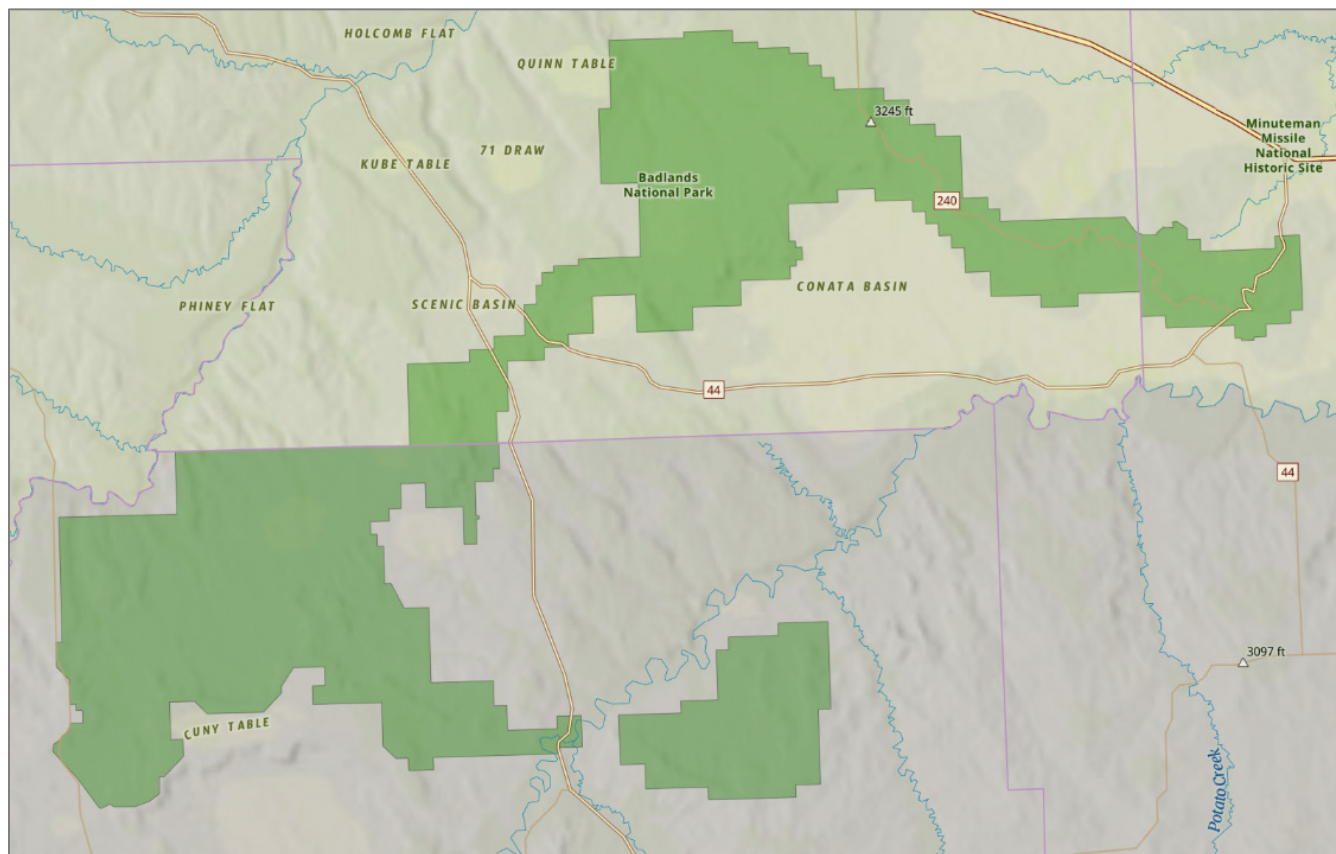




Exploring Spatial Patterns of Overflights at Badlands National Park



Map of Badlands National Park.

Map service layer credits: Esri, USGS, South Dakota Game Fish and Parks, HERE, Garmin, SafeGraph, FAO, METI/NASA, EPA, and NPS.

Exploring spatial patterns of overflights at Badlands National Park

Science Report NPS/SR—2024/115

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Abstract

This study explored spatial patterns of overflights at Badlands National Park (BADL). Overflights were analyzed from July 13, 2022 to August 27, 2022 (46 days) using Automatic Dependent Surveillance-Broadcast (ADS-B) data. There were 26 days of data and 20 days of missing data due to technical difficulties with the ADS-B logger. The first phase of analysis focused on all overflights and found overflights above most areas of BADL. The second phase of analysis focused on low-level overflights that fly below 7,000ft mean sea level (MSL) and fly within 10-miles of the BADL boundary, which found a concentration of flights between 4,000–7,000 feet MSL near the eastern boundary of BADL. The third phase of analysis removed all overflights known not to be air tours. Figures were produced that display all the flights of the cleaned dataset, waypoints across AGL altitudes, waypoints across MSL altitudes, flightpaths for fixed-wing single engine, flightpaths for rotorcraft, flight paths for fixed-wing multi engine, and flightpaths for specific air tour operators. This information can be used for planning and management purposes and this study serves as a resource for future research.

List of Acronyms

AGL: Above ground level

ADS-B: Automatic Dependent Surveillance-Broadcast

BADL: Badlands National Park

DEM: Digital Elevation Model

FAA: Federal Aviation Administration

GIS: Geographic information systems

MSL: Mean sea level

NPS: National Park Service

NPATMA: National Parks Air Tour Management Act

Introduction

Badlands National Park (BADL) was designated as a national park in 1978 and it has been protected since 1929 as a national monument (Stoffer, 2003). BADL is located in southwestern South Dakota and nearby to the west is Mount Rushmore National Memorial, Wind Cave National Park, and Jewel Cave National Monument. BADL encompasses 244,000 acres of scenic landscapes, unique geologic formations, diverse wildlife, hiking trails, and designated wilderness. Also, it is located far from major cities which contributes to it exceptionally dark night skies that are known for outstanding star gazing (National Park Service, 2020). The highest elevation within BADL is 3,282 feet above mean sea level (MSL) on Sheep Mountain Table and the lowest elevation is 2,460 feet MSL along Sage Creek (Stoffer, 2003). BADL receives approximately 1,000,000 visitors per year. In 2020, BADL received 916,932 visitors, in 2021 it received 1,224,226 visitors, and in 2022 it received 1,006,809 visitors (National Park Service, 2023a). BADL is also popular to view from air tours.

In 2019, commercial air tour operators reported conducting a total of 1,349 air tours at BADL (Lignell, 2019), while in 2020 operators reported 2,264 air tours (Ward & Shields, 2023). The National Parks Air Tour Management Act of 2000 (NPATMA) (Public law 106-81) requires the National Park Service (NPS) to manage air tours at all units that receive more than 50 air tours per year, with the exception of Grand Canyon National Park and all national parks in the State of Alaska (Beeco & Joyce, 2019). The purpose of this report is to provide examination of the spatial patterns of overflights at BADL.

As of January 1, 2020, the Federal Aviation Administration (FAA) requires all aircraft that enter designated airspace to be equipped with ADS-B technology (see 14 CFR § 91.225 and 14 CFR § 91.227) (Federal Aviation Administration, 2023). BADL is located under uncontrolled airspace, which means ADS-B is not required on aircraft that fly above BADL. Regardless of the airspace designation, prior studies suggest a rather ubiquitous adoption of ADS-B by aircrafts in the United States.

ADS-B signals are transmitted from aircraft and provide location information and unique identifiers to improve airspace safety and air traffic efficiency (Federal Aviation Administration, 2023). This study analyzed overflights using ADS-B technology to track flights that flew above BADL. The data discussed in this report span from July 13th, 2022 to August 27th, 2022 and include 26 days of data (there were 20 days of missing data). After the data were screened of flights known not to be air tours, the dataset was comprised of 118 flights.

Methods

Data Collection

Data were collected by one ADS-B terrestrial data logger, which was located near the northeast entrance kiosk of BADL (43.788352, -101.903583, Figure 1). The data logger was positioned with an unimpeded and expansive skyward exposure. The logger recorded ADS-B signals as text files.

