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Making civilian drones safe: performance standards, self-certification, and post-sale data collection

By Henry H. Perritt* & Albert J. Plawinski **

ABSTRACT

With millions of small drones in private hands, the FAA continues its struggle to develop an effective regulatory regime to comply with Congress's mandate to integrate them into the national airspace system. Thousands of individuals and small businesses have obtained authorization from the FAA—"section 333 exemptions"—allowing them to fly their drones commercially. Farmers, TV stations, surveyors, construction-site supervisors, real estate agents, people selling their properties, and managers seeking cheaper and safer ways to inspect their facilities, want to hire the exemption holders, but many are holding back until the FAA clarifies the groundrules.

The FAA understands that its traditional approach for testing and licensing pilots, scrutinizing every detail of a new aircraft before it can be flown, and controlling flight operations of helicopters and airplanes have little relevance to the risks presented by small drones. In any event, traditional aviation regulations are unenforceable against tens or hundreds of thousands of drone owners who know nothing about the FAA or the FARs, are not part of the aviation culture, and who fly mainly in their backyards or customers' parking lots.

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Over the past ten years, Mr. Plawinski worked at a Polish youth camp, Camp Vista, and became the camp manager during the past five years. His leadership at Camp Vista brought new creative changes to the camp curriculum. He has designed the camp logo and camp merchandise, photographed camp activities for promotional material, and organized major events like the camp's 50th anniversary.

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Mr. Plawinski enjoys photography and experiments with vintage film cameras. He built several tube amplifiers, and collects vinyl. Mr. Plawinski runs a small blog about current legal issues in the drone industry and brainstorms legal and technological frameworks for autonomous drone flight for food and package delivery.

Ultimately, the agency will be drawn to regulate drones at the point of sale—to say to Amazon: "you can't sell one of these unless it has certain built-in safety capabilities—unless it is law-abiding out of the box." The FAA acknowledges that the traditional approach to "airworthiness certification," which costs tens of millions of dollars and takes years is not the answer for a $1,000 DJI Phantom 3.
Law-abiding drone performance standards must define performance capabilities rather than engineering details; they must allow manufacturers to self-certify compliance—just as they do with computers, Wi-Fi equipment, automobiles, and trucks. Automatic post-sale data transmission by the drones will permit manufacturers and the FAA to analyze actual behavior, thereby refining their understanding of actual, rather than theoretical, risks, and to determine the reliability of automated safety systems. Lawless drones will be subject to recalls in extreme cases, and designers and manufacturers will pay the price in tort liability for reckless decisionmaking.

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I. INTRODUCTION

¶1 The Federal Aviation Administration ("FAA") acknowledges that its traditional processes for assuring the safety of airplanes and helicopters are unsuitable for the growing number of small drones:

> [T]he FAA's current processes for issuing airworthiness . . . certificates were designed to be used for manned aircraft and do not take into account the considerations associated with civil small UAS [Unmanned Aircraft Systems] . . . .
>
> [O]btaining a type certificate and a standard airworthiness certificate . . . currently takes about 3 to 5 years . . . . [I]t is not practically feasible for many small UAS manufacturers to go through the certification process required of manned aircraft. This is because small UAS technology is rapidly evolving at this time, and consequently, if a small UAS manufacturer goes through a 3-to-5-year process to obtain a type certificate, which enables the issuance of a standard airworthiness certificate, the small UAS would be technologically outdated by the time it completed the certification process. For example, advances in lightweight battery technology may allow new lightweight transponders and power sources within the next 3 to 5 years that are currently unavailable for small UAS operations.[1]

¶2 Some advocates for traditional aviation and engineers of $15 million military drones[2] sneer at small UAS as "toys,"[3] but Amazon sold 300,000 small civilian drones in 2014.[4] More than 2,000 purchasers have gone to the trouble of filing petitions with the FAA, under Section 333 of the FAA Modernization and Reform Act of 2012 ("Section 333"),[5] for exemptions to permit them to fly the drones commercially, and the FAA has granted more than 2,000 Section 333 exemptions.[6] These exemptions cover, among other things, support for precision agriculture, motion picture and television production, event photography, newsgathering, and infrastructure inspection.[7] The market for drones is outrunning regulation, despite broad agreement that some kind of regulation is appropriate to mitigate the risks associated with widespread use of drones.

