

Worldwide C-17 Availability to Support 82nd Airborne Operations from Fort Bragg/Pope Field

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Preface

The Global Response Force (GRF) must respond to a variety of potential missions across a range of military operations. In addition to traditional missions, GRF is the force called on in any national threat necessitating rapid response. Recent defense guidance further expanded possible roles for the GRF by increasing the types and numbers of missions they will be called on to undertake, thus challenging existing ways those forces operate. RAND Arroyo Center was tasked to provide operational and organizational analysis of the many challenges facing the 82nd Airborne Division GRF. This report focuses on the availability of C-17 aircraft to support the GRF, a subset of the research of the RAND fiscal year 2014 study “Enabling the Global Response Force to Meet Future Needs.”

The purpose of the RAND research presented here was to determine the availability of C-17s deployed worldwide to assist the GRF with rapid response to a national threat. This research represents only part of the overall research effort. Research dealing with other challenges facing the GRF can be found in John Gordon’s work on scenarios for future 82nd Airborne operations and Christopher G. Pernin et al., *Enabling the Global Response Force: Access Strategies for the 82nd Airborne Division*, RAND Corporation, RR-1161-A. The findings presented here should be of interest to defense policymakers, the air mobility community (specifically, Air Force Air Mobility Command), and U.S. Air Force and Army planners.

This research was sponsored by US Army Forces Command and conducted within the RAND Arroyo Center’s Force Development and Technology Program. RAND Arroyo Center, part of the RAND Corporation, is a federally funded research and development center sponsored by the United States Army.

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Summary

The Army 82nd Airborne Division constitutes a large portion and the highest headquarters of the Global Response Force (GRF), and it is tasked to respond to national threats requiring a rapid response and must rapidly deploy up to a full brigade plus enablers and Division command post elements for myriad operations. The 82nd Airborne has held this role for decades, and it has spent a number of years deployed in support of efforts in Operation Iraqi Freedom and Operation Enduring Freedom. Also, it sent its 2nd Brigade Combat Team to Haiti in the wake of the 2010 earthquake while operating with a majority of personnel and resources focused elsewhere. Now, with operational tempo in the Middle East slowing, the 82nd must analyze how best to leverage its capabilities in support of the GRF mission.

A subset of these capabilities is related to the U.S. Air Force's (USAF) ability to provide capability and capacity for joint mission success. This report deals with the Air Force's ability to provide strategic airlift, in the form of C-17 aircraft, to the 82nd Airborne Division for GRF activities.

The RAND analysis presented here allows the reader to determine how many aircraft should be expected to be available within any given time constraint and how long the wait might be for any selected number of aircraft. For example, if only 55 aircraft are needed, they can be ready in 25–31 hours. Or if a time constraint of 12 hours is imposed, then possibly 1–6 (or more likely 1–2) aircraft will be available. Since the actual number of airplanes and times of their arrivals varies hour to hour depending on how many C-17s are fully mission capable (FMC) and how they are being used, no exact numbers can be given, but a reasonable range can be identified as well as best-case and worst-case scenarios.

To determine the availability of FMC C-17s, RAND sought to first understand how many C-17s could be provided in support of GRF activities. Although the C-17 fleet includes 213 aircraft,¹ only some of them are available at any given time. Some are in maintenance, others are on loan, and still others are only partially mission capable—able to fly but with limited utility. RAND sought to determine how many airplanes were fully capable of performing the GRF mission when called on.

Next, RAND determined how long it would take for those mission-capable assets to become available while respecting their in-progress activities and required crew rest. Although some assets were, in effect, sitting on the tarmac waiting to be tasked, many more were actively performing sorties in support of U.S. Transportation Command/USAF activities. Use of these

¹ 187 on active duty, 12 with the Air National Guard, and 14 with the Air Force Reserve. U.S. Air Force, 2014; U.S. Air Force. Only 208 tails appeared in the Logistics, Installations, Mission Support-Enterprise View (LEMS-EV) data. The other five C-17s' locations are unknown.

aircraft would require that they complete their current activities and allow the crew to rest before they could be flown to Fort Bragg/Pope Field. And in all cases, the crews needed additional rest after reaching Fort Bragg/Pope Field.

RAND's analysis of maintenance and use records led to the conclusion that, on average, about half of the C-17 inventory is FMC and available for GRF use given appropriate lead time. Most commonly, 104 C-17s would be available, although this number occasionally was as high as 126 airplanes and as low as 68. Further, all FMC aircraft could be at Fort Bragg/Pope Field and the crews rested and ready for activity within, at most, 87 hours of a request for their services. More commonly, the entire FMC fleet could be available within about 55 hours of the request. Obviously, all FMC C-17s are not needed at once for most missions. Demand for a smaller number of aircraft makes it more likely that the aircraft can be ready sooner. The analysis showed that within 24 hours, there is a reasonable expectation that between 24 and 47 airplanes could be made available to Fort Bragg/Pope Field for possible GRF deployment.

Given that typical planning for GRF deployments might happen over a few days and require two dozen or so aircraft to transport the personnel and equipment² in an initial deployment, analysis shows that there is a high probability those planes could be made available barring other demands on the force.

A major assumption in this report is that GRF support is the highest priority for C-17s. In reality, some C-17s will be in use transporting the President, Vice President, Secretary of State, Secretary of Defense, and others as well as undertaking various tasks around the globe and be unavailable for GRF use. This will reduce the number of C-17s available at any given time. Because the data provided to us do not indicate when C-17s are used in these roles, we cannot accurately estimate this use in the context of our analysis. Instead, we choose to alert the reader here that some reduction in availability will exist. This report also does not consider the logistics of moving large volumes of C-17s and the equipment, weapons, vehicles, etc., of the GRF through Ft. Bragg/Pope Field in a short time period. We are concerned only with determining if and when C-17s can reach Ft. Bragg/Pope Field.

² Estimates are derived from Nicholson, Condrey, and Lambert, 2013, and Stiner and Schroeder, 2009.

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We must also thank Army Forces Command for its sponsorship of this study, for providing the foundation on which the research could be conducted, and for its continued work with RAND through the Arroyo Center in support of gaining a better understanding of problems that face the Army.

Finally, we thank our RAND colleagues Peter Buryk for providing the availability and use data on which this work is founded and Liz Cole, Lovancy Ingram, Patricia Bedrosian and Stephanie Lonsinger for their efforts in administrative assistance and editing; Muharrem Mane and Lt. Col. Harmon S. Lewis, Jr., and the members of the 82nd Airborne also provided thoughtful insights.

Abbreviations

AFMC	Air Force Materiel Command
FMC	fully mission capable
GRF	Global Response Force
GRIP	Global Reach Improvement Program
kt	knots
LIMS-EV	Logistics, Installations, Mission Support-Enterprise View
nm	nautical miles
PMC	partially mission capable
USAF	U.S. Air Force

1. Introduction

The Global Response Force (GRF) must prepare for a variety of potential missions across a range of military operations. In addition to traditional missions, it may be called on to respond to national threats necessitating rapid response, ranging from humanitarian assistance to forcible entry fighting off-the-ramp-type operations, that is, operations where the landing site is neither secure nor friendly. Units in the GRF will react in days and weeks and thus must have the supporting operational concepts and technical and tactical capabilities to conduct those types of rapid-response missions.

Recent defense guidance has further expanded possible roles for the GRF in terms of the types and numbers of missions it will be called on to undertake, thus challenging existing ways those forces operate. And recent RAND analysis demonstrates the complexity of coordinating the joint efforts required to effectively perform those missions and the challenge that these missions will present to joint forces capabilities, in terms of geographic access and anti-access and area denial assembled to conduct them.³ Given the missions that the GRF must be prepared to conduct, analysis is needed to ensure that the GRF, and specifically the ready brigade of the 82nd Airborne Division, have the capabilities available to maintain effectiveness.

One important factor for the GRF is rapid access to strategic lift, such as C-17s. Past experiences have shown tens, and at times over a hundred, airplanes marshalled for lifting ready brigades (or portions thereof) as part of their global response role. To help with planning for GRF operations, it is important to assess the accuracy of planning assumptions regarding the marshaling of aircraft given current fleets and operational considerations.

This report briefly analyzes when and how many C-17s can be made available for a mission departing from Fort Bragg/Pope Field. This report is one of several from a study being performed for the 82nd Airborne Division related to access concepts for the GRF.⁴

Taking into account crew rest and a need to finish missions under way, RAND found that most mission-capable C-17s can reach Fort Bragg/Pope Field and be ready to leave on a mission within 55 hours. RAND also found that roughly half of the C-17 fleet is fully mission capable (FMC) at any given time, with an additional 25 percent partially mission capable (PMC) as a result of some combination of maintenance and supply issues. The remaining 25 percent of the fleet is unavailable as a result of contract work, maintenance, depot work, etc. This report discusses the data used to complete this analysis, the methodology, the results of the analysis, and future work that could be undertaken using these data or analytical approach.

³ Gordon and Matsumura, 2013.

⁴ Drawn from John Gordon's work for the RAND Corporation on scenarios for future 82nd Airborne operations and from Pernin et al., 2016.

A major assumption of this report is that GRF support is the highest priority for C-17s. In reality, some C-17s will be in use transporting the President, Vice President, Secretary of State, Secretary of Defense, and others as well as undertaking various tasks around the globe and will be unavailable for GRF use. This will reduce the number of C-17s available at any given time. Because the data provided to us do not indicate when C-17s are used in these roles, we cannot accurately estimate this use in the context of our analysis. Instead, we choose to alert the reader here that some reduction in availability will exist.

This report also does not consider the logistics of moving large volumes of C-17s and the equipment, weapons, vehicles, etc., of the GRF through Ft. Bragg/Pope Field in a short time period. We are concerned only with determining if and when C-17s can reach Ft. Bragg/Pope Field.

