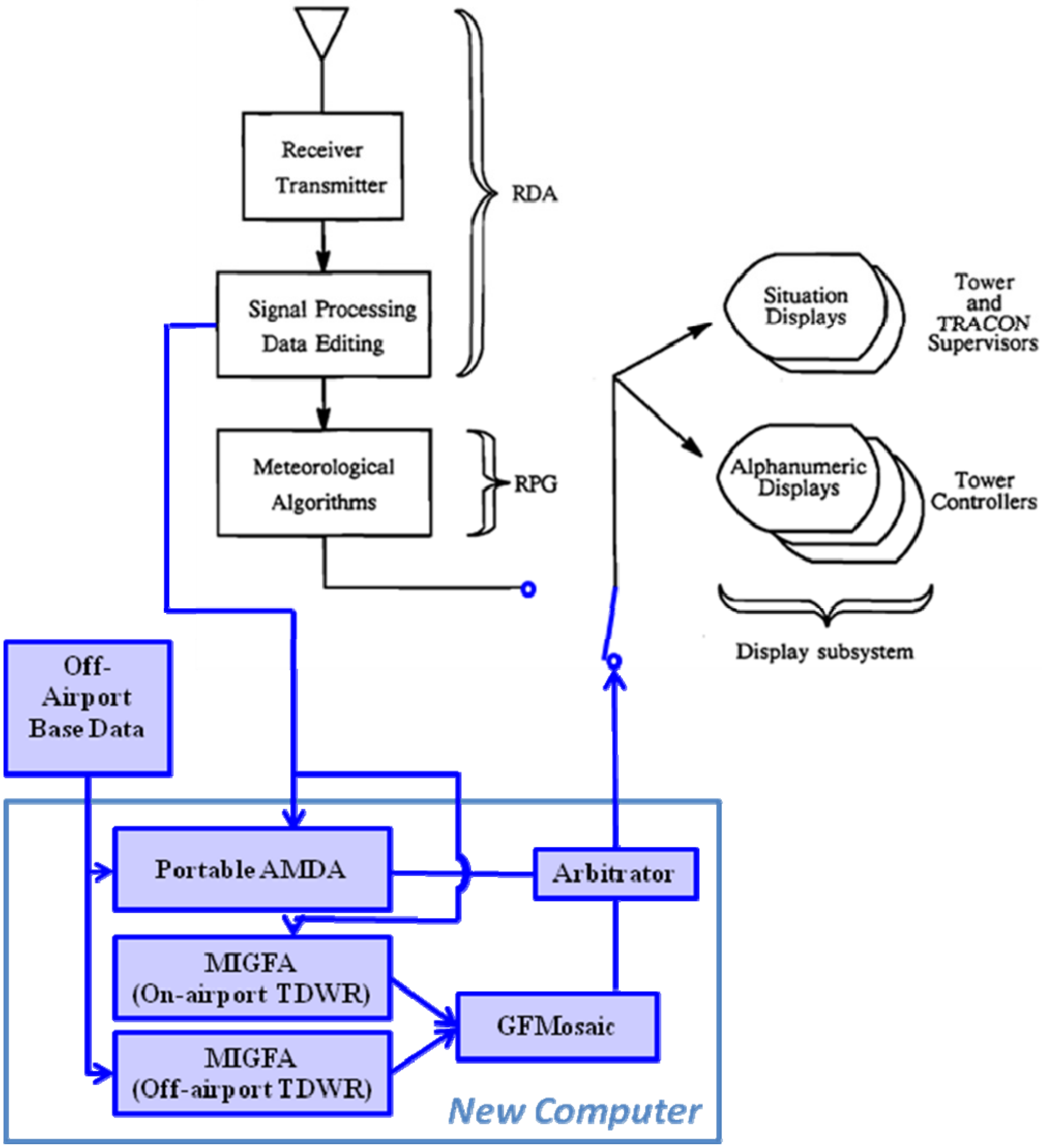


*Figure F-1. Block diagram of the basic TDWR data flow with a new outboard wind shear algorithm processor (adapted from Merritt [1991]). The modifications are shown in blue. A more detailed diagram of the gust front algorithm modifications including GFUP is shown in Figure F-6.*

This system would be hosted on a separate computer. Base data from both TDWRs would bypass the RPG and be channeled into this computer. The Portable ASR-9 Microburst Detection Algorithm (Portable AMDA), which was developed by LL and can be configured for different radars, would be used for microburst detection. For gust fronts, base data from the two TDWRs would be processed by individual MIGFAs and the results mosaicked using the GFMosaic algorithm developed by LL (see Section F2.3). The alerts issued by Portable AMDA and GFMosaic would then go through an arbitration process using the same logic and situational information that are present in the RPG before being output to the displays. Note that a direct data link from the off-airport TDWR should be established; relying on an indirect connection via ITWS would negate the status of the TDWR wind shear products as a back up to the ITWS wind shear products.

