THE REAL CONSEQUENCES OF FLYING TOY DRONES IN THE NATIONAL AIRSPACE SYSTEM

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Executive Summary

A COMMON MISCONCEPTION is that Toy Drones are the same as Unmanned Aircraft. However, Toy Drones are not designed or built with the same aerospace standards; they pose a hazard to both operators and innocent bystanders with their lack of insurability; and they require no significant training to operate. With the large number of Toy Drones sold per month, it is reasonable to state that a Drone Strike between a manned aircraft and a Toy Drone is inevitable.

The purpose of our study is to outline the safety risks of flying Toys Drones in the national airspace. We explore what will happen when a collision occurs between a Toy Drone and a manned aircraft, and the potential for damage and death. To understand this, we look at examples of damage from Bird Strikes and compare current FAA guidelines for Bird Strikes versus Drone Strikes.

It is historically proven that Bird Strikes can cause catastrophic damage to manned aircraft and loss of human life, a danger so significant that the FAA has stringent guidelines and design requirements for aircraft manufacturers. According to current estimates, Bird Strikes cost nine hundred fifty-one million U.S. dollars ($951,000,000) per year in the United States alone. The impact of a Toy Drone, consisting of plastic, metal, and engineered materials, with a manned aircraft in a Drone Strike can therefore be seen as even more catastrophic.

We address FAA regulations for design standards pertaining to Bird Strikes, as well as mathematically testing these design standards against the impact of a Drone Strike.

FINDINGS

Through a scientific impact analysis, we were able to determine the damage a Drone Strike would cause to a manned aircraft by comparing the kinetic energy of Bird Strikes into manned aircraft with the relative kinetic energy of a Drone Strike.

Results showed that a Drone Strike to the windshield and engine ingestion of a commercial airliner would cause damage and economic losses, while a head-on rotorcraft Drone Strike would cause significant damage and be non-survivable. Toy Drones pose a catastrophic threat to manned rotorcraft, posing a risk to the pilots, passengers, and bystanders on the ground if the aircraft were to crash.

The risk of Toy Drone collisions is great and safety is paramount. A balanced solution is called for that is focused on public education, additional testing, dedicated operating areas, air-traffic separation, and airworthiness certification.

Aero Kinetics is currently exploring the possibility of building a consortium to conduct further research. The results could help shape the future of manned aircraft design requirements and Toy Drone regulation.

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Definitions

TOY DRONE:

A fixed-wing, rotary-wing, or multi-rotor unmanned aerial vehicle weighing under fifty (50) pounds that is fitted with an autopilot, and intended to be controlled, through a remote radio communications link, by an individual on the ground.

THESE AERIAL VEHICLES ARE NOT:

a) Designed to conform with generally accepted aerospace grade engineering and design principals; and,
b) Fitted with aerospace grade avionics systems including: (i) guidance, (ii) navigation, (iii) communications, and (iv) transmitter-responders; and,
c) Certificated (or otherwise pedigreed) by the Federal Aviation Administration as Airworthy Aircraft.

UNMANNED AIRCRAFT SYSTEM:

A fixed-wing, rotary-wing, or multi-rotor Unmanned Aircraft System ("**UAS**") which consists of: (i) the Unmanned Aircraft ("**UA**"), (ii) the Ground Control Station ("**GCS**"), (iii) all associated support equipment necessary to operate the Unmanned Aircraft by an authorized operator.

UNMANNED AIRCRAFT SYSTEMS ARE:

a) Designed to conform with generally accepted aerospace grade engineering and design principals; and,
b) Fitted with aerospace grade avionics systems including: (i) guidance, (ii) navigation, (iii) secure communications links (data and telemetry), (iv) transponders, and (v) autopilots; and,
c) Certificated or able to be Certificated (or otherwise pedigreed) by the Federal Aviation Administration as Airworthy Aircraft.

REMOTELY PILOTED AIRCRAFT:

A Remotely Piloted Aircraft ("**RPA**") is a form of UAS which is non-autonomous in its capacities, the aircraft being subject to direct human control at all stages of flight despite operating 'remotely' by that human from a remote pilot station.

ADS-B IN & OUT:

Automatic Dependent Surveillance – Broadcast ("**ADS-B**") is a cooperative surveillance technology in which an aircraft determines its position via satellite navigation and periodically broadcasts it, enabling it to be tracked. The information can be received by air traffic control ground stations as a replacement for secondary radar. It can also be received by other aircraft to provide situational awareness and allow self-separation.

Definitions *(continued)*

MID-AIR COLLISION:

A Mid-Air Collision ("**MAC**") is an aviation accident in which two or more aircraft come into unplanned contact during flight statistically resulting in very severe damage or the total destruction of at least one of the aircraft involved.

NEAR MID-AIR COLLISION:

A Near Mid-Air Collision ("**Near Mid-Air**") is an incident associated with the operation of an aircraft in which a possibility of a Mid-Air Collision occurs as a result of one aircraft in proximity of less than 500 feet to another aircraft (FAA, 2015)

BIRD STRIKE:

A Bird Strike ("**Bird Strike**") is an aviation incident in which there is a collision between an airborne animal (usually a bird or bat) and a manned aircraft.