Chapter 2 discusses the methodology used to determine airplane availability and the time to respond to a request for services. Chapter 3 reviews the input data gathered from Logistics, Installations, Mission Support-Enterprise View (LIMS-EV) that give the location and status of the C-17 fleet. Chapter 4 analyzes the model output focused on a heatmap of airplane availability in the hours following a request for services. Chapter 5 lists conclusions drawn from the analysis and discusses potential future work. Appendix A details the steps used to error-check and format the LIMS-EV data, and Appendix B expands on the methodology discussion from Chapter 2 in more detail.

This report does not directly address the availability of airdrop-qualified crew. Subsequent discussions with Air Force personnel found that not all C-17 crews are airdrop-qualified.⁵ Air Mobility Command, Studies and Analysis Division, conducted a probabilistic analysis of C-17 airdrop crew availability to support a no-notice GRF tasking in 96 hours. That analysis showed that there is a very high likelihood that 27 augmented⁶ C-17 crews would be available when both active duty and air reserve component C-17 crews are considered. The details of this analysis are sensitive and can be obtained through AMC/A9 or AMC/A3DT.

⁵ AMC/A9A, 2014.

⁶ An augmented C-17 crew carries an extra pilot and loadmaster extending the maximum crew duty day from 16 to 24 hours.

2. Methodology

To examine where C-17s were at all points during fiscal year (FY) 2013, we divided the fiscal year into discrete one hour blocks. This chapter describes the steps used to determine airplane status and location at each block and calculate the time needed to reach Fort Bragg/Pope Field and to rest the crew before departure. These steps enable generation of the heatmap figure that displays availability over time and that is examined in detail in the next chapter.⁷

Determining Airplane Status and Location

We used a brute force method to determine airplane location and status because this method is simple and the analysis can be completed within a few minutes. Status and location for each airplane were calculated for each hour of FY13 and then placed into time lines that were used to determine the time needed to reach Fort Bragg/Pope Field. The more restrictive status was picked for time periods where a conflict existed. For example, an airplane listed as both PMC⁸ and FMC during the same hour would be considered PMC. This was done to maintain the conservative estimate of assuming the most restrictive condition to be the correct one. An example portion of the assembled time line for one particular C-17 is described in Figure 2.1.

In addition, once the location time line of the airplane was constructed, the distance, and therefore time, to Fort Bragg/Pope Field could be calculated for any point along that time line.

Determining Time Until the Aircraft Is Ready to Leave Fort Bragg/Pope Field: A Summation

Once the distance to Fort Bragg/Pope Field was known, the time until the C-17 could take off from Fort Bragg/Pope Field could be calculated. The time until an aircraft can leave Fort Bragg/Pope Field is the sum of time remaining in the current flight (if any), time for shutdown after the current mission,⁹ time for crew rest,¹⁰ pre-flight¹¹ before leaving the current location,

⁷ A more detailed discussion of the material in this chapter can be found in Appendix B.

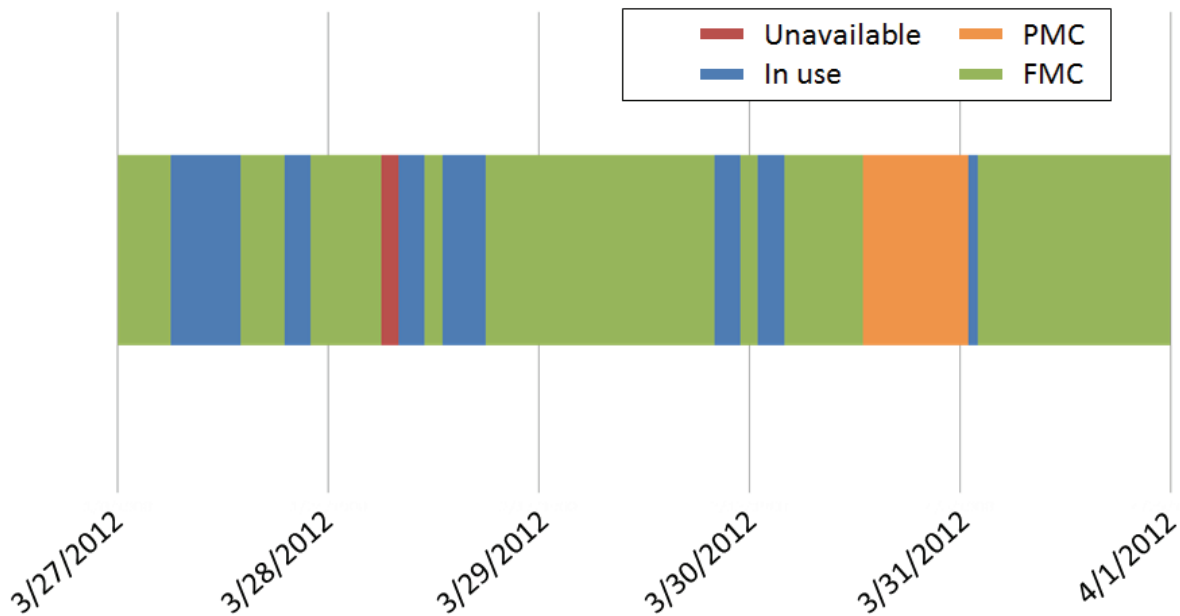
⁸ For this analysis, PMC aircraft were considered to be unavailable for use. See Figures 4.6 and 4.7 to view the potential impact if they were able to support the GRF mission.

⁹ Approximately 45 minutes

¹⁰ “The crew rest period is normally a minimum 12-hour non-duty period before the flight duty period begins.” U.S. Air Force, 2010, Vol. 3, Paragraph 9.4.5. Although this number can vary slightly because of certain rest or waiver conditions, 12 hours represents the amount of time in a rest period in the majority of cases.

¹¹ 3.75 hours for airland, 4.25 hours for airdrop. We considered only airland times in this analysis. Any airdrop would occur after leaving Fort Bragg/Pope Field, so results for a GRF airdrop mission would be identical to those presented here, but delayed by 30 minutes.

Figure 2.1. An Example Time Line from 3/27/12 00:00 to 4/1/12 00:00 for One C-17



flight time to Fort Bragg/Pope Field, and shutdown, crew rest, and pre-flight needed before the crew could take off from Fort Bragg/Pope Field. For unavailable aircraft, the time until departure from Fort Bragg/Pope Field was irrelevant as the aircraft could not take off at all. It was assumed in all cases that the crew remains with the aircraft. Without any information on crew availability and duty days for specific aircrews in the data we examined, this assumption is necessary and conservative if spare crews are sometimes available to be substituted in shorter time frames.

Only in-use aircraft had remaining flight time. This was calculated as the arrival time of the current flight minus the current time under consideration. For unavailable, PMC, or FMC aircraft, this value was zero.

Crews must perform approximately 45 minutes of post-flight shutdown activity and rest for 12 hours between flights. So, for airplanes in use at the time under consideration, the time remaining until the crew was rested was 12.75 hours plus the time left on the current sortie. For unavailable, PMC, and FMC aircraft, it was 12.75 hours minus the time already spent on the ground since the previous sortie. Pre-flight activity of 3.75 hours was also added to all cases.

Flight time to Fort Bragg/Pope Field was obtained from the block speed table in AFPAM 10-1403.¹² For flights longer than 4,000 nautical miles (nm), the time was considered to be the composite of the time for a 4,000 nm flight, the time for a flight consisting of the remaining distance, and the ground time given in AFPAM 10-1403 of 2.25 hours.¹³ For simplification purposes, no specific stopover points were used. It was assumed that some airport was available

¹² U.S. Air Force, 2011, Table 4, p. 13.

¹³ U.S. Air Force, 2011, Table 4, p. 14.

at which to stop and refuel at 4,000 nm from the point of origin. Additionally, for flights over ~7,200 nm, crew rest requirements will force a stopover somewhere, adding an additional 16.5 hours (0.75 hours shutdown, 12 hours rest, 3.75 hours pre-flight). The block speed table used in this analysis is shown in Table 2.1.

Table 2.1. C-17 Block Speed from AFPAM 10-1403

Distance (nm)	Block Speed (kt)	Ground Time (h)	Time to Reach Fort Bragg/Pope Field (h)
0	0	0	0
500	335	0	1.49
1000	384	0	2.60
1500	400	0	3.75
2000	405	0	4.94
2500	406	0	6.16
3000	406	0	7.39
3500	409	0	8.56
4000	412	0	9.71
4500	412 (first 4000nm) 335 remainder	2.25	13.45
5000	412 (first 4000nm) 384 remainder	2.25	14.56
5500	412 (first 4000nm) 400 remainder	2.25	15.71
6000	412 (first 4000nm) 405 remainder	2.25	16.90
6500	412 (first 4000nm) 406 remainder	2.25	18.12
7000	412 (first 4000nm) 406 remainder	2.25	19.35
7500	412 (first 4000nm) 409 remainder	2.25 + 16.5	37.02
8000	412 (first 4000nm) 412 remainder	2.25 + 16.5	35.92
8500	412 (first 8000nm) 335 remainder	2.25 + 16.5	39.66
9000	412 (first 8000nm) 384 remainder	2.25 + 16.5	40.77
9500	412 (first 8000nm) 400 remainder	2.25 + 16.5	41.92
10000	412 (first 8000nm) 405 remainder	2.25 + 16.5	43.21
10500	412 (first 8000nm) 406 remainder	2.25 + 16.5	44.33
11000	412 (first 8000nm) 406 remainder	2.25 + 16.5	45.56