## F2. ITWS WIND SHEAR PRODUCTS

The ITWS production code was developed by Raytheon based on specifications from the LL prototype system. It is now under the control of the FAA PSF. In order for an organization other than the PSF to develop modifications to its algorithms, either the production source code must be made available by the PSF or the original LL prototype need to be resurrected and brought up to date. Since we do not have access to the production code at this time, we limit ourselves to outlining the required functional modifications to the LL prototype wind shear algorithms.

Base data from the Newark TDWR are already ingested by the New York ITWS. Therefore, no new data link is needed for this purpose.

### F2.1. Microburst detection

A significant amount of effort would be required to upgrade the ITWS Microburst Detection Algorithm (or Lincoln Advanced Microburst Detection Algorithm, LAMBDA) for on-airport siting. A new playback module to read and preprocess the TDWR base data, the "LAMBDA_BaseData_Preprocessor" (Figure F-2) (FAA, 2002), would be needed. Software changes will then be required within the "Radial_Shear_Map_Computation" and "Microburst_Alert_Generation" modules to facilitate reading the new data structure. These changes are not needed in the production code but are necessary in the LL prototype code.

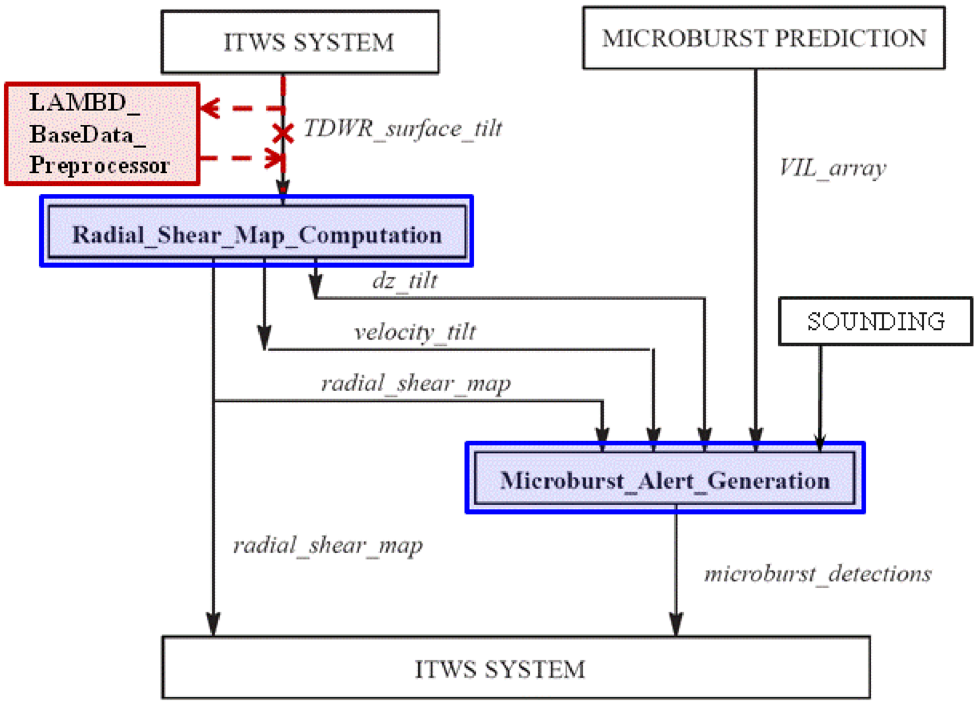


*Figure F-2. Block diagram of the ITWS microburst detection algorithm or LAMBDA with modifications highlighted in red and blue (adapted from FAA [2002]).*

For optimal close-range and overhead microburst detection, the radial shear computation should take place across the origin instead of beginning at the origin. The necessary coordinate transformation for compositing each radial with its complement is implemented in AMDA (Newell and Cullen, 1993) and is illustrated in Figure F-3. The discontinuity in the velocity signature of an overhead microburst, as the range passes through the origin, is removed after the transformation (Figure F-3b). Note that even with the coordinate system transformation algorithm, data from two to three range gates closest to the TDWR will still be missing (due to the minimum observable range limitation) and will need to be interpolated. This data gap is the reason for recommending the installation of a minimal LLWAS system to complement the on-airport TDWR (Section 3.5.2).

