Exponent®

UAS Safety Analysis

December 16, 2014

**Exponent Project No.
1408989.EX0**

Exponent

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Mr. Matthew Bieschke
UAS America Fund, LLC
2020 K St. NW, Suite 520
Washington, DC 20006

Mr. Brendan Schulman
Kramer Levin Naftalis & Frankel LLP
1177 Avenue of the Americas
New York NY 10036

Subject: UAS Safety Analysis
Exponent Project No. 1408989.EX0

Dear Mr. Bieschke and Mr. Schulman:

Attached please find the UAS Safety Analysis report, prepared at the request of UAS America Fund, LLC and Kramer Levin Naftalis & Frankel, LLP.

Sincerely,

Adam Dershowitz, Ph.D., P.E.
Managing Engineer

Introduction

At your request, Exponent Failure Analysis Associates (Exponent) has conducted a preliminary analysis of some of the risks related to micro Unmanned Aerial Vehicles (UAVs) operating in the National Airspace System (NAS). While currently there is little data available for any impacts that might have occurred, there is significant data available on bird strikes on aircraft. Accordingly, birds were used as an analog to UAVs for the purposes of this analysis. This report sets forth the conclusions reached from the analysis.

Background

UAVs, commonly referred to as “drones,” are unmanned flying vehicles. The FAA is currently going through the process of developing new regulations for the use of these vehicles in the NAS. However, there is a dearth of data about the risks posed by the operation of these vehicles. As the vehicles, by definition, do not have anyone on board, there is no risk to any passengers. However, there is potential risk to others that might be presented by Unmanned Aerial Systems (UASs[1]). One of the large concerns relates to the interactions between UAVs and manned aircraft in the NAS, and the risk posed by these interactions.

It is common for aerospace vehicles to be segregated by weight for analysis and regulation. In many countries that have adopted or proposed regulations for UASs, the regulations are governed by weight category. For the purpose of this report, a weight of three (3) pounds and below is used to define this category of vehicle (micro UAVs).

In order to assess the risk to existing manned aircraft posed by micro UAVs, some data is required. Data is currently lacking as to damage caused by micro UAVs; however, there is a large FAA Wildlife Strike Database (http://wildlife.faa.gov/). The full FAA database includes both military and civilian reports. While this database does not include every bird strike, the FAA estimates that it represents 39% of all bird strikes.[2] It is likely that less significant events are more highly under-reported. No attempt was made to adjust for any such potential bias that might occur in the database. The database was downloaded in August of 2014, and includes bird strike data going back to 1990. Since the inception of the bird strike database, the FAA has encouraged reporting of wildlife aircraft strikes. On 12/22/04 it issued Advisory Circular 150/5200-32A which “explains the importance of reporting collisions between aircraft and wildlife”. On 5/31/2013 it was updated as 150/5200-32B which states, “Studies have shown that strike reporting has steadily increased over the past two decades.”

As birds are similar in weight to micro UAVs, Exponent decided to assess whether birds could be used as a surrogate for UAVs in evaluating collisions, and then to use the birdstrike database to analyze the risk presented to aircraft by micro UAVs until better data becomes available. Using birdstrike data is reasonable because while there are many factors involved in the detailed impact dynamics between two objects, the most important is kinetic energy. The kinetic energy (KE) of an impact is defined as:

$$KE=1/2*m*V^2$$

Where m is the mass of the incoming object, and V is the closing velocity. The specifications of several current micro UAVs were reviewed and found to have a maximum speed of approximately 35 MPH. Maximum bird speeds are generally higher, although like UAVs they have a very wide range depending on the species[3] and do not often fly at maximum speed.

[1] A “UAS” represents the system made up of components including such things as the vehicle (UAV), the operator and the radio control system

[2] http://www.nbaa.org/ops/safety/20120921-dot-asks-faa-to-do-more-to-reduce-bird-strikes.php

[3] https://web.stanford.edu/group/stanfordbirds/text/essays/How_Fast.html

While specific collision geometry is important, the closing speed of these impacts is dominated by aircraft flight speed. Similar sized birds and UAVs are thus likely to have similar impact kinetic energy. The details of the impact can be relevant, but the primary determination of damage is the KE.

