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INDIGENOUS PEOPLES OF THE UNITED STATES

June 10, 2020

Mr. Raymond M. Sauvajot
Associate Director
Natural Resource Stewardship & Science
National Park Service
1849 C Street NW
Washington, DC 20240

Mr. Kevin Welsh
Executive Director
Office of Environment & Energy
Federal Aviation Administration
800 Independence Avenue SW
Washington, DC 20591

Re: Voluntary Agreements or Air Tour Management Plans at Hawai‘i National Park Service Units

Dear Mr. Sauvajot and Mr. Welsh,

Thank you for your January 28th response to my earlier letter requesting expedited implementation of voluntary agreements (VA) or air tour management plans (ATMP) at Hawai‘i National Park Service (NPS) units.

I am writing to follow up on our exchange in light of the May 1st U.S. District of Columbia Circuit Court of Appeals decision on the petition for a writ of mandamus *In re: Public Employees for Environmental Responsibility and Hawai‘i Coalition Malama Pono*. As you know, the Court in that case ordered the NPS and the Federal Aviation Administration (FAA) to produce a schedule within 120 days for bringing all required parks into compliance with the National Parks Air Tour Management Act (NPATMA) within two years.

As your agencies work to address the Court's order, I again urge you to prioritize efforts at the Hawai‘i Volcanoes National Park and Haleakalā National Park. As of NPS's most recent annual report, these parks have the first and fourth most tour flights in the nation. These air tours cause extensive disruption to the parks and the surrounding communities, and implementing a strong VA or ATMP will have a real impact in the betterment of our parks and communities.

Additionally, I wanted to direct you to the attached article, "Evaluating the Use of Spatiotemporal Aircraft Data for Air Tour Management Planning and Compliance," from the recent *Journal of Park and Recreation Administration*. The article confirms that over 55% of tour flights in the vicinity of and over Haleakalā National Park are not complying with minimum altitude requirements, and substantial numbers are not complying with other conditions and agreements directed at minimizing disruption to the park. Considering that far too many tour flights are flouting requirements with direct impacts on park users and communities, what actions are FAA and NPS taking to ensure compliance with all requirements on tour flights over National Parks? Please let me know if I can take actions, such as legislation or funding, to help your agencies enforce existing and future air tour flight requirements.

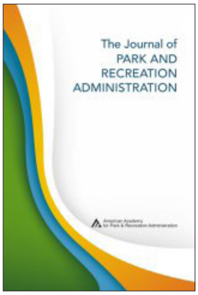
Thank you for your prompt attention and reply to these concerns. Please advise of any questions.

With aloha,

Ed Case

Congressman Ed Case
Hawai‘i – First District

Enclosure



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Special Issue on Innovative Methodologies in Park and Recreation Management

Evaluating the Use of Spatiotemporal Aircraft Data for Air Tour Management Planning and Compliance

J. Adam Beeco, Damon Joyce, and Sharolyn J. Anderson

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Special Issue

Evaluating the Use of Spatiotemporal Aircraft Data for Air Tour Management Planning and Compliance

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Executive Summary

Examining visitors' spatiotemporal movement patterns within parks and protected areas (PPAs) has become an informative methodology for management actions and understanding visitor behavior. This work has given managers and researchers a better understanding of visitor spatial behaviors, spatiotemporal resource impacts, and theoretical and organizing frameworks for approaching this type of research. However, few studies have examined the spatial patterns of air traffic, specifically low-level air tours, above PPAs and the resulting impacts to visitors' experience and the natural soundscapes. This need is particularly relevant in the U.S. due to legislative mandates that the National Park Service (NPS) and Federal Aviation Administration (FAA) have to manage air tours over NPS units. Further, prior studies have shown how air tours negatively impact both visitors' experience and the natural soundscapes. Understanding the spatiotemporal patterns of air tours is critical for the managers working with air tour operators and the FAA for planning, ensuring compliance with management decisions, and examining the effects of aircraft noise on PPA resources and the on-the-ground visitors.

Recently enacted laws and regulations across the globe, including the U.S., are requiring all aircraft operating in controlled airspace to equip air traffic tracking technology called Automatic Dependent Surveillance-Broadcast (ADS-B) Out avionics. ADS-B Out broadcasts an unencrypted and publicly accessible signal that relays latitude, longitude, altitude, and unique identification code. In the U.S., this code can then be cross-referenced to a publicly accessible database with information including the type/model of aircraft and the registered owner. Only a single prior study has examined ADS-B data over NPS units, finding both potential and limitations to this new technology for tracking air tours. This study seeks to expand methodological improvements and ADS-B's potential to inform management actions by exploring ADS-B data at Haleakalā National Park (HALE). This study explores the use of ADS-B data at HALE for monitoring compliance with spatially explicit conditions within a preexisting agreement established between the park and air tour operators.

The study identified 321 air tours, compared with 454 air tours reported by operators over the same time period. Compliance with the spatially explicit agreement conditions was generally high, though better for lateral offsets than minimum altitude requirements. Overall, this study advances methodological uses of ADS-B logging to track air tours over PPAs and advances knowledge about the potential utility and current limitations of using ADS-B tracking systems for compliance in PPA contexts.

Keywords

Recreation ecology; noise impacts; air tours; visitor use; spatial analysis

Introduction

Spatiotemporal data of visitors' movement patterns are some of the most basic but relevant data on recreation use in parks and protected areas (PPAs; Hallo et al., 2012). This information can be used for numerous park planning purposes, including visitor use management, transportation management, wildlife management, interpretative programming, law enforcement, and many other uses.

There are also numerous research benefits to understanding where visitors go, why they go there, associated resource impacts, how visitor interactions effect spatial distribution, and how space can be effectively managed (Riungu et al., 2019). Further, visitor movement patterns can also inform other social, economic, operational, informational, and spatial factors (Taczanowska et al., 2017).

Understanding visitor spatiotemporal patterns extends beyond the on-the-ground visitors to air traffic, especially commercial air tours that fly at low altitudes above PPAs. Air traffic over PPAs is a common noise source, and in some PPAs is the predominant noise source, especially large natural resource-based parks with wilderness or backcountry (Buxton et al., 2017). Understanding the spatiotemporal patterns of air traffic over PPAs can give insights to managers and researchers about both fixed routes departing and arriving at airports as well as localized sightseeing air tours (Beeco & Joyce, 2019). The problem that this article seeks to address is that managers lack comprehensive and quantitative information about air traffic travel patterns. Visual observations of aircraft by managers and staff tend to be limited to specific locations and short durations of time. Much like on-the-ground visitor tracking, tracking of air traffic is beneficial for a multitude of planning purposes, and most specifically, is needed for air tour planning over U.S. National Park Service (NPS) units as required by the National Park Air Tour Management Act (2000; NPATMA). New technologies and governmental regulations are beginning to open opportunities to close this information gap.

