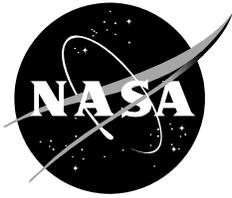


NASA Contractor Report NASA/CR-2008- 214751



Completion of the Edwards Air Force Base Statistical Guidance Wind Tool

Joseph G. Dreher
*Applied Meteorology Unit
Kennedy Space Center, Florida*

October 2008

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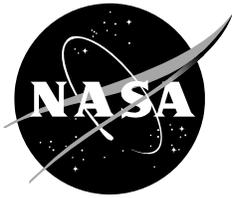
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Acknowledgements

All wind tower data used in this study were archived and quality controlled by Dr. Lee Burns at Marshall Space Flight Center. The author also thanks Mr. Richard Lafosse and Mr. Brian Hoeth of the Spaceflight Meteorology Group for providing testing and valuable feedback on the graphical user interface.

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Executive Summary

The peak winds near the surface are an important forecast element for Space Shuttle landings. As defined in the Shuttle Flight Rules (FR), there are peak wind thresholds that cannot be exceeded in order to ensure the safety of the shuttle during landing operations. The National Weather Service Spaceflight Meteorology Group (SMG) is responsible for weather forecasts for all shuttle landings. They indicate peak winds are a challenging parameter to forecast. To alleviate the difficulty in making such wind forecasts, the Applied Meteorology Unit (AMU) developed a PC-based graphical user interface (GUI) in 2003 for displaying peak wind climatology and probabilities of exceeding peak-wind thresholds for the Shuttle Landing Facility (SLF) at Kennedy Space Center (KSC) in Florida. However, the shuttle may land at Edwards Air Force Base (EAFB) in southern California when weather conditions at KSC are not acceptable, so SMG forecasters requested that a similar tool be developed for wind towers at EAFB. In 2004, Marshall Space Flight Center (MSFC) began work to replicate the KSC SLF tool using several wind towers within EAFB, but due to higher priority work did not start development of the GUI. The goal of this task was to complete development of the GUI using the EAFB wind tower data that were already quality-controlled (QC'ed) and analyzed by MSFC personnel. This objective was met successfully.

MSFC personnel QC'ed the 2-minute average and 10-minute peak wind speeds from Towers 44/220/224 (adjacent to shuttle runway) and Tower 350 for all months in the period 1997-2004. They calculated wind climatologies and probabilities of peak wind occurrence based on the average speed for each tower and month. The climatologies consisted of peak and average wind speed means and standard deviations including the number of observations used in each calculation stratified by hour, direction, and direction/hour.

For the probabilities of peak wind occurrence, MSFC calculated empirical and modeled probabilities of meeting or exceeding specific 10-minute peak wind speeds using probability density functions (PDFs). The empirical, or observed, probabilities were calculated first. The empirical PDFs were asymmetrical and bounded on the left by each 2-minute average wind speed. MSFC created parametric PDFs by fitting a Generalized Extreme Value (GEV) distribution to each empirical distribution. This was done to smooth and interpolate over variations in the empirical data due to possible under-sampling of certain peak winds and to estimate probabilities associated with average winds outside the observed range. The individual probabilities of meeting or exceeding specific 10-minute peak wind speeds were calculated by integrating the area under each PDF. Both the empirical and parametric probabilities assist SMG forecasters in assessing FR for various 2-minute average wind speeds.

During initial work on this task the AMU discovered several missing parametric wind values for given towers and months, especially at Tower 350. The parametric values were missing because they did not fit the GEV distribution well. SMG recommended that data from Tower 350 not be included in the GUI since they rarely use its data for evaluating FR due to its location well south of the main runway.

The GUI was developed to allow SMG forecasters to easily access the climatology and probability values calculated by MSFC. The AMU obtained and reformatted the MSFC data into Microsoft® Excel PivotTables, which allow users to display different values with point-click-drag techniques. Even though the PivotTables contain all the desired information, they can be difficult to interpret in a fast-paced operational environment. Therefore, the PC-based GUI was developed from the PivotTables by modifying the Visual Basic for Applications code developed for the KSC SLF GUI. The GUI is run through a macro in Microsoft® Excel and allows forecasters to quickly display and interpret peak wind climatologies and probabilities. The GUI was designed to look and operate exactly the same as the KSC SLF tool since SMG forecasters were already familiar with that product. SMG feedback was continually incorporated into the GUI ensuring the end product met their needs.

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1. Introduction

The peak winds near the surface are an important forecast element for space shuttle landings. As defined in the Flight Rules (FR), there are peak wind thresholds that cannot be exceeded in order to ensure the safety of the shuttle during landing operations. The National Weather Service Spaceflight Meteorology Group (SMG) is responsible for weather forecasts for all shuttle landings, and is required to issue surface average and 10-minute peak wind speed forecasts. They indicate peak winds are a challenging parameter to forecast. To alleviate the difficulty in making such wind forecasts, the Applied Meteorology Unit (AMU) developed a PC-based graphical user interface (GUI) for displaying peak wind climatology and probabilities of exceeding peak-wind thresholds for the Shuttle Landing Facility (SLF) at Kennedy Space Center (KSC; Lambert 2003). However, the shuttle occasionally may land at Edwards Air Force Base (EAFB) in southern California when weather conditions at KSC in Florida are not acceptable, so SMG forecasters requested a similar tool be developed for EAFB.

1.1 KSC SLF Peak Wind Tool

The development of the KSC SLF tool was done in two phases. In Phase I (Lambert 2002), climatologies and probabilities of occurrence of the 5-minute peak winds were created for all towers in the KSC/Cape Canaveral Air Force Station network used for evaluating both Launch Commit Criteria (LCC) and FR. The results from Phase I were valuable to the 45th Weather Squadron in evaluating LCC; however, SMG uses a 10-minute peak from the SLF wind towers for evaluating the wind speed FR. Therefore, the goal of Phase II (Lambert 2003) was to recalculate the climatologies and probabilities using a 10-minute peak wind for Towers 511, 512, and 513 at the SLF. The AMU also created a PC-based GUI for the forecasters to quickly display the desired information in an operational environment.