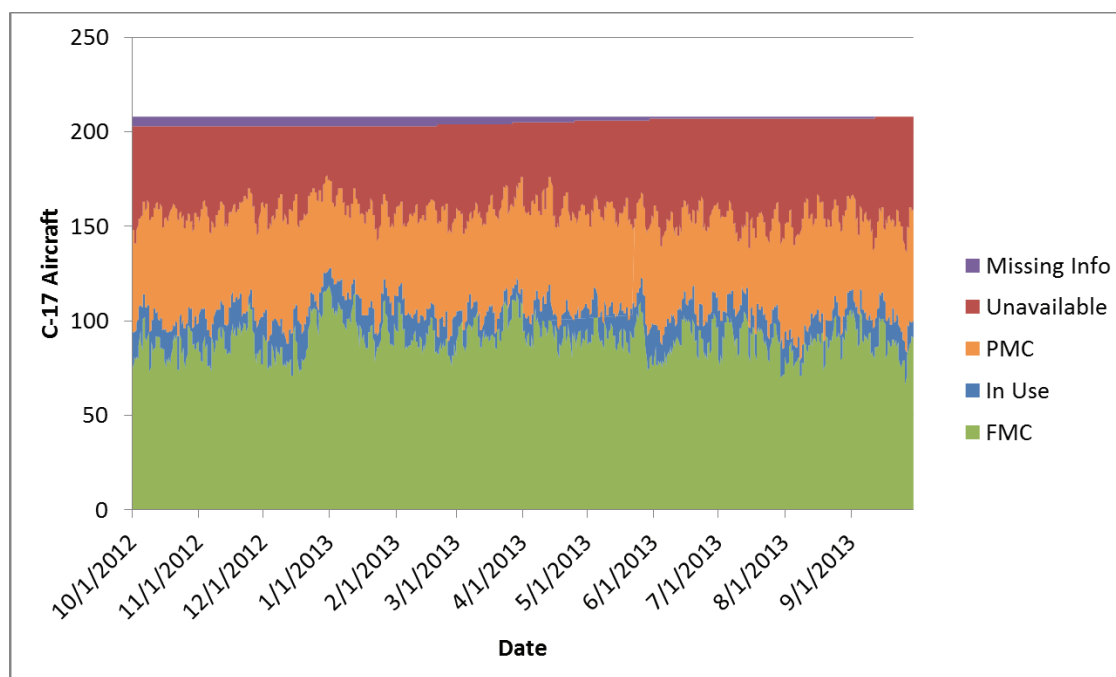
Finally, 16.5 hours of shutdown, crew rest, and pre-flight at Fort Bragg/Pope Field was added to all airplanes not already at Fort Bragg/Pope Field. Airplanes that were in use on their way to Fort Bragg/Pope Field or PMC and FMC and already at Fort Bragg/Pope Field had this crew rest covered with the previous crew rest calculation step.

As with all previous calculations, the time until the airplane can leave Fort Bragg/Pope Field was calculated for each C-17 at every hour of FY13.

Data on Time Until Departure from Fort Bragg/Pope Field Can Indicate How Much of the Fleet Is Available

Figure 2.2 shows the C-17 fleet’s availability during FY13. On average, at any given hour, 43 percent of the C-17 fleet are listed as FMC and not in use. Another 7 percent are in the air. This means that half the fleet is fully capable of being used at any time, after allowing for the completion of current sorties. Additionally, another 25 percent of C-17s are listed as PMC on average. Some fraction of these could be usable, depending on the particular issue keeping them from being FMC and the intended mission; however, we lacked sufficient data to identify those airplanes in this analysis. The remaining quarter of the fleet is, in general, unavailable.¹⁴

Figure 2.2. C-17 Fleet Availability over Time



¹⁴ On average, 1.5 percent of the fleet has an unknown status. This number is larger early in the fiscal year because of missing data for the previous fiscal year. This number drops to <1 percent for snapshots of time in the latter half of FY13.

No consideration was given to pending status changes in the data when the analysis was performed. That is, when the aircraft are directed to Ft. Bragg/Pope Field, any in-use or FMC aircraft are assumed to remain in flying condition and not land in a PMC or unavailable status, even if looking forward in the data set indicates that this would happen. Conversely, if the data indicated that an unavailable or PMC aircraft would become FMC an hour or two after airplanes were directed to Ft. Bragg/Pope Field, these C-17s were not made available and were assumed to stay in PMC/unavailable status.

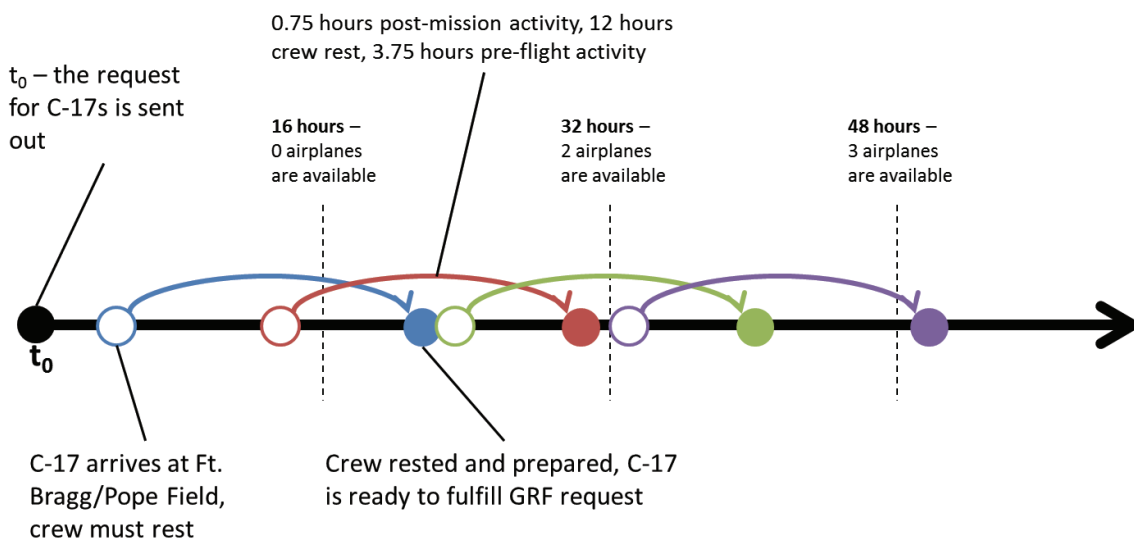
Creating an Availability Heatmap

To get a more nuanced picture of aircraft availability, we created a heatmap that imposed frequency onto a plot of *Time until departure from Fort Bragg/Pope Field* v. *Number of Airplanes Available*. Time until departure from Fort Bragg/Pope Field is calculated as the length of time from the current hour under investigation, t_0 , to the hour when the airplane is ready to leave Fort Bragg/Pope Field. No specific departure time-of-day is used, only 1, 2, 3, ... hours after the request is made. See Figure 2.3 for an example.

Time until departure from Fort Bragg/Pope Field takes into account finishing current missions, crew rest (both after current activities and after reaching Fort Bragg/Pope Field), and time to transit to Fort Bragg/Pope Field. “Hotter” colors indicate of the most likely number of airplanes available to depart within a given time window.

The heatmap represents a collection of cumulative distributions, one for each hour of FY13. The coloring indicates the frequency with which these distributions cross points on the graph.

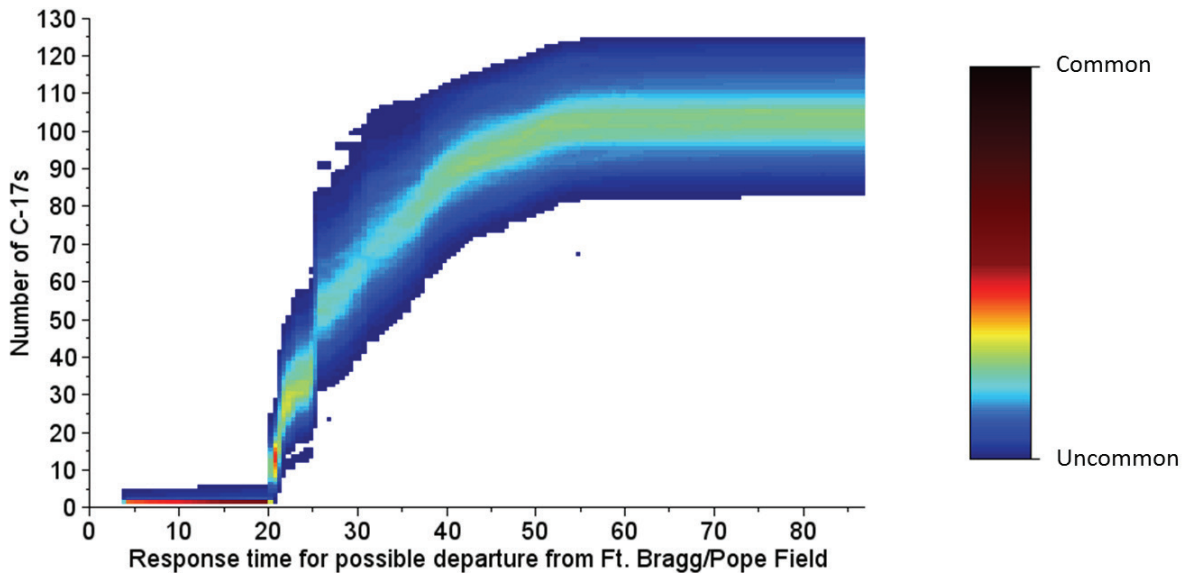
Figure 2.3. A Notional Example: Airplanes Need Rested Crews to Be Ready for GRF Use; Their Locations and Activities Dictate When They Arrive



For instance, many of the distributions go through the 21 hours, 15 airplanes point, meaning that it is common to have 15 airplanes available within 21 hours. On the other hand, it is uncommon to have 60 airplanes available within 24 hours, hence the “cooler” colors at that point.