Literature Review

Research Framework

Beeco and Brown (2013) proposed that the relationship between space and visitor use is a spatially-conditioned process that affects visitors' experiences and cultural and natural resources. Beeco and Brown (2013) proposed four general spatial processes:

- Diffusion: how visitors are spread across space
- Interaction: how visitor spatial behavior is influenced by space and non-space factors (e.g., motivations)

- Impacts: how use and impact (physical and experiential) correlate within a space
- Segmentation: how space can be managed

Numerous tracking studies have examined the relationship between space and visitor use (Riungu et al., 2019). A few of these studies include how visitor spatial behavior varies dependent on season (Kim et al., 2018), how visitor activity type impacts trail conditions (Beeco et al., 2013), how visitors create informal trails (Coppes & Braunish, 2013; D'Antonio & Monz, 2016), whether educational strategies influence visitors' off-trail behavior (Kidd et al., 2015), visitor impacts on wildlife (Gutzwiller, D'Antonio, & Monz, 2017; Katselidis et al., 2013), and recreational conflict between different activities types (Wolf et al., 2017). These studies all examined potential solutions to protecting or minimizing natural resource or visitor experience impacts by examining space.

Despite some GPS-based visitor tracking studies occurring as early as 2005 (Hallo, et al., 2005), methodically focused tracking studies are still common. Most of these recent method-focused studies have focused on reducing cost, using smartphones, and crowdsourced data (Kim, Thapa, & Jang, 2019; Korpilo, Virtanen, & Lehvävirta; 2017; Rice et al., 2019). These articles and others continue to suggest that tracking visitor movement patterns can inform researchers and managers about both natural resource and visitor experience conditions (Riungu et al., 2019).

The examination of travel patterns in spaces unconstrained by infrastructure, such as air tours, are particularly informed by tracking because of the freedom of movement. By tracking aircraft, managers can begin to understand air tour routes and altitudes (diffusion), how aircraft noise or visual impacts may be distributed across space (impacts), how that noise or visual impacts affects visitors and/or natural and cultural resources (impacts), and if there are spatiotemporal management solutions to reduce noise or visual impacts (segmentation) (Beeco & Joyce, 2019).

Noise Impacts

One of the primary reasons it is important to understand air traffic patterns above PPAs is to minimize, mitigate, or prevent the adverse effects of noise from aircraft, especially lower flying air tours, that can affect the natural and cultural resources, and the on-the-ground visitor experience that PPAs are designated to protect (Beeco & Joyce, 2019). Numerous studies have identified the value and importance of soundscapes as one of the motivations for visiting parks (Haas & Wakefield, 1998; McDonald, Baumgarten, & Iachan, 1995; Merchan, Diaz-Balteiro, Soliño, 2014; Miller, Taff, Newman, 2018), including in a cross-cultural context (Miller et al., 2018). Other studies have focused specifically on the effects of aircraft on the visitor experience both in PPAs and a laboratory setting, indicating that aircraft noise negatively impacts the visitor experience (Anderson et al., 2011; Ferguson, 2018; Mace et al., 2013; Rapoza, Sudderth, & Lewis, 2015).

Noise also impacts wildlife in a number of ways: altered vocal behavior, breeding relocation, changes in vigilance and foraging behavior, and impacts on individual fitness and the structure of ecological communities to name a few (Shannon et al., 2015; Kunc, McLaughlin, & Schimidt, 2016; Kunc & Schmidt, 2019). Understanding the relationships between air tour noise attributes (e.g., timing, intensity, duration, and location) and ecosystem responses is essential for developing management solutions (Gutzwiller et al., 2017).

Air Tours

When examining the noise impacts to PPAs, managers and researchers generally focus on air tours over U.S. National Park Service (NPS) sites for a couple of reasons. First, there are legislative authorities that require the management of air tours over NPS units. The National Parks Overflight Act of 1987 requires the management of air tours over Grand Canyon National Park and required studies of aircraft overflight issues across the rest of the NPS system. NPATMA, as amended, requires the Federal Aviation Administration (FAA) and NPS to jointly manage air tours at all NPS units that have more than 50 air tours per year—excluding Grand Canyon National Park and all NPS units in the State of Alaska. Additionally, natural sounds are one of the many natural and cultural resources protected under the National Park Service Organic Act (1916). The need for managing air tours over NPS units derived from both safety and noise issues that detract from a visitor's enjoyment of national parks (NPS Story Map, 2018).

The second reason managers and researchers have focused on NPS units is the number of reported air tours. The amended version of the NPATMA (2012), requires operators to report their number of air tours over NPS units regardless of the number of tours conducted, including reporting zero tours (Lignell, 2019). There were approximately 47,109 reported commercial air tours over NPS units (excluding units in the state of Alaska) in 2018, down from a high of 89,752 in 2014 (Lignell, 2019). Additionally, operators at Grand Canyon National Park flew between 60,000 and 120,000 commercial air tours and related flights in 2017 (K. Lusk, personal communication, January 29, 2020). Although there are many legitimate aviation uses over NPS units (such as commercial jet traffic, military flights, commercial air tours), noise from aircraft may adversely affect natural and cultural soundscapes and visitor experience.

Air Tour Management

Generally, there are four broad phases to consider within U.S. National Park Service planning and management of visitor use in parks: 1) clarifying a project's purpose and need, 2) defining use management direction, 3) identifying management strategies and action, and 4) monitoring how strategies and actions are working (IVUMC, 2016). With respect to air tours over NPS units, the final two phases would be especially served by detailed information on air tour operations.

NPATMA established two different avenues for managing air tours: air tour management plans (plans) or voluntary agreements (agreements). Plans and agreements may establish "conditions for the conduct of commercial air tour operations over a national park, including commercial air tour routes, maximum or minimum altitudes, time-of-day restrictions, restrictions for particular events, maximum number of flights per unit of time, intrusions on privacy on tribal lands, and mitigation of noise, visual, or other impacts" (NPATMA; 49 USC§ 40128(b)(3)(B)). Again, the management actions outlined by NPATMA highlight the need for understanding air tour operations both before/during planning efforts and for monitoring the effectiveness of and compliance with management actions.

