

## P2.3 SURFACE LANDING SITE WEATHER ANALYSIS FOR NASA'S CONSTELLATION PROGRAM

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### 1. Introduction

Weather information is an important asset for NASA's Constellation Program in developing the next generation space transportation system to fly to the International Space Station, the Moon and, eventually, to Mars. Weather conditions can affect vehicle safety and performance during multiple mission phases ranging from pre-launch ground processing of the Ares vehicles to landing and recovery operations, including all potential abort scenarios. Meteorological analysis is an important contributor, not only to the development and verification of system design requirements but also to mission planning and active ground operations. Of particular interest are the surface weather conditions at both nominal and abort landing sites for the manned Orion capsule. Weather parameters such as wind, rain, and fog all play critical roles in the safe landing of the vehicle and subsequent crew and vehicle recovery. The Marshall Space Flight Center (MSFC) Natural Environments Branch/EV44 has been tasked by the Constellation Program with defining the natural environments at potential landing zones. This paper will describe the methodology used for data collection and quality control, detail the types of analyses performed, and provide a sample of the results that can be obtained.

### 2. Data Source

Climatological time series of operational surface weather observations are used to calculate probabilities of occurrence of various sets of hypothetical vehicle constraint thresholds. Hourly surface observations are available through the National Climatic Data Center (NCDC) archived database website ([www.ncdc.noaa.gov/oa/ncdc.html](http://www.ncdc.noaa.gov/oa/ncdc.html)). NCDC is part of the Department of Commerce, National Oceanic and Atmospheric Administration (NOAA), and the National Environmental Satellite, Data and Information Service (NESDIS). NCDC archives weather data obtained by the National Weather Service (NWS), Military Services, the Federal Aviation Administration (FAA), and voluntary cooperative observers. The data is edited and quality-controlled, taken primarily by 10 meter (m) standard-height wind towers at various locations around the

country and worldwide. There are more than twenty different types of hourly measurements, with time recorded in coordinated universal time (UTC) mode. The overall period of record (POR) for the database dates back to 1901 and remains current. However, the POR and types of measurements taken hourly for each site varies based on when the instrumentation was established, for what purpose the site uses the data, and if the instrumentation is still in use today.

### 3. Methodology

#### 3.1 Application of Available Data Sets

As the Constellation Program and Orion Project focus on potential land landing zones, data is collected and the analyses are completed for each site or network of sites. As an example, three sites in the western United States will be analyzed as these sites have lakebeds that have the potential to be landing options. These sites include:

- Carson Sink, Nevada
- Edwards Air Force Base, California
- Utah Test and Training Range, Utah

However, sometimes weather instrumentation is not readily available close enough to a chosen zone to provide a representative set of weather data. In such cases, a weather tower closest to the zone is chosen based on proximity to the site(s) of interest, the quality of the data, and the validity of the POR. Table 3.1 shows which data sets were used to run the analyses for the three example landing sites.

LANDING SITE	DATA SITE	DISTANCE BETWEEN SITES (in kilometers)
Carson Sink	Fallon Naval Air Station	44
Edwards Air Force Base	EAFB-Rogers Lakebed	n/a
Utah Test & Training Range	Wendover Auxiliary Field	67

**Table 3.1** Location of sample landing and data sites and approximate distance between the two.

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Analysis results provide statistical descriptions of how often certain weather conditions are observed at the site(s) and the percentage of time the specified criteria thresholds are matched or exceeded. Outputs can be tabulated by month and hour of day to show both seasonal and diurnal variation. Of particular interest is horizontal wind speeds at the surface. Horizontal wind speed is a concern as it can affect how the vehicle reacts within the last 18-30 meters before impact with a landing surface. For this reason, wind values are sometimes analyzed at different heights based on the need to look at a particular area of interest. Since standard wind tower data “surface” measurements are taken at an altitude of 10m, a wind profile power law must be used to extrapolate surface values to varying heights. For example, to find the equivalent wind value at the 61m level, the following neutral-stability formula can be used,

$$u(z) = u_{10} \left( \frac{z}{10} \right)^{\frac{1}{7}} \quad (1)$$

where  $u(z)$  is the wind speed at height  $z$  meters above natural grade (0 to 300m AGL), and  $u_{10}$  is the wind speed at 10m.