The heatmap effectively shows when airplanes are likely to be available.¹⁵ This heatmap can be seen in Figure 2.4.

Figure 2.4. A Heatmap of C-17 Availability



Discontinuities Align with Commonly Used Airports

When examining Figure 2.3, a number of discontinuities are apparent. Crossing certain time barriers creates a sudden increase in the number of airplanes available. Table 2.1 gives a likely explanation for these discontinuities.

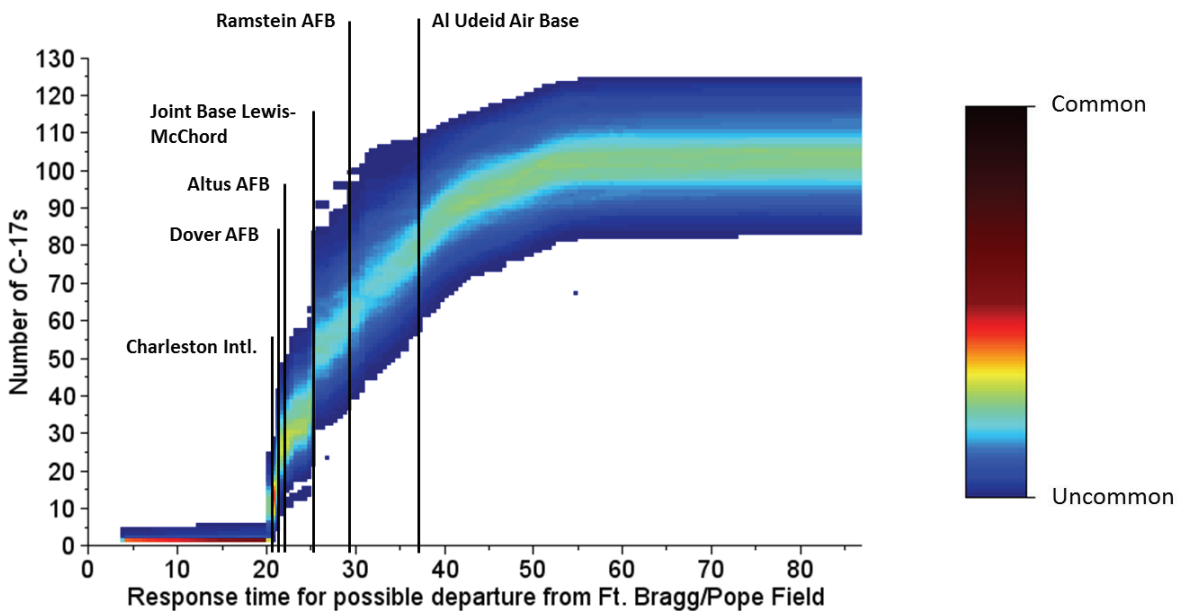
It should be expected that at the times listed in Table 2.1, or slightly after in the case of crews that still need some rest, many airplanes will suddenly be ready to leave Fort Bragg/Pope Field, since many planes are often located at or traveling through the listed locations. Figure 2.5 illustrates this point. The times of sudden jumps in availability correlate well with the most commonly used locations.

¹⁵ As noted above, this analysis assumed that GRF is the top priority for all C-17s worldwide. In reality, some C-17s are tasked to various other missions that take priority over the GRF mission. This will reduce the number of C-17s available to GRF and possibly delay their arrival as well.

Table 2.1. Most Commonly Used C-17 Locations

Location	Time Until C-17 at This Base Can Be Ready to Leave Fort Bragg/Pope Field (h)	Rank: Most Used C-17 Locations
Charleston International Airport	20.7	1
Joint Base Lewis-McChord	25.4	2
Altus Air Force Base	22.9	3
Ramstein Air Force Base	29.4	4
Dover Air Force Base	21.2	5
Al Udeid Air Base	37.7	6

Figure 2.5. Airport Locations Correspond to Discontinuities



One additional hurdle to consider is the need to clear non-GRF aircraft from Fort Bragg/Pope Field to make room for GRF C-17s. Since C-17s not already at or on their way to Fort Bragg/Pope Field for normally scheduled activity will take at least 4.25 hours to arrive (3.75 hours pre-flight and 30 minutes to reach the closest airport), the presence of non-GRF aircraft should not be an issue so long as they can be moved in this time.

Since crews need 3.75 hours from pre-flight before they leave for Fort Bragg/Pope Field and 0.75 hours to perform post-landing work, 12 hours of rest, and 3.75 hours from pre-flight when they leave Fort Bragg/Pope Field (for a total of $3.75 + 0.75 + 12 + 3.75 = 20.25$ hours, plus flight time to Fort Bragg/Pope Field), all data showing availability before approximately 18 to 20 hours

must be airplanes already at Fort Bragg/Pope Field with crews already resting. This idea correlates well with the chart, which shows that often, a few airplanes are available within 20.25 hours.

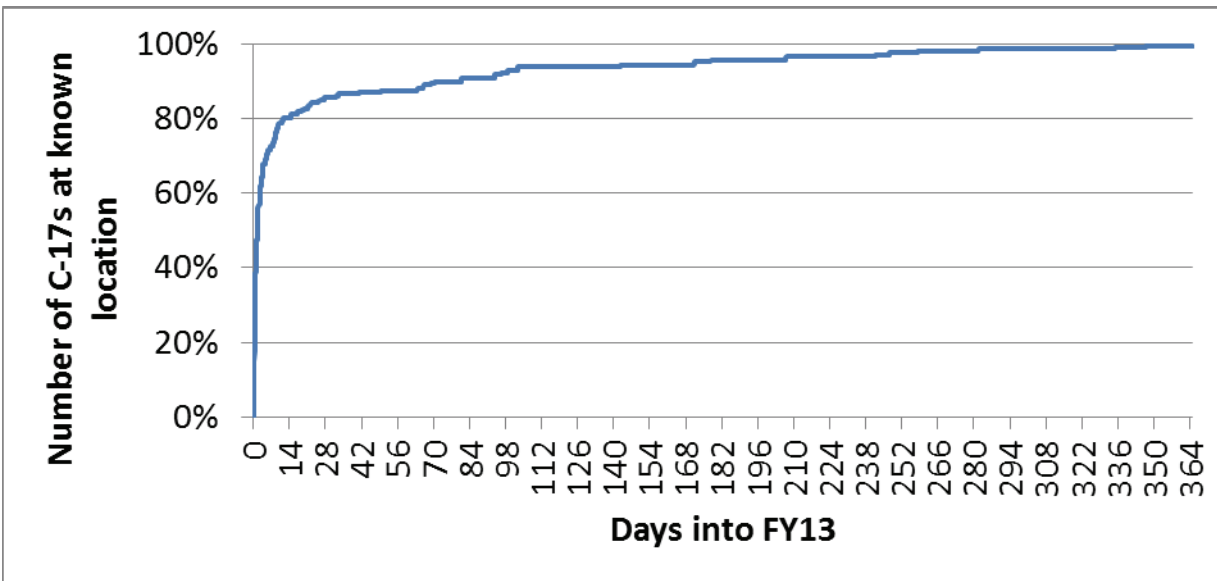
3. Data Overview

RAND acquired data detailing C-17 activity during FY13 from the Air Force's LIMS-EV system. One set of data contained information on sorties carried out by C-17s. The other data set contained information on status changes for each C-17. The sortie data detailed all flights taken by C-17s in FY13. It included tail number, date and time of the sortie, departure and arrival locations, and the purpose of the sortie (channel mission, specific Combatant Command use, training, etc.). The sortie data allowed us to determine the location of all C-17s at any time in FY13. The data on status changes gave the status of each C-17 and the duration of the status. It included tail number, the date and time the status condition began and ended, and the airplane's status. Broadly, these statuses were FMC, in use, PMC, and unavailable. For this analysis, RAND focused on FMC and in-use airplanes. Airplanes whose status was PMC or unavailable were all considered to be unavailable. PMC aircraft could provide additional availability but a lack of insight into exactly what maintenance problems these airplanes had and whether those problems would affect the mission from Fort Bragg/Pope Field meant that their availability could not be guaranteed.

Locating the Airplanes

The sortie data showed aircraft locations, but only as departure and arrival points when the airplanes took part in a sortie. Between sorties, the airplanes were assumed to be at their last known arrival location. This means that at the beginning of the fiscal year, most locations are unknown because the most recent sorties for those airplanes are contained in FY12 data, which we did not possess. The issue quickly resolves itself as the C-17s fly sorties, revealing their locations. Figure 3.1 shows that within the first four days, the locations of most airplanes are known. By mid-December (approximately 75 days) around 90 percent of airplanes are in known locations. It is worth noting that many of the airplanes that remain at unknown locations well into the fiscal year are unavailable (and hence do not complete sorties to reveal their locations), so their locations are not important.

Figure 3.1. By the End of December, over 90 Percent of C-17s' Locations Are Known



Categorizing the Statuses

The original data contained 164 unique status conditions encompassing 208¹⁶ airplanes over one year. RAND condensed these into four: FMC, in use, PMC, and unavailable. The FMC airplanes were a one-to-one matching: Only airplanes listed as FMC in the data were considered as FMC in our analysis. Any airplane performing a sortie was considered in use, meaning that it would be FMC once it landed. Airplanes were listed as PMC for maintenance issues, supply issues, or both. Our analysis labeled all of these aircraft as PMC. Finally, airplanes that were damaged, in depot, performing contract work, or otherwise unable to reach Fort Bragg/Pope Field were considered unavailable.

¹⁶ Although the USAF C-17 fleet has 213 airplanes only 208 appeared in the LIMS-EV, Air Force Materiel Command (AFMC) and Global Reach Improvement Program (GRIP) data.