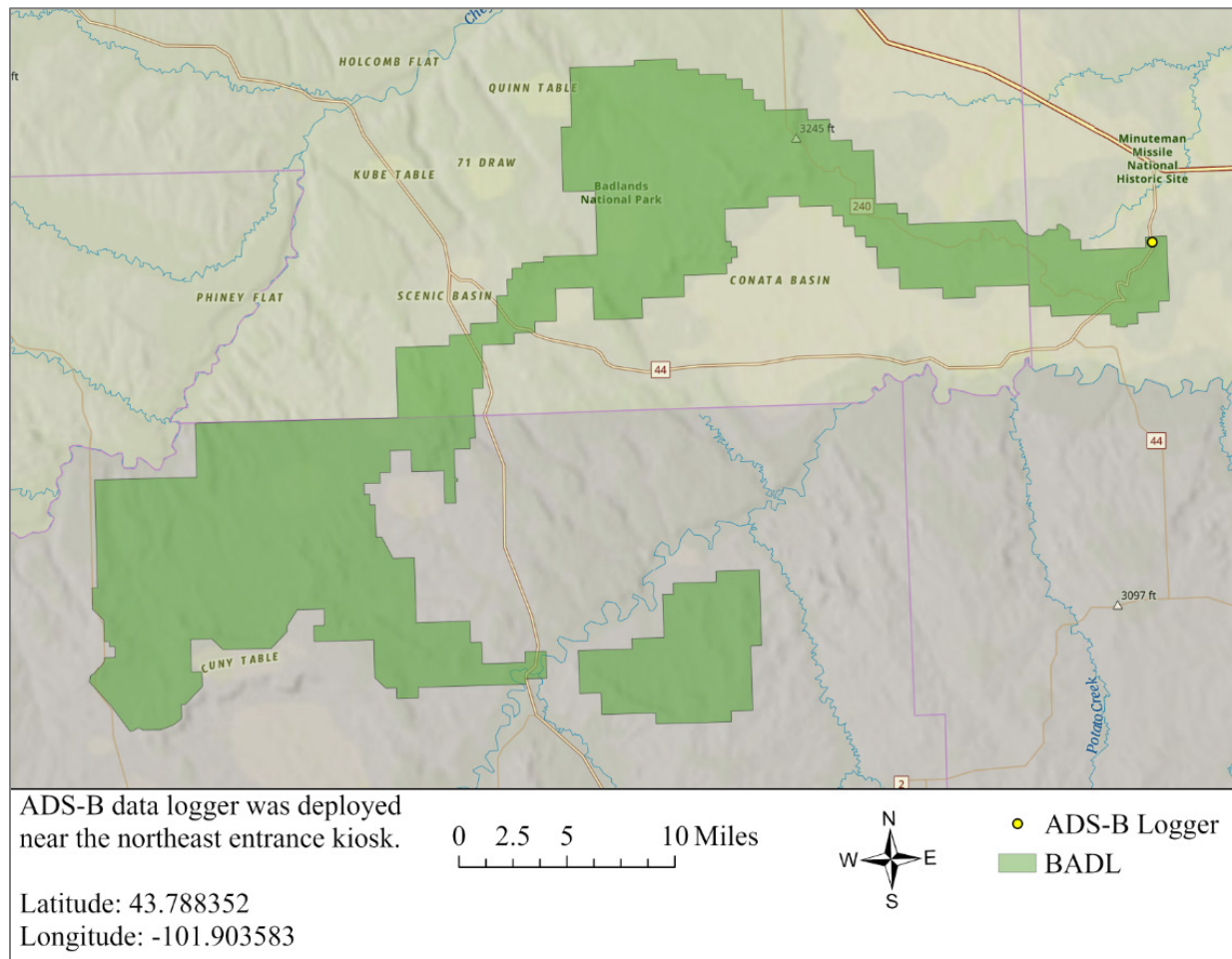


Figure 1. Location of ADS-B data logger.

Data Processing and Cleaning

Data processing, cleaning, and analysis were accomplished using a custom ArcGIS Pro toolbox with multiple Python-based geoprocessing tools that automated and simplified processing and analysis of ADS-B data. The toolbox conducted the following tasks: processed raw ADS-B data files, created waypoint and flightline feature classes (spatial reference = North American Datum 1983 Universal Transverse Mercator Zone 13N), merged daily waypoints and flightlines, screened for suspected flights known not to be air tours (discussed in the next paragraph), summarized waypoint altitudes, summarized number of flights across several temporal scales (monthly, daily, hourly), and

summarized number of flights across aircraft types (rotorcraft, fixed-wing single engine, fixed-wing multi engine).

This report expresses altitude using mean sea level (MSL) and above ground level (AGL). Altitude expressed in MSL refers to the altitude of an aircraft above sea level, regardless of the terrain below it, whereas altitude expressed in AGL is a measurement of the distance between the ground surface and the aircraft. To calculate AGL altitudes for each waypoint, a 10-meter digital elevation model (DEM) was used (United States Geological Survey, 2021). The AGL altitudes were calculated by subtracting the reported altitudes of the ADS-B logger minus the elevation of the DEM for every point location (x,y) (see Beeco et al., 2020 for exact method).

ADS-B technology can use barometric altitude or geometric altitude. Barometric altitude is determined by measuring air pressure and must be regularly calibrated. Geometric altitude is calculated using the Global Positioning System (GPS). While error can result from each type of technology, GPS is generally considered a more reliable and accurate measure, but the aviation industry has long used barometric altitudes during flight. Aircraft owners/operators determine which system to use on their aircraft. The analysis in this report does not attempt to correct for any error associated with altitude information, as this would be nearly impossible and overly burdensome. Therefore, calculations of AGL can in some cases be negative. This can occur for low flying aircraft that have an ADS-B system reporting an altitude lower than actual. Further, AGL is calculated using 10x10m Digital Elevation Models (DEM). This level of resolution can also introduce some error. If negative AGL values exist, they are reported in the analysis.

To explore spatial patterns of overflights at BADL, analysis was conducted in three phases. Phase 1 and Phase 2 report altitudes using MSL, while Phase 3 uses AGL. This is because MSL is better suited for understanding aircraft patterns across a larger space or scale because the baseline (sea level) does not change. However, because Phase 3 includes more detailed examinations of the data, AGL analysis was used because it better contextualizes how flights pass over undulating terrain and associated terrestrial resources and visitors' experiences. All maps produced during analysis used Esri basemaps with service layer credits for: Esri, USGS, South Dakota Game Fish and Parks, HERE, Garmin, SafeGraph, FAO, METI/NASA, EPA, and NPS; and all data were projected to North American Datum 1983 Universal Transverse Mercator Zone 13N.

Phase 1 Methods

The purpose of the first phase was to explore all overflight paths above BADL regardless of flight type or altitude. Thus, the flightline feature class was not cleaned of any flight types nor was an altitude threshold implemented. To understand how flight paths extended beyond the park boundary, a 10-mile buffer around the BADL boundary was used. One map was produced and shows all overflights during data collection (July 13th, 2022–August 27th, 2022).

Phase 2 Methods

The purpose of the second phase was to understand low-level overflights above BADL regardless of flight type. Similar to Phase 1, a 10-mile buffer was used. Low-level overflights were identified as having an altitude less than 7,000ft MSL. This altitude was chosen because the highest point at

BADL is 3,282 feet on top of Sheep Mountain (Stoffer, 2003), and approximately 4,000ft above the highest point in the park would capture flights that had the greatest impact on the acoustic environment within the park. To understand flight altitudes, a waypoint feature class was used. One map was produced that show all overflights that flew beneath 7,000ft MSL and within 10 miles of BADL. This map classified waypoints using MSL altitudes.

Phase 3 Methods

The purpose of the third phase was to focus on flights that were likely air tours. The toolbox also joined ADS-B data to the FAA Releasable Database via aircraft unique identifiers to determine aircraft tail number, type registrant (e.g., government), and engine type. Using this info along with ADS-B data, the toolbox screened for suspected flights known not to be air tours by cleaning the data of 1) civil patrol flights, 2) major airlines, 3) straight-line flights, 4) flights with a flightpath less than a mile in length, and 5) survey flights. Civil patrol flights were identified as government aircraft (FAA Releasable Database type registrant = 5). Major airlines were identified using a list of major airlines (e.g., American Airlines, Delta Airlines, Southwest Airlines) entered into the Python-based tool. Straight-line flights were assessed by calculating sinuosity values. Sinuosity is a measure of how much a linear feature deviates from a straight-line condition and can be calculated as the ratio of total flight path length to the straight-line distance between a flight's initial and final waypoint. A perfectly straight flight path would have a sinuosity of one, but as the number of meanders in the path increases (e.g., the characteristic back and forth of survey flight behavior) sinuosity will begin to approach zero. All overflights that received sinuosity values greater than or equal to 0.80 were visually inspected to validate straight-line paths were flown and these were subsequently removed from analysis. Flights less than a mile in length were removed due to data integrity issues. Lastly, survey flights were removed from analysis because of their undue influence on analysis, infrequent nature, and known flight purpose. Survey flights were clearly identifiable by their flight patterns. Removal of survey flights was the last cleaning procedure because this step requires visual analysis which is easier to conduct after the other cleaning procedures have been accomplished. Survey flight behavior can be identified when a flight route consists of consecutive back and forth lateral movements in a parallel progression. Conversely, air tour behavior generally consists of flight routes that veer toward sightseeing locations and consist of sporadic S-turns and loops (Beeco & Joyce, 2019). After this cleaning step, the remaining flights are likely to be air tours, but without cross checking with every operator or plane owner, a definitive confirmation that all remaining flights are air tours is not possible.