MODEL AIRCRAFT:

A Model Aircraft ("**Model Aircraft**") is a small-sized Remote Controlled (R/C) airborne vehicle or, in the case of a scale model, a replica of an existing or imaginary aircraft, controlled through the use of a radio communications link within the line-of-sight of an enthusiast for recreational purposes.

DRONE STRIKE:

A Drone Strike ("**Drone Strike**") is an aviation incident in which one or more Toy Drones come into contact with a manned aircraft during any phase of flight.

Abstract

THE QUESTIONS ARE:

What will happen when a Drone Strike occurs with a Manned Aircraft?

What is the real potential for damage, destruction, and death from a Drone Strike in the National Airspace System?

As novelty, the Toy Drone industry has generally avoided these tough questions; however, this paper outlines the very real potential consequences and dangers of flying Toy Drones in the national airspace by comparing current FAA guidelines for Bird Strike energy directly to Drone Strike energy.

Silicon Valley, foreign corporations, and fast money investors have accelerated the growth of the Toy Drone industry without regard for time-tested aerospace engineering, design, and regulatory principals that have allowed the United States to enjoy one of the safest airspace systems in the world. The speed of Toy Drone development, production, and sales has increased steadily since their introduction to the market. Consumers and corporations alike are enamored with the ability to capture aerial video they never before thought possible with relative ease.

The Federal Aviation Administration ("**FAA**"), dealing with perennial budget challenges and short-term reauthorizations, is being told to keep pace with a Toy Drone industry that has billions of dollars at its disposal to maintain a vertical technological growth curve. In addition, the Toy Drone industry is in its infancy; thus in many cases the data points required to draft applicable regulation do not yet exist.

Toy Drones are not Unmanned Aircraft, yet the public and corporate adopters alike commonly see no difference between the two. The advanced autopilot capabilities of Toy Drones have created the perception that they are fitted with aerospace-grade avionics, even though most of their autopilot systems are derivations of video game and smart phone technology. Transponders, ADS-B In & Out, command and control radio links, and aviation radios, all among the most basic aerospace grade avionics packages, are an afterthought to the public and the manufacturers, and therefore are seldom found in Toy Drones.

Toy Drones are not designed and built with aerospace standards in mind, let alone to conform to any kind of FAA airworthiness process, which have provided for public safety since the 1920's. They are not insurable in the same manner as unmanned aircraft, leaving potentially significant gaps in insurance coverage for both operators and innocent bystanders on the ground (or in the air), and they require no significant training to operate.

Toy Drones are accessible to the general public, easily purchased at big box stores, online, and at your local mall. With the estimate that over two hundred thousand (200,000) (Booth, 2014) Toy Drones are sold per month, it is quantitatively reasonable to determine that a Drone Strike between a manned aircraft and a Toy Drone is a virtual certainty. It is statistically a matter of time. Drone fever has taken hold; however, there are real consequences and life-threatening hazards associated with flying Toy Drones both recreationally and commercially in the national airspace system.

Introduction

In order to quantifiably determine the damage a Drone Strike would cause to a manned aircraft in real terms, we conducted a scientific impact analysis comparing the kinetic energy of Bird Strikes into manned aircraft with the relative kinetic energy of a Drone Strike. Bird Strikes are intensely studied, highly quantifiable, and a subject matter of interest for the FAA, aviation insurance providers, aviation trade groups, aircraft manufacturers, and others. As a result, a great deal of empirical data, historical knowledge, and scientific understanding is available for Bird Strikes.

As historically proven, Bird Strikes can cause catastrophic damage to manned aircraft as exemplified by US Airways Flight 1549, KLM Flight 1673, PHI Sikorsky S-76C++ Helicopter Registration No. N748P, and many others. The danger to manned aircraft is considered so great that the FAA has promulgated guidelines and design requirements for aircraft manufacturers, which include stringent specifications that must be met in the airworthiness certification process to ensure both the integrity of the aircraft and the safety of the souls onboard in the event a Bird Strike occurs.

In 2013 alone four hundred forty-four (444) Bird Strikes resulted in damage to manned aircraft in the United States National Airspace System ("**USNAS**"). It is estimated that Bird Strikes cost upwards of ***Nine Hundred Fifty-One Million U.S. dollars*** ($951,000,000) per year in the United States alone. Between the years 1990 and 2013 there were seventeen thousand five hundred (17,500) (FAA & USDA) Bird Strikes while manned aircraft were in the process of taking off, and fifty-four thousand eight hundred twenty-two (54,822) (FAA & USDA) Bird Strikes while manned aircraft were in the process of landing. During the same period fifty-nine thousand eight hundred and twenty-two (59,822) (FAA & USDA) Bird Strikes occurred at five hundred feet (500ft) above ground level ("**AGL**") or below. In addition, the location on the aircraft of the Bird Strikes are distributed as follows: forty-three percent (43%) (Garcia, 2014) to the front of the craft (nose, radome, and windshield), twenty-nine percent (29%) (Garcia, 2014) to the wing or engine, and thirteen percent (13%) (Garcia, 2014) to the fuselage and tail. Below are a few images showing some of the damage a bird can do to an aircraft, unfortunately the data points for these specific impacts are not available.