Wind analyses can be performed for each site individually and in combination as multi-site network configurations for the three example sites. For the individual site analyses, the following abbreviations will be used and refer to the following data sets:

- CAR: Carson Sink, NV
  - Data set used: Fallon Naval Air Station, NV
  - POR: 01/1951- 05/2006
- EAFB: Edwards Air Force Base Cuddeback Lake, CA
  - Data set used: Edwards Air Force Base Rogers Lakebed, CA
  - POR: 12/1941 – 03/2007
- UTTR: Utah Test & Training Range, UT
  - Data set used: Wendover Auxiliary Field
  - POR: 08/1942- 09/2006

## 4. Example Analysis and Results

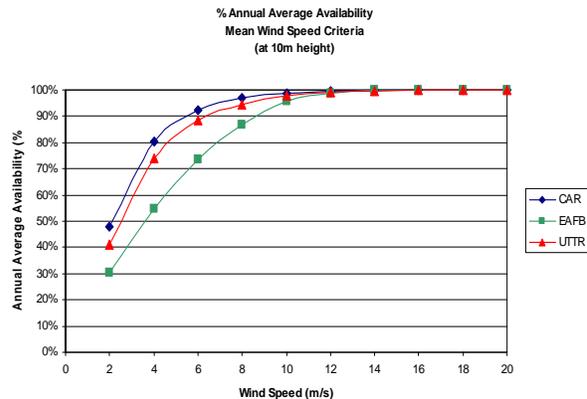
### 4.1 Single Site Results

Hourly, monthly, and annual average availabilities were calculated for the three example sites for mean and peak wind speed criteria. Values are in units of meters per second (m/s) unless otherwise noted. Availability percentage values mean that, for a given wind speed threshold, the wind speed did not equal or exceed that value that percentage of the time.

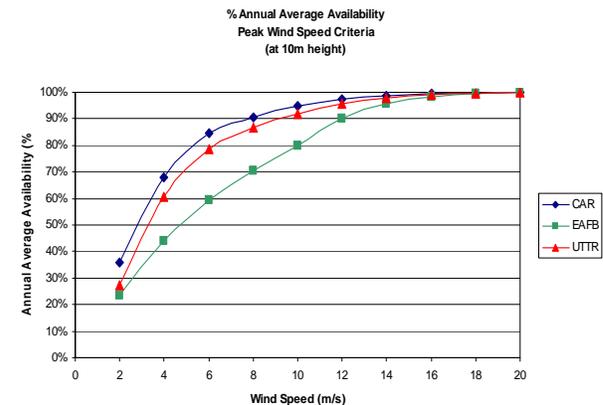
#### 4.1.1 Annual averages

Figures 4.1 and 4.2 are sample outputs showing the annual average availability percentage for the three

example landing sites. Analysis was performed to look at wind speed threshold criteria in increments of 2 m/s for both mean (Figure 4.1) and peak (Figure 4.2) wind speeds. Overall availability increases as the wind speed threshold is increased. Peak wind speeds greatly influence availability. As an example, for an 8 m/s threshold, the worst-case site of EAFB has a mean wind speed availability of nearly 90% but only 70% peak wind speed availability for the same threshold value.



**Figure 4.1** Annual average availabilities for mean wind speed thresholds of 0 to 20 m/s at 10m (surface).



**Figure 4.2** Annual average availabilities for peak wind speed thresholds of 0 to 20 m/s at 10m (surface).

#### 4.1.2 Monthly averages

Outputs can be tabulated to show monthly average availabilities for individual sites or multi-site configurations. Looking at monthly averages in comparison to the annual average provides information on seasonal effects throughout the POR. In Tables 4.1 through 4.3 below, the monthly wind availabilities for CAR, EAFB, and UTTR – respectively – are represented. Mean wind availabilities are represented by the green tables (left) and peak wind availabilities are represented by the orange (right) tables for each site. For all sites, availability values tend to be lower during

the spring and early summer months than any other time of year as weather events during the warmer months trigger higher wind events.

