Frequency of ADS-B Equipped Manned Aircraft Observed by the OpenSky Network

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Identify Manned Aircraft Intruders

Objective: Identify types of manned aircraft that a sUAS may encounter, particularly at low altitudes below 1200 or 500 feet AGL

- The low altitude airspace needs to be characterized and modeled to quantify airborne collision risk

- Airborne collision risk is dependent on the size and speed of encountered aircraft
  - Encounter models based on speed and dynamics of aircraft
  - New encounter models use aircraft type as a surrogate for size

- Characterizing the type and size of low altitude aircraft can inform surveillance requirements and the simulations to estimate the likelihood of a collision

- Leveraging crowdsourced ADS-B reports, aircraft registries, and open datasets to identify low altitude aircraft
• Overview

• Data Source and Processing
  • Distributions Given Airspace Class and Altitude Layer
  • Distributions Given Aircraft Seats

• Summary
Data Source: OpenSky Network

- Community-based receiver network which continuously collects air traffic surveillance
  - Archives raw data and makes it accessible to researchers
  - Eight trillion+ ADS-B and Mode S messages collected from more than 1000 global sensors
  - 40 million+ daily worldwide ADS-B messages

**MIT LL Collected Data Available for Processing**

**Example Temporal Distribution**
The OpenSky Network weekly makes easily accessible the abstracted raw data from the previous Monday (UTC) with observations at least 10 seconds apart. Only the last 10-15 Mondays are made the easily most accessible. MIT LL has aggregated data on the LLSC since 2018, but not continuously. Raw data available in hourly segments, although no guarantee all 24 hours of a day were made available.

### 89 Mondays Processed

| 2018-02-05 | 2018-04-23 | 2018-10-22 | 2019-01-07 | 2019-03-18 | 2019-06-03 |
|------------|------------|------------|------------|------------|------------|
| 2018-02-12 | 2018-05-14 | 2018-10-29 | 2019-01-14 | 2019-03-25 | 2019-06-10 |
| 2018-02-19 | 2018-05-21 | 2018-11-05 | 2019-01-21 | 2019-04-01 | 2019-06-17 |
| 2018-02-26 | 2018-09-03 | 2018-11-12 | 2019-01-28 | 2019-04-08 | 2019-06-24 |
| 2018-03-05 | 2018-09-10 | 2018-11-26 | 2019-02-04 | 2019-04-15 | 2019-07-01 |
| 2018-03-12 | 2018-09-17 | 2018-12-03 | 2019-02-11 | 2019-04-22 | 2019-07-08 |
| 2018-03-19 | 2018-09-24 | 2018-12-10 | 2019-02-18 | 2019-04-29 | 2019-07-15 |
| 2018-03-26 | 2018-10-01 | 2018-12-17 | 2019-02-25 | 2019-05-06 | 2019-07-22 |
| 2018-04-02 | 2018-10-08 | 2018-12-24 | 2019-03-04 | 2019-05-13 | 2019-07-29 |
| 2018-04-09 | 2018-10-15 | 2018-12-31 | 2019-03-11 | 2019-05-20 | 2019-08-05 |
| 2018-04-16 | | | | | |
Analysis Scope

• Analysis scoped based on administrative boundaries and altitude
  – Only considered observations over the United States, Puerto Rico, and Virgin Islands
  – Limited observations to altitudes below 18,000 feet AGL and MSL

• Considered barometric and geometric altitudes and data from 2018 and 2019
  – No statistical difference between barometric and geometric altitude-based results
  – No statistical difference between years
  – Presented results focus on processed barometric altitude from 2019

• Identify aircraft type using the ICAO24 address
  – Use registries from multiple civil aviation authorities*
  – Leverage registries from multiple years

  Analyzed 380,000+ flight hours below 18,000 feet MSL with 52,000+ flight hours
  at altitudes of 50 – 1,200 feet AGL
• Overview