Examples of Damage

FIGURE 1: Engine Inlet Damage FAA States "Non-Hazardous Engine Effects"

(FOD News)

FIGURE 2: Nose Cone Damage FAA States "Safe Flight/Safe Landing"

(Birdstrike Consulting & Training)

FIGURE 3: Helicopter Windshield Damage FAA States "Non-Dangerous Fragments"

(Helicopter EMS)

FIGURE 4: Engine Cowling Damage FAA States "Non-Hazardous Engine Effects"

(FOD News)

Examples of Damage

FIGURE 5: Bell 407 Windshield Damage FAA States "Non-Dangerous Fragments"

(BirdStrike Consulting & Training)

FIGURE 6: KLM PH-BTC Nose Gear Failure at Landing, Aircraft Total Loss
(FS Passengers, 2008)

FIGURE 7: US Airways N106US Dual Engine Power Failure, Aircraft Total Loss
(Bureau d'Archives des Accidents Aéronautiques -Aircraft Crashes Record Office, 2009)

FIGURE 8: Windshield Strike N748P - Catastrophic Failure, Fatalities, Aircraft Total Loss
(Metcalf, 2010)

Impact

The impact of a bird, an animal that consists of more than fifty percent (50%) water (Maclean, 1996), with a manned aircraft has proven to be catastrophic. After reviewing these images, the impact of a Toy Drone, consisting of plastic, metal, and engineered materials, with a manned aircraft in a Drone Strike can be qualitatively extrapolated to be catastrophic.

The starting point to quantitatively determining the real danger of a Drone Strike is a review of the published FAA regulations for design standards pertaining to Bird Strikes, which is then followed by mathematically testing these design standards against the impact of a Drone Strike. The resulting scientific impact analysis quantifiably demonstrates the potential damage that could result.

It should be noted that no two impacts are exactly the same, and it is difficult to quantify the actual force of the impacts without full-scale scientific impact testing. However, launching the Toy Drones at multi-million dollar test aircraft proved cost prohibitive, thus the comparative methodology provides the most relevant, reliable, and comparable data points.

The Science of Impact

In mechanics, an impact is a high force or shock applied over a short time when two or more bodies or objects collide. A Drone Strike is a comparatively high-velocity collision, and in such collisions the majority of the applied forces translate into fracturing the materials of either object. To calculate the energy and forces involved with such collisions, the equations for kinetic energy (1) and momentum (2) are used.

$$KE = \frac{1}{2}mv^2$$

Equation 1: Kinetic Energy

$$P = mv$$

Equation 2: Momentum

Where m is the mass of the Toy Drone, and v is velocity relative to the Toy Drone along the aircrafts flight path. The aircraft used and the data required for the calculations are listed below.

Aircraft	Mass (m)	Velocity (v)
DJI Phantom II[1]	1300g	15 $\frac{m}{s}$
DJI Inspire[1]	2935g	22 $\frac{m}{s}$

Table 1: Unmanned Aircraft Data

[1] (DJI Hobby, 2015) See Reference Page

Aircraft	Velocity (v)
Bell 407	133 knots or 68 $\frac{m}{s}$
EC 130	130 knots or 67 $\frac{m}{s}$
737 (Approach)	130 Knots or 67 $\frac{m}{s}$
737 (Take Off)	150 knots or 77 $\frac{m}{s}$

Table 2: Manned Aircraft Data

Taking the data in Tables 1 and 2, FAA guidelines listed in Table 3, and conducting a scientific impact analysis through both equations allows us to quantitatively compare a Drone Strike to a Bird Strike.

THE EFFECT OF

Impulse

The scientific impact analysis, given impact resistance decreases with an increase in the modulus of elasticity of an object(s), does not fully account for the difference in the material make up between a Bird and a Toy Drone. A bird consists of organic material, is generally lightweight, and is mostly fluid; whereas a Toy Drone consists of metals, plastics, carbon fibers, and is generally more solid and structurally rigid than a bird. In order to explain why this is important, the concept of Impulse needs to be introduced and defined.

$$\text{Impulse} = Ft = \Delta(mv)$$

Equation 3: Impulse

Impulse is the integral of force over the time interval for which it acts, and when applied to an object produces an equivalent vector change in its linear momentum, providing that if the duration of the impact were known, the average force could be calculated.

With the help of a simple Physics scenario,

the difference between a “soft” bird and a “hard” Toy Drone can be explained. Assume you are an IndyCar driver driving in the Indy 500, your brakes fail, and you need to stop. You see two options. Option A: the concrete wall, or Option B: the Steel and Foam Energy Reduction (“**SAFER**”) barrier. Common sense says that hitting the softer SAFER barrier would be a better option than the harder concrete wall. Physics explains that with impulse, the more time you take to slow down (i.e. the compression of the foam), the more time to lower your momentum, which in turn decreases the average force felt by the impact, making it survivable.

In a Drone Strike, the relatively low modulus of elasticity of a Toy Drone results in higher impact forces with greater Impulse at a given velocity than in a Bird Strike of equivalent mass. This fact is not accounted for in our scientific impact analysis, given that the inorganic materials of a Toy Drone, such as lithium batteries, titanium, aluminum, and carbon fiber, will most certainly cause more damage than a bird, serving only to intensify the results of our analysis.