%MONTHLY AVERAGE AVAILABILITY								%MONTHLY AVERAGE AVAILABILITY							
MEAN WIND SPEED (m/s)								PEAK WIND SPEED (m/s)							
	2	4	6	8	10	12	14		2	4	6	8	10	12	14
JAN	59%	88%	94%	97%	99%	100%	100%	JAN	47%	76%	88%	93%	95%	98%	100%
FEB	57%	87%	92%	95%	98%	99%	100%	FEB	40%	70%	83%	90%	94%	97%	98%
MAR	42%	74%	83%	87%	91%	93%	100%	MAR	31%	62%	73%	80%	82%	85%	93%
APR	47%	72%	81%	85%	88%	91%	100%	APR	23%	53%	64%	71%	76%	82%	91%
MAY	38%	74%	83%	87%	91%	93%	100%	MAY	24%	53%	64%	71%	76%	82%	91%
JUN	40%	77%	91%	95%	98%	100%	100%	JUN	28%	62%	73%	80%	84%	88%	100%
JUL	43%	83%	90%	93%	96%	100%	100%	JUL	30%	65%	76%	83%	87%	91%	100%
AUG	47%	88%	95%	98%	100%	100%	100%	AUG	33%	73%	84%	91%	95%	98%	100%
SEP	54%	87%	93%	96%	100%	100%	100%	SEP	40%	75%	86%	93%	96%	99%	100%
OCT	63%	88%	93%	96%	100%	100%	100%	OCT	47%	79%	91%	95%	97%	99%	100%
NOV	67%	87%	93%	96%	100%	100%	100%	NOV	48%	78%	90%	95%	97%	99%	100%
DEC	67%	88%	94%	97%	99%	100%	100%	DEC	49%	77%	88%	92%	95%	98%	100%

Table 4.1 Monthly average availability for CAR.

%MONTHLY AVERAGE AVAILABILITY								%MONTHLY AVERAGE AVAILABILITY							
MEAN WIND SPEED (m/s)								PEAK WIND SPEED (m/s)							
	2	4	6	8	10	12	14		2	4	6	8	10	12	14
JAN	48%	74%	85%	89%	93%	96%	100%	JAN	47%	64%	77%	84%	90%	95%	98%
FEB	32%	60%	69%	73%	77%	79%	100%	FEB	32%	55%	70%	75%	80%	85%	93%
MAR	28%	53%	72%	80%	85%	89%	100%	MAR	23%	41%	58%	63%	70%	80%	93%
APR	19%	42%	64%	82%	93%	98%	100%	APR	19%	31%	48%	61%	70%	80%	93%
MAY	16%	35%	63%	80%	93%	98%	100%	MAY	12%	25%	42%	58%	70%	80%	93%
JUN	13%	36%	69%	82%	94%	98%	100%	JUN	10%	22%	41%	56%	71%	80%	93%
JUL	15%	41%	70%	88%	95%	100%	100%	JUL	11%	28%	48%	65%	79%	88%	100%
AUG	23%	49%	75%	91%	98%	100%	100%	AUG	15%	34%	57%	77%	84%	94%	100%
SEP	32%	61%	82%	93%	98%	100%	100%	SEP	20%	49%	69%	79%	88%	95%	100%
OCT	38%	69%	84%	94%	99%	100%	100%	OCT	30%	57%	74%	82%	90%	95%	100%
NOV	43%	73%	85%	93%	99%	100%	100%	NOV	34%	62%	77%	83%	89%	95%	100%
DEC	48%	75%	88%	95%	99%	100%	100%	DEC	40%	68%	79%	88%	93%	98%	100%

Table 4.2 Monthly average availability for EAFB.