1.2 EAFB Peak Wind Tool

In 2004, Marshall Space Flight Center (MSFC) began work to replicate the KSC SLF tool using several wind towers on EAFB. They completed the analysis and quality control (QC) of the data, but did not start development of the GUI due to higher priority work. Therefore, the goal of this task for the AMU was to create a GUI using the EAFB wind tower data that were already QC'ed and analyzed by MSFC personnel. The EAFB GUI was developed by modifying the code developed in Lambert (2003). The peak wind data were obtained for all months covering the period of record (POR) August 1997 – December 2004. Data from Towers 44, 220, 224 (adjacent to the EAFB main runway), and 350 at an elevation of 30-ft were collected in the POR. The locations of the wind towers in relation to the main runway are shown in Figure 1.

Section 2 provides a description of the peak wind data obtained from MSFC. Section 3 gives an overview of the PC-based GUI including a description of the parameters and how it was developed. A summary of the project is given in Section 4.

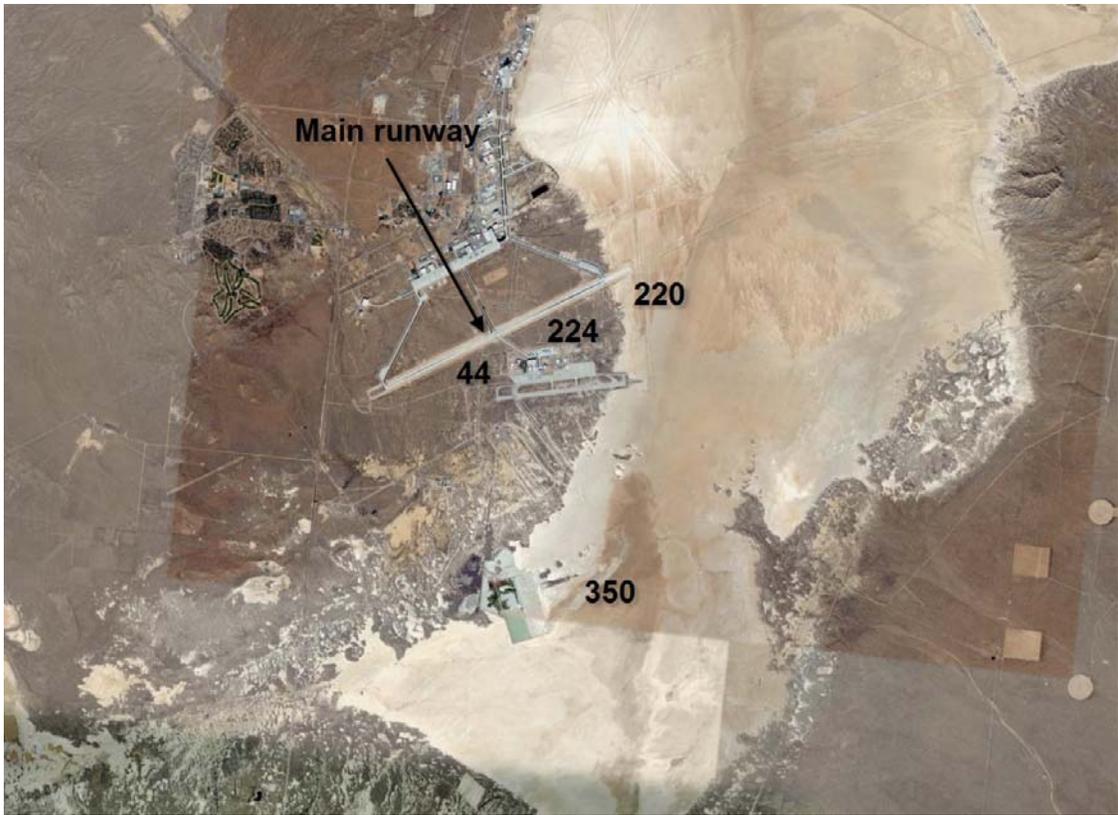


Figure 1. A map showing the locations of the wind towers at EAFB that were used in this task. Background image taken from Google Earth.

2. MSFC Data

The data obtained from MSFC included 2-minute average wind speed and direction for all months in the POR from Towers 44, 220, 224, and 350. All observations were recorded at a height of 30 ft above the surface. Five and 10-minute peak wind speed and direction were included in the archived data set. The peak wind is defined as the maximum 1-second wind speed recorded by the instrument during a given amount of time. Even though the data were already processed and QC'ed by MSFC, the raw text files needed to be reformatted for input to Microsoft[®] Excel (hereafter Excel) as a first step towards creating the GUI. Therefore, the AMU developed a FORTRAN program in order to speed up this reformatting process and to ensure there were no issues with the data. Since SMG only uses a 10-minute peak from the EAFB wind towers in evaluating the FR, the 5-minute data were not included in development of the GUI, but are available to the user within the formatted Excel worksheets.

2.1 10-Minute Peak Wind Climatology

For each of the towers and months, MSFC calculated average and peak wind climatologies and probabilities of peak wind occurrence based on the average speed. Both the climatology and probability data were stratified by tower number and month. The climatologies consisted of peak and average wind speed means and standard deviations stratified by hour, direction (10° sectors), and direction (45° sectors)/hour. The number of observations for each of the climatologies was also included in the MSFC calculations. The MSFC data stratifications are exactly the same as those created for the KSC SLF peak wind task. Further details and examples of the stratifications can be found in Lambert (2003).

2.2 10-Minute Peak Wind Empirical Distributions

MSFC calculated empirical probabilities of meeting or exceeding a specific 10-minute peak wind speed based on a chosen 2-minute average wind speed. These probabilities assist SMG forecasters in evaluating the probability of peak wind thresholds violating the FR. The empirical distributions were created from the observed values in the form of probability density functions (PDFs). The empirical PDFs were calculated to display the observed distribution of 10-minute peak winds for each tower, month, and value of 2-minute average wind speed. The PDF is calculated by dividing the number of individual peak speed observations associated with an average speed by the total number of observations of the average speed. This produces a value that represents the fractional occurrence of each peak speed in the distribution. The sum of all the fractional numbers in the distribution is 1, and a graph of these fractional values is called the PDF.