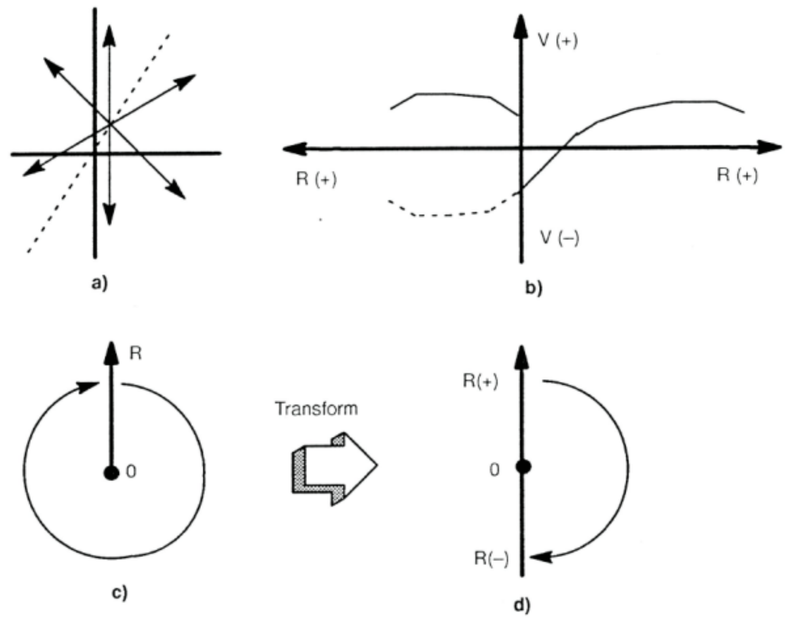


*Figure F-3. Coordinate system transformation to support overhead microburst detection (Newell and Cullen, 1993). a) Flow pattern of a microburst centered over the radar. b) The discontinuity of the velocity signature, as the range passes through zero is removed after the transformation (dashed line). c) A 0°–360° coordinate system. d) A 0°–180° coordinate system after the transformation. This algorithm is currently implemented in AMDA but not in TDWR or ITWS MDA.*

### F2.2. Microburst prediction

For microburst prediction, code in the “BaseDataPreprocessor” block needs to be modified to read and mosaic data from two TDWRs to generate a 3-D grid of reflectivity (Figure F-4) (FAA, 2002). Logic needs to be implemented to take care of issues such as different scanning modes and timing. The “BaseDataPreprocessor” block also needs to account for the coarser azimuthal resolution of the more distant TDWR.