%MONTHLY AVERAGE AVAILABILITY								%MONTHLY AVERAGE AVAILABILITY							
MEAN WIND SPEED (m/s)								PEAK WIND SPEED (m/s)							
	2	4	6	8	10	12	14		2	4	6	8	10	12	14
JAN	67%	88%	92%	95%	97%	99%	100%	JAN	48%	77%	88%	92%	95%	97%	98%
FEB	52%	87%	93%	96%	98%	99%	100%	FEB	37%	71%	84%	89%	92%	95%	98%
MAR	38%	70%	82%	87%	91%	93%	100%	MAR	28%	63%	73%	80%	85%	90%	93%
APR	28%	67%	83%	90%	95%	98%	100%	APR	18%	48%	67%	77%	85%	92%	98%
MAY	25%	62%	83%	92%	97%	99%	100%	MAY	16%	44%	63%	74%	82%	90%	96%
JUN	24%	62%	84%	93%	97%	99%	100%	JUN	15%	44%	70%	81%	88%	94%	98%
JUL	27%	66%	88%	95%	98%	100%	100%	JUL	16%	47%	74%	85%	92%	98%	99%
AUG	31%	71%	88%	95%	98%	100%	100%	AUG	21%	52%	77%	87%	93%	97%	99%
SEP	38%	77%	97%	99%	100%	100%	100%	SEP	27%	61%	82%	90%	94%	97%	99%
OCT	49%	83%	92%	97%	99%	100%	100%	OCT	37%	71%	88%	91%	95%	97%	98%
NOV	54%	82%	91%	96%	98%	99%	100%	NOV	39%	73%	89%	93%	94%	97%	99%
DEC	59%	84%	92%	98%	99%	99%	100%	DEC	44%	76%	87%	91%	94%	97%	99%

Table 4.3 Monthly average availability for UTTR.

#### 4.2 Multi-site Network Analyses

Sites can also be grouped together, correlated, and analyzed for a common availability. To perform multi-site network availability calculations, all possible network site configurations are analyzed. Landing availability is computed with respect to surface weather for month and hour of day for each network configuration and wind speed threshold. In order to correlate sites, it has to be determined which times have coincident measurements at all network sites. For each month and hour of day, the network availability is calculated using,

$$P = \left( 1 - \frac{N_{Fail}(h,m)}{N_{Total}(h,m)} \right) \times 100\% \quad (2)$$

where  $N_{Total}(h,m)$  is the total number of coincident measurement periods and  $N_{Fail}(h,m)$  is the number of measurement periods where one or more constraints were violated at all network sites. The formula is then iterated over a range of wind speed threshold values. As long as one site within the network configuration was available, the network is considered available. If all sites fail, then the network is unavailable.

#### 4.2.1 Network annual availabilities

For the three example sites, Figure 4.3 shows all two-site combinations and the three-site combination network mean wind speed availabilities. Figure 4.4 shows peak wind speed availabilities for the same configurations. Combined together, the three-site network configuration has an overall better availability than any of the two-site combinations. Though individual sites may have low availabilities, as seen in section 4.1, availability improves as sites are combined together. The more sites available for nominal or abort landing attempts, the better the probability of being able to land at at least one site in the network.

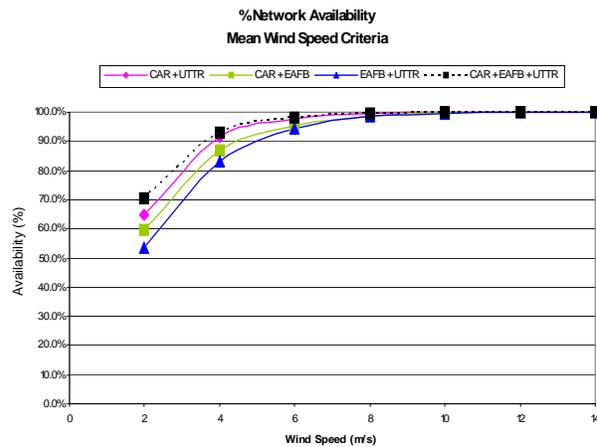


Figure 4.3 CAR-EAFB-UTTR network availabilities for mean wind speed thresholds of 0 to 14 m/s. The dotted line represents the three-site network configuration.