The empirical PDF for the 2-minute average of 12 kts in March at Tower 224 is shown in Figure 2. The y-axis displays the fractional occurrence of the observed peak wind speed and the x-axis displays the various peak wind speeds observed during the POR. Note that the distribution is bounded on the left-hand-side at a 10-minute peak wind speed of 14 kts while a maximum fractional occurrence of 0.2 occurs at 17 kts and then decreases towards the right with increasing wind speeds. The maximum observed peak speed associated with a 2-minute of average of 12 kts was 33 kts. The empirical PDFs for all observed 2-minute wind speeds at Tower 224 in March are shown in Figure 3. For each of these observed distributions, MSFC calculated the probability of meeting or exceeding certain peak speeds by integrating the area under each curve from that chosen threshold to the maximum observed peak wind speed in each distribution.

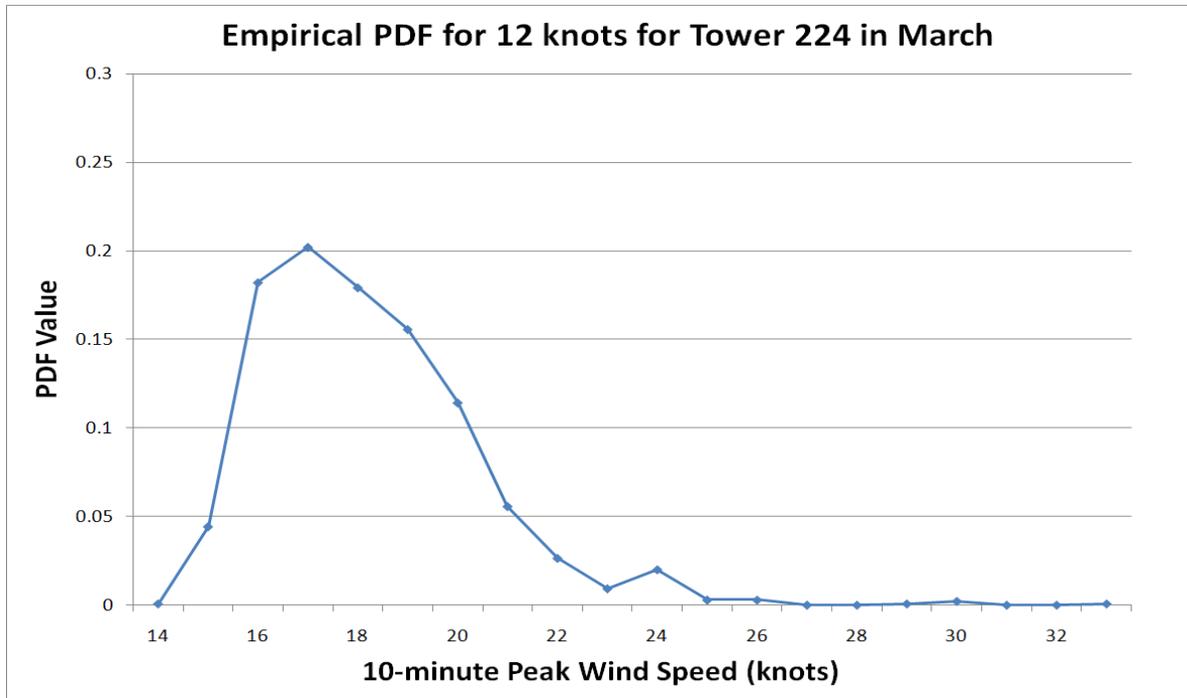


Figure 2. The empirical PDF of the March 10-minute peak wind speed distribution for the 2-minute average speed of 12 kts for Tower 224. The values on the y-axis indicate a fractional value for each 10-minute peak wind speed in knots as shown on the x-axis.