• Data Source and Processing

• Distributions Given Airspace Class and Altitude Layer

• Distributions Given Aircraft Seats

• Summary
Airspace Class and Altitude Layer

- Airspace class discretized into four categories: Class B, Class C, Class D, Other
  - Same discretization as MIT LL uncorrelated encounter models*
  - Other includes controlled Class E and uncontrolled Class G airspaces

- Altitude reports discretized into 100 feet intervals
  - Smaller interval than used by MIT LL encounter models*
  - Assessed barometric and geometric altitude, although results agnostic to altitude source

- Analysis an aggregation of altitude reports across the entire time window
  - No conclusions can be drawn about the distribution at a specific location
  - Initial networks of previous MIT LL encounter models have a similar constraint
ADS-B Equipped Fixed-Wing Multi-Engine Processed Barometric Altitude Reports in 2019

- Fixed-wing multi-engine aircraft tend to operate at higher altitudes.
- Substantial observations across altitudes in Class B airspace.
- Distributions reflect altitude ceilings of different airspace classes.

Aircraft Frequency - AGL = Above Ground Level
AJW 10/30/20
ADS-B Equipped Fixed-Wing Single Engine Processed Barometric Altitude Reports in 2019

Limited observations in terminal airspaces

Observations less frequent as AGL altitude increases

AGL – Above Ground Level
ADS-B Equipped Rotorcraft Processed Barometric Altitude Reports in 2019

Majority of rotorcraft observations were outside of terminal airspace

Majority of rotorcraft observations below 2000 feet AGL

AGL – Above Ground Level
• Altitude distribution is strongly dependent on aircraft type

• All aircraft types have sufficient observations below 500 feet AGL
  – Majority of rotorcraft observed below 3000 feet AGL
  – Fixed-wing single engine rarely observed in controlled terminal airspace
  – Fixed-wing multi-engine have the most relative observations in Class B airspace

• Analysis indicates that, across the aggregate, smaller UAS can expect to encounter all three different manned aircraft types at low altitudes

• This analysis did not consider the size of the aircraft potentially encountered
  – Fixed-wing multi-engine can vary in size by over a hundred feet
  – Speeds and behaviors of aircraft vary based on airspace and altitude
Overview

Data Source and Processing

Distributions Given Airspace Class and Altitude Layer

Distributions Given Aircraft Seats

Summary
Aircraft Size Frequency Analysis
Organized by Number of Seats, Not Individual Aircraft Models

- Aircraft size can be identified by correlating an aircraft’s ICAO 24-bit address with aircraft registries to find aircraft manufacturer and model
  - Reduce number of unknown aircraft by using annual registries from United States, Canada, Ireland, and the Netherlands
  - Calculate average number of seats across all instances of the same aircraft model

- Aircraft registries have good quality control on aircraft type and number of seats, but aggregating aircraft manufacturer and aircraft models is challenging
  - Inconsistent data or similar variants: “Cessna 172” vs. “Textron C172” vs. Cessna 172s
  - Natural language processing techniques applied to improve aircraft registries
  - Further registry processing can be improved as future work

- Distribution of size is more important than relative frequency between different models
  - Aircraft size tends to increase with the quantity of seats
  - Probability of detecting an aircraft is dependent upon the aircraft’s size
  - Selecting aircraft for flight tests is easier based on seats, than seeking specific aircraft
### ADS-B Equipped Fixed-Wing Multi-Engine