The Wildlife Strike Database divides birds by size into three categories. Instead of providing strict weight divisions, the FAA presents examples of each. A sparrow is considered small, a gull is considered medium, and a vulture is considered large. As gulls can weigh up to 3.8 pounds, the small and medium birds in the database were used to represent the micro UAVs of interest, with a maximum weight of 3 pounds.

While the FAA has not yet released proposed rules for UAS operation, several options for proposed rules have been discussed. For this analysis, it was assumed that initial regulations would require that micro UAVs, at or below 3 pounds., would operate 5 miles or more from airports and would remain at or below 400 feet. Most civilian airplanes operate at or above 500 feet from the ground.

It should be noted that some aircraft types have certification requirements for safety against bird strikes. Transport category turbine powered aircraft are certified to continue flying safely after receiving an 8 lb bird strike to the tail and a 4 lb bird strike to the windshield or other structure at specified velocities. The engines must not have a “hazardous engine effect” after ingesting up to an 8.03 lb bird (the specific bird weight depends on engine inlet throat area).[4] Recent transport category rotorcraft are certified for at least a safe landing after impact with a 2.2 lb bird[5]., Most General Aviation aircraft and helicopters do not have any bird strike resistance or testing as part of their certification basis. They are not required to have engines or canopies/windshields resistant to any particular size, weight, or closing velocity of birds.

[4] Federal Aviation Regulations 25.571, 25.631, 25.775 and 33.76

[5] Federal Aviation Regulation 29.631

Analysis

The FAA Wildlife Strike Database was found to contain a total of 151,305 strike reports for the 24.5 years catalogued from 1990 to the present. Of these, 136,624 (90%) included small or medium sized birds. There are 13,906 (9%) reports where there was an indication of damage to an aircraft and there are 230 (0.15%) reports with an injury or a fatality involved.

The database was used to analyze the number of collisions reported in the database that occurred where UAVs would be allowed to operate under the proposed regulations discussed above. The initial database searches were for to small- and medium-size birds strike reports that occurred 5 or more miles from airports and at or below 400 ft. Using those parameters, no injuries or fatalities were caused by small or medium birds in the database. That same search shows two cases of damage to aircraft, both reported as minor ("simple repairs or replacements"). In one of the instances with damage, there was a hole in the chin bubble of a helicopter, and in the other there was delamination of the radome of an airplane.

For completeness the search was also repeated with a reduced exclusion area of three miles from airports, and reproducing the altitude threshold of 400 ft. For small- and medium-size birds, there are no fatalities and no injuries. This search finds five reports of damage to aircraft, all minor . (Note that these five include the two listed above for the five-mile radius search.) There are 15 reports of any impacts, with or without damage, occurring 3 or more miles from airports and at or below 400 feet, and 3 for the 5 mile threshold. This demonstrates both that the database does include non-damaging impacts, and additionally that a large portion of reported impacts include some damage.

The above searches include only records that indicate both an altitude and a distance from an airport. Many entries have one or both of those fields blank, and a manual review of the data revealed that some of those contained bird strikes for such things as pipeline patrols, helicopters ferrying personnel to oil rigs, or law enforcement activities over a city. Even though many of these incidents may be within a few miles of an airport, an additional search was run to include them as if they were all far away from an airport.

Searching for records that indicate an altitude at or below 400 ft, AND that have a phase of flight of "En Route" when no distance is available, to the 3 mile results above gives a total of 37 reports of damage to aircraft, 6 with injuries, and no fatalities. For a 5 mile threshold, this expanded search gives a total of 34 reports of damage to aircraft, 6 with injuries and no fatalities.

Finally, the database was searched to locate all fatalities associated with small- or medium-size birds in any location. This very broad search returned three reports. However, two of those reports were cases in which witnesses reported birds near the aircraft, but the NTSB was not able to confirm that there were in fact bird strikes[6]. The above results are summarized in Table 1.