Two more figures were produced to spatially compare AGL and MSL waypoint trends. The first figure displays waypoint altitudes between 0–5,000ft AGL using a 1,000ft AGL interval. The second figure displays waypoint altitudes between 2,460–8,125ft MSL (2,460ft MSL is the lowest elevation in BADL).

Next, descriptive analyses were conducted to understand waypoint frequencies across AGL and MSL altitudes; number of flights across months, day of the week, and hour of the day; and number of flights across aircraft types. To gain insight into overflight travel patterns across aircraft types, two more figures were produced for fixed-wing single engine aircraft and rotorcraft aircraft (no fixed-

wing multi engine aircraft were included in Phase 3). Lastly, three figures were produced that display flight routes of operators who conducted the most flights.

Results

Results — Phase 1

Data were collected by a data logger located near the BADL northeast entrance kiosk. The data were collected for 46 days (Figure 1). There were 26 days of data and 20 days of missing data due to technical difficulties with the ADS-B logger. Figure 2 shows all overflights collected ($n=1,381$) from July 13th, 2022 to August 27st, 2022. This figure reveals the overall patterns of flights above BADL across the entire airspace. Visual analysis of these data suggests that most flights above BADL seem to be heading to or departing from Rapid City, SD.

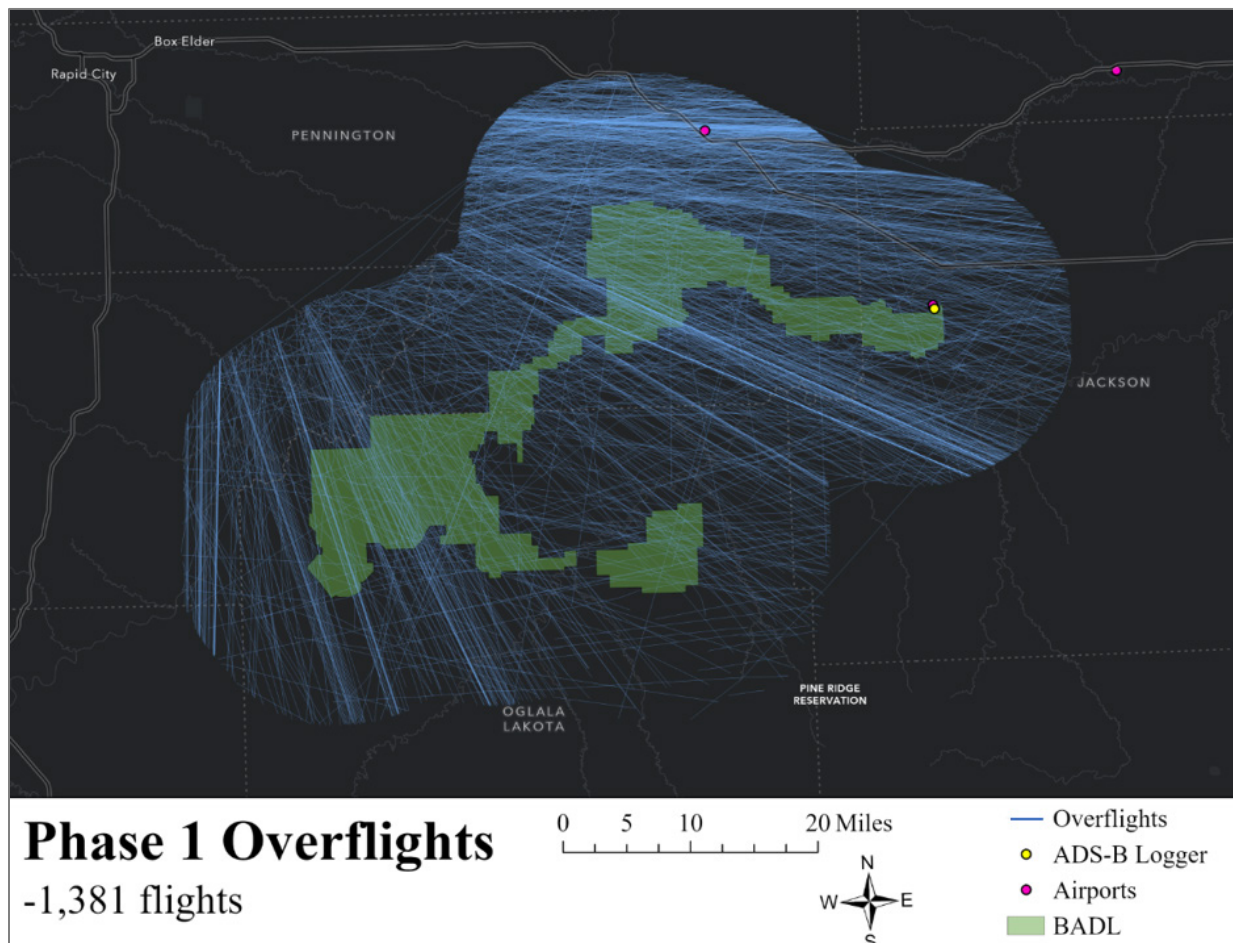


Figure 2. All overflights collected from July 13th, 2022 to August 27th, 2022.

Results — Phase 2

The research team mapped low-level overflights that flew below 7,000 feet MSL regardless of flight type. Figure 3 shows the waypoints of low-level overflights extending 10 miles from the BADL perimeter. A total of 55,467 waypoints were analyzed. The lowest altitude was 2,400 feet MSL, which occurred to the northeast of BADL. There are not any clear flight path patterns when examining these low-level flights. Further, while it appears that the northeastern portion of the park has more flights, this could be due to the location of the logger unit.