The FAA also prescribes minimum safe altitudes for all aircraft in 14 CFR § 91.119 (2011). Fixed wing aircraft are required to maintain an altitude of 500 feet above ground level and a distance of 500 feet from any person, structure, vehicle or vessel when operating over sparsely populated areas. Helicopters may operate below these minimums but must comply with any routes or altitudes specifically prescribed for helicopters by the FAA. Recognizing that excessive aircraft noise can result in annoyance, inconvenience, or interference with the uses and enjoyment of property and can adversely affect wildlife, the FAA recommends pilots fly no less than 2,000 feet above ground level (AGL; 609 meters) over parks, wildlife refuges, and areas with wilderness characteristics (FAA, 2014). With such a high level of freedom of movement, tracking air tours provides information for managing air tours, and effects on natural and cultural resources, and on-the-ground visitors. Commercial air tours over most parks operate under these FAA rules and advisories.

However, there are about a dozen parks that do have special flight rules or established agreements that include specific operating conditions. Special flight rules have been established on or near the Grand Canyon National Park, Statue of Liberty National Monument, and Governors Island National Monument. To date, a few other parks have air tour management agreements (under the authority of NPATMA) including, Big Cypress National Preserve, Biscayne National Park, Glen Canyon National Recreation Area, and Rainbow Bridge National Monument (Lignell, 2019). Haleakalā National Park (HALE) is a bit unique because the park and seven air tour operators agreed to certain routes and operating conditions in 1998, prior to the passage of NPATMA. This agreement, discussed below, includes specific spatially explicit operating conditions and is the location of focus for this paper.

Additionally, ensuring operator compliance with the number of flights and all other spatiotemporal operating parameters is critical to effective air tour management (NPOAG meeting notes, 2018). Air tour plans and agreements may include provisions to ensure the stability of, and compliance with the planning outcomes. Compliance and enforcement has been a primary topic over the past three National Parks Overflights Advisory Group meetings (NPOAG meeting notes, 2018). The Advisory Group views tracking air tours as a potential mechanism for ensuring compliance.

Air Tour Tracking

Information on air tour routes, altitudes, type of aircraft, daily or weekly number of air tours, weather patterns, or other factors affecting air tours are one of the primary data needs for air tour planning. This information is needed for accurate noise modeling, identifying primary attractions air tours are visiting, and helps managers and planners understand some of the operator constraints (e.g., distance from the park). The current method of collecting information is to request that air tour operators draw routes, altitudes, and air speeds on paper maps, which are then digitized and used for noise modeling (Beeco & Lignell, 2019). While this method has proven effective for providing inputs for modeling aircraft noise, air tour tracking at other parks has found that actual flight paths can vary as much as three miles (Beeco & Joyce, 2019). Additionally, weather or temporary flight restrictions may cause pilots to fly an entirely different route for safety reasons (Beeco & Joyce, 2019). Noise models assume flights are occurring on specific routes at specific altitudes, and while this is immensely important for quantifying noise intensity and spread, understanding the actual variation of flight paths provide managers and decision makers with a better awareness of how noise impacts may vary spatially.

Automatic Dependent Surveillance-Broadcast (ADS-B) is a newer technology that enables the tracking of aircraft. It is designed to provide more precision and reliability than the current radar system, increasing situational awareness, and enhancing safety and efficiency of the airspace (FAA, 2019a). ADS-B is a part of FAA's plan to transform air traffic control from a radar-based system to a satellite-based system. It consists of both "Out" and "In" technologies, which involve protocols for transmitting and receiving flight information. ADS-B Out uses GPS to transmit an unencrypted and publicly accessible signal that relays latitude, longitude, altitude, and unique identification code. This unique code can be cross-referenced to a publicly accessible FAA Releasable Aircraft Database providing the aircraft tail number, model, and owner. ADS-B In allows pilots to view real-time air traffic data inside the cockpit. This study focuses only on ADS-B Out, which we shorthand in most places to "ADS-B". Beginning January 1, 2020, aircraft must be equipped with ADS-B Out avionics to fly in most controlled airspace (see 14 CFR § 91.225 and 14 CFR § 91.227).

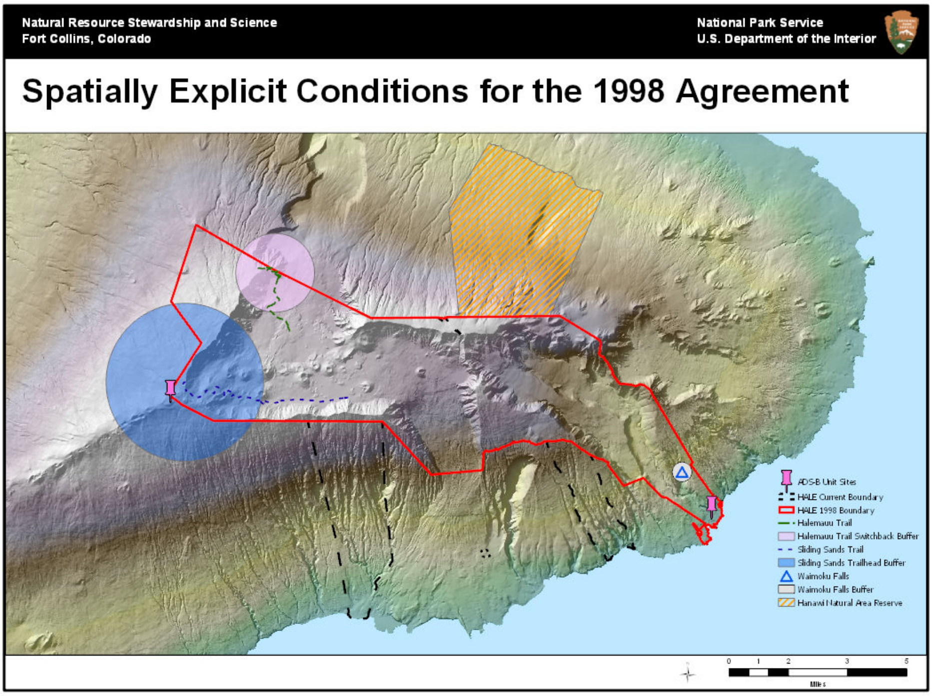
This study represents a follow up on a previous air tour tracking study by Beeco and Joyce (2019), which used an initial ADS-B logger design for phase I and a significantly improved design for phase II. This study continues to improve the design (as outlined in the Method section), and the analysis below suggest an improvement in data capture volume and air tour capture rates (as compared to reporting) compared to the first study. The direct improvements at HALE from the first study to this study do represent a comparison to the phase I design, and not the phase II.