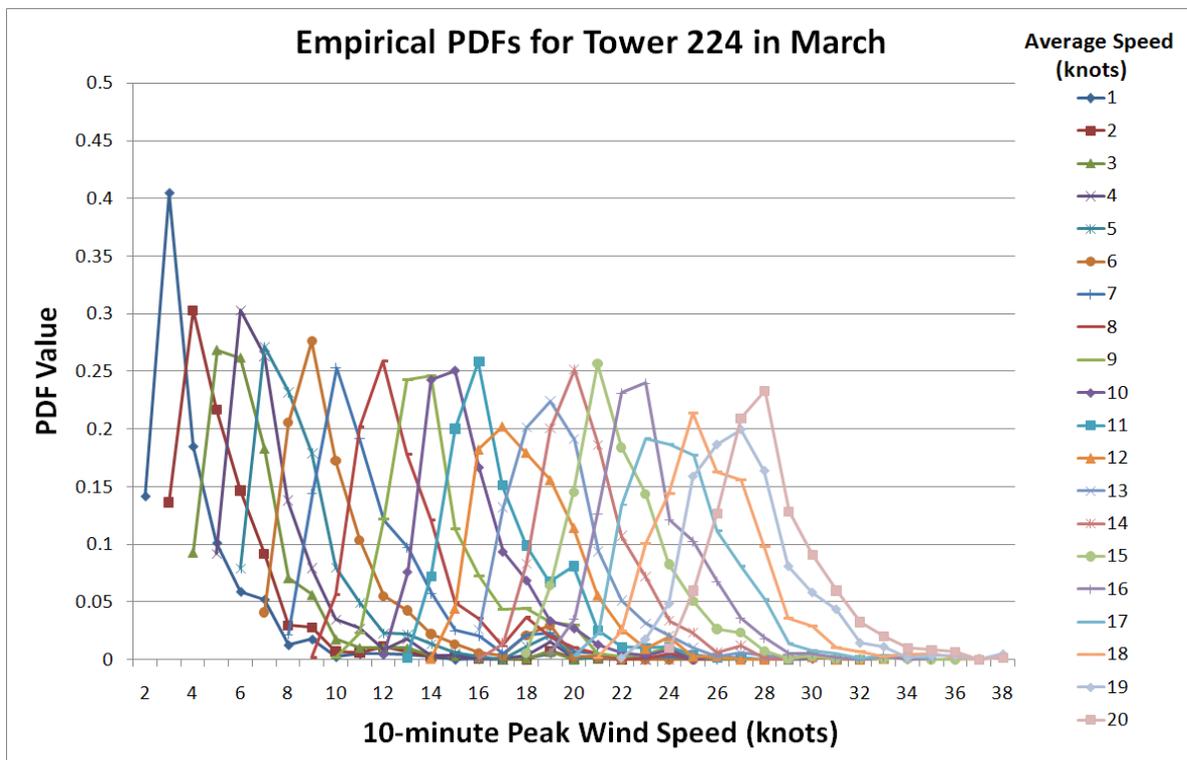


Figure 3. All empirical PDFs of the March 10-minute peak wind speed distributions at Tower 224 associated with each 2-minute average wind speed, as shown by the legend on the right. The values on the y-axis indicate a fractional value of the PDF for each 10-minute peak wind speed in knots shown on the x-axis.

2.3 10-Minute Peak Wind Parametric Distributions

Based on previous work done in Lambert (2003), MSFC fit a modeled or parametric distribution to the observed peak wind speed data. This was done in order to smooth and interpolate over variations in the observed values due to possible under-sampling of certain peak winds and to estimate probabilities associated with average winds outside the observed range (Wilks 2006). The PDFs calculated by MSFC were asymmetrical (i.e. not Gaussian) and bounded on the left by the average wind speed. Wilks defines these PDFs as extreme value distributions since they are bounded on the left by the average wind speed and the tail of the distribution contains the various peak wind speeds. MSFC determined that a generalized extreme value (GEV) distribution fit the empirical distributions best. It provided a much better fit for the EAFB wind tower data than the Weibull, Gamma, or Gumbell distributions, which are the most often mentioned distributions in the literature for modeling peak wind speeds. Note that Lambert (2003) found that the theoretical gamma distribution gave the best fit for the empirical PDFs used in the KSC SLF study. The PDF for the GEV distribution is given by:

$$F(x) = \frac{1}{\sigma} \left[1 + \xi \left(\frac{X - \mu}{\sigma} \right) \right]^{-\frac{1}{\xi}} \text{EXP} \left\{ - \left[1 + \xi \left(\frac{X - \mu}{\sigma} \right)^{-\frac{1}{\xi}} \right] \right\}$$

where X is the variable of interest (in this case peak wind speed), μ is the location parameter that determines where the origin will be located, ξ is the shape parameter that governs the tail behavior of the distribution, and σ is the scale parameter that determines the width or spread of the distribution. The estimated GEV PDFs for Tower 224 in March are shown in Figure 4. These parametric PDFs more likely represent the PDFs of the entire wind speed population since the empirical PDFs are bounded by the number of observations contained in the POR. Note that the estimated PDFs look very similar to the empirical PDFs shown in Figure 3, but appear smoother since they interpolate over variations in the observed data.

While reformatting the data into the desired format, the AMU discovered several missing parametric wind distributions for given towers and months, especially for Towers 224 and 350 (Table 1). After discussions with Dr. Lee Burns at MSFC it was determined the values were missing because they did not fit the GEV distribution well and were subsequently discarded. It is possible that for those missing parametric wind speeds no such combination of parameters gave a theoretical fit to the empirical values or there were not enough observed values in the given POR. The AMU notified SMG about the missing values and they decided that it was beyond the scope of the current task to determine why those parametric values were missing. Additionally, SMG recommended not including data from Tower 350 in the GUI since many of the missing parametric peak wind speeds were at that tower. Due to Tower 350's location well south of the main runway, SMG forecasters rarely use the data for evaluating the FR. For missing parametric values at the other three towers, missing data flags were inserted into the Excel worksheets to indicate data that did not fit the distribution used.