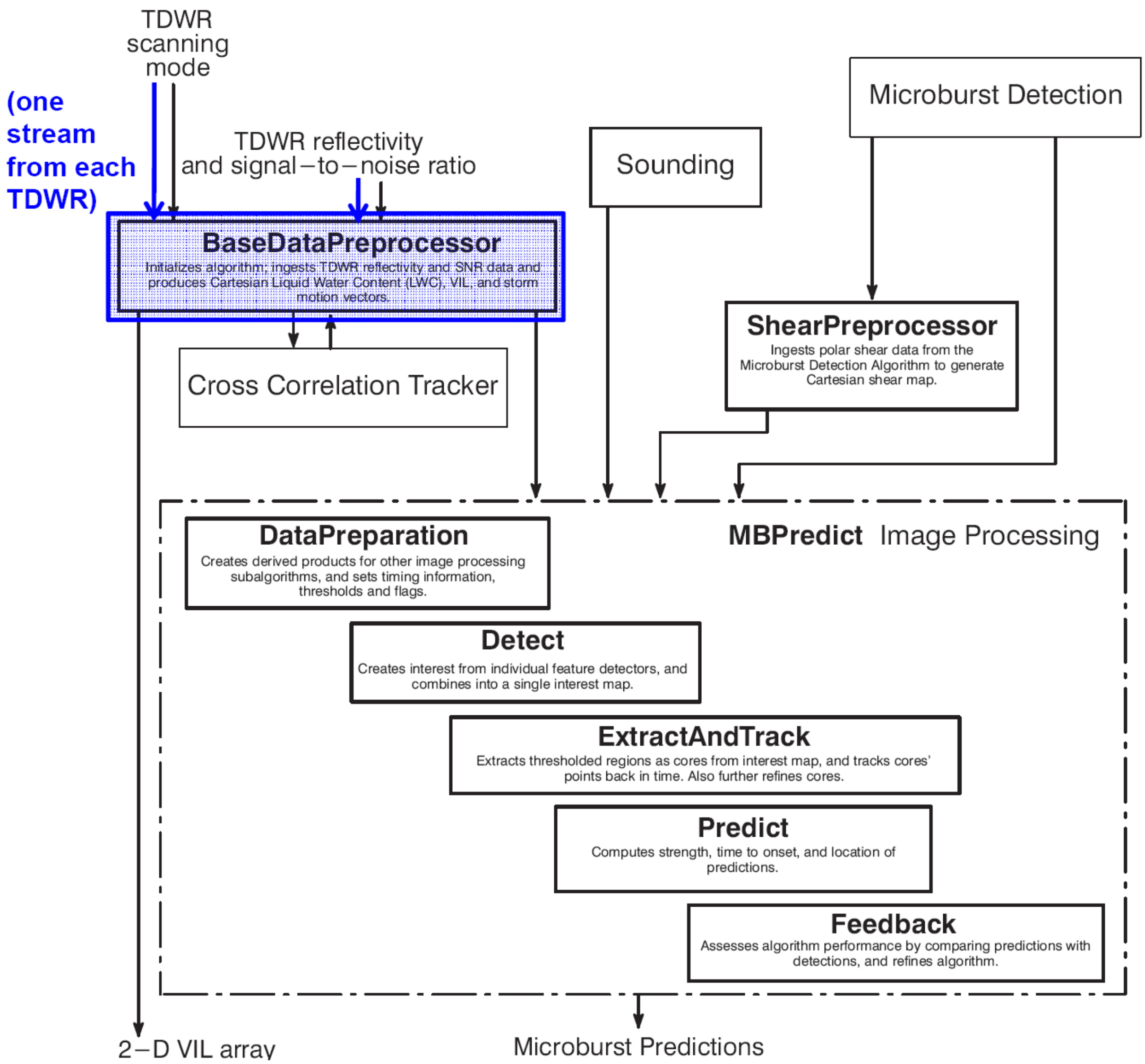


*Figure F-4. Block diagram of the ITWS microburst prediction algorithm with modifications highlighted in blue (adapted from FAA [2002]).*

Note that the reduced azimuthal resolution of the reflectivity grid over the "cone-of-silence" region due to the distance of the off-airport TDWR may, to some extent, attenuate some of the estimated 1%–2% gain in microburst detection performance attributed to the availability of overhead data. The reduced reflectivity resolution, however, is not expected to significantly impact the false alarm reduction capability realized via overhead threshold level of VIL.

### F2.3. Gust front detection and prediction

Currently, ITWS integrates MIGFA products from multiple TDWR data through the gust front terminal radar approach control (TRACON) map (GFTMAP) (Figure F-5) (S. Troxel, personal communication). The system receives the MIGFA products of the individual TDWRs, then it simply selects one product for display based on a set of site-specific static rules that says "display gust fronts from Radar A in this region and gust fronts from Radar B in this other region," etc. This process is not optimal because the integration does not merge information in regions of overlapping coverage. For example, if Radar A detects a gust front in a region that is assigned for display only by Radar B while Radar B does not sense it, no gust front will be displayed.