HALE Operator Agreement

On January 7, 1998, the Hawaii Air Tour Association, Maui (seven air tour operators) and HALE signed a letter of agreement for air tour operations around and above HALE. This agreement included numerous spatially explicit conditions that are listed in Table 1 and spatially displayed in Figure 1.

Figure 1

Map Displaying the Spatially Explicit Conditions of the 1998 Agreement



When the agreement was developed, the technology to track air tours over this remote part of the island did not exist. Compliance with this non-regulatory agreement has been monitored through on-the-ground observations and by air tour operators in the skies, making proof of non-compliance difficult. ADS-B presents a new opportunity to examine to what extent current operators are following the operating conditions outlined in the 1998 agreement.

Objectives

The objective of this study was to test the viability of using ADS-B data for tracking aircraft compliance generally, and specifically with the 1998 letter of agreement (detailed in the Method section below). The research questions included:

Q1: Are data sufficient for analyzing the detailed spatial conditions contained in the 1998 agreement?

Q2: Can two ADS-B receivers capture all signal data in such varied terrain?

Q3: Can the data from each logger efficiently and effectively be linked in post processing?

Q4: How can the vast amount of data collected from the ADS-B receivers be most efficiently processed?

Method

The methods of this study focused on HALE and site selection; the design of the ADS-B loggers; data handling (including cleaning, screening, and validating) in the most efficient manner; and analysis of the ADS-B data for compliance with the 1998 agreement.

Study Area: Haleakalā National Park

Extensive acoustic monitoring has taken place at HALE over the last three decades, revealing that its natural soundscape is largely intact, and that the most prevalent noise contribution is from aircraft (Wood, 2015). Further, the Haleakalā crater has recorded sound pressure levels as low as 10 decibels—which are close to the noise floor of the recording equipment (Lynch, 2012; Wood, 2015). Sound levels this low are extremely rare, making the soundscape of HALE a vital natural and experiential resource. These low levels also make the soundscape highly sensitive to the influence of external noise sources (Lynch, 2012). Because aircraft are the primary noise source affecting the soundscape at HALE, management of air tours is an important consideration.

Operators at HALE have reported a very consistent number of air tours since 2013 (when reporting requirements began) ranging between 4,500 and 5,000 per year (Lignell, 2019). Air tours occur year around at HALE with a fairly even distribution across the year. The quarterly numbers for 2018 air tours were 1,146; 1,092; 1,235; 1,284 for first through fourth quarters respectively. Air tours occur seven days a week, but generally do not occur during inclement weather. This results in an average of about 13 air tours per day over HALE.

HALE was chosen as a research site for this study for multiple reasons. First, air tours depart from Kahului Airport, which is Class B airspace. Beginning January 1, 2020, ADS-B Out will be required to access Class B airspace (FAA, 2019b), effectively meaning that every aircraft on the Island of Maui will be equipped with ADS-B by January 1, 2020, if not already equipped. Also, the 1998 agreement established specific spatially explicit conditions on air tour operations. This gave us the chance to test the capability of using ADS-B data for detail analysis, and to examine the level of compliance with the terms of the agreement by current operators. Further, a prior ADS-B study that took place in HALE gave us insights into where to place multiple loggers for optimal spatial coverage and testing how data could be linked post-processing (Beeco & Joyce, 2019). Since the agreement was signed, two of the original signatories are no longer operating. Currently, there are six operators with the authority to conduct air tours over HALE. All current operators are reportedly following the operating conditions in the 1998 agreement.

Two sites within HALE were selected to capture aircraft ADS-B signals. These sites were chosen based upon findings from a prior study (Beeco & Joyce, 2019). The first logger was placed at the same location as the first study, near the summit of Haleakalā (20.706988, -156.255991), and covered the south and west portions of the park thoroughly. A second logger was placed in the eastern portion of the park, on top of the Kiphulu Visitor Center (20.660779, -156.255991). The ADS-B loggers were placed where known air tour activity occurs, and near some of the spatial restrictions in the 1998 agreement. The loggers were deployed at HALE from March 15 to April 15, 2019.

Figure 1 displays the spatially explicit operating parameters of the 1998 agreement along with locations of the ADS-B loggers. It is important to note that the boundary of HALE has changed between 1998 and present day (Figure 1). All analysis assumed the 1998 park boundary, which was in existence at the time of the letter of agreement.

Design and Materials

The ADS-B loggers decode signals from aircraft equipped with ADS-B Out. When the logger receives a signal from an aircraft, it logs that information and assigns a time stamp to the record. The information includes an aircraft identifier (hexid), latitude, longitude, and altitude at mean sea level. The total cost per logger was roughly $270. The components used are listed below, and prices are approximate:

- Raspberry Pi 3 Model B+ running custom software
- 2x USB SDR (software-defined radio) dongle
- 2x External antennas (978 megahertz and 1090 megahertz)
- Real-time clock
- 5V AC-DC regulator
- EMI shielded aluminum enclosure
- Thermal transfer pads
- 50’ AC power cable

After re-evaluating the previous design (Beeco & Joyce, 2019), it was determined that the constant opening and closing of the enclosure was compromising the weatherproof seal of the lid. In addition, shutting down the system to offload the data meant that the lack of feedback to the user on the status of the logger hid any system errors at restart.

The software was refined to add local wireless communication capabilities. The logger created its own WiFi hotspot, and allowed a researcher to connect to the hotspot and wireless transfer data to a laptop or mobile phone. This eliminated the need to both open the enclosure and shut down the system for the weekly download. A bluetooth service was also incorporated to display summary statistics about the data for the day, giving concrete feedback that the system was functioning correctly.

Data Cleaning and Screening

The methods used in this study generally followed those outlined in Beeco and Joyce (2019). The ADS-B logger receives the signal and decodes the data to a text file, which includes a timestamp when the signal was decoded, latitude, longitude, altitude, and a unique identification code. An R script automatically cross-references the unique identification code with an FAA database, providing more information on each data point, including aircraft tail number, model, type, and owner.