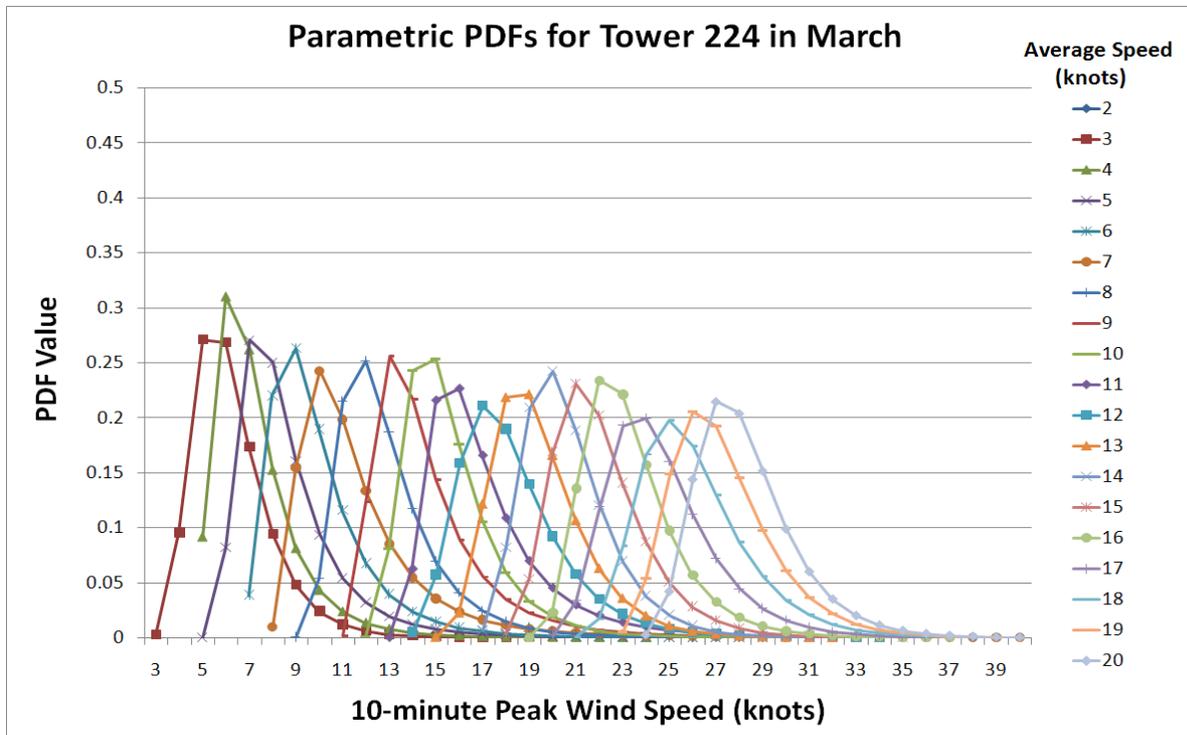


Figure 4. The estimated parametric PDFs of the March 10-minute peak wind speed distributions associated with each 2-minute average wind speed as shown by the legend on the right for Tower 224. The values on the y-axis indicate a fractional value of the PDF for each 10-minute peak wind speed in knots shown on the x-axis.

Table 1. Missing parametric 10-minute peak wind speed distributions denoted by the average 2-minute speed for each tower and month.

<i>Month</i>	<i>Towers</i>			
	<i>44</i>	<i>220</i>	<i>224</i>	<i>350</i>
January	18	9	18, 19, 20	18, 19, 20
February	-	16	18	9, 10, 19
March	2	-	2	2, 15, 17, 19
April	2	2	2, 18	2, 4, 8
May	2	2	2	2
June	2	2	2	2
July	2	2	2, 19	2, 15
August	2	2	2, 18	2, 15
September	-	-	2, 16	14, 15, 16, 17, 18, 19, 20
October	-	-	17	17
November	-	18	-	8
December	17, 18	15, 17, 19	8, 10, 11, 16, 18	13, 17, 18, 19

3. Graphical User Interface

The climatology and probability data described in Section 2 were imported into Excel PivotTables, as was done in Lambert (2002, 2003). The PivotTables allow the user to display the desired peak wind information in any stratification with point-click-drag techniques; however they can be cumbersome to manipulate and interpret in an operational environment. Therefore, similar to the KSC SLF tool, a PC-based GUI was developed for quick and efficient display of desired information.

The EAFB GUI was created by modifying the existing Microsoft® Visual Basic for Applications (VBA) code developed in Lambert (2003) and is run through a macro contained in Excel. The VBA code is an object-based, or event driven, code built directly into the Microsoft® Office suite. This allows the flexibility of coding applications specific to Excel so data can be pulled directly from the PivotTables. The GUI was designed to look and operate exactly the same as the KSC SLF tool since SMG forecasters were already familiar with that product. The final product pulls in the desired information from the PivotTables.

3.1 Input GUI

The input GUI is opened through the macro named Get_EAFBwinds within Excel. The macro can be opened, run, and edited from an Excel window (Figure 5) or it can be run from a Microsoft® Windows shortcut key (Ctrl + w). The shortcut key allows the user to access the application easily in a fast-paced operational environment. Once the macro is executed, an input window is displayed on the screen where the user can click the Climatology (Figure 6a) or Probability tab (Figure 6b). On both tabs, the user can select the tower and month for the requested climatology or probability from Towers 44, 220, and 224 for all 12 months via drop-down lists.

On the Climatology tab, the user selects to output an hourly, directional, or directional/hourly stratification for the chosen tower and month. After the choices are made, the user clicks the “Get Climatology...” button and a separate output form will display the requested information. The Probability tab is similar except the user can choose to output empirical or parametric probabilities of exceeding certain 10-minute peak wind thresholds for a given tower, month, and 2-minute average wind speed. The empirical drop-down list contains all 2-minute average wind speeds observed for that selected month and tower, whereas the modeled drop-down list includes the 2-minute wind speeds fit to the GEV distribution model described in Section 2. Once the user has made the selections, clicking the “Get Probabilities...” button will display a separate form with the requested peak wind speeds and their probabilities of occurrence. The VBA code populates the output forms through the information contained in the PivotTables.

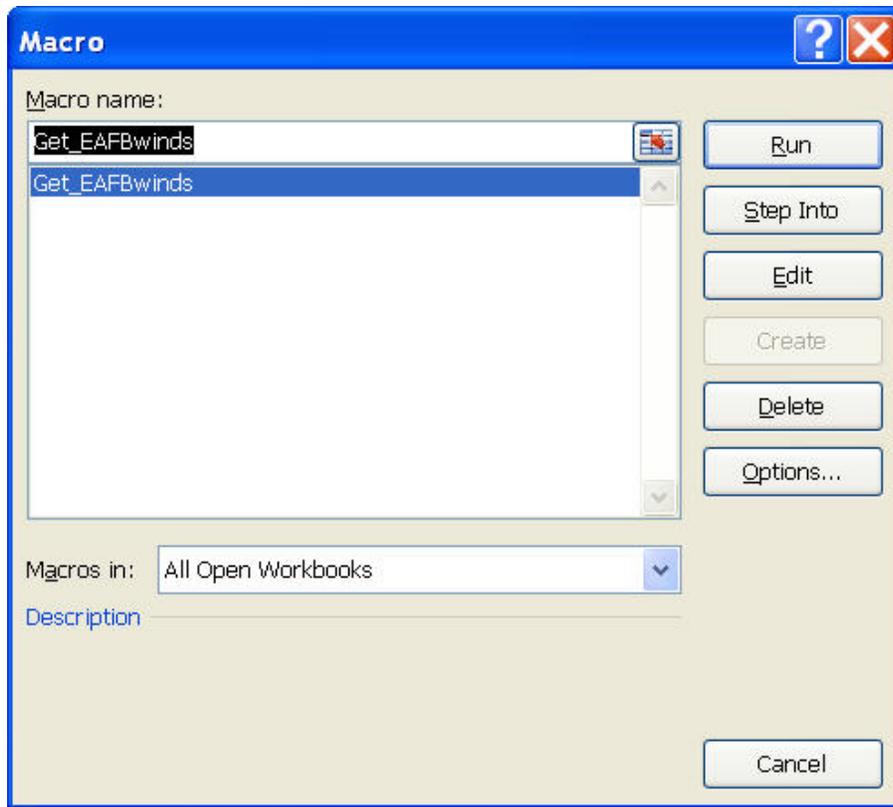


Figure 5. Microsoft® Excel window that enables the user to run or edit the EAFB peak wind GUI macro.