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[1] Notice of Proposed Rulemaking: Operation and Certification of Small Unmanned Aircraft Systems, 80 Fed. Reg. 9544, 9549 (proposed Feb. 23, 2015) [hereinafter *NPRM*].

[2] *MQ-9 Reaper*, U.S. AIR FORCE (Sept. 23, 2015), http://www.af.mil/AboutUs/FactSheets/Display/tabid/224/Article/104470/mq-9-reaper.aspx [http://perma.cc/L7ER-3FGH] (reporting 2006 price of $64.2 million for a package of four Reaper drones).

[3] *See* Chris Cole, *Drones Aren't Just Toys that Cause a Nuisance. They're Still Killing Innocent People*, THEGUARDIAN (Mar. 20 2015), http://www.theguardian.com/commentisfree/2015/mar/20/drones-nuisance-killing-innocent-people [http://perma.cc/L5D8-K58L] (lamenting attention given to "toys" rather than military drones).

[4] Alan Levin, *Santa Delivering Drones for Christmas Amid Rising Safety Concern*, BLOOMBERG BUSINESS (Dec. 17, 2014, 11:47 AM), http://www.bloomberg.com/news/articles/2014-12-17/santa-delivering-drones-for-christmas-amid-rising-safety-concern [http://perma.cc/4326-LR97] (reporting Amazon sales of 10,000 per month); Jason Reagan, *Drone Sales Figures for 2014 are Hard to Navigate*, DRONELIFE (Jan. 24, 2015), http://dronelife.com/2015/01/24/drone-sales-figures-2014-hard-navigate/ [http://perma.cc/5T5J-7L9G] (evaluating various sales figures, most in the hundreds of thousands or more).

[5] *See* FFA Modernization and Reform Act of 2012, Pub. L. 112-95, § 333, 126 Stat. 11, 75-76 (2012).

[6] *Section 333*, FEDERAL AVIATION ADMINISTRATION, https://www.faa.gov/uas/legislative_programs/section_333/ [https://perma.cc/D6N5-K2G8?type=source] (last visited Oct. 30, 2015) (reporting 2,020 Section 333 petitions granted as of 22 October 2015).

[7] *See* FFA Modernization and Reform Act § 333.

¶3 On July 9, 2014, Modovolate Aviation[8] filed a petition for rulemaking with the FAA proposing that the FAA streamline the regulation of microdrones by imposing pre-sale technology requirements that would make the drones law-abiding right out of the box, obviating the need for detailed conventional operating rules and pilot certification requirements.[9] Eight months later, the FAA issued a notice of proposed rulemaking ("NPRM"),[10] proposing a new part 107 to the Federal Aviation Regulations ("FARs") that would establish operating rules and a new category of airman certification for drone operators ("DROPs"). Subsequently, in a series of articles, the managers of Modovolate Aviation explained how the law-abiding-drone approach fits within the overarching regulatory regime proposed in the NPRM.[11]

¶4 A lingering question is how the law-abiding-drone proposal can be implemented without imposing requirements that suffer from the vices of traditional airworthiness and type certification. This article addresses that question.

¶5 It argues that the FAA can specify the characteristics of a law-abiding drone by imposing performance requirements regarding autonomous safety features, allowing self-certification of compliance by drone vendors, and by making use of the extensive flight and system-performance data already being collected in thousands of microdrone flights. Performance standards alone, however, are not enough. The FAA might still require preapproval before sale premised on the vendors demonstrating that performance standards are satisfied. Similarly, self-certification by vendors is not enough; test protocols to ensure satisfaction of the performance standards may be so extensive that substantial cost and delay would result before the vendor can certify compliance.

¶6 The FAA should, following the example of the FCC, prohibit sale of any drone for which the vendor has not issued a certificate of conformity. This would certify that the vendor has done whatever is necessary to assure safety and the reliable operation of certain fail-safe features. It would be left entirely up to the vendor to determine the basis for such self-certification.

¶7 Drone safety will be backstopped by the possibility of product recalls and tort liability for vendors who do not install reliable autonomous safety systems and for consumers who disable them.

¶8 Part II of the article explains how regulation of all kinds works best when it focuses on bottlenecks [12] in the chain of distribution, and that drone regulation should concentrate on the point of sale rather than on thousands of individuals and small businesses flying drones. Part III summarizes the FAA's traditional airworthiness and type certification process for airplanes and helicopters and explains why it is unsuitable for drones. Part IV acknowledges that point-of-sale requirements for autonomous safety features easily can

[8] Modovolate Aviation, LLC (www.movoaviation.com) is an Illinois limited liability company founded and controlled by Henry H. Perritt, Jr. and Eliot O. Sprague.