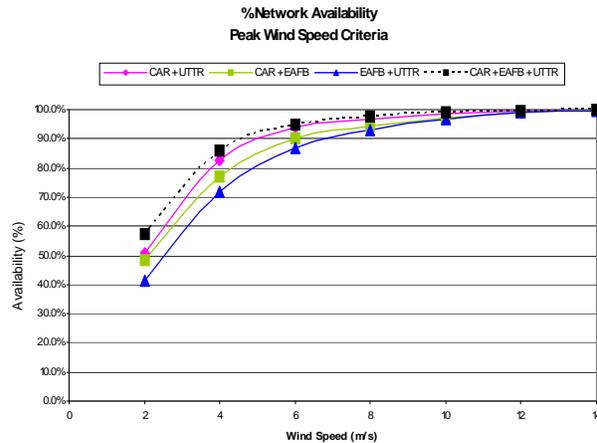


Figure 4.4 CAR-EAFB-UTTR network availabilities for peak wind speed thresholds of 0 to 14 m/s. The dotted line represents the three-site network configuration.

#### 4.2.2 Worst time of day availabilities

Analyses can also be performed to look at the worst time of day availabilities when weather is occurring that

NETWORK: CAR-EAFB-UTTR												
Average probability (%) that network is available due to lack of wind speed constraint violation, thunderstorms, or precip for worst time of day (12pm thru 5pm local standard time) @ 10m height												
Peak Wind Speed Constraint (m/s)	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
2	62.8	50.1	32.9	26.7	20.6	22.5	25.6	31.1	38.5	49.8	55.5	62.8
4	88.3	82.8	68.9	60.8	58.7	61.4	69.0	74.8	80.0	85.6	86.4	87.5
6	94.6	92.0	84.8	81.0	83.8	87.6	93.8	95.0	94.1	94.2	94.3	94.5
8	96.6	94.6	89.8	86.6	88.9	92.2	96.3	96.9	96.5	96.1	96.9	96.5
10	98.2	97.1	94.7	92.6	94.3	96.6	98.6	98.9	98.4	98.2	98.5	98.1
12	99.3	98.8	97.9	97.2	97.8	98.7	99.6	99.7	99.7	99.4	99.4	99.4
14	99.9	99.6	99.5	99.2	99.5	99.7	100.0	100.0	100.0	99.8	99.7	99.7
16	99.9	99.9	99.8	99.8	99.9	99.9	100.0	100.0	100.0	100.0	99.8	100.0

**Table 4.4** CAR-EAFB-UTTR average worst time of day network availabilities for the afternoon hours of 12pm through 5pm local time. Availability was generated based on both weather (precipitation/thunderstorm presence) and peak wind speed criteria.

could affect operations. Certain times of day tend to have a higher likelihood of precipitation and high wind events caused by diurnal effects. For example, for the three-site network, the worst availability tends to occur in the afternoon. Knowing that, the analysis can be focused on those worst hours for each month. In the example below, the hours were converted from UTC time to local time for each site. The weather criteria analyzed included looking at peak wind speed thresholds at the 10m height and whether precipitation and/or thunderstorms were present at the site at the time of the observation. Network availabilities were then calculated for the worst five hours of the day (from 12pm through 5pm local time). Table 4.4 shows the average availability over those five hours for the example three-site network for each month and distributed for the peak wind speed thresholds shown. Afternoons in the late spring/early summer months yield the lowest probability that the vehicle would be able to land somewhere within the network of sites. Information such as this can be critical to the Constellation Program when evaluating potential launch and landing scenarios for the Orion vehicle.

#### 4.3 Ponding Effects

Soil conditions at the surface can also affect the landing and recovery phases of a mission. Natural environment affects, such as rain and snow melt, can cause standing water – referred to as “ponding” – to occur on sites out west, such as lakebeds. On the east coast, an abort can cause a vehicle to land in shallow water or along the beach where there is wet sand. If surface conditions are not nominal, this can have an affect on how a vehicle lands and/or how the crew and vehicle can be recovered.