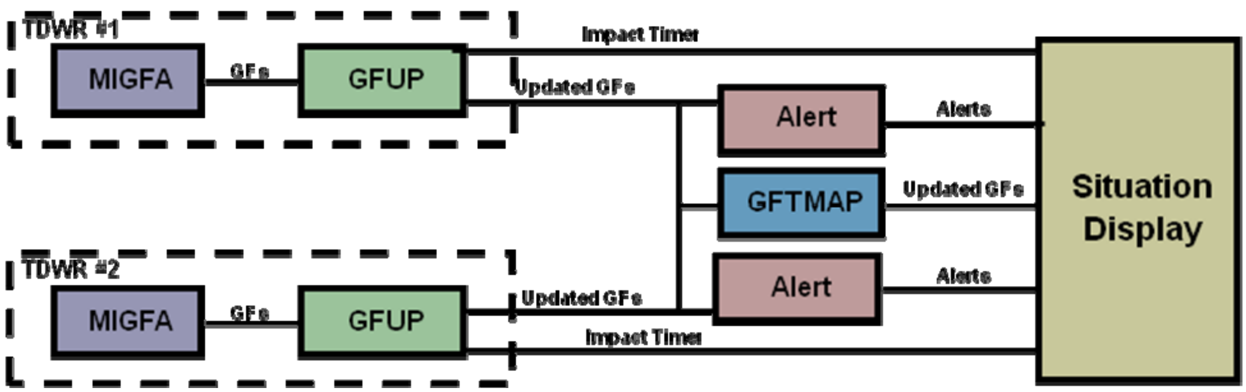


*Figure F-5. Block diagram of the current ITWS GFTMAP for gust front integration of multiple radars (S. Troxel, personal communication).*

An alternative algorithm, gust front mosaic (GFMosaic), provides product-based integration that is more robust than GFTMAP (Figure F-6) (Shaw et al., 2000; S. Troxel, personal communication). Gust fronts from any of the radars in the coverage area are fused by combining the gust front detection locations produced by the gust front update (GFUP) algorithm, which uses MIGFA forecast information to extrapolate the positions of the gust fronts at 1-min intervals in between the 5-min MIGFA output intervals. Thus, GFMosaic would be better at covering gust fronts that pass directly over the on-airport TDWR compared to GFTMAP.

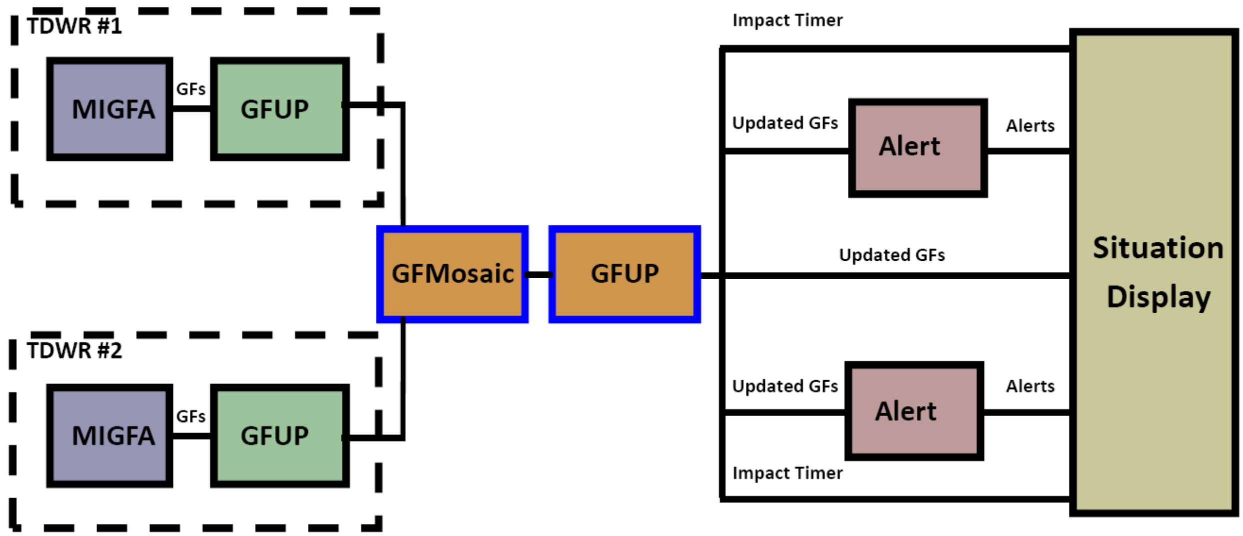


*Figure F-6. Block diagram of the proposed ITWS GFMosaic for gust front integration of two radars (S. Troxel, personal communication).*

As shown in Figure F-6, a separate GFUP process would also be needed to process the gust front detections produced by GFMosaic in order to produce the 1-minute updated gust front positions and impact timer products that are utilized downstream by the TDWR alert generator and situation display. No modifications are needed to the GFUP algorithm to support this.