3314 FAR	Description	Components	Bird Mass	Aircraft Speed*	Condition
23.775	General Aviation Fix Wing	Windshield	2 lbs.	v_{fe}	Must Withstand
25.775	Commercial Aviation Fix Wing	Windshield	4 lbs.	v_c	Must Withstand
27.775	General Aviation Rotor Craft	Windshield	-	-	Non-Dangerous Fragments
29.775	Commercial Aviation Rotor Craft	Windshield	-	-	Non-Dangerous Fragments
33.75/33.76	Turbine Aircraft Engines Design	Turbine Engine	0.77 lbs. – 8 lbs.	v_1 - 200 knots	Non-Hazardous Engine Effects
25.631	Fixed Wing Bird Strike	Empennage	8 lbs.	v_c	Safe Flight/Safe Landing
29.631	Rotor Craft Bird Strike	General Craft	2.2 lbs.	v_{NE} or v_H	Safe Flight/Safe Landing
35.36	Propeller Design	Propeller	4 lbs.	-	Non- Hazardous Propeller Effects

Table 3: FAA Guidelines, * See Appendix B for V Speeds

Summary Results

Impact Analysis

- **HEAD-ON ROTORCRAFT DRONE STRIKE**:

  A head-on rotorcraft Drone Strike will cause the catastrophic failure of the rotorcraft's windshield resulting in significant damage to the aircraft and most likely injury to the pilot. The damage and injury qualitatively show to be non-survivable based upon the kinetic energy of the impact.

- **COMMERCIAL AIRLINER WINDSHIELD DRONE STRIKE:**

  A head-on Drone Strike into the windshield of a commercial airliner on approach or departure is most likely survivable based upon the kinetic energy of the impact, but would result in damage to the aircraft and economic losses.

- **COMMERCIAL AIRLINER ENGINE INGESTION DRONE STRIKE:**

  A head-on Drone Strike into the inlet of a turbine engine on a commercial airliner on approach or departure would cause severe damage to the engine and potentially a catastrophic failure, in either case resulting in damage to the aircraft and economic loss. More testing and data is needed to fully determine the potential and extent of the danger.

Impact Analysis

(continued)

BELOW ARE THE TABLES OF THE IMPACT RESULTS for the various FAA guidelines, and the aircraft specifically chosen for this study. The results clearly show that the current regulations for Bird Strikes into rotorcraft are insufficient for a Toy Drone Strike, as the energy is at least fifty percent (50%) higher than a Bird Strike. As for commercial fixed-wing aircraft, the windshield and empennage design requirements seem to be sufficient to provide for aircraft survivability; however, further testing and experiments are required to empirically prove aircraft survivability.

Turbine engines, the radome, and the fuselage of the aircraft are the areas of greatest risk for commercial fixed-wing aircraft. The FAA guidelines for the minimum design requirement for engine impacts is less than the impact energy of a Toy Drone Strike; however, the maximum design requirement is not exceeded. The resulting conclusion is that some turbine engines would assuredly suffer a catastrophic failure that may not be survivable, while others potentially would only require inspection and repairs. Regulatory guidelines and Bird Strike data pertaining to the fuselage, radome, or wings of commercial fixed-wing aircraft could not be found. In this respect additional testing and data would be required to quantitatively determine the potential risks and damage, but qualitatively the real potential for a catastrophic loss exists if a Drone Strike were to occur with these areas of a commercial aircraft. Detailed explanations can be found below with corresponding calculations listed in Appendix A as attached.

A. Commercial Airliner Windshield Impact Study

Situation	Kinetic Energy (J)	Momentum (N·s)
FAA Guideline 25.775	**47,896.89**	**416.85**
Phantom II → Boeing 737-700 A	**4,370.60**	**106.60**
Phantom II → Boeing 737-700 D	**5,501.60**	**118.3**
Inspire → Boeing 737-700 A	**11,624.06**	**261.22**
Inspire → Boeing 737-700 D	**14,382.96**	**290.57**

Table 4: FAA Commercial Fix Wing Windshield Requirements

FAA GUIDELINE 25.775 IS THE WINDSHIELD DESIGN REQUIREMENT, *"Windshield panes directly in front of the pilots in the normal conduct of their duties, and the supporting structures for these panes, must withstand, without penetration, the impact of a four-pound bird when the velocity of the airplane (relative to the bird along the airplane's flight path) is equal to the value of V_c, at sea level."* (Federal Aviation Administration, 2014) Speed has an exponential effect on kinetic energy, which explains the significant differences in the table above between the guidelines and the Toy Drone strike data. Standard airliners typically do not reach cruising speed at an altitude where Bird Strikes are likely, causing the FAA design requirement to have a built-in factor of safety. Thus, making the data on Toy Drone Strikes appear less dangerous at approach and departure speeds. The results predict that a head-on Drone Strike into the windshield of a commercial airliner on approach or departure is most likely survivable based upon the kinetic energy of the impact, however, the impact would certainly result in damage to the aircraft and associated economic losses as a result of required inspections and repairs.