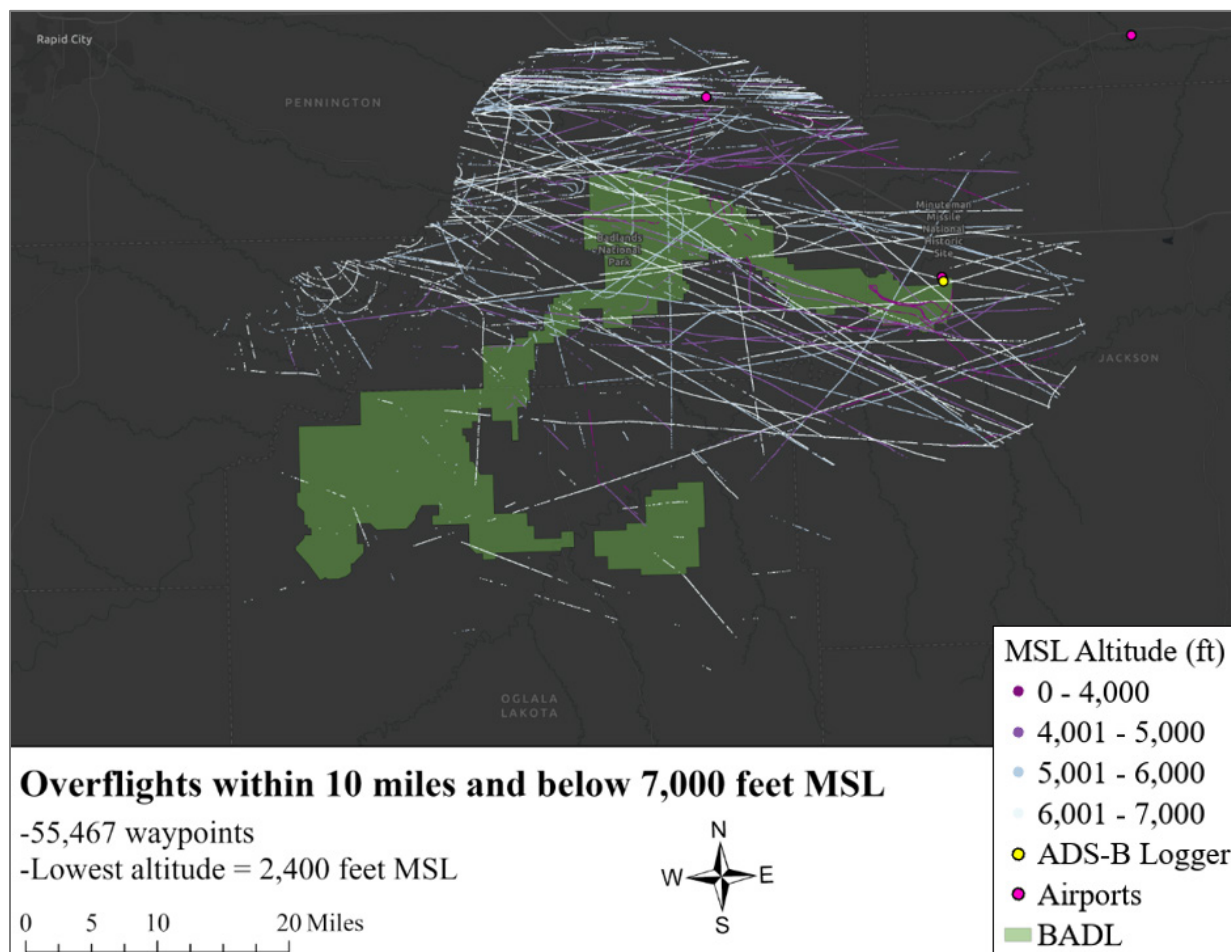


Figure 3. Low-level overflights within 10 miles of BADL.

Results — Phase 3

Data were cleaned of all flights known not to be air tours, which resulted in the following numbers of flights removed: 7 civil patrol flights, 19 major airlines flights, 1,237 straight-line flights, and 1 flight with a flightpath less than a mile in length. This left 118 flights that flew within 10 miles of BADL (Figure 4).

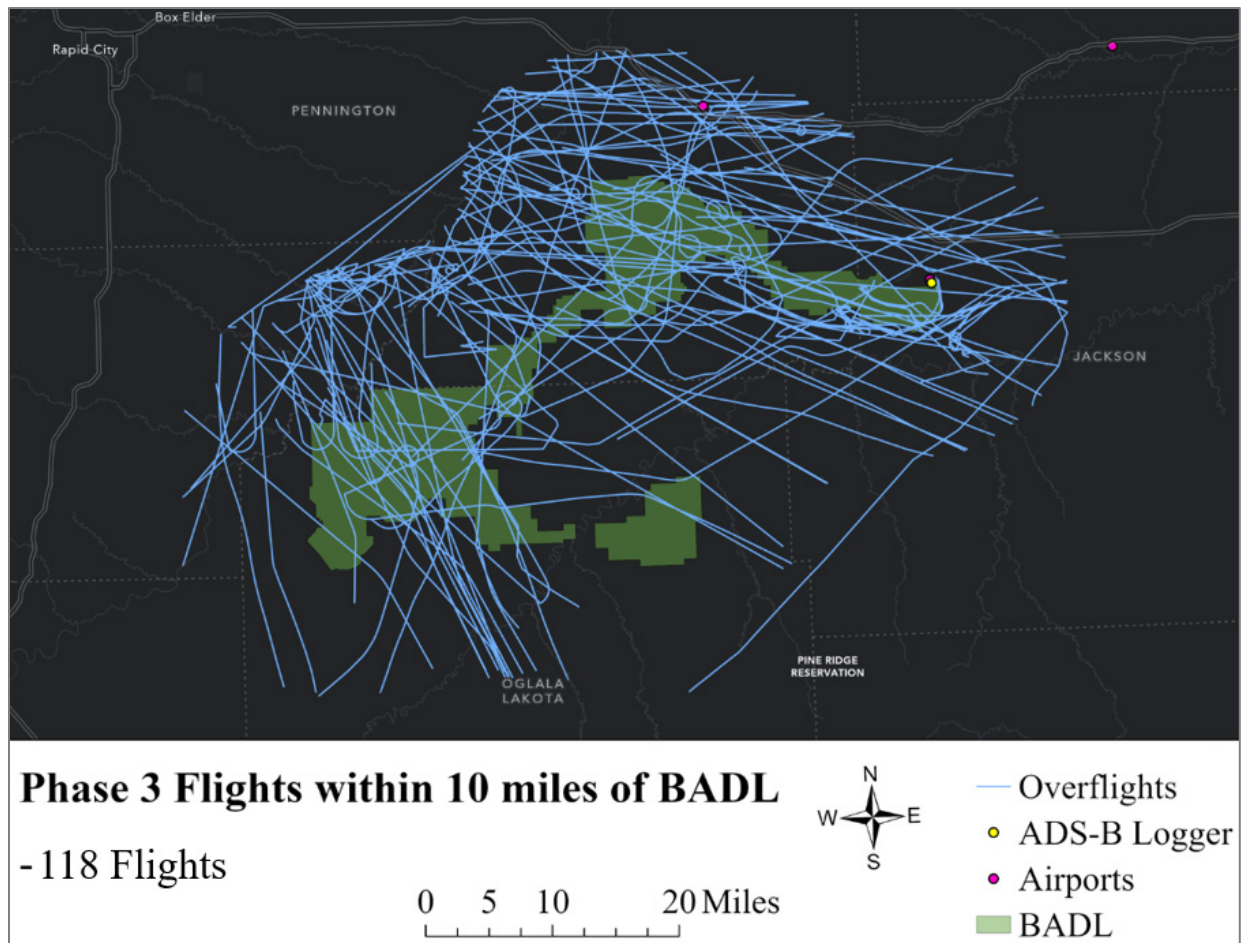


Figure 4. Overview of Phase 3 flights.

Next, analysis focused on waypoints within a half-mile of the BADL perimeter to understand which areas of the park are impacted by low-level overflights. Flights beyond a half-mile of the park boundary were removed, which left 37 flights. To further understand altitude trends of waypoints, two visualizations were produced. Figure 5 (altitudes ranging from 0–5,000ft AGL) displays AGL altitude trends directly above BADL and show variability in flight altitudes. Figure 6 displays waypoints classified as MSL altitudes. This figure shows altitudes ranging from the lowest point in BADL (2,460ft MSL) to the highest waypoints detected (8,125ft MSL).