83%+ had greater than 10 seats and subject to a TCAS mandate*  

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**Table:**

| Year | Altimeter | ? Seats | [1,10] Seats | [11,31] Seats | [32, ∞] Seats |
|------|-----------|---------|--------------|---------------|---------------|
| 2018 | Barometric | $6.9 \times 10^7$ (0.3%) | $5.1 \times 10^8$ (21.9%) | $3.9 \times 10^9$ (17.0%) | $1.4 \times 10^{10}$ (60.7%) |
| 2018 | Geometric  | $6.9 \times 10^7$ (0.3%) | $5.0 \times 10^8$ (21.9%) | $3.9 \times 10^9$ (17.0%) | $1.4 \times 10^{10}$ (60.7%) |
| 2019 | Barometric | $1.2 \times 10^8$ (0.3%) | $7.3 \times 10^9$ (17.5%) | $6.2 \times 10^9$ (14.9%) | $2.8 \times 10^{10}$ (67.2%) |
| 2019 | Geometric  | $1.2 \times 10^8$ (0.3%) | $7.3 \times 10^9$ (17.6%) | $6.2 \times 10^9$ (14.9%) | $2.8 \times 10^{10}$ (67.2%) |
| 2018 | Barometric | $1.2 \times 10^7$ (1.0%) | $2.6 \times 10^8$ (22.6%) | $1.9 \times 10^8$ (16.7%) | $7.0 \times 10^8$ (59.6%) |
| 2018 | Geometric  | $9.7 \times 10^6$ (0.9%) | $2.5 \times 10^8$ (22.4%) | $1.8 \times 10^8$ (16.5%) | $6.8 \times 10^8$ (60.3%) |
| 2019 | Barometric | $1.2 \times 10^7$ (0.6%) | $3.6 \times 10^8$ (18.7%) | $3.0 \times 10^8$ (15.3%) | $1.2 \times 10^9$ (65.4%) |
| 2019 | Geometric  | $1.1 \times 10^7$ (0.6%) | $3.5 \times 10^8$ (18.6%) | $2.8 \times 10^8$ (15.0%) | $1.2 \times 10^9$ (65.8%) |

\* 14 CFR § 135.180
Percentages organized by row
## ADS-B Equipped Fixed-Wing Single Engine

Majority had 6 or less seats

| Year | Altimeter | Seats | [1,6] Seats | [7,10] Seats | [11, ∞] Seats |
|------|-----------|-------|-------------|--------------|---------------|
| 2018 | Barometric | $6.3 \times 10^7$ (0.5%) | $1.1 \times 10^{10}$ (86.8%) | $6.2 \times 10^8$ (4.8%) | $1.0 \times 10^9$ (7.9%) |
| 2018 | Geometric | $6.3 \times 10^7$ (0.5%) | $1.1 \times 10^{10}$ (86.9%) | $6.2 \times 10^8$ (4.8%) | $1.0 \times 10^9$ (7.8%) |
| 2019 | Barometric | $2.3 \times 10^8$ (1.0%) | $1.9 \times 10^{10}$ (84.9%) | $1.1 \times 10^9$ (5.2%) | $2.0 \times 10^9$ (8.9%) |
| 2019 | Geometric | $2.3 \times 10^8$ (1.0%) | $1.9 \times 10^{10}$ (85.0%) | $1.1 \times 10^9$ (5.2%) | $2.0 \times 10^9$ (8.8%) |
| 2018 | Barometric | $1.8 \times 10^7$ (0.9%) | $1.9 \times 10^9$ (95.1%) | $4.4 \times 10^7$ (2.2%) | $3.5 \times 10^7$ (1.8%) |
| 2018 | Geometric | $1.7 \times 10^7$ (0.9%) | $1.8 \times 10^9$ (95.3%) | $4.1 \times 10^7$ (2.1%) | $3.1 \times 10^7$ (1.7%) |
| 2019 | Barometric | $6.6 \times 10^7$ (1.8%) | $3.2 \times 10^9$ (91.6%) | $1.3 \times 10^8$ (3.9%) | $9.9 \times 10^7$ (2.7%) |
| 2019 | Geometric | $6.5 \times 10^7$ (1.9%) | $3.2 \times 10^9$ (91.6%) | $1.3 \times 10^8$ (3.9%) | $9.2 \times 10^7$ (2.6%) |