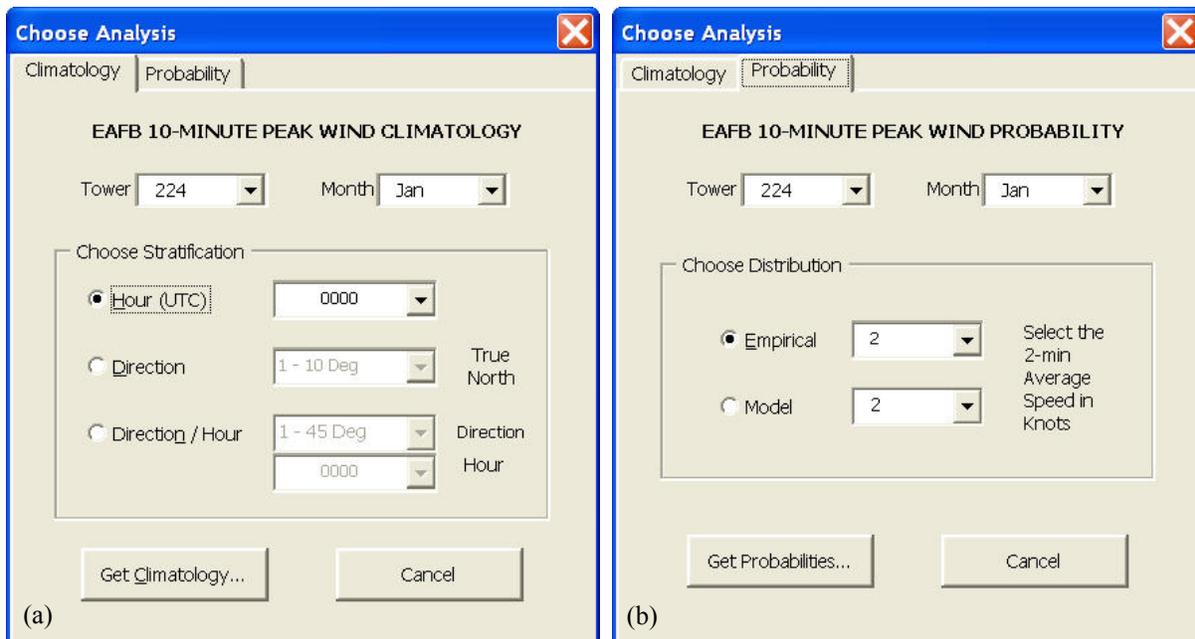
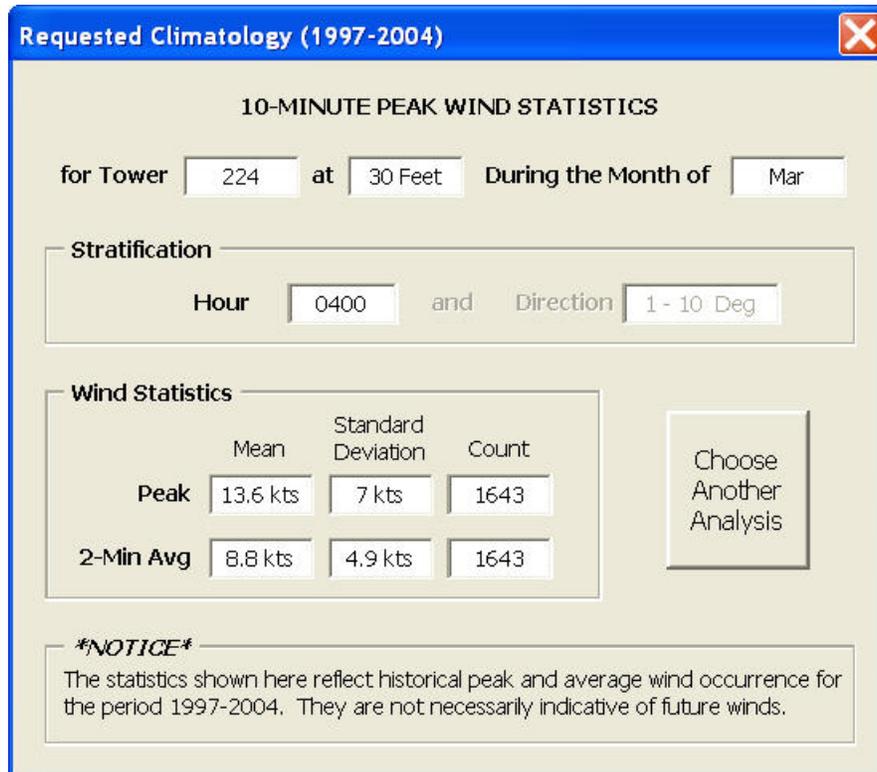


Figure 6. EAFB peak wind GUI input forms: (a) used to retrieve climatology data for a given month, tower and stratification, and (b) used to retrieve probability data for a given month, tower, and 2-minute average speed. The “Climatology” and “Probability” tabs located at the top of the GUI allow the user to choose the desired panel.