Next, the text files from each ADS-B logger were combined and data points within 3,280 feet (1,000 meters) of the Kahului airport were deleted. This eliminated data points from aircraft that may have been resting on the helipad with the ADS-B transmitter still active. Subsequently, the data points were segmented into unique flights by the unique identifier and timestamp of the records. A gap of more than 15 minutes between consecutive data points from the same aircraft on the same day was assumed to be the start of a new unique flight. Deleting the points in and around the airport ensured that the data from the same aircraft, flying multiple trips on the same day, will always be counted as separate tours.

Data were then read into ArcGIS for further segmenting and cleaning. Only data within 5 miles (8 kilometers) of the park boundary were kept for analysis. This was due to the volume of data, and that data outside this range from the park did not address the research questions. All flight segments that had at least one track point within 0.5 mile (0.8 km) of the park boundary and were below 15,000 ft (4,572 meters) mean sea level were flagged for inclusion in analysis.

Once the data were cleaned, using the automated processes in R, and then ArcGIS, data were visually analyzed. The vast majority of overflights at HALE were helicopters, so this analysis focuses only on helicopters. Three flights were removed at this step. The first flight neared the Kīpahulu portion of the park (never entering), and then diverted southeast toward the Island of Hawaii. The other two flights were registered to an owner called Medical Transport Corporation. Data from these flights were not typical of an air tour so the data were deleted.

Validating altitude of ADS-B data

We used a Medical Transport Corporation flight to examine the accuracy of our model assumptions about the ADS-B altitude of the flights. Medical transport flights typically land on the ground to recover patients and deliver them to the nearest hospital. Judging by the travel patterns of one of the Medical Transport Corporation flights, it looked as though the flight landed. Therefore, when we ran an analysis to determine AGL (see below), we could assume the lowest altitude of this Medical Transport Corporation flight would be at or near ground level. However, the analysis revealed that the lowest AGL for this flight was -210 ft (-64 meters). This revealed significant vertical error in all the AGL estimates. Due to the error in the AGL estimates, altitude requirements associated with each condition were reduced 200 ft (61 meters) to account for this error. For example, for requirement 1 and 5, instead of identifying flights that flew below 500 ft, we chose to identify flights that flew below 300 ft (91 meters).

Data Analysis

The cleaned ADS-B data and the 1998 spatial explicit operating parameters were mapped together. Similar to Beeco and Joyce (2019), the ADS-B data were first analyzed as multi-point lines, which aggregates the points to a line, but keeps the points as metadata. This improves data processing due to the reduced size of the point files. This worked well for analysis that did not require AGL estimates. Specifically, multi-point lines were used for analysis of conditions 2, 3, and 4 from the 1998 agreement. Visually counting flights and the 'selection by location' tool were used to count the number of flights that crossed into avoidance areas.

A shortcoming of using multi-point lines is that the timestamp and altitude for each point are not accessible in the aggregation of the data. This was a problem for analysis of conditions 1, 5, 6, and 7, because AGL calculations were needed for each point in space. A four-step process was used for these four analyses to identify the AGL for each point. First, the 'multipoint to point' tool was used to break up the multi-point line to a point file. Second, a 10x10 meter digital elevation model (DEM) was used to compare the altitude of each ADS-B point (mean sea level) to the elevation of the land below. The 'extract values' tool was used to extract the value of the raster DEM into the ADS-B point file. Next, the 'attribute calculate' tool was used to subtract the altitude of each ADS-B point altitude from the DEM value to calculate the AGL.

Results

The two ADS-B loggers successfully ran for the 31-day collection period. A total of 7,657,259 data points were collected, as compared to the 531,139 data points collected in the 2018 study (Beeco & Joyce, 2019). After the automated cleaning and screening were completed in R, there were 407 unique flights that comprised 843,936 points. Once the spatial window was reduced to within 5 miles of the park boundary, there were 324 unique flights and 183,017 points. After visually analyzing the data, a total of 321 helicopter air tours were identified during the March 15–April 15, 2019 period–totaling 182,505 points. This is a significant improvement over the prior study, which identified 68 air tours using ADS-B compared with 158 self-reported air tours (Beeco & Joyce, 2019), while in this study the ADS-B loggers identified 321 air tours compared with 454 of operator reported data for the same time period (70%).

Of the 321 helicopter air tours, there were five identified operators, 14 different aircraft (tail numbers), and five different models of aircraft. The number of flights identified per day ranged from 0 to 19 with an average and median of 10 flights per day over the 31 days of data collection.

Figure 2 displays the spatial and density distribution of these helicopter air tours by model of aircraft. The displayed points are set to 90% transparency, so areas where the points are opaquer represent a greater concentration of data. This map reveals a generally consistent (albeit incomplete) travel pattern for air tours. Airs tours approach the park from the west, flying near the south rim of the crater, perform an 'S' turn or loop heading south, and then progress east toward Kīpahulu. At this point, flights either head north of the Kīpahulu Visitor Center (where the eastern ADS-B logger was located) or south of the visitor center over the ocean. From that point the ADS-B signal is lost as the air tours return to the airport on the north side of the park.

Spatial Compliance

The next step of this study was to compare these air tour travel patterns with the seven spatially explicit conditions in the 1998 agreement. As mentioned earlier, while the park boundary has significantly expanded since the 1998 agreement, compliance with this agreement was assessed, using the 1998 boundary. Of the seven spatially explicit parameters, conditions 1, 5, 6, and 7 had both lateral offsets (i.e., horizontal or X,Y) and minimum altitudes (i.e., vertical, AGL, or Z). Conditions 2, 3, and 4 only had lateral offsets.