*Percentages organized by row*
### ADS-B Equipped Rotorcraft

Majority of had 5, 6, 7, or 8 seats

| Year | Altimeter  | Seats | [1,4] Seats | [5,8] Seats | [9, ∞] Seats |
|------|------------|-------|-------------|-------------|--------------|
| 2018 | Barometric | 3.5×10^7 (1.4%) | 5.3×10^8 (21.9%) | 1.5×10^9 (63.0%) | 3.3×10^8 (13.6%) |
| 2018 | Geometric  | 3.5×10^7 (1.4%) | 5.3×10^8 (21.9%) | 1.5×10^9 (62.9%) | 3.3×10^8 (13.7%) |
| 2019 | Barometric | 8.5×10^7 (1.8%) | 7.3×10^8 (15.9%) | 3.2×10^9 (70.4%) | 5.4×10^8 (11.9%) |
| 2019 | Geometric  | 8.5×10^7 (1.8%) | 7.4×10^8 (16.0%) | 3.2×10^9 (70.3%) | 5.5×10^8 (11.9%) |
| 2018 | Barometric | 1.3×10^7 (0.8%) | 4.4×10^8 (25.3%) | 1.1×10^9 (62.6%) | 1.9×10^8 (11.3%) |
| 2018 | Geometric  | 1.2×10^7 (0.7%) | 4.4×10^8 (25.7%) | 1.0×10^9 (62.4%) | 1.9×10^8 (11.3%) |
| 2019 | Barometric | 3.3×10^7 (1.0%) | 6.3×10^8 (19.7%) | 2.2×10^9 (69.5%) | 3.1×10^8 (9.8%) |
| 2019 | Geometric  | 3.3×10^7 (1.0%) | 6.4×10^8 (19.7%) | 2.2×10^9 (69.7%) | 3.1×10^8 (8.8%) |
## Most Observed ADS-B Equipped Aircraft in 2019
\( \leq 18,000 \text{ feet AGL and All Airspace Classes} \)

| Type                              | Manufacturer | Model    | # Seats (Mean) | Flight Hours (\( \leq 18,000 \text{ ft AGL} \)) | Flight Hours (\( \leq 1200 \text{ ft AGL} \)) |
|-----------------------------------|--------------|----------|---------------|---------------------------------------------|---------------------------------------------|
| Fixed-Wing Multi-Engine           | Boeing       | 737      | 164           | 12,485                                      | 657                                         |
| Fixed-Wing Multi-Engine           | Embraer      | ERJ-170  | 86            | 11,646                                      | 563                                         |
| Fixed-Wing Multi-Engine           | Airbus       | A320     | 198           | 8,223                                       | 406                                         |
| Fixed-Wing Multi-Engine           | Airbus       | A321     | 304           | 7,578                                       | 332                                         |
| Fixed-Wing Multi-Engine           | Bombardier   | CL-600   | 54            | 7,175                                       | 285                                         |
| Fixed-Wing Multi-Engine           | Airbus       | A319     | 161           | 6,027                                       | 318                                         |
| Fixed-Wing Single Engine          | Cessna       | 172s     | 4             | 4,488                                       | 1,012                                       |
| Fixed-Wing Multi-Engine           | Embraer      | EMB-145LR| 55            | 4,239                                       | 122                                         |
| Fixed-Wing Multi-Engine           | Bombardier   | DHC-8    | 59            | 3,682                                       | 196                                         |
| Fixed-Wing Single Engine          | Cessna       | 172r     | 4             | 2,683                                       | 616                                         |

Across all altitudes, majority of observed aircraft were fixed-wing multi-engine.
### Most Observed Low Altitude ADS-B Equipped Aircraft in 2019 ≤ 1200 feet AGL and All Airspace Classes

| Type                        | Manufacturer | Model   | # Seats (Mean) | Flight Hours (≤ 18,000 ft AGL) | Flight Hours (≤ 1200 ft AGL) |
|-----------------------------|--------------|---------|----------------|-------------------------------|-------------------------------|
| Fixed-Wing Single Engine    | Cessna       | 172s    | 4              | 4,488                         | 1,012                         |
| Rotorcraft                  | Airbus       | AS-350b3| 7              | 970                           | 814                           |
| Rotorcraft                  | All American | AS-350b2| 6              | 850                           | 669                           |
| Fixed-Wing Multi-Engine     | Boeing       | 737     | 164            | 12,485                        | 657                           |
| Fixed-Wing Single Engine    | Cessna       | 172n    | 4              | 2,465                         | 630                           |
| Fixed-Wing Single Engine    | Cessna       | 172r    | 4              | 2,683                         | 616                           |
| Fixed-Wing Single Engine    | Beech        | 172s    | 4              | 2,637                         | 602                           |
| Rotorcraft                  | All American | AS-350b3| 6              | 724                           | 574                           |
| Fixed-Wing Multi-Engine     | Embraer      | ERJ-170 | 86             | 11,646                        | 563                           |
| Fixed-Wing Single Engine    | Blue Diamond | DA20-C1 | 2              | 1,957                         | 548                           |