3.2 Requested Climatology GUI

After the user clicks the “Get Climatology” button (Figure 6a) an output form is displayed with the requested wind climatologies (Figure 7). For each of the requested climatology stratifications, the output window is identical except for minor differences in the “Stratification” and “Wind Statistics” sections. Figure 7 illustrates the hourly peak wind climatology for 0400 UTC in the POR 1997-2004 at Tower 224 for March. A summary of the selected tower number and height, month, and stratification method is displayed at the top of the window. Note that in the stratification section the “Direction” text is grayed out to indicate the user has selected the hourly climatology. The statistics section of the window displays the mean, standard deviation, and number of observations for the peak and average wind speeds for the desired tower and month. The “Choose Another Analysis” button allows the user to return to the main input GUI. The text notification box on the bottom is intended to remind the user the displayed values are based on data taken from the POR 1997-2004 and are not necessarily indicative of future peak winds.



	Mean	Standard Deviation	Count
Peak	13.6 kts	7 kts	1643
2-Min Avg	8.8 kts	4.9 kts	1643

Figure 7. Requested climatology output GUI. The requested tower number, height, and month are displayed at the top, and selected stratification parameters are displayed in the “Stratification” section. The observed average and peak wind climatology including mean, standard deviation, and count are displayed in the “Wind Statistics” section.

The output window in Figure 8 is the result of choosing the directional climatology. In this example it shows the peak wind climatology for all observed winds between 241-250° in the POR 1997-2004 at Tower 224 for March. In the stratification section the “Direction” text is highlighted to indicate the user has selected a directional climatology, while the “Hour” text is grayed-out. The “Wind Statistics” section includes the same statistics as the hourly climatology.

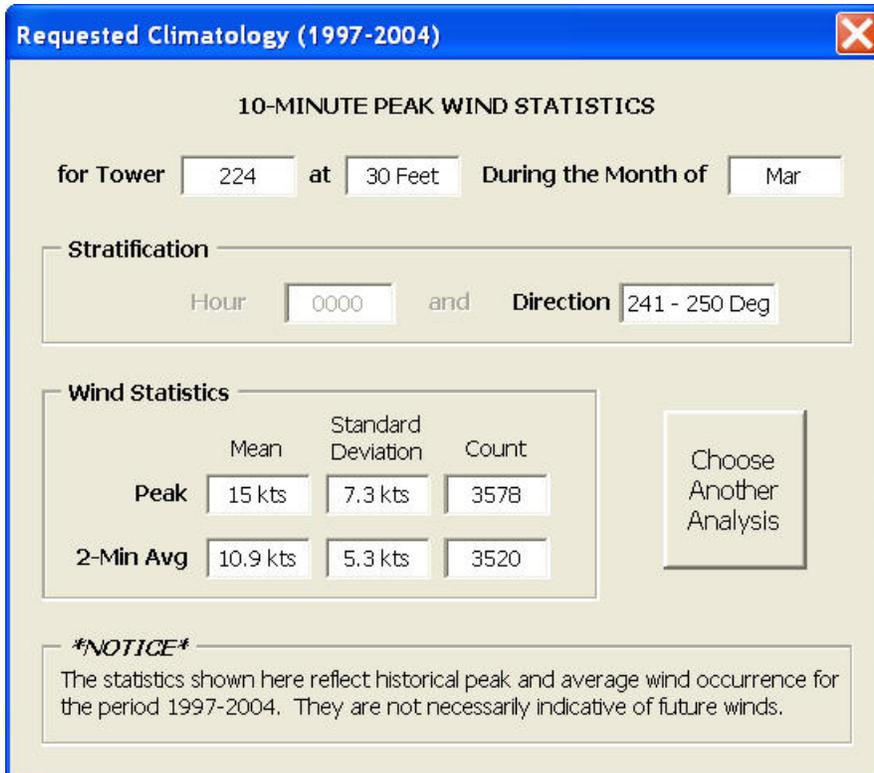


Figure 8. Requested climatology output GUI. The requested tower number, height, and month are displayed at the top, and selected stratification parameters are displayed in the “Stratification” section. The observed average and peak wind climatology including mean, standard deviation, and count are displayed in the “Wind Statistics” section.

An example of choosing the directional/hourly climatology is shown in Figure 9. It shows the 2-minute average and 10-minute peak wind climatology for 0400 UTC and from a direction between 226-270° for Tower 224 during March. Note the wind directions are stratified by 45° bins as opposed to the 10° bins for the direction only climatology. This stratification was developed and outlined in Lambert (2002) as requested by SMG forecasters and remains unchanged. The top of the window displays the same information as the previous climatology output windows. In the “Stratification” section both the “Hour” and “Direction” text is highlighted to indicate the user has selected the directional/hourly climatology. The “Wind Statistics” section includes the means and standard deviations of the 10-minute peak and 2-minute average wind; however the observation counts boxes (compare Figure 8 to Figure 9) are replaced by the percent of total observations in the hour boxes. These boxes display the percentage of chosen winds from that direction observed during the hour. In the example displayed in Figure 9, at 0400 UTC during March, 42% (41.3%) of the total mean 2-minute average (10-minute peak) observations were out of the west-southwest. This stratification helps forecasters determine the predominant wind regime for the various towers and months. There are eight directional sectors in this stratification. If the observations were evenly distributed, 12.5% of the observations would be in each sector. That just slightly less than 50% of the observations are from the west-southwest sector indicates this is a common wind direction for March at 0400 UTC.