Performance analysis for DFW and DAL showed improvement for GFMosaic compared to a single TDWR MIGFA (Shaw et al., 2000). At one point GFMosaic was even running in "shadow" mode in the New York ITWS site. One question that needs to be answered before forging ahead with the implementation of GFMosaic is whether to perform the data fusion at the interest field level or the product level. In theory the former approach is better, since more information is used from both radars. However, the implementation is more complicated and it has not been proven in practice that the performance is better. Therefore, the GFMosaic prototype needs to be resurrected and the two approaches need to be compared against each other using real data. Based on the results of the performance evaluation, a decision will be made whether interest field or product level fusion will be implemented.

# APPENDIX G
# TDWR SITE LAND OWNERSHIP STATUS

| ID | Airport | Radar Site Location | Status of Site's Land | Data Source | Remarks |
|---|---|---|---|---|---|
| ADW | Andrews AFB | Brandywine, MD | **permitted** to FAA | Ascrizzi's 6/23/04 e-mail message | No problem anticipated in renewing the no-cost permit/license. |
| ATL | Atlanta Hartsfield | Ellenwood, GA | owned by FAA | Moore's 6/18/04 e-mail message | |
| BNA | Nashville | Nolensville, TN | **leased** until 9/1/15 | Moore's 6/18/04 e-mail message | No problem anticipated renewing the lease, per Moore's 7/9/04 e-mail message. |
| BOS | Boston Logan International | South Weymouth, MA | owned by FAA | Gray's 6/22/04 e-mail message | |
| BWI | Baltimore-Washington International | Millersville, MD | owned by FAA | Ascrizzi's 6/22/04 e-mail message | |
| CLE | Cleveland-Hopkins | Grafton, OH | owned by FAA | Brady's 6/24/04 e-mail message | |
| CLT | Charlotte | Charlotte, NC | owned by FAA | Moore's 6/18/04 e-mail message | |
| CMH | Columbus | Pataskala, OH | owned by FAA | Brady's 6/28/04 e-mail message | |
| CVG | Covington/Cincinnati | Walton, KY | owned by FAA | Moore's 6/18/04 e-mail message | |
| DAL | Dallas Love Field | Irving, TX | **leased** until 9/1/13 ($2,084/yr) | Perkins' 6/24/04 e-mail message | Falcon's 6/28 e-mail message said they don't anticipate any problems renewing the lease. |
| DAY | Cox Dayton International | Troy, OH | owned by FAA | Brady's 6/24/04 e-mail message | |
| DCA | Washington Reagan National | Ft. Washington, MD | owned by FAA | Ascrizzi's 6/22/04 e-mail message | |
| DEN | Denver International | Bennett, CO | owned by FAA | Hurley's 6/17/04 e-mail message | |
| DFW | Dallas / Ft. Worth | Lewisville, TX | **leased** until 6/1/08 (no cost) | Perkins' 6/24/04 e-mail message | |
| DTW | Detroit | Belleville, MI | owned by FAA | Brady's 6/24/04 e-mail message | |
| EWR | Newark International | Woodbridge, NJ | **permitted** to FAA | Ascrizzi's 6/23/04 e-mail message | No problem anticipated in renewing the no-cost permit/license. |
| FLL | Ft. Lauderdale | Sunrise, FL | **leased** until 9/1/17 | Moore's 6/18/04 e-mail message | No problem anticipated renewing the lease, per Moore's 7/9/04 e-mail message. |
| HOU | Houston Hobby | Friendswood, TX | **leased** until 9/1/09 (no cost) | Perkins' 6/24/04 e-mail message | |
| IAD | Washington-Dulles International | Leesburg, VA | **soon to be** owned by FAA | Ascrizzi's 6/22/04 e-mail message | |
| IAH | Houston Bush Intercontinental | Tomball, TX | **leased** until 9/1/12 (no cost) | Perkins' 6/24/04 e-mail message | |
| ICT | Wichita | Clearwater, KS | owned by FAA | Synder's 6/30/04 e-mail message | |
| IND | Indianapolis | Mooresville, IN | owned by FAA | Brady's 6/24/04 e-mail message | |
| **JFK** | John F. Kennedy International / LaGuardia | Brooklyn, NY | **owned by Interior Dept, National Park Service** | 6/12/03 land transfer agreement | **Must vacate by 1/29/23 unless the 9/13/99 agreement between DOT and DOI is revised.** |
| LAS | Las Vegas McCarran | Las Vegas, NV | **permitted** to FAA | Spitt's 7/16/04 e-mail message | BLM can, but probably won't, terminate FAA's occupancy at any time. |
| MCI | Kansas City International | Dearborn, MO | **leased** until 9/30/13 ($600/yr) | Synder's 6/30/04 e-mail message | |
| MCO | Orlando International | Kissimmee, FL | **leased** until 9/1/11 | Moore's 6/18/04 e-mail message | No problem anticipated renewing the lease, per Moore's 7/9/04 e-mail message. |
| MDW | Chicago-Midway | Crestwood, IL | owned by FAA | Brady's 6/24/04 e-mail message | |
| MEM | Memphis International | Nesbit, MS | **leased** until 9/1/12 | Moore's 6/18/04 e-mail message | No problem anticipated renewing the lease, per Moore's 7/9/04 e-mail message. |