4. Interpreting the Results

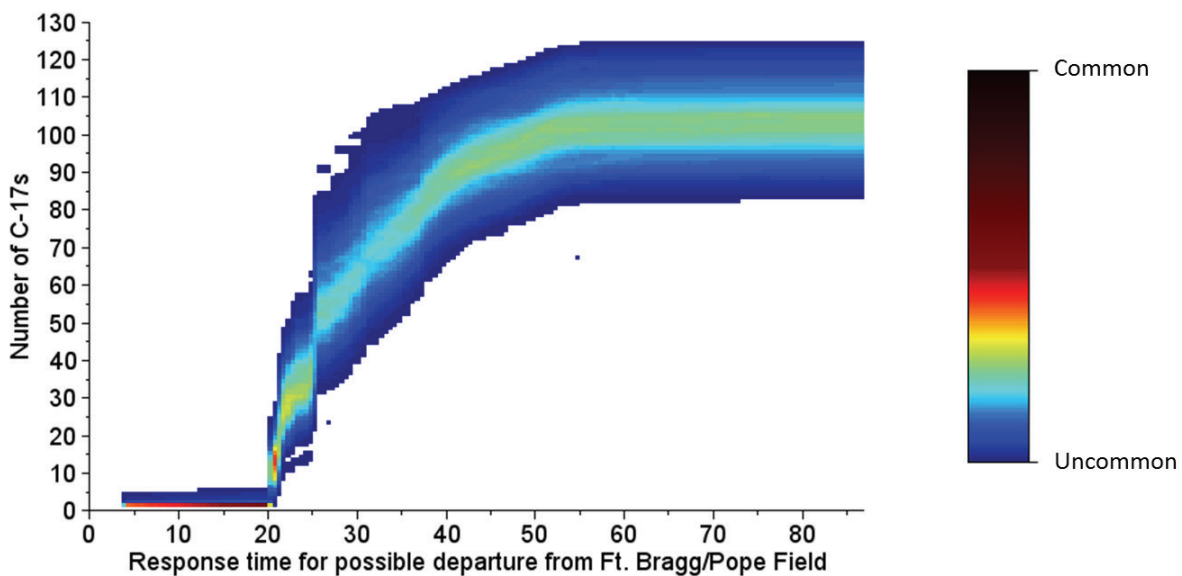
Expected FMC status

The heatmap can help determine how many airplanes can be expected to be FMC or in use at any given time. If we assume that all FMC airplanes are either in use or awaiting orders somewhere in the world, then eventually they will be able to reach Fort Bragg/Pope Field. If we examine the heatmap as shown in Figure 4.1, we can find the range for this number.¹⁷

Within 50–65 hours, all airplanes that are FMC can reach Fort Bragg/Pope Field and be ready to depart on a GRF mission. Figure 4.1 shows this to be approximately 80–125 airplanes.

If we examine a “slice” of the heatmap at any point along the x-axis, such as at 87 hours shown in Figure 4.2, the result is a histogram showing the availability of airplanes that can reach Fort Bragg/Pope Field within that amount of time.

Figure 4.1. FMC Availability Can Be Measured from the Heatmap



¹⁷ As noted above, some reduction in C-17 availability will occur as they are required to support other missions. That reduction could not be captured with our available data and is not measured in this analysis.

Figure 4.2. A Slice of the Heatmap at 62 Hours Can Be Examined to Determine Average Fleet Availability

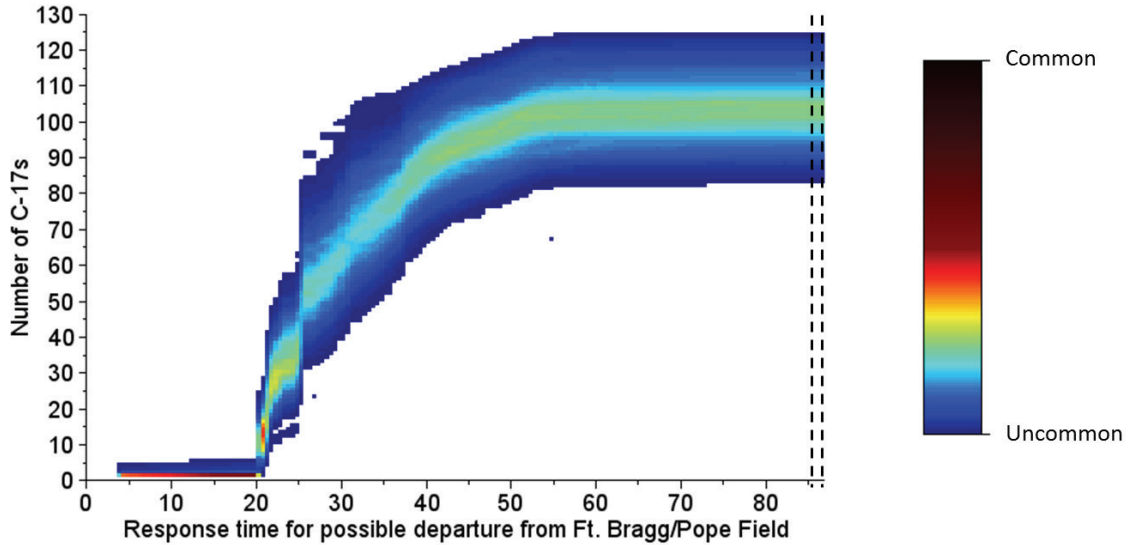


Figure 4.3 examines the slice of the heatmap at 87 hours from Figure 4.2, the longest time it took an in-use airplane to complete its mission and reach Fort Bragg/Pope Field. This gives us an idea of overall fleet availability.

Figure 4.3. Roughly Half of the C-17 Fleet Is Available at Any Time, Although This Number Fluctuates Between ~40 and 60 Percent

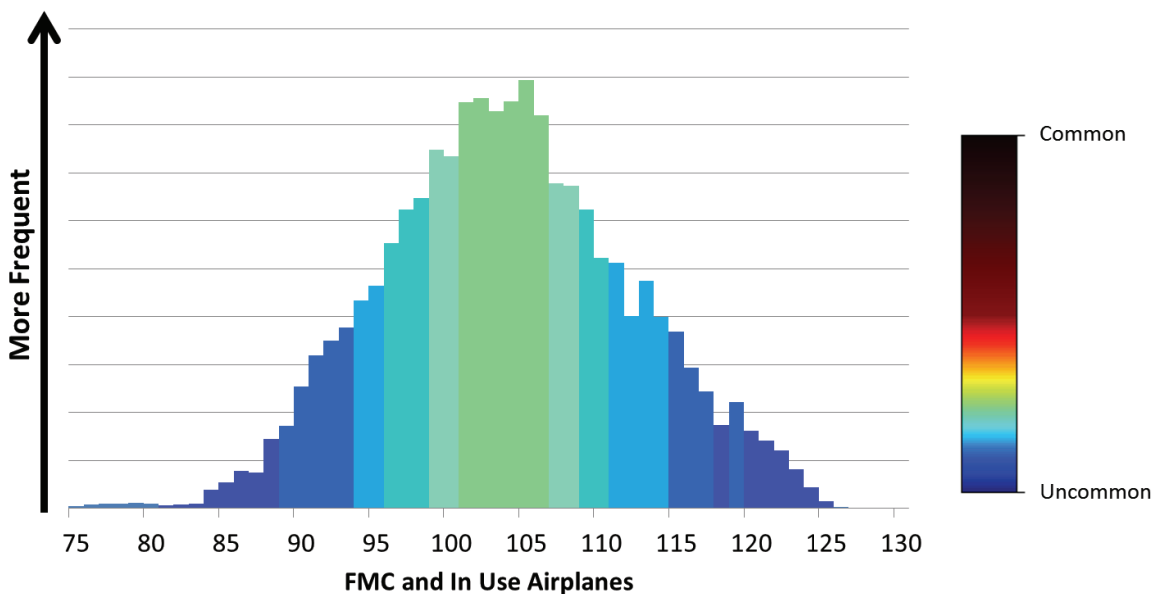


Figure 4.3 shows that, most commonly, around 104 airplanes, or roughly half of the C-17 fleet, are FMC and in use. This availability was below 70 airplanes at some times and as high as 126 airplanes at others.

Interpreting the Heatmap

Using the heatmap in Figure 4.1 allows us to tell, at a glance, when and how many airplanes are likely to be available.

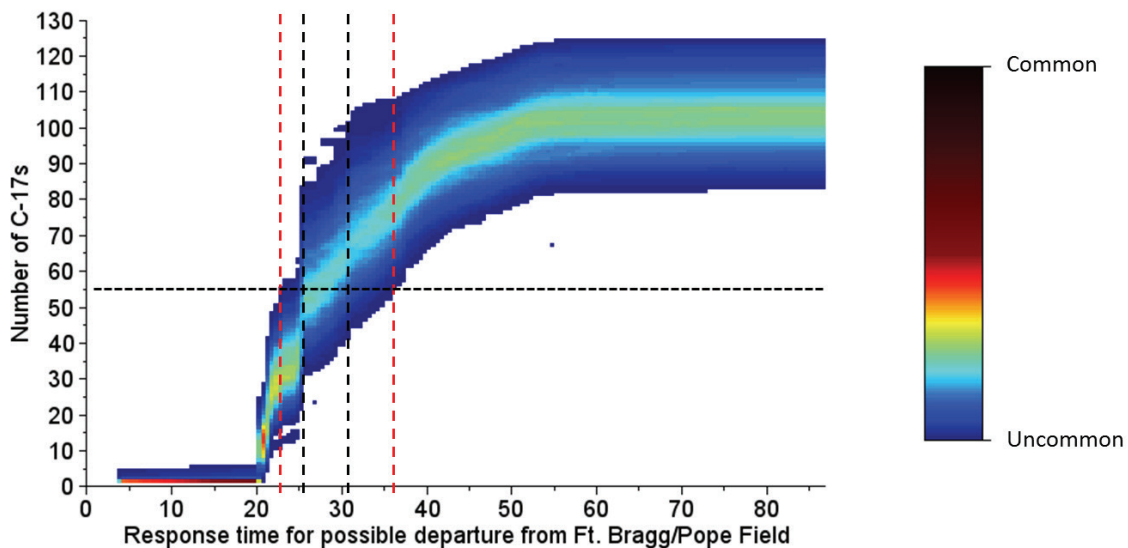
How Soon Can Airplanes Arrive?