Figure 2

Map Displaying the HALE Air Tour Travel Patterns between March 15 and April 15, 2019

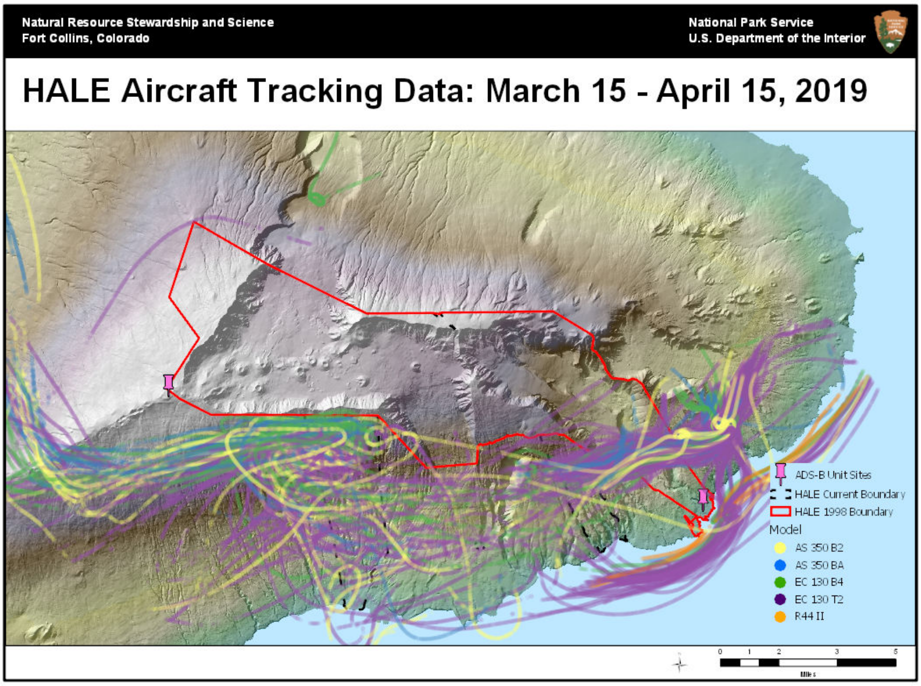


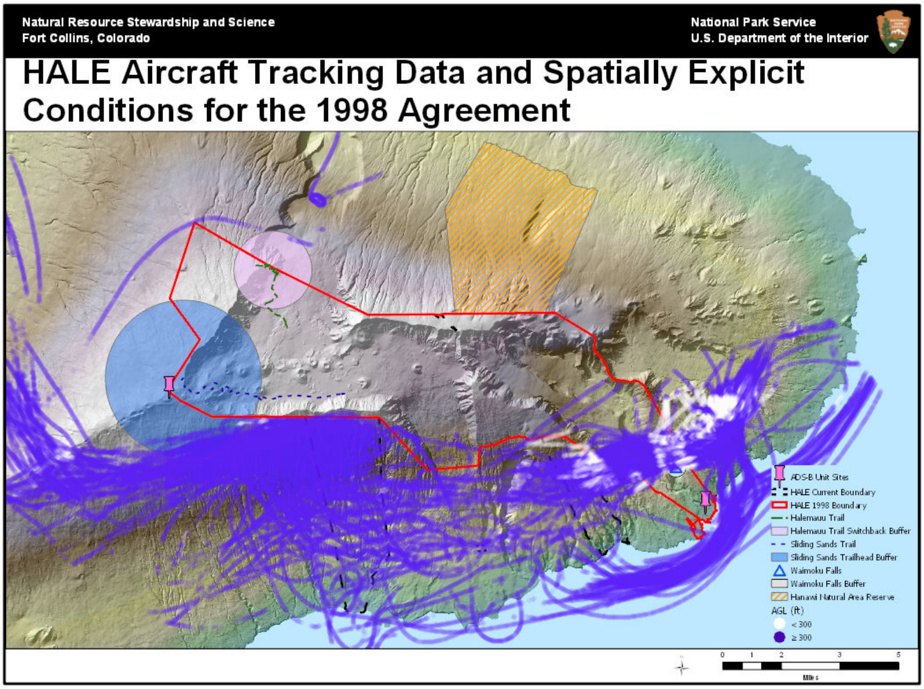
Figure 3 displays a map of these analyzes, while Table 1 displays the written results. Results for each of the spatially explicit conditions were as follows for each condition:

1. There were 179 of the 321 flights that flew below 300 ft within one mile of HALE along the south boundary near the crater rim or over the Kīpahulu area of the park. These points are displayed in white in Figure 3 and mostly concentrate over the Kīpahulu area of the park. These 179 flights are comprised of 10 tail numbers and four operators.
2. There were 21 of the 321 flights that flew within the two-mile radius of the Sliding Sands Trailhead. These deviations occurred on the southern boundary of the buffer outside the park. Of these 21 flights, there were eight unique tail numbers and four different owners.
3. There were three flights that crossed the boundary of the park in the vicinity of the crater rim. This occurred just south of the end of the Sliding Sands Trail as mapped. Of the three flights there was a single tail number and operator.
4. The Kaupo Gap is the portion of the crater depression that protrudes south at the center of the park's southern boundary and is within the park. There were nine flights that crossed the park boundary near the Kaupo Gap Flight Corridor. Of the nine flights there were five different tail numbers and two different operators.
5. There were 31 of the 321 flights that flew lower than 300 ft above ground level in the area of Waimoku Falls. However, no circling was overserved. Of the 31 flights, six tail numbers and three operators were identified. These 31 flights are most likely a part of the 179 flights identified in Condition 1 above.

6. There were zero flights identified that flew near or over the Hanawi Natural Area Reserve.
7. Only one flight was identified as having crossed into the buffer around the Halemau'u Trail switch back area. This singular flight was below 1,500 ft AGL.

Figure 3

Map Displaying the HALE Air Tour Travel Patterns Over the Spatially Explicit Conditions of the 1998 Agreement



Discussion

There are a number of findings from this study that have implications for site specific air tour management, air tour management more generally, methodological and data management issues, and considerations for future studies.

Site-Specific Management Implications

The 321 air tours identified using the cleaning and screening process fell short of the 454 operator reported flights, even when considering this study focused specifically on helicopter tours, but improved significantly over the prior study (Beeco & Joyce 2019). The prior study captured 45% of reported tours at HALE while this study captured 70% (Beeco & Joyce, 2019). This suggests an improvement in the ADS-B logger and also that most, if not all, air tour helicopters on the Island of Maui are already equipped with ADS-B The data quantity and quality captured from both loggers was adequate for examining operator compliance with the 1998 agreement (research question 1). However, no fully complete routes were captured due to the varied terrain over such a large area of analysis—leaving a mixed result for research question 2.