B. Turbine Aircraft Engine Impact Study

Situation	Kinetic Energy (J)	Momentum (N·s)
FAA Guideline 33.76 Minimum	**1,144.89**	**28.26**
FAA Guideline 33.76 Maximum	**19,212.66**	**373.42**
Phantom II → Boeing 737-700 A	**4,370.60**	**106.60**
Phantom II → Boeing 737-700 D	**5,501.60**	**118.3**
Inspire → Boeing 737-700 A	**11,624.06**	**261.22**
Inspire → Boeing 737-700 D	**14,382.96**	**290.57**

Table 5: FAA Fix Wing Turbine and Engine Design Requirements

FAA SECTION 33.76 CONTAINS PROCEDURES AND DESIGN REQUIREMENTS FOR BIRD INGESTION, relative to certain sizes and weights, depending on the inlet throat area of an engine. Due to the fact section 33.76 outlines a range, the calculations were commutated at the extremes of the range to provide for the greatest possible sample size and integrity of the data. The kinetics energy of a Commercial Airliner Engine Ingestion Drone Strike falls in the middle of the prescribed range for the design guideline. An ingestion Drone Strike on approach or departure would cause severe damage to the engine, and potentially a catastrophic failure, in either case resulting in damage to the aircraft and economic loss from time out of service, inspections, and repairs. Potential damage could include: broken fan blades, cowling damage, uncontained failure, and engine fire. While engines can ingest some foreign matter, parts from a Toy Drone and lithium polymer batteries could prove catastrophic. More testing and data is needed to fully determine the potential and extent of the danger relative to engine size and the specific effect of impulse.

C. Fixed-Wing Empennage Impact Study

Situation	Kinetic Energy (J)	Momentum (N·s)
FAA Guideline 25.631	**95,820.18**	**833.94**
Phantom II → Boeing 737-700 A	**4,370.60**	**106.60**
Phantom II → Boeing 737-700 D	**5,501.60**	**118.3**
Inspire → Boeing 737-700 A	**11,624.06**	**261.22**
Inspire → Boeing 737-700 D	**14,382.96**	**290.57**

Table 6: FAA Commercial Fix Wing Empennage Requirements

THE EMPENNAGE IS THE REAR TAIL SECTION OF THE AIRCRAFT, specifically the stabilizing control surfaces. *"The empennage structure must be designed to assure capability of continued safe flight and landing of the airplane after impact with an 8-pound bird when the velocity of the airplane (relative to the bird along the airplane's flight path) is equal to V_C at sea level, selected under Sec. 25.335(a). Compliance with this section by provision of redundant structure and protected location of control system elements or protective devices such as splitter plates or energy absorbing material is acceptable. Where compliance is shown by analysis, tests, or both, use of data on airplanes having similar structural design is acceptable."* (Federal Aviation Administration, 2014) The data for an empennage impact is similar to the windshield impacts, due to the same reasons and built-in factor of safety. The results as listed above predict that a direct Drone Strike into the empennage of a commercial airliner on approach or departure is most likely survivable based upon the kinetic energy of the impact, however, the impact would certainly result in damage to the aircraft and associated economic losses as a result of required inspections and repairs.

D. Rotorcraft Impact Study

Situation	Kinetic Energy (J)	Momentum (N·s)
FAA Guideline 29.631 EC130*	**2,129.73**	**65.19**
Phantom II → EC 130*	**4,370.60**	**106.60**
Inspire → EC 130*	**11,624.06**	**261.22**
***Eurocopter EC 130**		

Table 7: FAA Rotor Craft General Strike Requirements

Impact Analysis

(continued)

FAA REGULATION 29.631 PERTAINING TO GENERAL BODY STRIKES OF A ROTORCRAFT STATES, *"The rotorcraft must be designed to ensure capability of continued safe flight and landing (for Category A) or safe landing (for Category B) after impact with a 2.2-lb (1.0 kg) bird when the velocity of the rotorcraft (relative to the bird along the flight path of the rotorcraft) is equal to V_{NE} or V_H (whichever is the lesser) at altitudes up to 8,000 feet. Compliance must be shown by tests or by analysis based on tests carried out on sufficiently representative structures of similar design."* (Federal Aviation Administration, 2014) The data shows that the design regulations for rotorcraft are not adequate to provide for a Drone Strike. A head-on Drone Strike with an EC-130 will cause the catastrophic failure of the rotorcraft's windshield resulting in significant damage to the aircraft and most likely injury to the pilot. The damage and injury qualitatively show to be non-survivable based upon the kinetic energy of the impact.

Situation	Kinetic Energy (J)	Momentum (N·s)
FAA Guideline 29.631 Bell 407	**2,335.96**	**68.28**
Phantom II → Bell 407	**4,477.85**	**107.90**
Inspire → Bell 407	**11,886.75**	**264.15**

Table 8: FAA Rotor Craft General Strike Requirements

Impact Analysis

(continued)

THE REGULATIONS ARE THE SAME FOR THE BELL 407, yet the aircraft fly at differing speeds; therefore it has different calculations. The data shows the kinetics energy of a Drone Strike into a Bell 407 is significantly higher than the design regulations.

One of the primary issues with the regulations for rotorcraft is they do not have a predetermined design standard for the windshields. The regulations for both part 27.775 and part 29.775 state "*Windshields and windows must be made of material that will not break into dangerous fragments*." (Federal Aviation Administration, 2014) This is why Bird Strikes often breech windshields, causing damage to the aircraft and often the pilots. A Bird Strike, with significant kinetic energy, is one of the reasons for the crash and death of two pilots and six passengers flying in a Sikorsky S-76C++, N748P. Below is a paragraph from the NTSB report on that accident.