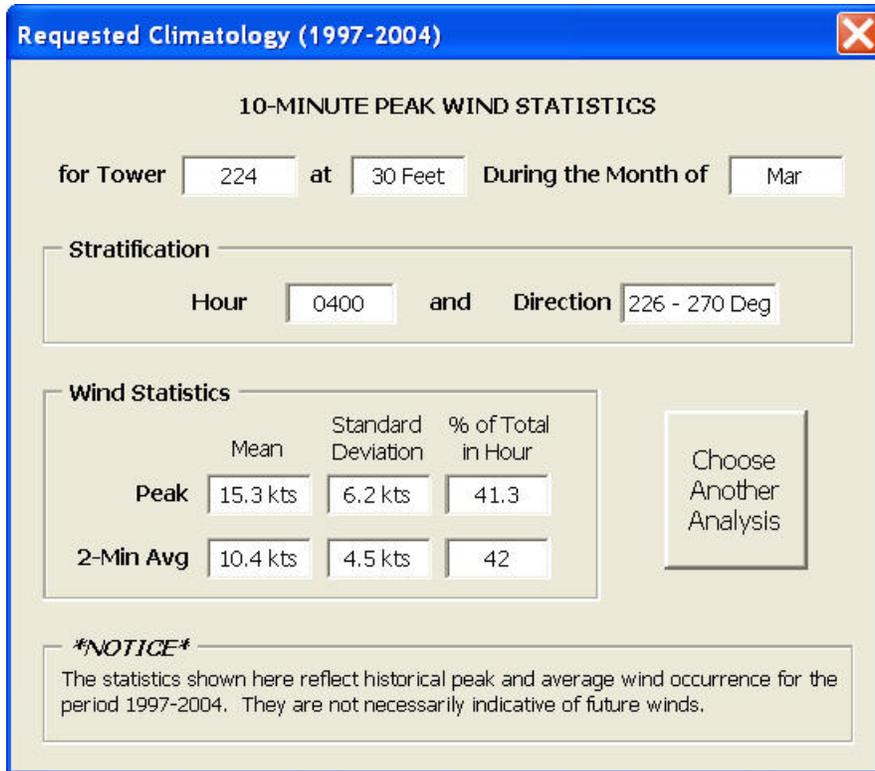


Figure 9. Requested climatology output GUI. The requested tower number, height, and month are displayed at the top, and selected stratification parameters are displayed in the “Stratification” section. The observed average and peak wind climatology including mean, standard deviation, and the percent of total observations in the hour are displayed in the “Wind Statistics” section.

3.3 Requested Probability GUI

The output window in Figure 10 is displayed when the user clicks the “Get Probabilities” button (Figure 6b). SMG forecasters reported the probability of exceeding certain peak wind thresholds is the most important information contained in the GUI since it is used directly for assessing the FR. The example displayed in Figure 10 shows the empirical probabilities of meeting or exceeding a range of peak wind speeds when the 2-minute average wind speed is 10 kts for Tower 224 during March. A similar window would have been displayed if the user requested the modeled distribution. The distribution type (empirical or modeled) is displayed at the top of the window. The tower number, height, month, and selected 2-minute average wind speed are shown just below the distribution type.

The “Peaks and Probabilities” section contains three rows. The first row contains the first 12 peak wind speeds associated with the chosen empirical or modeled average 2-minute wind speed shown at the top of Figure 10. The second row contains the empirical or modeled probabilities in percent of meeting or exceeding each peak wind speed; and the last row contains the probability of occurrence in percent for that peak wind speed. The probability values in the second row were calculated by summing over each PDF value (shown in the third line) to the right tail of the distribution. The values shown in the probability section are rounded to the nearest integer. The number of “Peaks and Probabilities” boxes displayed in the GUI is the result of a FR that defines a violation when the peak speed is 11 kts or greater than the average speed. Displaying the first 12 values in the range ensures that the probabilities for the peak speeds in question will be displayed. The letters “N/A” are displayed in the probability boxes where empirical data were not observed during the POR or in the case of modeled data did not fit the GEV distribution. The “Retrieve Another Probability Range” button allows the user to go back to the main input GUI in order to choose another analysis or close the GUI.



Figure 10. Requested empirical probabilities output GUI. The requested distribution, tower number and height, month, and 2-minute average wind speed are displayed at the top. The probabilities for 12 peak wind speeds are displayed in the “Peaks and Probabilities” section.

4. Summary

The goal of this task was to develop a GUI using EAFB wind tower data similar to the KSC SLF peak wind tool that is already in operations at SMG. In 2004, MSFC personnel began work to replicate the KSC SLF tool using several wind towers at EAFB. They completed the analysis and QC of the data, but due to higher priority work did not start development of the GUI. MSFC personnel calculated wind climatologies and probabilities of 10-minute peak wind occurrence based on the 2-minute average wind speed for several EAFB wind towers. Once the data were QC'ed and analyzed the climatologies were calculated following the methodology outlined in Lambert (2003). The climatologies were calculated for each tower and month, and then were stratified by hour, direction (10° sectors), and direction (45° sectors)/hour. For all climatologies, MSFC calculated the mean, standard deviation and observation counts of the 2-minute average and 10-minute peak wind speeds.

MSFC personnel also calculated empirical and modeled probabilities of meeting or exceeding specific 10-minute peak wind speeds using PDFs. The empirical PDFs were asymmetrical and bounded on the left by the 2-minute average wind speed. They calculated the parametric PDFs by fitting the GEV distribution to the empirical distributions. Parametric PDFs were calculated in order to smooth and interpolate over variations in the observed values due to possible under-sampling of certain peak winds and to estimate probabilities associated with average winds outside the observed range. MSFC calculated the individual probabilities of meeting or exceeding specific 10-minute peak wind speeds by integrating the area under each curve. The probabilities assist SMG forecasters in assessing the shuttle FR for various 2-minute average wind speeds.

The AMU obtained the processed EAFB data from Dr. Lee Burns of MSFC and reformatted them for input to Excel PivotTables, which allow users to display different values with point-click-drag techniques. The GUI was created from the PivotTables using VBA code. It is run through a macro within Excel and allows forecasters to quickly display and interpret peak wind climatology and probabilities in a fast-paced operational environment. The GUI was designed to look and operate exactly the same as the KSC SLF tool since SMG forecasters were already familiar with that product. SMG feedback was continually incorporated into the GUI ensuring the end product met their needs. The final version of the GUI along with all climatologies, PDFs, and probabilities has been delivered to SMG and will be put into operational use.

References

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List of Acronyms

AMU	Applied Meteorology Unit
EAFB	Edwards Air Force Base
FR	Flight Rules
GUI	Graphical User Interface
KSC	Kennedy Space Center
LCC	Launch Commit Criteria
MSFC	Marshall Space Flight Center
QC	Quality Control
PC	Personal Computer
PDF	Probability Density Function
POR	Period of Record
SLF	Shuttle Landing Facility
SMG	Spaceflight Meteorology Group
UTC	Universal Coordinated Time
VBA	Visual Basic for Applications

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