Considering the value and uniqueness of the natural soundscape of the Haleakalā crater, condition 3 of the 1998 agreement was designed to ensure that air tours do not

Table 1
Compliance Results Summary for 1998 Agreement Conditions

Conditions	Description	Number of flights out of compliance	Number of different aircraft out of compliance	Number of different operators out of compliance
1	Operators may fly at 500 ft. above ground level (AGL) when within one mile of HALE along the south boundary and Kīpahulu area of the park.	179	10	4
2	Operators will maintain at least a two-mile radius distance from Sliding Sands Trailhead located at the HALE Visitor Center parking lot.	21	8	4
3	Operators will fly outside the south rim of the park boundary in the vicinity of the crater rim.	3	1	1
4	Operators must fly outside the boundary of the park near the Kaupo Gap Flight Corridor.	9	5	2
5	Operators may cross (without circling) through the Waimoku Falls Corridor at 500 ft AGL. The corridor is defined as a zone lying in a southeasterly/northeasterly direction, ½ mile wide, and ¼ mile toward the mountain, and ¼ mile toward the ocean of Waimoku Falls. When weather conditions prevent the use of this corridor, operators may fly as far towards the sea as necessary to effect a safe crossing.	31	6	3
6	Operators will avoid overflights of the Hanawi Natural Area Reserve completely. If a flight must be conducted through this airspace, the minimum altitude will be 3,000 ft AGL.	0	0	0
7	Operators must maintain 1,500 ft AGL and fly no closer than 1 mile radius from the Halemau'u Trail switchback area.	1	1	1

enter or fly above the crater. Results found that three flights crossed the park boundary at the southern rim of the crater. While this represents less than 1% of flights captured during this study, it is highly likely these aircraft were more audible inside the crater than flights which did not cross the park boundary. Similarly, only nine flights were found to have crossed the park boundary near the Kaupo Gap (condition 4), but again, because of the terrain, the noise these flights produced also likely carried well into the crater.

Perhaps one of the most significant findings of this study is that deviations from the 1998 agreement conditions were mostly associated with minimum altitude guidelines. Compliance was much higher with lateral offsets than it was with minimum altitude requirements. Specifically, condition 2 had the most lateral offset deviations (21 of 321 flights; 6.5%), compared with the minimum AGL deviations for condition 1 (179 of 321; 55.7%), and condition 5 (31 of 321 flights; 9.6%). The vast majority of these deviations occurred over the Kīpahulu area of the park, not near the crater. Outreach and education to the operators about raising flight altitudes around this area of the park might vastly improve compliance with the operating conditions 2 and 5.

There were very few ADS-B track flights captured north of the park. This resulted in broad compliance with conditions 6 and 7. Specifically, only two flights were captured by the loggers north of the park (Figure 2). These findings could be a result of our loggers being shielded by the terrain for flights north of the park and/or suggests that air tours simply do not explore the northern boundary of the park.

Overall, this study found broad compliance with the 1998 agreement. Any future agreements should probably focus more on lateral offset and minimum altitude requirements due to greater compliance. Aircraft tracking data could also help HALE in any soundscape management plan by informing the park of the specific routes and common deviations of these routes.

Broad Management Implications for Air Tour Management

The results from this study demonstrate the potential for using ADS-B to track air tours over PPAs. Most of the challenges associated with using ADS-B for air tour management at NPS units were largely overcome in this study. Specifically, these challenges include vast terrain changes, low level flights, and the park not being within required ADS-B airspace. HALE was specifically chosen because it would be a challenging environment to test the utility of ADS-B for tracking air tours and that while air tours depart from Kahului Airport (Class B airspace) the park itself is outside Class B airspace. The challenges with terrain and low levels flight were mostly overcome by using two loggers to track air tours, though additional loggers may be needed to cover the north side of HALE. However, while each flight identified gradually improve our understanding of the travel patterns overall, no single flight was captured by both loggers from end-to-end on the southern portion of the park boundary, much less the entire route from takeoff to landing. While, the data did prove to be complete enough for monitoring compliance with the 1998 agreement, other parks, planning efforts, or different research questions may prove challenging with incomplete data.

With the identification of 321 air tour routes, a general understanding of the travel patterns evolved. Supporting a finding of the prior study (Beeco & Joyce, 2019), these travel patterns cover very wide corridors rather than concentrating on specific routes. While this spreads the noise across a larger area, it creates challenges for modeling noise from air tour routes. Noise modeling requires a very specific route, with specific altitude changes, and speeds (Beeco & Lignell, 2019). The data from this study suggest that mapping an "average" route for noise modeling, while still exceptionally useful, may provide incomplete information, if used alone. Thus, ADS-B tracking seems to provide a useful complement for planners and decision makers.

Prescribed minimum altitudes are common for air traffic management; however, the results from this study suggest that compliance with lateral offsets is much higher than AGL requirements. This could be due to weather or other variables needed to maintain safety. Nevertheless, low level flights are much louder than higher elevation flights, causing increased noise impacts to visitors and other park resources. Routing flights away from noise sensitive resources may be more effective for mitigating noise impacts than setting minimum altitudes. Of course, using both lateral offsets and minimum altitudes may work best. For example, the Air Tour Management Agreement at Rainbow Bridge National Monument states that all operations must maintain a minimum altitude of 5,000 ft (1,524 meters) mean sea level and 2,000 ft (609 meters) lateral distance from the bridge at all times (B. Lignell, personal communication, January 29, 2020).

It is difficult to compare the results of this study to prior aircraft tracking projects, especially studies that focus on PPAs, because so few studies have been conducted. However, after January 1, 2020, when U.S. compliance with new ADS-B regulations becomes mandatory, these studies should become more reliable because of an increase in aircraft being equipped.

Methodological and Date Management Considerations

Recent research into visitors' spatiotemporal movement patterns for on-the-ground visitors has been moving toward more cost-effective and/or passive technologies of tracking visitors, such as smartphone applications or crowdsourced data (Kim, et al., 2019; Korpilo et al., 2017; Rice et al., 2019). This study furthers that trend because ADS-B tracking is only collecting publicly available signals being pushed from aircraft. Additionally, ADS-B tracking does not require permission from visitors or air tour operators. Yet, regardless of the type of data, all these studies still obtain significant amounts of data and require novel efforts for handling, processing, and analyzing.