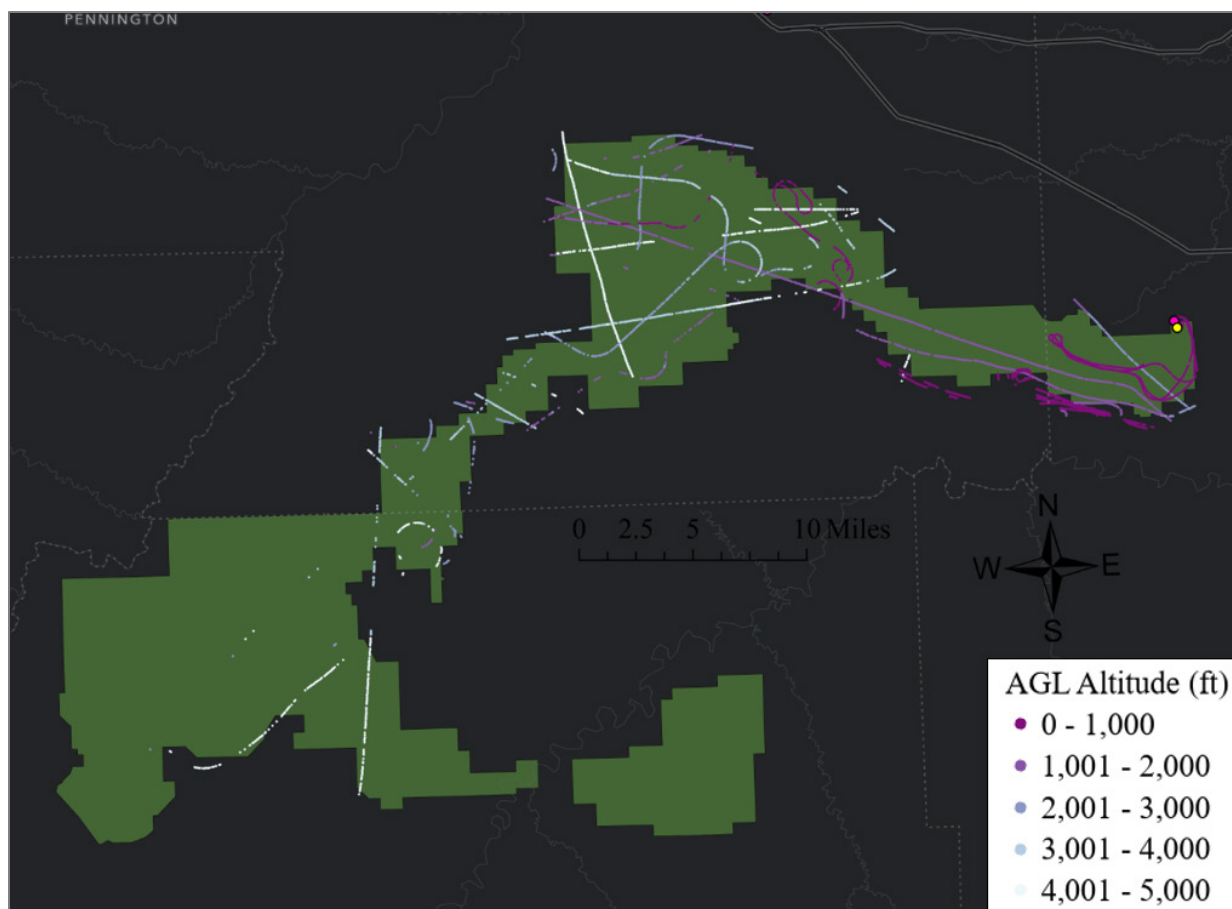


Figure 5. AGL altitude trends of altitudes ranging from 0–5,000ft AGL for waypoints within 0.5-mile of the BADL boundary ($n=5,448$ waypoints).

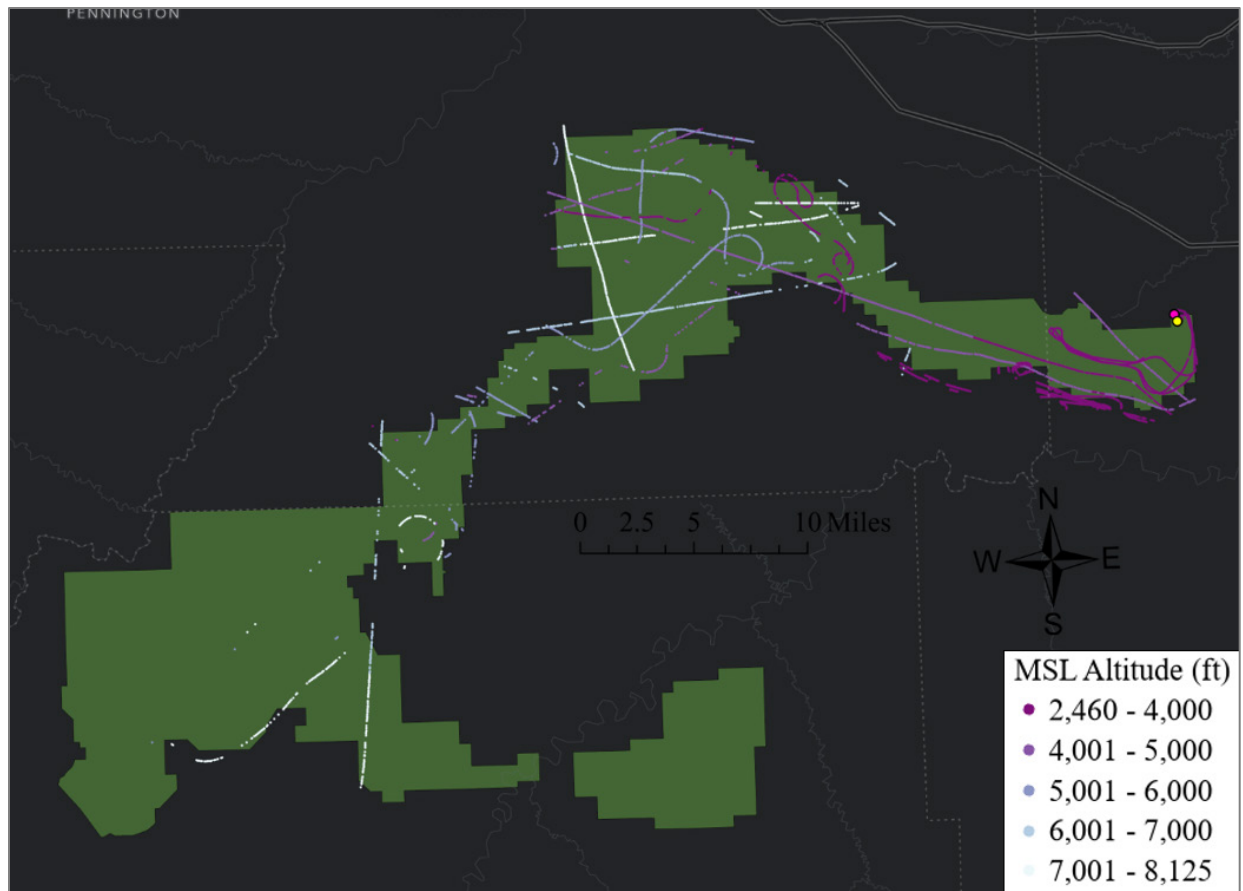


Figure 6. MSL altitude trends of altitudes ranging from 2,460–8,125ft MSL for waypoints within 0.5-mile of the BADL boundary ($n=5,448$ waypoints).

The information displayed in Figures 5 and 6 were entered into tables to quantitatively understand which altitude intervals had the highest percentage of waypoints. Table 1 shows analysis of waypoints across AGL altitudes (number of waypoints = 5,448) and Table 2 shows analysis the same waypoints across MSL altitudes (number of waypoints = 5,448). The AGL altitude interval that received the highest percentage of waypoints was 1,501–2,000ft (Table 1), but note that the following altitude intervals had high percentages of waypoints: 501–1,000ft AGL and 1,001–1,500ft AGL. The MSL altitude interval that received the high percentage of waypoints was 3,501–4,000ft MSL (Table 2), but note that the following altitude intervals had a high percentage of waypoints: 2,460–3,000ft MSL, 3,001–3,500ft MSL, 3,501–4,000ft MSL, 4,001–4,500ft MSL, and 6,501–7,000ft MSL.

Table 1. Number and percentage of waypoints across AGL altitude intervals ($n=5,448$).

AGL altitude	Number of waypoints	Percentage of waypoints
0–500ft	508	9.3
501–1,000ft	1007	18.5
1,001–1,500ft	749	13.7
1,501–2,000ft	1108	20.3
2,001–2,500ft	349	6.4
2,501–3,000ft	320	5.9
3,001–3,500ft	223	4.1
3,501–4,000ft	367	6.7
4,001–4,500ft	416	7.6
4,501–5,000ft	401	7.4

Table 2. Number and percentage of waypoints across MSL altitude intervals ($n=5,448$).

MSL altitude	Number of waypoints	Percentage of waypoints
2,460–3,000ft	635	13.3
3,001–3,500ft	742	15.5
3,501–4,000ft	985	20.6
4,001–4,500ft	684	14.3
4,501–5,000ft	469	9.8
5,001–5,500ft	281	5.9
5,501–6,000ft	433	9.0
6,001–6,500ft	72	1.5
6,501–7,000ft	488	10.2

Next, overflights were analyzed across months, days of the week, and hours of the day (total flights analyzed = 36). Table 3 shows number of days air tour data were collected, overflights per month, and average number of flights per day for the data collection duration, which occurred from July 13th, 2022 to August 27th, 2022. BADL received the most overflights during July of 2022 (1.68 average number of flights per day).

Table 3. Number and percentage of overflights across months ($n=36$).

Month	Number of data collection days *	Number of overflights	Average Number of overflights per day
July 2022	19	32	1.68
August 2022	7	5	0.71
Total	26	37	1.42

* Data collection did not occur every day because of equipment failure.