If a specific number of airplanes is needed, the heatmap in Figure 4.1 allows us to determine the range of time we should expect to wait for these airplanes. Figure 4.4 serves as an example.

If 55 C-17s are needed for a particular mission from Fort Bragg/Pope Field (dashed horizontal line in Figure 4.4), then the wait time could be anywhere from 23–36 hours (dashed vertical red lines). Although 81 percent of the time, as indicated by the lighter color and shown by the dashed vertical black lines, the wait time would be 25–31 hours.

This analysis can be repeated at any point along the y-axis to determine how long the wait would be for a given number of airplanes.

Figure 4.4. If 55 Airplanes Are Desired, Expect to Wait 25–31 Hours



How Many Airplanes Can Be Expected in X Hours?

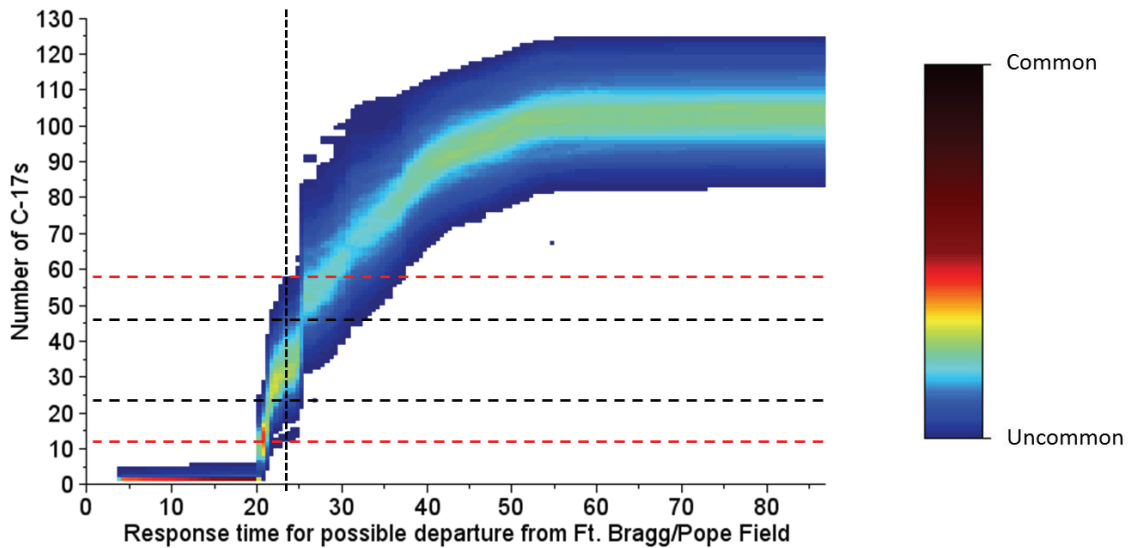
A more general use of the “slicing” method used to find how much of the C-17 fleet is FMC/in use at any time can be used to determine how many airplanes might be available for a

mission from Fort Bragg/Pope Field in a given time frame, excluding other mission taskings. Figure 4.5 shows an example of this.

If airplanes must leave Fort Bragg/Pope Field within 24 hours for a mission (dashed vertical line in Figure 4.5), then 12–58 C-17s could be available (dashed horizontal red lines). Although 89 percent of the time, as indicated by the lighter color and shown by the dashed horizontal black lines, 24–47 airplanes would be available.

This analysis can be repeated at any point along the x-axis to determine how many airplanes will likely be ready to leave Fort Bragg/Pope Field under a given time constraint.

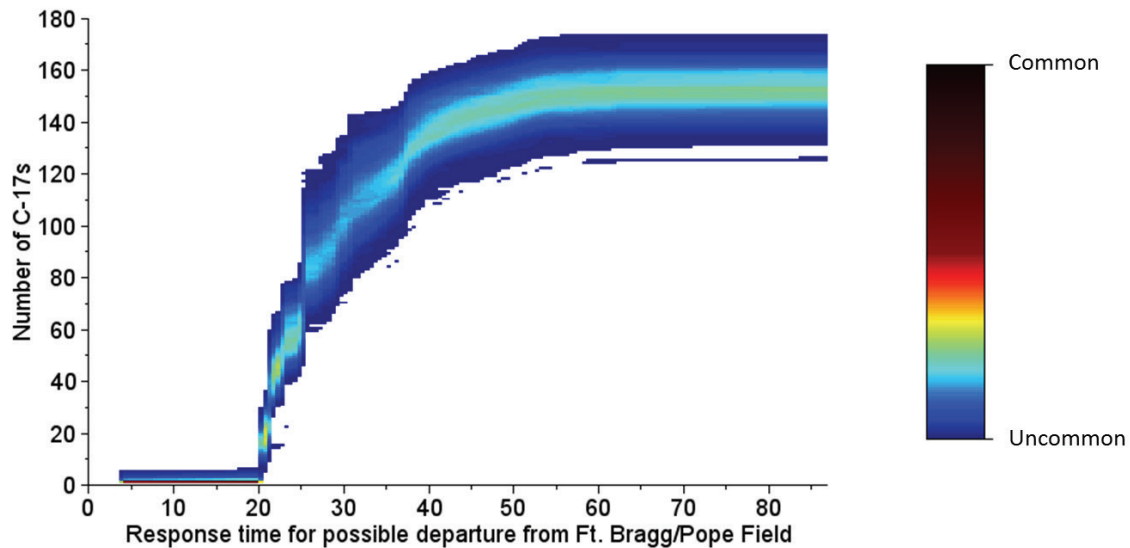
Figure 4.5. Within 24 Hours, Roughly 24–47 Airplanes Will Be Available



The Impact of PMC Aircraft

Around 25 percent of the C-17 fleet is in PMC status at any given point. This can be caused by maintenance issues where the plane is flightworthy but has some issues preventing it from performing to listed specifications or supply issues where the necessary parts and consumables are not available to restock the airplane. The data RAND drew from LEMS-EV do not distinguish PMC status with any more detail than this, and to learn which specific maintenance and supply issues would still enable GRF use would require careful study of GRF operations as they relate to C-17 use. However, we can quickly determine the range of potential assistance PMC aircraft would give. Figure 4.6 shows the availability heatmap if, in addition to FMC and in use airplanes, all PMC airplanes were also available.

Figure 4.6. Adding PMC C-17s to the GRF Pool May Significantly Increase Availability

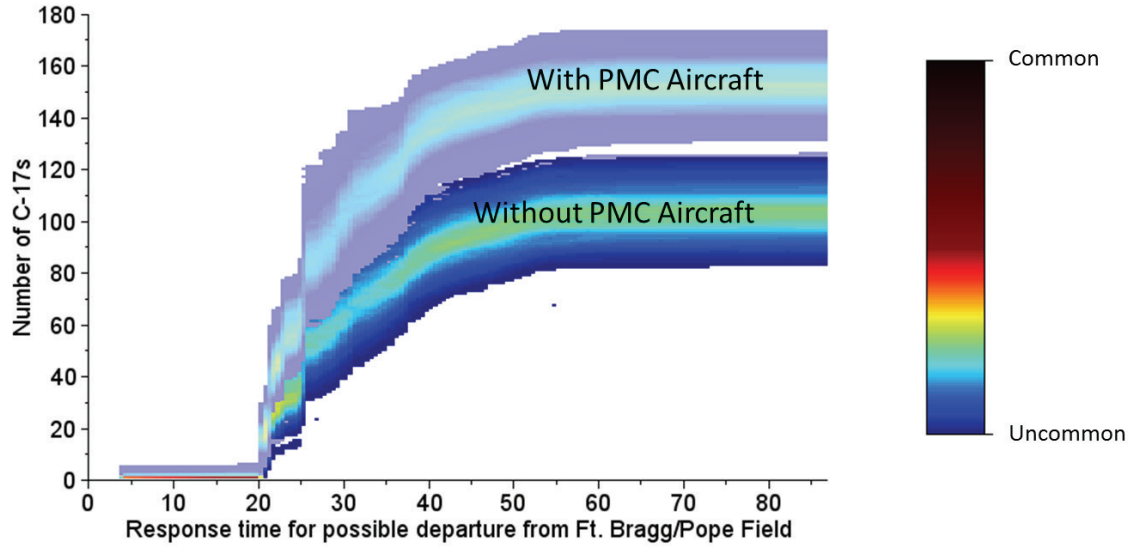


Many more airplanes are available if PMC aircraft are included. Where before it was 81 percent likely that 55 C-17s would take 25–31 hours to be ready for GRF use, when PMC aircraft are included that range, the time is 22–24.5 hours. This is a significant savings in terms of both the breadth of expected arrival times and latest expected arrival time. Again, it is important to remember that some or all PMC aircraft will not be usable by GRF because of being damaged in a way that affects GRF use or because they cannot be repaired in time for GRF use,¹⁸ so the true number of available aircraft lies somewhere between the two solutions.

Figure 4.7 compares the heatmap with and without making PMC aircraft available to the GRF. The discontinuities are in the same positions, indicating that airplanes are still departing and arriving from the same locations, but more airplanes are available at any time because of the larger pool.