[6] NSTB numbers: FTW94FA158, NYC98FA073, and CEN09MA117

Table 1 Summary of database query results

Threshold	#Events with Damage	#Events with Injuries	#Events with Fatalities	#Events w/o Damage
400 ft/5 miles	2	0	0	1
400 ft/3 miles	5	0	0	10
400 ft/5 miles or enroute	34	6	0	
400 ft/3 miles or enroute	37	6	0	
All reports	13906	230		
All small/medium birds in any location			3	

Additionally, the NTSB Aviation Accident Database was searched for fatal bird strikes prior to 1990. Only three fatal accidents were found that could be potentially small or medium sized birds, in addition to those mentioned above. In these three the bird size was not listed, so it was not possible to determine if any of them were a good surrogate for micro UAV impact. All three occurred prior to 1990, so would not have been included in the FAA Wildlife Database[7].

There are some limitations in this analysis. The analysis assumes that UAVs and birds will operate in the same way, and will be distributed in the NAS the same way. Birds tend not to fly at high altitudes, and thus the database would be expected to show more strikes at low altitude. Additionally, it assumes that any impact severity is primarily governed by velocity and mass. In fact, the specific structure and density of the objects involved will play a part in the details of any collision. This analysis is also based on the assumption that UAVs will not be intentionally operated near manned aircraft, such as those conducting law enforcement and news related activities. Despite these limitations, until better data is available bird effects may serve as an approximation of the effects of UAVs on the NAS. Birds and micro UAVs can both operate over a very wide speed range, so a general-impact speed cannot be assumed for either one.. UAVs will probably fly much less frequently than birds do so simply comparing populations and extrapolating numbers may not lead to reliable conclusions.

[7] NTSB numbers: MIA67A0043, LAX80FA005, and ATL82FLJ03

Conclusions

It is estimated that there are 10 billion birds in the United States[8]. While these birds do not fly at all times, they do spend a large amount of their time in the air. The extreme rarity of any collisions between birds and aircraft away from airports and at low altitude, despite the population of 10 billion birds, suggests that unintentional impact between UAVs and manned aircraft away from airports and low altitude will always remain extremely unlikely.

Analysis of the full 24.5 years of available FAA data using the proposed UAV regulations of 400 ft. and 5 miles from airports (including “en route” operations of unreported distance from airport), with small- and medium-size birds as a surrogate for UAVs, shows that there were 34 cases of damage to aircraft in collisions with small and medium size birds. This search found only 6 collisions resulting in injuries and none resulting in fatalities within these parameters. Based on the FAA Wildlife Strike database there is no indication that allowing UAVs of three pounds or less to operate at least 5 miles from airports and at or below 400 feet will pose a significant increase in risk to manned aircraft.

[8] *See, e.g.*, http://www.nytimes.com/2011/01/18/science/18birds.html?_r=0 and http://www.motherjones.com/kevin-drum/2011/03/how-many-birds. For a collection of sources concerning this estimate, *see* http://birdstuff.blogspot.com/2002/07/how-many-birds-are-there.html

Limitations

The study presented in this report is intended for use by UAS America Fund, LLC and its counsel Brendan Schulman to assist with a proposal for rulemaking related to operations of micro UASs, and is not intended to address all issues with respect to operation of micro UASs. Application of this report requires recognition and understanding of the limitations of both the scope and methodology of the study. Any use of the conclusions in this report is at the sole risk of the reader.

The scope of the study was the analysis of the FAA Wildlife Strike Database using birds as surrogates to UAVs to assess some of the risk posed by micro UASs.

The risk assessment methodology forming the basis of the results presented in this report is based on mathematical and statistical modeling of physical systems and processes as well as data from third parties. Given the nature of these evaluations, significant uncertainties are associated with the various hazard and loss computations. These uncertainties are inherent in the methodology and subsequently in the generated hazard and loss results. These results are not facts or predictions of the loss that may occur as a result of future events or any specific event; as such, the actual losses relevant to this study may be materially different from those presented in this study. Furthermore, the assumptions adopted in determining these loss estimates do not constitute the exclusive set of reasonable assumptions, and use of a different set of assumptions or methodology could produce materially different results.