"*The NTSB determined that the probable cause of this accident was (1) the sudden loss of power to both engines that resulted from impact with a bird (Red-Tailed hawk), which fractured the windshield and interfered with the engine fuel controls, and (2) the subsequent disorientation of the flight crewmembers, which left them unable to recover from the loss of power. Contributing to the accident were (1) the lack of FAA regulations and guidance, at the time the helicopter was certified, requiring helicopter windshields to be resistant to bird strikes; (2) the lack of protections that would prevent T-handles from inadvertently dislodging from their detents; and (3) the lack of master warning light and audible system to alert the flight crew of a low-rotor-speed condition."* (Board, 2010) The lack of windshield resilience to impacts could prove even more dangerous as Toy Drones are even more widely introduced to the National Airspace. It is clear that a head-on rotorcraft Drone Strike will cause the catastrophic failure of the rotorcraft's windshield resulting in significant damage to the aircraft and most likely injury to the pilot. The damage and injury qualitatively show to be non-survivable based upon the kinetic energy of the impact.

Discussion

The purpose of the study is to clearly define and qualitatively identify the safety risks of flying Toys Drones in the United States National Airspace. In this study the impact energies are assumed to be inelastic collisions, due to the large mass differences and the material makeup of both manned aircraft and a Toy Drone. The exact force of the impacts could not be derived due to the unknown length of time of the impact. Also of note is that while several of the Drone Strike energies in this study are below regulatory guidelines, it is not possible to conclude that a manned aircraft will not sustain significant damage as a result of the impact. The aircraft could be forced to make a precautionary or emergency landing, causing the consumer to be delayed and the aircraft operator to incur significant economic losses.

Conclusion

THE RESULTS IN THIS PAPER outline the real consequences of flying Toy Drones in the United States National Airspace. Toy Drones pose a catastrophic threat to manned rotorcraft in all phases of flight, including cruise, based upon their typical operating altitudes. Airborne law enforcement, emergency medical helicopters, news gathering helicopters, and utility and corporate rotorcraft operators are all at risk of suffering a Drone Strike, posing a real danger to the pilot, passengers, and bystanders on the ground if the aircraft were to crash.

Toy Drones pose a real threat to commercial fixed-wing aircraft primarily during approach and departure. Airliners face a lesser potential for a catastrophic Drone Strike given they both reach cruising speed at a significantly higher altitude and have existing design regulations for impacts. Commercial aircraft are at the greatest risk during take off and landing, and an Engine Ingestion Drone Strike during these phases of flight would cause severe damage to the engine and potentially a catastrophic failure, in either case resulting in damage to the aircraft and economic loss.

Solution

IT WILL TAKE A BALANCED AND HOLISTIC SOLUTION to provide for the safe operation of Toy Drones in the national airspace centered upon: (i) additional testing, (ii) public education, (iii) dedicated operating areas, (iv) air-traffic separation, and (v) airworthiness certification.

To more fully understand the risks and damage illustrated by this study, real world testing should be done on commercial and public service manned aircraft under the parameters applicable to shared airspace with Toy Drones. Every surface of the aircraft should be tested to better understand the danger posed by a Drone Strike. Further testing may provide new insight and potentially a level of assurance that fixed-wing aircraft can operate and land safely after a Drone Strike occurs. Laboratory testing to more fully illustrate the results of this study and theoretical damage would require significant funding and working consortium consisting of leading aircraft manufacturers, engine manufacturers, sub-system providers, and the FAA.

Aero Kinetics is currently exploring the possibility of building a consortium to conduct follow-on research. In phase two, Aero Kinetics would more fully study the damage of the energies of Drone Strike impacts by using an air-cannon designed and built to propel a Toy Drone at the velocities shown into a test aircraft on the ground. These tests would be conducted on the critical structures of the aircraft, for example windshields, engines, and leading edges of wings. The results of phase two could help shape the future of manned aircraft design requirements and coming Toy Drone regulation.

Perhaps the key to integrating Toy Drones into the National Airspace System is the education of the public and potential commercial operators regarding the danger Toy Drones pose to manned aircraft and innocent bystanders on the ground. The aerospace industry as a whole in conjunction with the FAA must launch a comprehensive public awareness campaign and overall education program to effectively communicate the risks to the public at large. We have call before you dig, perhaps a call before you fly program is needed. In any case solutions outside the box need to be considered.

In addition it is critical that the industry work with the FAA to establish dedicated operating areas set aside with specific airspace such as altitudes under one hundred feet AGL that allow for the public's operation of Toy Drones for recreational and amusement purposes over property of the operator or with the permission of the landowner. Perhaps all Toy Drones are required to have a hardwired software altitude limit or other technology to ensure Toy Drones are not flown in navigable airspace. In any case Toy Drones must not be allowed to potentially conflict with manned aircraft operations. The risks as outlined in this study are simply too great.