¹⁸ Maintenance and repair of the C-17s away from their home stations will also take longer than normal because of reduced organic capability and lack of parts, especially at Ft. Bragg/Pope Field where an enormous number of C-17s are moving through.

Figure 4.7. Adding PMC Aircraft to the GRF Pool of Resources Increases the Number of C-17s Available at Any Time



5. Conclusions and Future Work

This analysis showed the expected time and available quantities of C-17s based on common assumptions made in Air Force planning and in readily available data. The analysis showed that within 24 hours, there is an 89 percent likelihood that between 24 and 47 airplanes could be made available to Fort Bragg/Pope Field for possible GRF deployment. Given that typical planning for GRF deployments might happen over a few days and entail two dozen or so aircraft for the initial deployment, there is a good chance that those planes could be made available, barring other demands on the force.

A number of interesting topics are natural next steps from this work. Incorporating additional data, such as that from Air Mobility Command's Global Decision Support System which may have information on requirements to transport important passengers and could allow us to estimate the resulting reduction in availability discussed in Chapter 1. The volume of airplanes passing through Fort Bragg/Pope Field in a short time presented in this analysis is not constrained by real-world conditions. Future work could determine these real-world throughput limits and investigate having the C-17s queue nearby until space is available. The same analysis presented here could be used to determine availability at other air bases. It could potentially be used to compare the effectiveness of staging points for urgent missions. Bases could be ranked on a "level of urgency," for instance, time required to gather some number of airplanes needed for GRF missions. If likely deployment locations are also known, the time to reach these locations could also be incorporated into the level of urgency ranking. This ranking could help determine which bases are best for hosting GRF forces. If more data can be gathered for previous fiscal years, then comparisons of availability over time (whether it be annual, monthly, etc.) can be made to find trends and potentially learn lessons on how to increase availability or when to be aware of likely decreased availability.

The same analyses could also be performed on other similar airplanes, such as the C-5 or C-130, although consideration for limited range must be given to smaller airplanes such as the C-130.

Appendix A: Cleaning the Data

Some cleanup was necessary before the data could be used in a meaningful way. There were many status conditions, and we grouped them into four categories: FMC, PMC, in use, and unavailable. Some airplanes were missing status and location information, mainly at the beginning of the fiscal year, and others had conflicting statuses with overlapping time frames. Also, tail numbers were not always written in a consistent manner: In some instances, leading digits were dropped.

In total, 164 unique status conditions encompassing 208¹⁹ airplanes over one year were present in the data, most being some type of in-use code for the aircraft. Aircraft listed as FMC were considered FMC. Aircraft that were in use were considered FMC after they completed their sortie and had sufficient crew rest. Aircraft that were listed as PMC because of maintenance issues, supply issues, or both were considered PMC.²⁰ Aircraft listed as damaged, non-mission capable, out for contract work, in depot, or doing aerospace vehicle transfer were all considered unavailable.

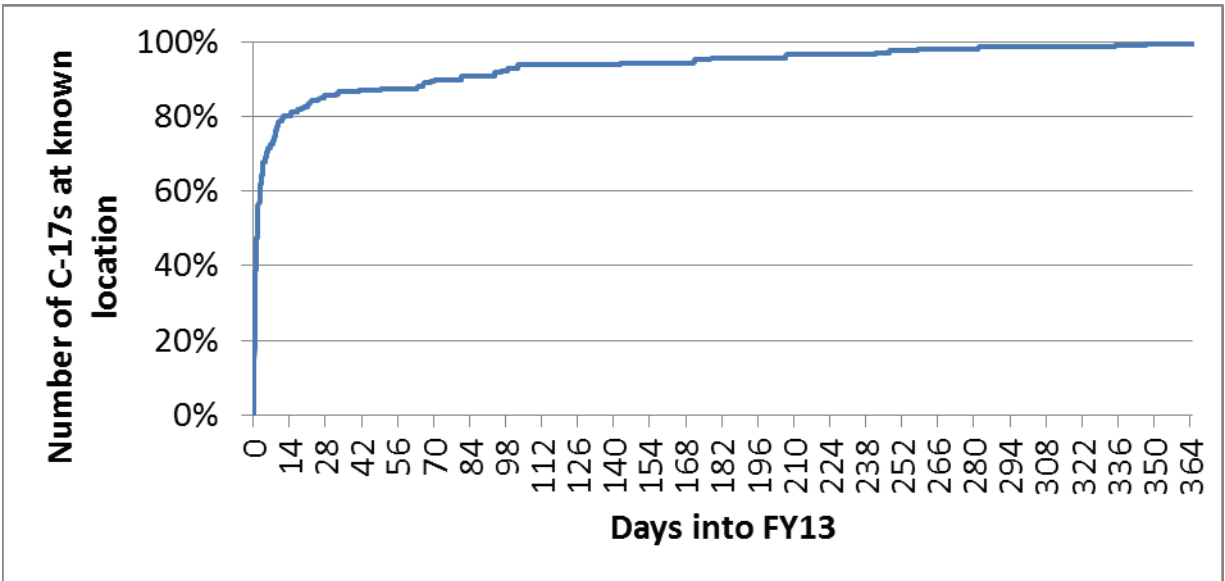
If an airplane's status was not available, it was listed as having an unknown status. This happened mainly at the beginning of the fiscal year. Because data on status changes had an entry only for each time an aircraft's status changed, it is probable that statuses carrying over from FY12 are missing simply because the data selected were for entries in FY13 only. In these cases the airplane retained an "unknown" status until its status changed and an entry appeared in the FY13 data. Only five airplanes of the 208 present in the data suffered from this issue, although for all of these, it was months into the fiscal year before their status changed. In one case, the status did not change until September 2013, nearly a whole year later. These "missing" airplanes were considered unavailable, contributing a small degree to a conservative undercounting of availability.

The airplanes are all assumed to be at their last known location until they fly a sortie to move them to a new location. This means that at the beginning of the fiscal year, most locations are unknown, but the issue quickly resolves itself as the C-17s fly sorties, revealing their locations. Figure A.1 shows that, within the first four days, the locations of most airplanes are known. By mid-December, around 90 percent of airplanes are in known locations. It is worth noting that many of the airplanes that remain at unknown locations well into the fiscal year are unavailable (and hence do not complete sorties to reveal their locations), so their location is not important.

¹⁹ Although the USAF C-17 fleet has 213 airplanes, only 208 appeared in the LIMS-EV, AFMC and GRIP data

²⁰ For this analysis, PMC aircraft were considered to be unavailable for use, although they were still tracked separately. See Figures 4.6 and 4.7 to view the potential impact if PMC aircraft are capable of supporting the GRF mission.

Figure A.1. By the End of December, over 90 Percent of C-17s' Locations Are Known



As with the problem of unknown status, this problem arises from our data set starting in October 2012 and a lack of ability to see where the airplanes were before that time. A necessary result of the large amount of missing data is that the first four days of the fiscal year (October 1–4) were excluded from analysis because of the incompleteness of the location data. After this time period, the large majority of the C-17 fleet is accounted for, and 362 days of data yet remain.

To ensure a conservative estimate of aircraft availability, if an airplane had overlapping status conditions, the most restrictive condition was assumed to be the correct one. For example, an airplane listed as unavailable from October 1, 2012 to October 4, 2012, and FMC from October 3, 2012 to October 6, 2012, would be considered unavailable from October 1–4 and FMC from October 5–6. Whichever status was considered correct also determined the location to be used. In the above example, the airplane was said to be at the location associated with the unavailable status from October 1–4.

Tail numbers in the C-17 data sometimes dropped leading digits. Comparing these shortened tail numbers to the group of longer tail numbers led to an easy matching between the two.

Appendix B: Simulation Details

Determining Airplane Status and Location via Brute Force

We used a brute force method to determine airplane location and status. The input data consisted of roughly 150,000 lines of status and location data. This means that there were just over 700 lines to search per airplane. Although some searches will terminate within the first few lines and some will have to search nearly all the entries for the airplane, the average search can be considered to be about 350 lines. One year has 8,760 hours, and each hour is compared to the start and end times of the input data. Therefore, around 625,000 comparisons must be made per airplane to determine its status and location throughout the year. This takes around 3–5 seconds to calculate per airplane, or 10–20 minutes for the entire fleet. Because this brute force method is relatively quick, no further effort was made to streamline the algorithm.

Status and location for each airplane were calculated for each hour of FY13. The algorithm first searches to see if the airplane is unavailable, then to see if it is PMC, then in use, and finally FMC. When a match is found, the search stops and does not look to see if the airplane has a conflicting, more available status. So an airplane found to be PMC at hour X is not checked to see if it is also listed as in use or FMC at that same time. This is done to maintain the conservative estimate of assuming the most restrictive condition to be the correct one. For each hour, the algorithm searches all lines of the airplane’s status data, in “most restrictive availability” and chronological order, until it finds a line where the current hour being searched is between beginning and end time of that line. The status and location associated with this line are the airplane’s status and location at that time. Figure B.1 shows this visually with a notional example. If all of these searches come up empty, then the status information on the airplane is unavailable, as discussed in the Data Overview section, and location is assumed to be the last known location of the airplane, or unknown if no previous location information is given.