| ID | Airport | Radar Site Location | Status of Site's Land | Data Source | Remarks |
|---|---|---|---|---|---|
| MIA | Miami International | Miami, FL | **leased** with U.S. Immigration and Naturalization Service until 9/1/13 | Moore's 6/18/04 e-mail message | No problem anticipated renewing the lease, per Moore's 7/9/04 e-mail message. |
| MKE | Milwaukee | Franksville, WI | **leased** until 9/30/14 | Brady's 6/25/04 e-mail message | |
| MSP | Minneapolis / St. Paul International | Woodbury, MN | owned by FAA | Brady's 6/24/04 e-mail message | |
| MSY | New Orleans | Norco, LA | **leased** until 9/1/08 ($2,500/yr) | Perkins' 6/24/04 e-mail message | Falcon's 6/28 e-mail message said they don't anticipate any problems renewing the lease. |
| OKC | Oklahoma City World Rogers | Norman, OK | **leased** until 9/1/14 ($4,800/yr) | Perkins' 6/24/04 e-mail message | Falcon's 6/28 e-mail message said they don't anticipate any problems renewing the lease. |
| ORD | Chicago-O'Hare | McCook, IL | owned by FAA | Brady's 6/24/04 e-mail message | |
| PBI | West Palm Beach | Loxahatchee, FL | owned by FAA | Moore's 6/18/04 e-mail message | |
| PHL | Philadelphia | Pennsauken, NJ | **permitted** to FAA | Ascrizzi's 6/23/04 e-mail message | No problem anticipated in renewing the no-cost permit/license. |
| PHX | Phoenix Sky Harbor | Phoenix, AZ | owned by FAA | Spitt's 7/16/04 e-mail message | |
| PIT | Pittsburgh | Georgetown, PA | owned by FAA | Ascrizzi's 6/22/04 e-mail message | |
| RDU | Raleigh-Durham | Wake Forest, NC | **leased** until 9/1/14 | Moore's 6/18/04 e-mail message | No problem anticipated renewing the lease, per Moore's 7/9/04 e-mail message. |
| SDF | Louisville | Mt. Washington, KY | **leased** until 9/1/14 | Moore's 6/18/04 e-mail message | No problem anticipated renewing the lease, per Moore's 7/9/04 e-mail message. |
| SJU | San Juan Luis Munoz Marin Int'l | Levittown, PR | **leased** with Dept of the Air Force, PRANG, until 2/28/08 | Moore's 6/18/04 e-mail message | No problem anticipated renewing the lease, per Moore's 7/9/04 e-mail message. |
| SLC | Salt Lake City | Farmington, UT | owned by FAA | Hurley's 6/17/04 e-mail message | |
| STL | St. Louis Lambert Field | St. Charles, MO | owned by FAA | Synder's 6/30/04 e-mail message | |
| TPA | Tampa | MacDill AFB, FL | owned by Defense Dept; **leased** with MacDill AFB until 7/14/08 | Moore's 6/18/04 e-mail message | No problem anticipated renewing the lease, per Moore's 7/9/04 e-mail message. |
| TUL | Tulsa | Broken Arrow, OK | owned by government | Perkins' 6/24/04 e-mail message | |

**Summary**

22 owned by FAA
8 permitted or leased from government agency to FAA; no problem expected in renewing the leases/permits.
**1 permitted from Department of Interior; must vacate by January 29, 2023.**
14 leased by FAA from private owners; no problem expected in renewing the leases.

45 total operational TDWR sites