Solution *(continued)*

Given the dangers presented by Toy Drones outlined in this study it is critical to devise a means to provide for airborne separation between Toy Drones and manned aircraft. Collisions outlined in this paper can be avoided by simply installing an ADS-B and having the Toy Drone industry follow the registration standard for manned aircraft that is already in place. However, simply installing an ADS-B is not a blanket solution as unfortunately, not all general aviation airplanes are equipped with this technology. Alternative technologies to provide separation may not fully be developed to the point it can be implemented in the short order, which may require stringent operational restrictions and regulatory requirements be placed on Toy Drones in the now-term that can be relaxed on a go-forward basis through emerging technologies. Certainly the aerospace industry would embrace the support of the Toy Drone manufacturers to work in concert to develop specific avionics packages for Toy Drones that will assist in the ensuring separation from manned aircraft.

Another fundamental tenement of ensuring public safety is for the Toy Drone industry to recognize and take advantage of the systemic body of knowledge and established process for FAA airworthiness certification. Since the 1920's the FAA has certified aircraft under type certification process, and the FAA has a strong track record of adapting certification basses for new and emerging technology such as rotorcraft and tilt-rotor certification efforts. It is paramount that Toy Drones adhere to some level of airworthiness certification to provide for the public safety, either the current airworthiness certification process in conjunction with the Pathfinder Program, or some form of to be determined airworthiness certification included in the proposed Part 107. The form of airworthiness certification is not nearly as important as the substance.

Finally, it is important that the FAA and the aerospace industry work together with industry at large to ensure corporations and other potential users of unnamed aircraft technology are fully educated in the safe operations of the unmanned aircraft. Toy Drones should not be enlisted or pressed into service for commercial applications unless they meet the regulatory guidelines for airworthiness that is achievable today under the Pathfinder Program.

We cannot control when and where birds fly but we do have the ability to regulate drone activity to mitigate the risk of drone strikes and protect the flying public. It may take time to develop a full set of airworthiness regulations and operational protocols for Toy Drones, but the time required to do so is certainly worth it considering the results of this study and potential lives at stake by forcefully integrating Toy Drones into the U.S. National Airspace System for the sake of profit.

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Appendix A

Kinetic Energy FAA Guideline 25.775:

$$\frac{1}{2}\cdot 1.814\text{Kg}\cdot 229.8\frac{\text{m}^2}{\text{s}} = 47{,}896.89\text{ J}$$

Momentum FAA Guideline 25.775:

$$1.814\text{Kg}\cdot 229.8\frac{\text{m}}{\text{s}} = 416.85\text{ N}\cdot\text{S}$$

Kinetic Energy FAA Guideline 33.76 Min:

$$\frac{1}{2}\cdot 0.349\text{Kg}\cdot 81\frac{\text{m}^2}{\text{s}} = 1{,}144.89\text{ J}$$

Momentum FAA Guideline 33.76 Min:

$$0.349\text{Kg}\cdot 81\frac{\text{m}}{\text{s}} = 28.26\text{ N}\cdot\text{S}$$

Kinetic Energy FAA Guideline 33.76 for Max:

$$\frac{1}{2}\cdot 3.629\text{Kg}\cdot 102.9\frac{\text{m}^2}{\text{s}} = 19{,}212.66\text{ J}$$

Momentum FAA Guideline 33.76 Max:

$$3.629\text{Kg}\cdot 102.9\frac{\text{m}}{\text{s}} = 373.42\text{ N}\cdot\text{S}$$

Kinetic Energy FAA Guideline 25.631 for 737-700:

$$\frac{1}{2}\cdot 3.629\cdot 229.8\frac{\text{m}^2}{\text{s}} = 95{,}820.18\text{ J}$$

Momentum FAA Guideline 25.631 for 737-700:

$$3.629\text{Kg}\cdot 229.8\frac{\text{m}}{\text{s}} = 833.94\text{ N}\cdot\text{S}$$

Kinetic Energy FAA Guideline 29.631 for EC130:

$$\frac{1}{2}\cdot 0.998\text{Kg}\cdot 65.33\frac{\text{m}^2}{\text{s}} = 2{,}129.73\text{ J}$$

Momentum FAA Guideline 29.631 for EC130:

$$0.998\text{Kg}\cdot 65.33\frac{\text{m}}{\text{s}} = 65.19\text{ N}\cdot\text{S}$$

Kinetic Energy FAA Guideline 29.631 for Bell 407:

$$\frac{1}{2}\cdot 0.998\text{Kg}\cdot 68.42\frac{\text{m}^2}{\text{s}} = 2{,}335.96\text{ J}$$

Momentum FAA Guideline 29.631 for Bell 407:

$$0.998\text{Kg}\cdot 68.42\frac{\text{m}}{\text{s}} = 68.28\text{ N}\cdot\text{S}$$

Kinetic Energy Phantom II → EC 130:

$$\frac{1}{2}\cdot 1.3\text{Kg}\cdot\left(15\frac{\text{m}}{\text{s}}+67\frac{\text{m}}{\text{s}}\right)^2 = 4{,}370.60\text{ J}$$

Momentum Phantom II → EC 130:

$$1.3\text{Kg}\cdot 82\frac{\text{m}}{\text{s}} = 106.6\text{ N}\cdot\text{S}$$

Kinetic Energy Phantom II → Bell 407:

$$\frac{1}{2}\cdot 1.3\text{Kg}\cdot\left(15\frac{\text{m}}{\text{s}}+68\frac{\text{m}}{\text{s}}\right)^2 = 4{,}477.85\text{ J}$$