Table 4 shows percentage of overflights across days of the week. The day of the week with the highest percentage of flights was Thursdays (44.40%). Tuesdays received no flights that were included in Phase 3 analysis. All Tuesday flights were removed from the initial dataset because they met criteria that clearly identified them as not being air tours. Table 5 shows percentage of overflights across hour of the day for when air tours are permitted. Most overflights occur from 9:00am to 2:00pm. Phase 3 did not have any flights collected from 6:00pm–7:00pm. Table 6 shows percentage of overflights across aircraft type. Fixed-wing single engine is the aircraft type most common among overflights at BADL. Phase 3 did not have any flights that were fixed-wing multi engine.

Table 4. Percentage of overflights by days of the week.

Day of the week	Percentage of overflights
Monday	8.30
Tuesday	–
Wednesday	13.90
Thursday	44.40
Friday	13.90
Saturday	8.30
Sunday	11.10

Table 5. Number and percentage of overflights by hours of the day for weekdays ($n=26$) and weekends ($n=7$).

Hour	Percentage of overflights
8:00am–9:00am	5.6
9:00am–10:00am	30.6
10:00am–11:00am	2.8
11:00am–12:00pm	11.1
12:00pm–1:00pm	5.6
1:00pm–2:00pm	16.7
2:00pm–3:00pm	8.3
3:00pm–4:00pm	2.8
4:00pm–5:00pm	8.3
5:00pm–6:00pm	5.6
6:00pm–7:00pm	–
7:00–8:00pm	2.8

Table 6. Percentage of overflights by aircraft type.

Aircraft type	Percentage
Fixed-wing single engine	93.55
Rotorcraft	6.45

Using the cleaned dataset, two more figures were produced to show overflight travel patterns by aircraft type. Figure 7 displays overflight travel patterns for fixed-wing single engine. Figure 8 displays overflight travel patterns for rotorcraft.

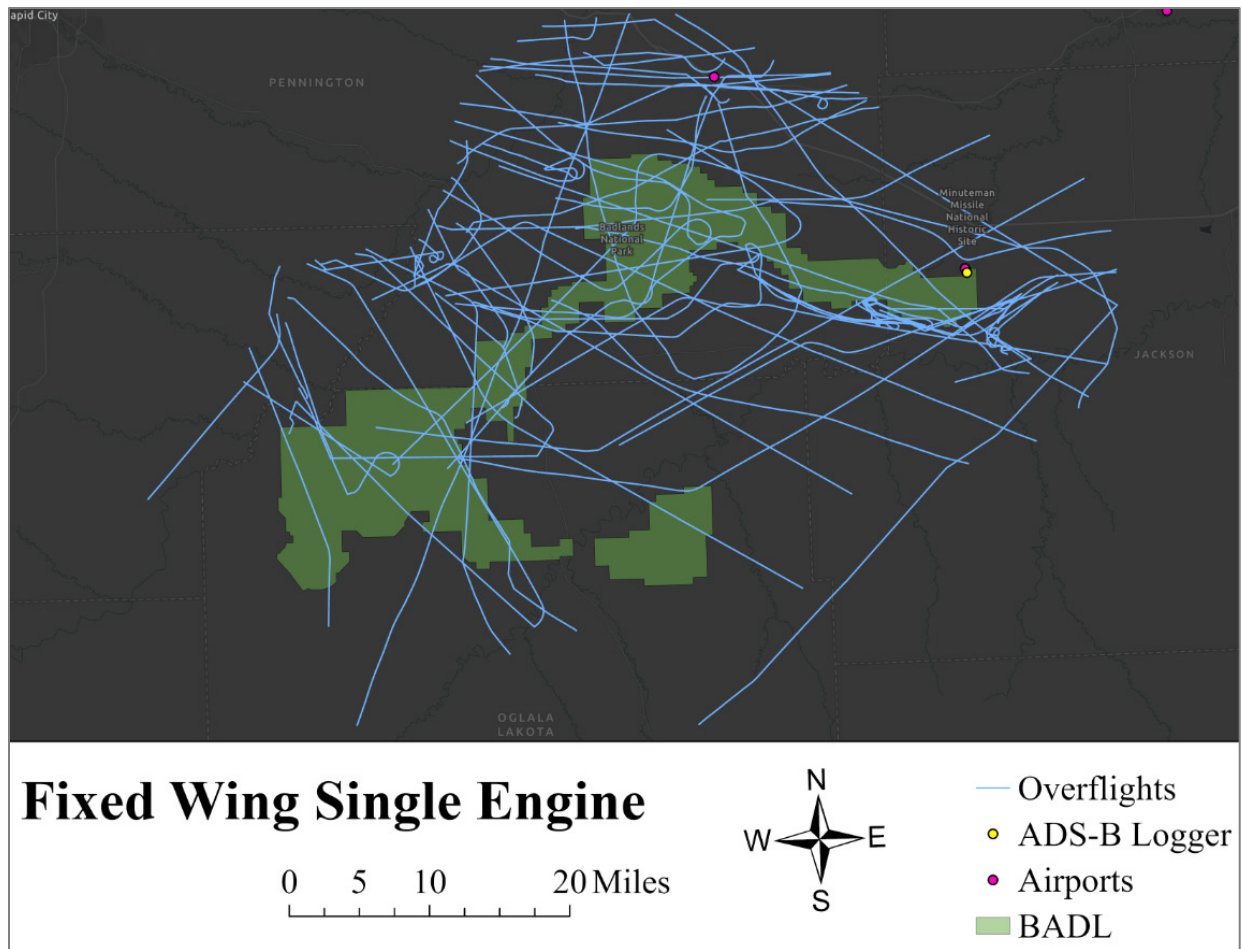


Figure 7. Phase 3 fixed-wing single engine overflight travel patterns.

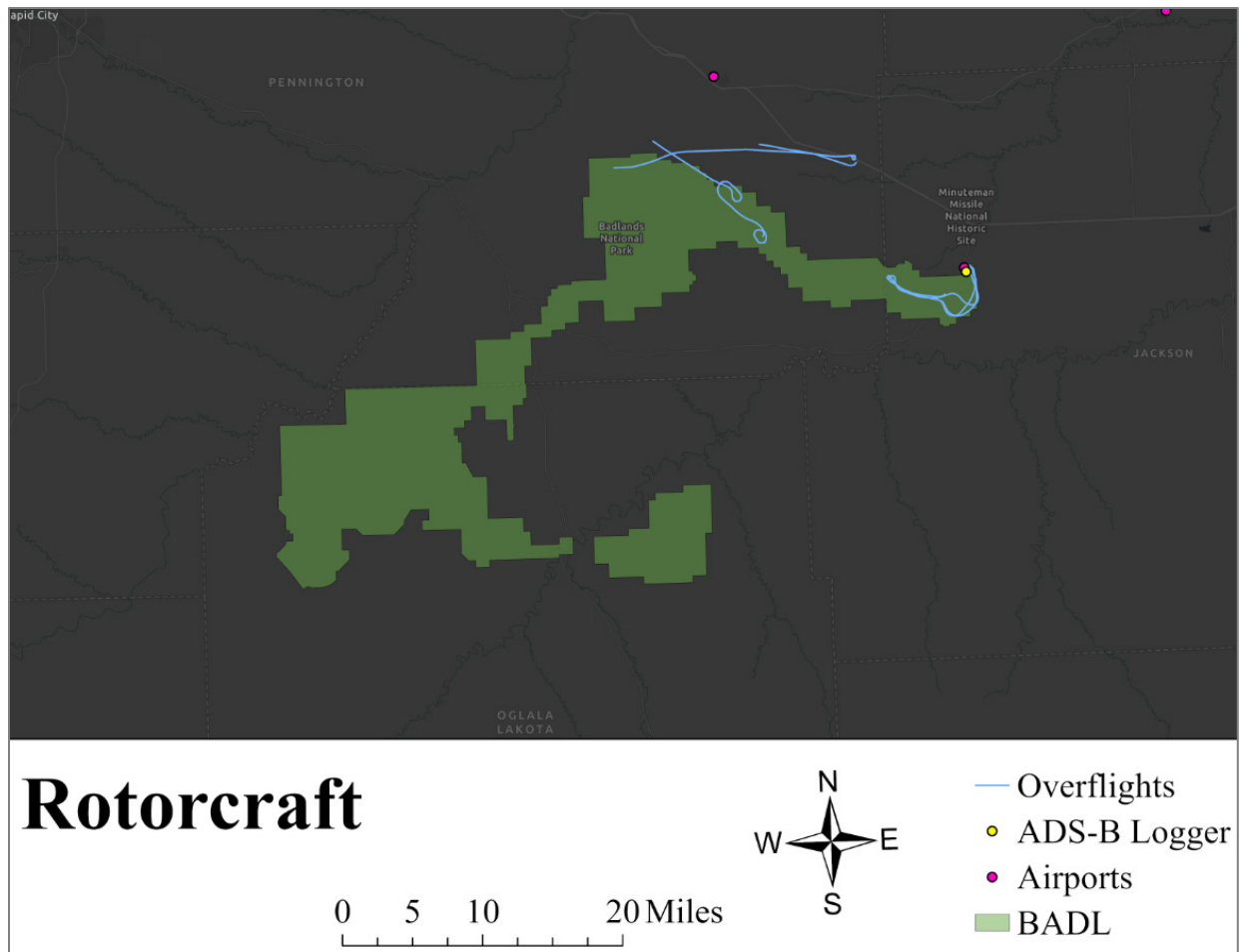


Figure 8. Phase 3 rotorcraft overflight travel patterns.