**Majority of observed ADS-B equipped aircraft at low altitudes had 7 or less seats**
Discussion on Distributions Based on Seats

Negligible variation in results between altitude source and year

- Similar distributions between comparing all altitude reports and just at low altitude.
- Observations of fixed-wing single engine skewed to six seats or less at low altitudes
  - Assumes non-transponding aircraft at low altitudes will also generally have six or less seats
  - Size of fixed-wing single engine and rotorcraft at low altitudes may be independent of transponder equipage
- Cessna 172 fixed-wing single engine variants were some of the most observed ADS-B equipped aircraft
- Results can inform simulations based on aircraft size
  - Supports an extension of J.W. Andrews on air-to-air visual acquisition*
  - Enables weighting simulations based on aircraft size and subsequent probability of detection

Distributions inform the size of ADS-B equipped aircraft encountered at low altitudes
• Overview
• Data Source and Processing
• Distributions Given Airspace Class and Altitude Layer
• Distributions Given Generalized Operational Regions
• Distributions Given Aircraft Seats
• Summary
Summary

• The continuing integration of unmanned aircraft systems operations into the NAS requires development of regulations and technology to maintain safety

• To support development and evaluation of UAS DAA systems, the low altitude airspace needs to be characterized and modeled

• Airborne collision risk is dependent on the size and speed of encountered aircraft

• Observations of ADS-B equipped aircraft by the OpenSky Network were analyzed based on three different factors
  – Airspace class and altitude layer
  – Number of seats on the aircraft

• Results inform aircraft types used in DAA simulations and testing
Thank You!

Questions?
Feedback?

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Most Observed ADS-B Equipped Aircraft in 2019
Fixed-Wing Multi-Engine

| Ranking | Manufacturer   | Model     | # Seats | Flight Hours (All) | Flight Hours (Low) |
|---------|----------------|-----------|---------|--------------------|--------------------|
| 1       | Boeing         | 737       | 164     | 12,485             | 657                |
| 2       | Embraer        | ERJ-170   | 86      | 11,646             | 563                |
| 3       | Airbus         | A320      | 198     | 8,223              | 406                |
| 4       | Airbus         | A321      | 304     | 7,578              | 332                |
| 5       | Airbus         | A319      | 161     | 6,027              | 318                |
| 6       | Bombardier     | CL-600    | 54      | 7,175              | 285                |
| 7       | Bombardier     | DHC-8     | 59      | 3,682              | 196                |
| 8       | New Piper      | PA-44     | 4       | 1,536              | 162                |
| 9       | Embraer        | EMB-145LR | 55      | 4,239              | 122                |
| 10      | Boeing         | 757       | 190     | 2,592              | 113                |
| 11      | Bombardier     | BD-100    | 8       | 1,472              | 83                 |
| 12      | Embraer        | ERJ-190   | 24      | 2,061              | 81                 |
| 13      | Boeing         | 717       | 100     | 1,838              | 71                 |
| 14      | Embraer        | EMB-505   | 9       | 1,291              | 70                 |
| 15      | Boeing         | 777       | 439     | 1,354              | 69                 |
| 16      | Embraer        | EMB-135KL | 37      | 1,762              | 68                 |
| 17      | Boeing         | 767       | 237     | 1,473              | 65                 |
| 18      | Embraer        | EMB-145XR | 55      | 2,024              | 59                 |
| 19      | McDonnell Douglas | MD-88     | 142     | 1,515              | 29                 |
| 20      | Cessna         | 402c      | 10      | 1,253              | 27                 |
## Most Observed ADS-B Equipped Aircraft in 2019
### Fixed-Wing Single Engine