Determining Distance to Fort Bragg/Pope Field via Lookup

Once the location for all airplanes was known at all times (or as well as the input data allowed because of missing information), the distance to Fort Bragg/Pope Field could be calculated. First, we constructed a table with the latitude and longitude of all locations where C-17s had arrived at or departed from in FY13. Knowing this and the latitude and longitude of Fort

Figure B.1. A Notional Example: The Algorithm Searches by Status, Then by Time

Where is the airplane at 10:00?		
Status	Start	End
Unavailable	1:00	5:40
PMC	8:05	11:30
In use	5:40	8:05
In use	11:45	13:20
FMC	10:15	11:45
FMC	13:20	20:30

At 10:00 the airplane is outside the bounds of the “unavailable” time period

But it is within bounds of the PMC time period, so it is considered PMC

Further conditions are not checked, even though there is an FMC status that overlaps the PMC time period

Bragg/Pope Field, the great circle distance between the two locations was calculated.²¹ Then, for each airplane at each hour, a simple lookup was done where the known location was used in Table B.1 to determine distance to Fort Bragg/Pope Field.

Determining Time Until the Aircraft Is Ready to Leave Fort Bragg/Pope Field: A Summation

Once the distance to Fort Bragg/Pope Field was known, the time until the C-17 could take off from Fort Bragg/Pope Field could be calculated. The time until an aircraft can leave Fort Bragg/Pope Field is the sum of time remaining in the current flight (if any), time for crew rest²² before leaving the current location, flight time to Fort Bragg/Pope Field, and crew rest needed before the crew could take off from Fort Bragg/Pope Field. For unavailable aircraft, the time until departure from Fort Bragg/Pope Field was irrelevant as the aircraft could not take off at all, but the value was still calculated. It was assumed in all cases that the crew remains with the aircraft. Without any information on crew availability, this assumption is necessary and conservative if spare crews are sometimes available to be substituted in shorter time frames.

Only in-use aircraft had remaining flight time. This was calculated as the arrival time of the current flight minus the current time under consideration. For unavailable, PMC, or FMC aircraft, this value was zero.

²¹ The great circle distance does not reflect the actual distance flown, as this is dictated by the specific flight plan of the aircraft. However, these distances are used in Table B.1 to determine time of flight, including the need to stop and refuel.

²² Time between missions consists of 0.75 hours post-mission shutdown, 12 hours crew rest, and 3.75 hours pre-flight.

Crews must shut down after completing a mission, which takes approximately 0.75 hours. Then, crews must rest for 12 hours and need 3.75 hours from alert until they are ready to take off. So, for airplanes in use at the time under consideration, this value was 16.5 hours. For PMC and FMC aircraft, it was 12.75 hours minus the time already spent on the ground since the previous sortie, plus 3.75 hours for pre-flight time.

Flight time to Fort Bragg/Pope Field was obtained from the block speed table in AFPAM 10-1403. For flights longer than 4,000 nm the time was considered to be the composite of the time for a 4,000 nm flight, the time for a flight consisting of the remaining distance, and the ground time given in AFPAM 10-1403 of 2.25 hours. For simplification purposes, no specific stopover points were used. It was assumed that some airport was available at which to stop and refuel at 4,000 nm from the point of origin. Also, because of crew duty day requirements, any flights longer than 7,200 nm require an additional crew rest period. The block speed table used in this analysis is shown in Table B.1.

Finally, 0.75 hours of post mission shutdown, 12 hours of crew rest, and 3.75 hours of preflight time at Fort Bragg/Pope Field were added to all airplanes not already at Fort Bragg/Pope Field. Airplanes that were in use on their way to Fort Bragg/Pope Field or PMC and FMC and already at Fort Bragg/Pope Field had this crew rest covered with the previous crew rest calculation step.

As with all previous calculations the time until the airplane can leave Fort Bragg/Pope Field was calculated for each C-17 at every hour of FY13.

Data on Time Until Departure from Fort Bragg/Pope Field Can Indicate How Much of the Fleet Is Available

On average, at any given hour, 43 percent of the C-17 fleet are listed as FMC and not in use. Another 7 percent are in the air. This means that half the fleet is fully capable of being used at any time, after allowing for the completion of current sorties. Additionally, another 25 percent of C-17s are listed as PMC on average. Some fraction of these could be usable, depending on the particular issue keeping them from being FMC and the intended mission. The remaining quarter of the fleet is, in general, unavailable.²³

Creating an Availability Heatmap

To get a more nuanced picture of aircraft availability, we created a heatmap that imposed frequency onto a plot of *Time until departure from Fort Bragg/Pope Field v. Number of*

²³ On average, 1.5 percent of the fleet has an unknown status. This number is larger early in the fiscal year because of missing data for the previous fiscal year. This number drops to <1 percent for snapshots of time in the latter half of FY13.

Table B.1. C-17 Block Speed from AFPAM 10-1403

Distance (nm)	Block Speed (kt)	Ground Time (h)	Time to Reach Fort Bragg/Pope Field (h)
0	0	0	0
500	335	0	1.49
1000	384	0	2.60
1500	400	0	3.75
2000	405	0	4.94
2500	406	0	6.16
3000	406	0	7.39
3500	409	0	8.56
4000	412	0	9.71
4500	412 (first 4000nm) 335 remainder	2.25	13.45
5000	412 (first 4000nm) 384 remainder	2.25	14.56
5500	412 (first 4000nm) 400 remainder	2.25	15.71
6000	412 (first 4000nm) 405 remainder	2.25	16.90
6500	412 (first 4000nm) 406 remainder	2.25	18.12
7000	412 (first 4000nm) 406 remainder	2.25	19.35
7500	412 (first 4000nm) 409 remainder	2.25 + 16.5	37.02
8000	412 (first 4000nm) 412 remainder	2.25 + 16.5	35.92
8500	412 (first 8000nm) 335 remainder	2.25 + 16.5	39.66
9000	412 (first 8000nm) 384 remainder	2.25 + 16.5	40.77
9500	412 (first 8000nm) 400 remainder	2.25 + 16.5	41.92
10000	412 (first 8000nm) 405 remainder	2.25 16.5	43.21
10500	412 (first 8000nm) 406 remainder	2.25 + 16.5	44.33
11000	412 (first 8000nm) 406 remainder	2.25 + 16.5	45.56

Airplanes Available. “Hotter” colors indicate more common occurrences of number of airplanes available to depart within a given time window.

To accomplish this, the data was transformed in Microsoft Excel. First, at each hour of FY13, it was determined how many airplanes were available to leave within 12, 12.5, 13, etc. hours. This data was reformatted into cumulative values for each hour in FY13 (3 airplanes can leave

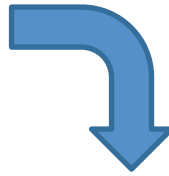
Fort Bragg/Pope Field within 12 hours, 5 within 13, ..., 105 within 80). Finally, the frequency of these cumulative values was counted in even spaced bins. This data was used to create a heatmap. See Figure B.2 for a notional example of this process.

The map of frequency into number of airplanes and time until departure gives a heatmap of when airplanes are likely to be available. This heatmap can be seen in Figure B.3.

Figure B.2. Transforming the Data for the Heatmap

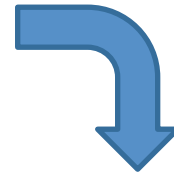
How Many Airplanes can be ready to leave Fort Bragg within a specified amount of time?

		Time until departure from Ft. Bragg		
		12 hours	12.5 hours	13 hours
Time into FY13	Hour 1	0	1	2
	Hour 2	2	0	1
	Hour 3	1	1	1
	Hour 4	0	2	1



How Many Airplanes can be ready to leave Fort Bragg within a specified amount of time (cumulative value)?

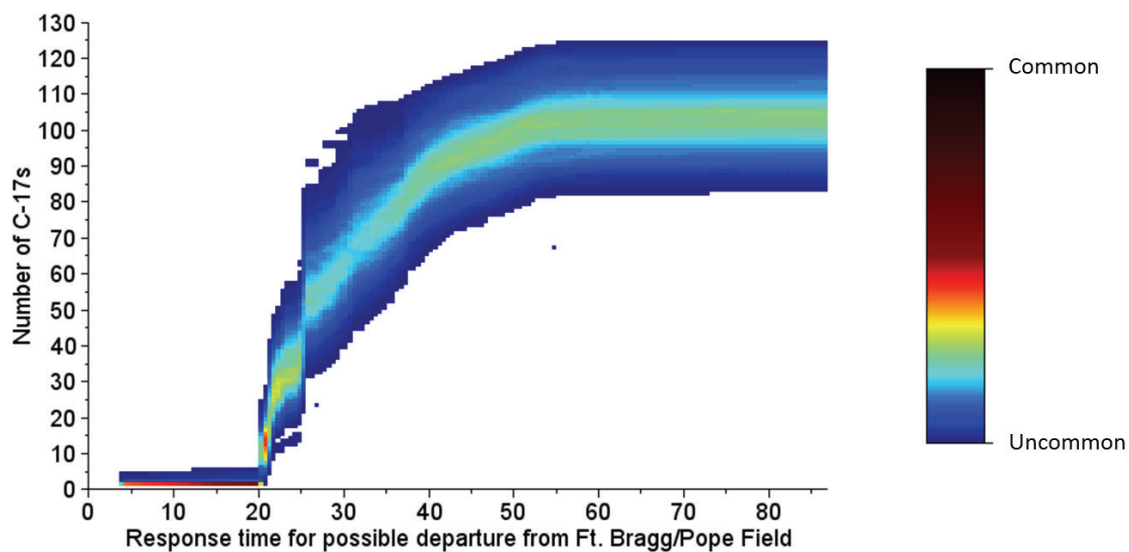
		Time until departure from Ft. Bragg		
		12 hours	12.5 hours	13 hours
Time into FY13	Hour 1	0	1	3
	Hour 2	2	2	3
	Hour 3	1	2	3
	Hour 4	0	2	3



How Many hours in FY13 had the specified number of airplanes ready to leave Fort Bragg within the specified amount of time?

Number of C-17s available	Time until departure from Ft. Bragg		
	12 hours	12.5 hours	13 hours
1	1	1	0
2	1	3	0
3	0	0	4

Figure B.3. Heatmap of C-17 Availability



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