Lastly, figures were produced for operators that conducted the most overflights. A 10-mile buffer around the BADL perimeter was applied to gain a better understanding of flight routes. Figure 9 displays Mesa Airlines. Figure 10 displays Air Methods. This figure shows a loop route above the central part of the park. This was a helicopter rescue conducted on July 20th, 2022 (National Park Service, 2023b). Figure 11 shows Dakota Rotors LLC.

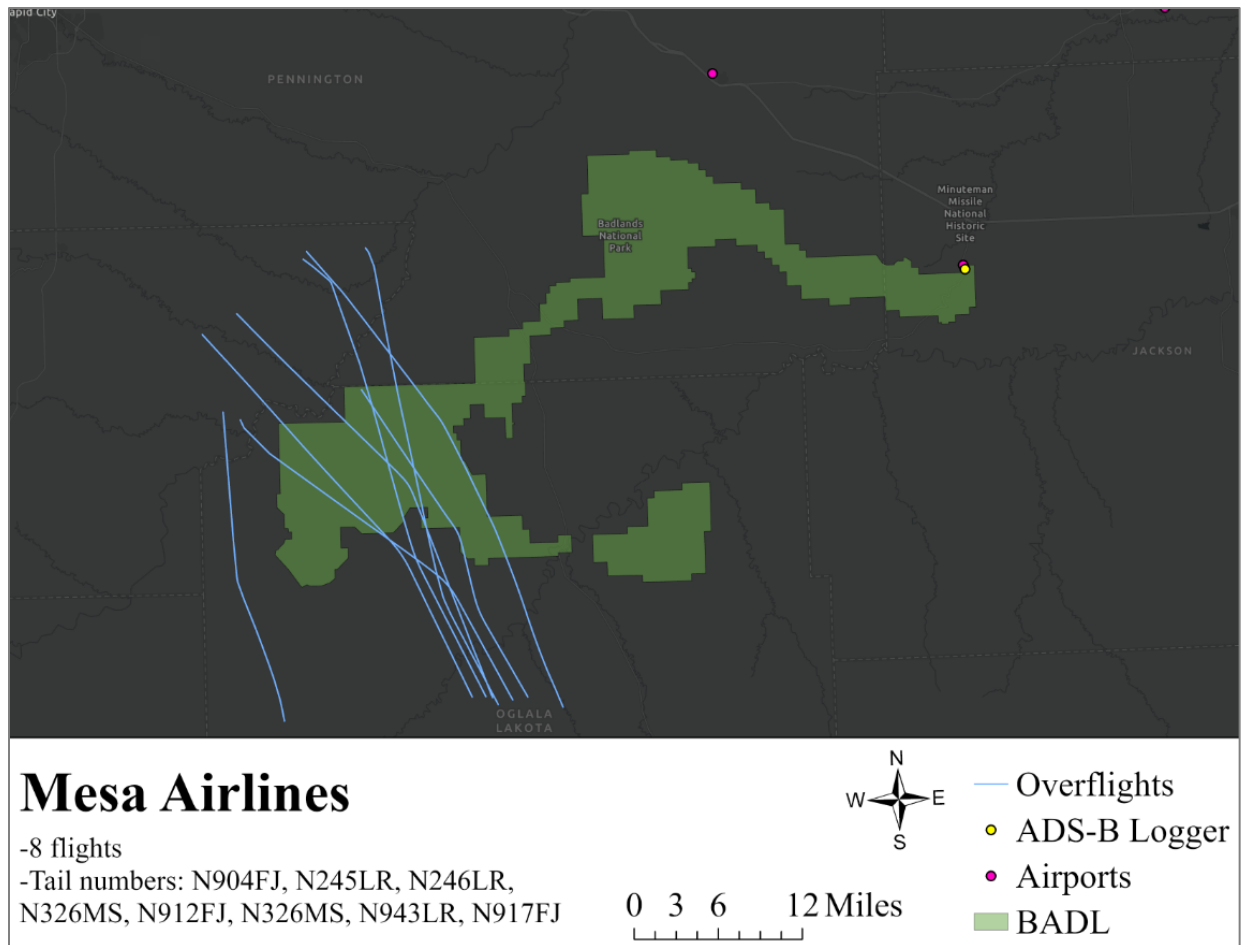


Figure 9. Overflight travel patterns for Mesa Airlines.

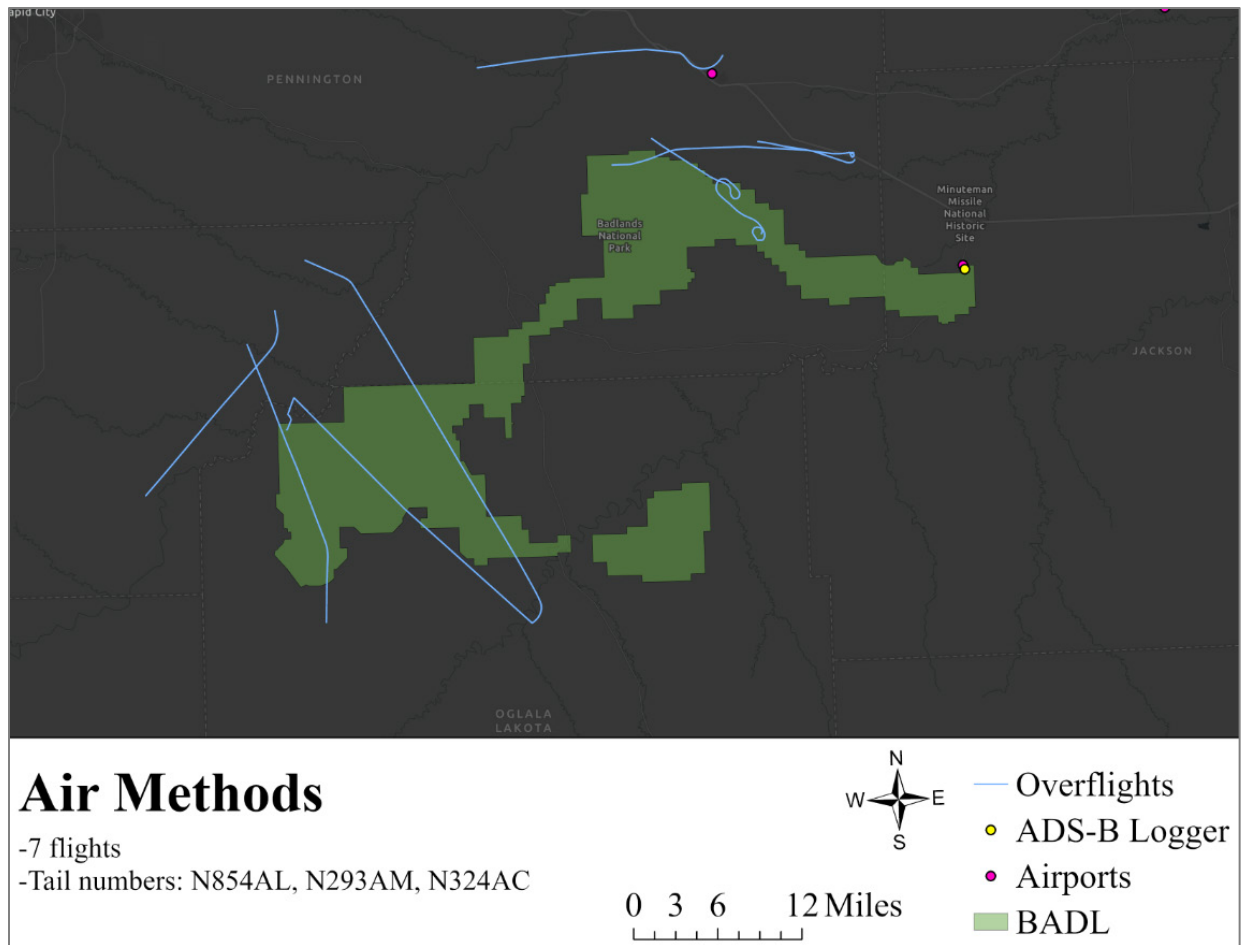


Figure 10. Overflight travel patterns for Air Methods.