Momentum Phantom II → Bell 407:

$$1.3\text{Kg}\cdot 83\frac{\text{m}}{\text{s}} = 107.9\text{ N}\cdot\text{S}$$

Kinetic Energy Phantom II → Boeing 737-700 Approach:

$$\frac{1}{2}\cdot 1.3\text{Kg}\cdot\left(15\frac{\text{m}}{\text{s}}+67\frac{\text{m}}{\text{s}}\right)^2 = 4{,}370.60\text{ J}$$

Momentum Phantom II → Boeing 737-700 Approach:

$$1.3\text{Kg}\cdot 82\frac{\text{m}}{\text{s}} = 106.6\text{ N}\cdot\text{S}$$

Kinetic Energy Phantom II → Boeing 737-700 Take Off:

$$\frac{1}{2}\cdot 1.3\text{Kg}\cdot\left(15\frac{\text{m}}{\text{s}}+77\frac{\text{m}}{\text{s}}\right)^2 = 5{,}501.60\text{ J}$$

Momentum Phantom II → Boeing 737-700 Take Off:

$$1.3\text{Kg}\cdot 91\frac{\text{m}}{\text{s}} = 118.3\text{ N}\cdot\text{S}$$

Kinetic Energy Inspire → EC 130:

$$\frac{1}{2}\cdot 2.935\text{Kg}\cdot\left(22\frac{\text{m}}{\text{s}}+67\frac{\text{m}}{\text{s}}\right)^2 = 11{,}624.06\text{ J}$$

Momentum Inspire → EC 130:

$$2.935\text{Kg}\cdot 89\frac{\text{m}}{\text{s}} = 261.22\text{ N}\cdot\text{S}$$

Kinetic Energy Inspire → Bell 407:

$$\frac{1}{2}\cdot 2.935\text{Kg}\cdot\left(22\frac{\text{m}}{\text{s}}+68\frac{\text{m}}{\text{s}}\right)^2 = 11{,}886.75\text{ J}$$

Momentum Inspire → Bell 407:

$$2.935\text{Kg}\cdot 90\frac{\text{m}}{\text{s}} = 264.15\text{ N}\cdot\text{S}$$

Kinetic Energy Inspire → Boeing 737-700 Approach:

$$\frac{1}{2}\cdot 2.935Kg\cdot\left(22\frac{m}{s}+67\frac{m}{s}\right)^2 = 11{,}624.06\,J$$

Momentum Inspire → Boeing 737-700 Approach:

$$2.935Kg\cdot 89\frac{m}{s} = 261.22\,N\cdot S$$

Kinetic Energy Inspire → Boeing 737-700 Take Off:

$$\frac{1}{2}\cdot 2.935Kg\cdot\left(22\frac{m}{s}+77\frac{m}{s}\right)^2 = 14{,}382.96\,J$$

Momentum Inspire → Boeing 737-700 Take Off:

$$2.935Kg\cdot 99\frac{m}{s} = 290.57\,N\cdot S$$

* (Airbus Helicopters, INC, 2014)
* (Bell Helicopter, 2014)
* (DJI Hobby, 2015)
* (Boeing, 2015)
* (Federal Aviation Administration, 2014)

*** Information from these sources was used in the calculations above.**

Appendix B: V-Speeds

V-Speeds are a common term for the different operational speeds of an aircraft.

HERE ARE SOME OF THE MOST COMMON V-SPEEDS:

- Vs : the aircraft's stall speed in clean, or cruise configuration (gear and flaps up).
- Vso : the aircraft's stall speed in dirty, or landing configuration (gear and flaps down).
- Vx : the airspeed that provides the best angle of climb (highest altitude in shortest distance). It is typically a fairly slow speed, and is most useful for taking off over obstacles like trees.
- Vy : the airspeed that provides the best rate of climb (highest altitude in least time). It is faster than Vy, and is most useful for getting to an altitude as quickly as possible (say, to avoid icing).
- Va : the maximum airspeed for turbulence. For a typical light civilian aircraft, Va will be approximately double Vs, to ensure that the plane will stall under forces greater than 4 Gs.
- Vfe : maximum airspeed for flap extension.
- Vno : (yellow line) maximum structural cruising speed, to be exceeded only in very calm air.
- Vne : (red line) airspeed not to be exceeded under any circumstances.
- Pilots of complex planes, multiengine planes, and transport planes often refer to additional v-speeds:
- V1 : critical engine failure recognition speed.
- V2 : takeoff speed.
- V2min : minimum takeoff speed.
- V3 : flap retraction speed.
- Vb : maximum gust intensity speed.
- Vc : cruise speed.
- Vd : diving speed.
- Vh : maximum level flight speed at full power.
- Vlo : maximum speed for extending the landing gear.
- Vmc : minimum controllable speed with an engine out; any slower and the control surfaces will not be able to counter asymmetric thrust.
- Vr : rotation speed, the speed to start raising the nose during the takeoff run.
- Vref : landing reference speed.

V-speeds are nearly always given as Indicated Airspeed (IAS), so that pilots can read them directly off the Airspeed Indicator.