| Ranking | Manufacturer | Model | # Seats | Flight Hours (All) | Flight Hours (Low) |
|---------|--------------|-------|---------|--------------------|--------------------|
| 1       | Cessna       | 172s  | 4       | 4,488              | 1,012              |
| 2       | Cessna       | 172n  | 4       | 2,465              | 630                |
| 3       | Cessna       | 172r  | 4       | 2,683              | 616                |
| 4       | Beechcraft*  | 172s  | 4       | 2,637              | 602                |
| 5       | Blue Diamond | DA20-C1 | 2     | 1,957              | 548                |
| 6       | Cessna       | 152   | 2       | 1,638              | 472                |
| 7       | Cessna       | 172m  | 4       | 1,473              | 376                |
| 8       | New Piper    | PA-28 | 4       | 1,798              | 354                |
| 9       | Cessna       | 172p  | 4       | 1,585              | 306                |
| 10      | Blue Diamond | DA40  | 5       | 1,349              | 239                |
| 11      | Aero Design  | SR-20 | 4       | 1,444              | 228                |
| 12      | Cessna       | 182t  | 4       | 617                | 79                 |
| 13      | Aero Design  | SR-22t | 5     | 1,288              | 70                 |
| 14      | Aero Design  | SR-22 | 4       | 1,096              | 55                 |
| 15      | Cessna       | 208b  | 12      | 2,133              | 48                 |
| 16      | Homekit      | Homekit | 11   | 1,156              | 44                 |
| 17      | Homekit      | Homekit | 12   | 1,162              | 40                 |
| 18      | Cessna       | T206h | 6       | 622                | 36                 |
| 19      | Beechcraft   | A36   | 6       | 673                | 25                 |
| 20      | New Piper    | PA-46 | 6       | 572                | 14                 |

#1: **Cessna 172 Skyhawk**  
#5: **Blue Diamond DA20-C1**
# Most Observed ADS-B Equipped Aircraft in 2019

## Rotorcraft

| Ranking | Manufacturer     | Model     | # Seats | Flight Hours (All) | Flight Hours (Low) |
|---------|------------------|-----------|---------|--------------------|--------------------|
| 1       | Airbus           | AS-350b3  | 7       | 970                | 814                |
| 2       | All American     | AS-350b2  | 6       | 850                | 669                |
| 3       | All American     | AS-350b3  | 6       | 724                | 574                |
| 4       | BHI Helicopters  | R-44      | 4       | 656                | 544                |
| 5       | Bell             | 407       | 8       | 855                | 541                |
| 6       | All American     | EC-130    | 7       | 934                | 467                |
| 7       | Bell             | 206b      | 5       | 459                | 427                |
| 8       | Airbus           | EC-130    | 8       | 917                | 407                |
| 9       | Bell             | 369ff     | 4       | 413                | 407                |
| 10      | All American     | EC-120b   | 5       | 330                | 316                |
| 11      | All American     | AS-350b2  | 7       | 377                | 276                |
| 12      | Bell             | 206L4     | 7       | 353                | 258                |
| 13      | BHI Helicopters  | R-22 Beta | 2       | 299                | 254                |
| 14      | Bell             | 429       | 9       | 324                | 220                |
| 15      | Bell             | 407       | 7       | 264                | 191                |
| 16      | All American     | AS-350b3  | 7       | 255                | 176                |
| 17      | Eurocopter       | MBBK-117  | 8       | 270                | 170                |
| 18      | Eurocopter       | EC-135p2  | 7       | 292                | 157                |
| 19      | BHI Helicopters  | R-66      | 5       | 166                | 127                |
| 20      | Bell             | 206L3     | 7       | 193                | 67                 |

**#1: Eurocopter AS350 (Now Airbus Helicopters H125)**

**#14: Bell 429**
Imagery Sources

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