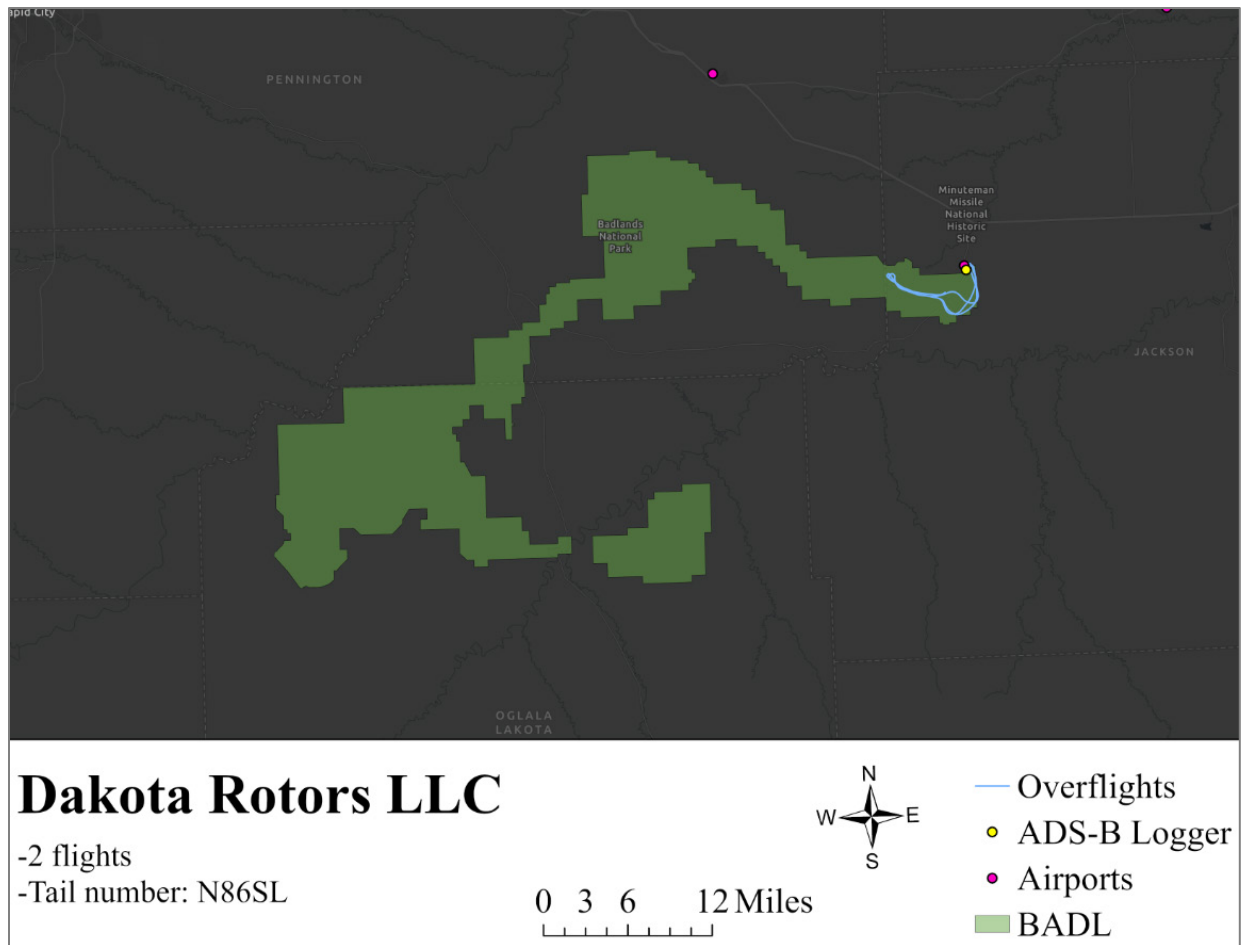


Figure 11. Overflight travel patterns for Dakota Rotors LLC.

Discussion

The purpose of this study was to explore the spatial and temporal patterns of overflights at BADL. Flight tracking data were analyzed from July 13, 2022 to August 27, 2022 and included 118 overflights. Analysis consisted of three phases.

The first phase focused on all overflights and showed a concentrated trend of overflights above BADL. Visual analysis of these data suggests overflights are less concentrated above the southwestern perimeter of the BADL boundary. However, this may be due to terrain shielding that blocks the data logger from receiving ADS-B signals. Further, most of the flights above BADL seem to be heading toward or departing from Rapid City, SD.

The second phase focused on low-level overflights and showed they fly at lower altitudes along the northeast boundary of BADL. Very few low-level overflights were detected above the western extent of BADL, which suggests either terrain shielding may have prevented robust data collection or few flights occur in this area of the park. Few clear patterns revealed themselves with the low-level overflights other than there were very few low-level overflights for a collection period of 26 days. These low-level overflights are known to transmit more intense noise than higher altitude flights which could affect ground resources and visitors' experiences. Thus, from an acoustic resources perspective, this may mean that BADL receives a low level of noise from aircraft. However, this could also be a result of few aircraft in the area being equipped with or are not using during flight ADS-B technology.

The third phase attempted to focus more specifically on air tours by removing flights known not be air tours. The dataset was cleaned of 7 civil patrol flights, 19 major airlines flights, 1,237 straight-line flights, and 1 flight with a flightpath less than a mile in length. This left 118 flights (Figure 4). However, for air tours specifically, only two operators have the required interim authority to conduct air tours over the park. One operator, Badger Helicopters Inc. (sister company to Dakota Rotors LLC), has a heliport just outside the park's northeast entrance and conducts the vast majority of air tours over BADL. Data were visually analyzed for flights arriving or departing from the helipad, and only two were identified. This could mean that only two tours took place during the collection period, or it could mean that not all the air tour aircraft used to conduct air tours at BADL have been equipped with or are not using ADS-B. Based upon previous reporting from the operators, it is most likely that air tours have been occurring but are not using ADS-B.

Table 1, which displays number of waypoints within specific AGL altitude bands, shows that the 501–1,000ft AGL, 1,001–1,500ft AGL, and 1,501–2,000ft AGL altitude intervals received the most waypoints. Table 2, which displays number of waypoints within specific MSL altitude bands, show that the 2,460–3,000ft MSL, 3,001–3,500ft MSL, 3,501–4,000ft MSL, and 4,001–4,500ft MSL altitude intervals received the most waypoints. Error associated with altitude can be a limitation when analyzing ADS-B data (see the Methods section for more details).

Figures 9–11 display travel patterns for the three operators who conducted the most Phase 3 overflights. These operators and their number of flights are: Mesa Airlines (8 flights), Air Methods (7

flights), and Dakota Rotors LLC (2 flights). Mesa Airlines had flights that cross above the western area of BADL and did not have flights above the eastern area of BADL. Whereas, Air Methods and Dakota Rotors LLC had flights above both the western and eastern areas of BADL. The Dakota Rotors flights are likely air tours.

Table 4 shows that the percentage of flights across days of the week are similar with the lowest percentage of flights occurring on Mondays and Saturdays (8.30%) and the highest percentage of flights occurring on Thursdays (44.40%). The second highest percentage of flights occur on Wednesdays and Fridays (13.90%). Table 5 displays percentage of overflights by hours of the day, revealing that the majority of flights begin at 9:00am and continue until 2:00pm. Table 5 shows that early morning (6:00am–8:00am) and evening (5:00pm–8:00pm) are the most free from low-level aircraft noise.

Much of the data from this study were located over the eastern portions of the park. This is likely due to the location of the ADS-B logger. Therefore, it is not clear if these data represent a comprehensive understanding of overflights over the entire park, especially the western portions of the park.

In conclusion, this study produced results to further understand overflights at BADL. This information can be used for planning and management purposes. Also, this study serves as a resource for future research.

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