If you have any questions or require additional information, please do not hesitate to contact me at (212) 895-8105 or adershowitz@exponent.com.

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Managing Engineer

Professional Profile

Dr. Adam Dershowitz is a Managing Engineer in Exponent's Thermal Sciences practice. Dr. Dershowitz specializes in aeronautical and astronautical engineering. He has expertise in aircraft and spacecraft systems and instrumentation. Dr. Dershowitz studies the interactions of complex systems, including human in the loop systems; airplane and helicopter icing; manned and unmanned space vehicles; cockpit displays; control of vehicles; decision making; safety critical software; and software failures. He models and analyzes vehicles, systems, and their accidents, and analyzes and presents high dimensionality and complex data.

Prior to joining Exponent, Dr. Dershowitz worked at Johnson Space Center for United Space Alliance. There, he worked in NASA's Mission Control Center on the motion control system of the International Space Station, designed and researched advanced technology solutions for Mission Control, and served as a member of the orbital debris analysis team for the Shuttle Columbia accident investigation. Dr. Dershowitz has significant teaching experience, both in the classroom and as a certified flight instructor.

Academic Credentials and Professional Honors

Ph.D., Aeronautics and Astronautics, Massachusetts Institute of Technology, 1998
M.S., Aeronautics and Astronautics, Massachusetts Institute of Technology, 1991
B.S., Aeronautics and Astronautics, Massachusetts Institute of Technology, 1989

NASA Certificate of Recognition from Inventions and Contributions Board, 2005; Nominated NASA Software of the year, 2003; NASA Spaceflight Awareness Award, 2002; Recipient Best Paper Award at AIAA Guidance, Navigation and Controls Conference, 2002; USA Superior Achievement Recognition Award for Technical Achievement, 2001; USA Employee of the month for Technical Achievement, August 2001; NASA Astronaut Selection Finalist, 2000; Nominated to be one of M.I.T. Aero/Astro XVI sixteen "whose innovation and vision for the future will help to create a future of opportunity," NASA Certificate of Recognition and cash award "For the creative development of a technical innovation which has been proposed for publication as a NASA Technical Brief, "August 1996; Distinguished Contributor, B.F. Goodrich Collegiate Inventors Program, April 1992; Hunsaker Teaching Fellowship at M.I.T., awarded 1991

Licenses and Certifications

Registered Professional Mechanical Engineer: California, #M33404; Connecticut, #PEN.0029945; Florida, #70277; New York, #093647; Pennsylvania, #PE81587; Aeronautical Engineer: Massachusetts, #50794; Certified Fire and Explosion Investigator (CFEI), #19090-

10709; Certified Flight Instructor in single and multiengine airplanes and instruments; Commercial Airplane, Glider, Instrument, aerobatic, and multiengine rated pilot; University of Southern California Aviation Safety and Security Certificate; USC System Safety Certificate (Courses include: Aircraft Accident Investigation; Human Factors in Aviation Safety; Software Safety; System Safety; Advanced System Safety; Human Error Analysis); Northwestern Accident Reconstruction Course; HAZWOPER Certified; NAUI Open Water SCUBA certified; First aid, CPR, and AED trained; 2nd degree black belt in Aikido; Certified Forklift Operator

Patents

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Publications

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Presentations

Dershowitz A, Weaver B. Engineering case studies of aircraft incidents, lessons learned. Chicago Bar Association Annual Meeting on Aviation Law, October 2007.

Dershowitz A. Failure analysis with case studies. Society for the Advancement of Materials and Process, ASM Failure Analysis Round Table, Cal State Northridge, April 26, 2006.

Dershowitz A, Reza A, Schroeder S. What happened? How an engineering laboratory can help you figure it out!" 2006 Winter Meeting of the California Conference of Arson Investigators, San Luis Obispo, CA January 30–February 1, 2006.

Professional Affiliations

- American Institute for Aeronautics and Astronautics (senior member)
- AIAA Systems Engineering Technical Committee (member)
- Human Factors and Ergonomics Society—HFES (member)
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