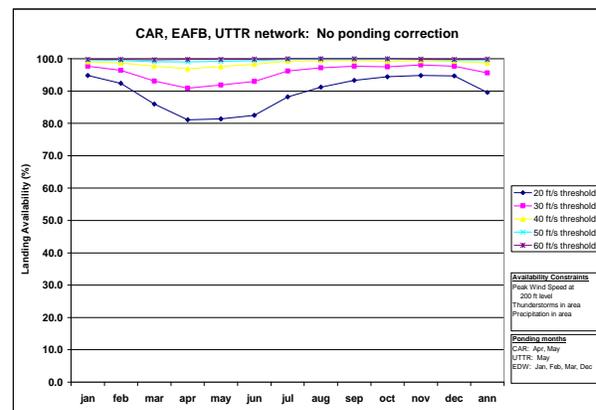
As surface soil conditions deteriorate, wind speeds become more significant as the vehicle might need to land in a low-wind environment. For example, a vehicle would want to approach muddy or water-covered surfaces slower so that it does not land in a way that would cause tipping or tumbling. The graphs below show the availabilities for the three-site network if ponding correction factors are applied during the month(s) of ponding at each site. Choosing months for each site as representative ponding months, a ponding correction factor was applied to each site as follows:

- CAR: April, May
- EAFB: January, February, March, December
- UTTR: May

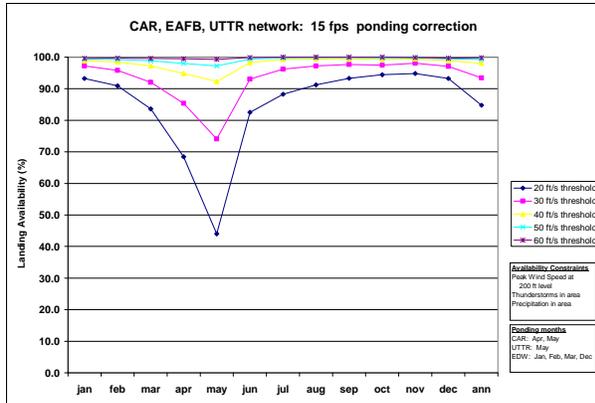
Based on this information, the analyses can be conducted on peak wind speed thresholds by applying some uncertainty value – or ponding correction factor – to the wind speeds during the months of concern. [Note: to show how a small change can affect the availability, this analysis is shown in values of feet per second (fps) and conducted at the 61m height rather than at the surface.] Figure 4.5 shows the availability if no correction factor is applied. Figure 4.6 represents the availability if a 15 fps correction factor is applied during the estimated months of ponding. Taking weather conditions into account (presence of precipitation and/or thunderstorms) for both runs, Figure 4.6 shows that reducing the wind speed for ponding greatly affects the overall availability of the individual networks.

#### 5. Discussion

Looking at how the natural environment can affect vehicle design and safety is an important role for the Natural Environments Branch at MSFC. The data analyzed feeds back into program requirements, decisions, design, and eventually operations. Weather information is critical to multiple mission phases of the



**Figure 4.5** Availability for the example three-site network with no ponding correction factor applied.



**Figure 4.6** Availability for the example three-site network with a 15 fps ponding correction applied.

new vehicle including pre-launch operations, launch operations, landing, recovery, and more. Looking at how the weather affects landing availabilities alone gives insight into just how important of a role weather can play. The different surface weather parameters – either alone or in combination with one another – can affect landing sites that might be available, how the vehicle will react as it descends and touches down, and what conditions recovery teams may have to deal with to get to the crew and vehicle. As the Constellation Program and Orion Project move forward, more questions will arise as to how weather will affect new design applications and requirements. Forward work continues to be discussed and planned for the Natural Environments Branch as NASA moves closer to building and launching the next generation vehicle.

## 6. References

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