In 31 days, over 7.5 million data points were collected. Processing and cleaning scripts in R, which were used prior to bringing the data into ArcGIS, proved to be valuable, saving time and reducing computer computational requirements. Even with so much automated processing in R, quality assurance and quality control of the data remains important, requiring time and effort. One potential solution to this problem is to only focus on the aircraft registration number, or tail number, which is usually painted on the tail of the aircraft. This solution has two primary limitations. First, there is not currently a requirement for air tour operators to provide the registration number in reporting to the NPS and FAA; however, this requirement may soon be in place, and the results from this study would support that effort. Second, periodically, reports arise about unauthorized operators from park staff, visitors, or other air tour operators. ADS-B could be a way to validate these claims, if we do not overly focus or depend on operator reported registration numbers.

Generally, the methods used here were effective in processing the data efficiently (research question 4). However, the study required significant data processing and analysis efforts, considering it produced results for a single park, and a dataset that only represented data for 31 days. Future studies should continue to explore ways to better automate processes with the target of further improving data processing efficiency. According to NPATMA, any park with more than 50 air tours per year is required to complete a plan or an agreement. According to 2018 air tour reporting data, 22 parks have more than 50 tours (Lignell, 2019). Additionally, three parks with less than 50 air tours have determined that they have noise sensitive resources. These parks will also require a plan or agreement to protect parks resources and visitor experiences. In all there were 47,109 air tours in 2018. Currently, considering the 25 parks that need plans or agreements, and the number of total air tours, ADS-B tracking could prove to be too burdensome to implement systemwide. Therefore, developing efficient and accurate data processing solutions will be critical for the long-term use of ADS-B for counting air tours, ensuring compliance with air tours management plans or agreements, and validating reports of non-compliance or low-level flights.

Validating what is and is not an air tour can also be a subjective decision at times. Operator tail numbers may assist. In the current study's dataset, one operator displayed a very different travel pattern than other operators. The ADS-B data for this operator only displayed data for three routes, all of which flew along the Kīpahulu coast, over the ocean. No data for this operator was logged over the island. We counted these three flights as air tours because they met our data cleaning criteria; nevertheless, it seems unlikely that this operator was actually conducting air tours, considering that they were not flying over the park (though it did come within .5 mile of the boundary –the 'NPATMA boundary'). Perhaps these three flights were actually general aviation flights (i.e., non-commercial flights). This is an example of one of the challenges with using ADS-B data to identify and count the number of air tours, as well as an example of the time it takes to ensure air tours are accurately counted.

Linking the ADS-B data in post processing was less challenging than expected (research question 3). The most effective method proved to be merging the data as text files before processing in R. This way, all data processing occurred on single set of data.

One limitation of this study was the AGL estimates. As mentioned in section 2.5, the estimated AGL values were surprisingly potentially inaccurate. We took the opportunity with a Medical Transport Corporation flight (that we assume landed on the ground) to examine the accuracy of the ADS-B altitude of the flights. Our analysis revealed that the AGL was -210 ft (-64 meters). There are two primary sources for this error. The first is that some ADS-B loggers report altitude based on barometric pressure measurements rather than GPS measurement. This requires constant calibration to account for changes in atmospheric conditions. This is likely the source of most of this error. Additionally, we used a 10x10 meter DEM to estimate AGL. In a place like Maui, terrain changes are drastic, so even a DEM of 10x10 meter can introduce additional error. Overall, of the total 182,505 points used to estimate AGL, only 2,114 were found to be negative (1.1%). All these instances represented locations where flights were flying low and terrain changes were drastic, and most were located outside of the park boundary. Whether the error is consistently underestimating AGL or whether some of the altitudes for points were overestimated, is unclear. Nevertheless, for this study, adding a margin of error of 200 feet to evaluate deviations in AGL seemed reasonable. Future studies should explore this challenge and more systemic ways to validate AGL.

Future Studies

While mapping aircraft travel patterns has been used for airport planning for decades, tracking aircraft for air tour planning over PPAs is in its infancy. Taczanowska and colleagues (2017), stated that human mobility data can inform social, economic, operational, informational, and spatial factors for park and landscape planning, making air tour tracking data a natural fit. Future research should include methods, techniques, and analysis that can benefit park and regional planning, the impacts of noise on cultural/natural resources and visitors, and deeply examine the relationship between the space in the skies and the visitors, communities, and resources on the ground.

Future studies should also examine the spatial relationships and patterns between park resources and visitor experience, specifically predictive models. For example, understanding the spatiotemporal patterns of aircraft as compared to the patterns of wildlife could benefit from predictive models of how recreation disturbance may affect wildlife response across large areas (Gutzwiller et al., 2017). Further, predicting visitor responses to modeled noise data could also help park planners generally, and specifically with setting thresholds of noise that require management action (Beeco & Lignell, 2019). Aircraft tracking, both air tours and all aircraft, could also fit into other planning effort and research techniques such as tranquility mapping (Watts & Pheasant, 2015; Watts & Marafa, 2017). Tranquility mapping is an approach to quantifying the noise and/or visual impacts of a setting in comparison to the natural features of the area. While this study primarily focused on air tour management, collecting aircraft tracking data as completed in this study also included commercial jets, general aviation, and some military activity. To date, no studies have focused on the overall aircraft traffic over a PPAs. Understanding the noise generated across and entire park or ecosystem could benefit planners and researchers to understand how noise can impacts a landscape, including ecosystems and social systems.

Finally, noise from air tours exist both within and outside of park boundaries, influencing local communities near or adjacent to parks. Solutions for both parks and communities may require larger regional planning. Coupling the spatiotemporal ADS-B data with other spatial data such as values mapping may help inform larger planning processes and help resolve issues between air tour operators, the local communities, and park managers. Values mapping has been used in prior studies to examine the different values of stakeholders, including locals versus tourists (Muńoz et al., 2019). By understanding the locations, community values, areas of ecological concern (both within and outside of park boundaries), and the destinations of value to air tour operators, solutions and compromises may be found.

In closing, this study represents a step forward in the use of ADS-B for tracking air tours over PPAs, and more specifically NPS units, by reinforcing the value of spatial considerations within visitor use management. This study also revealed an improvement in the ADS-B logger design and performance. While the limitations outlined here currently prevent the full scale use of ADS-B for tracking and reporting of all air tours across the NPS system, ADS-B presents a promising compliment to the current paper maps, provided by operators for 'average' routes. Noise modeling, reporting validation, ensuring compliance, general resource protection, and the visitor experience, will all benefit from the more accurate aircraft tracking in planning for air tour management.

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