[9] Modovolate Aviation, LLC, Petition for Rulemaking Seeking the Regulation of Small Unmanned Aircraft Systems (July 9, 2014).

[10] *NPRM*, *supra* note 3.

[11] *See generally* Henry H. Perritt, Jr. & Eliot O. Sprague, *Law Abiding Drones*, 16 COLUM. SCI. & TECH. L. REV. 385 (2015); Henry H. Perritt, Jr. & Eliot O. Sprague, *Developing DROP Discipline: Training and Testing Operators of Small Unmanned Aircraft Systems*, 7 HASTINGS SCI. & TECH. L.J. 143 (2015).

[12] A "bottleneck," in general, is a narrowing of a channel that restricts the flow through it. Referring to commerce, the term is a metaphor for places that concentrate the flow of goods, such as a publisher's printing plant concentrates the flow of books and an ecommerce portal concentrates the flow of goods sold on line.

become burdensome airworthiness certification but argues that a system of performance standards, self-certification by drone vendors, and safety performance data collected after sale can avoid the risk, while preserving the safety benefits. Part V presents a proposed FAA rule to effectuate the article's recommendations. Part VI explains how tort law sits in the background to encourage best practices by drone vendors.

II. THE CASE FOR REGULATING THE BOTTLENECK

¶9 The cost, delay, and innovation drag associated with vehicle airworthiness certification are reasons for avoiding vehicle requirements altogether. Indeed, that proposition persuaded the FAA to issue the NPRM. That NPRM's central theme is that the relatively modest risks associated with microdrones do not warrant the costs, delays, and innovation drag of traditional airworthiness certification.[13] Instead, the NPRM focuses on operator certification and operating limitations and avoided imposing any requirements as to the vehicle, except for an upper weight limit.[14] This approach is equally impractical, however. Enforcing operator certification requirements and operating limitations against thousands of individuals and small businesses flying low-cost drones and having no previous connection to aviation regulations is infeasible.[15]

¶10 In 1983, MIT political science professor Ithiel de Sola Pool explained that effective regulation must focus on bottlenecks in the regulated activities in order to be effective.[16] As an example, he discussed how copyright regulation had always focused more on bottlenecks like printers, publishers, and booksellers, rather than end users. The number of end users is so large, and their assets so small, that chasing them is infeasible. Instead, chasing a smaller number of bottlenecks with more assets is far more efficient. He advocated applying this principle to regulating emerging computer networking technologies.

¶11 De Sola Pool's insight also applies to drone regulation. Trying to detect rule violations committed by thousands of individuals and small businesses with no tie to the traditional aviation culture is unworkable.

¶12 The only solution is to regulate a bottleneck—the point of sale—and to prohibit the sale of drones unless they have built-in safety features.

III. TRADITIONAL AIRWORTHINESS AND TYPE CERTIFICATION

¶13 Traditional airworthiness and type certification of drones is not the solution, as the opening quotation acknowledges, despite the literal requirement that drones have such certification.

[13] *NPRM*, *supra* note 3, at 9548-49 (characterizing lower risk and noting practical infeasibility of subjecting microdrones to manned-aircraft certification process).

[14] *See id*. at 9546 (summary of proposed rule).

[15] *See* Henry H. Perritt, Jr. & Eliot O. Sprague, *Law and Order in the Skies*, TECH (June 13, 2014), http://tech.mit.edu/V134/N28/drones.html [http://perma.cc/H747-W7TM]; Henry H. Perritt, Jr. & Eliot O. Sprague, *Leashing Drones: Don't Drone Me Bro'*, ROTORCRAFT PRO, July 2014, at 37; Henry H. Perritt, Jr. & Eliot O. Sprague, *Law Abiding UAVs*, ROTOR & WING MAG. (Sept. 1, 2014), http://www.aviationtoday.com/rw/issue/features/Law-Abiding-UAVs_82916.html#.VgXIrbz9yf4 [http://perma.cc/XVG8-YVR5]; Henry H. Perritt, Jr. & Eliot O. Sprague, *Seeking Law Abiding Drones: What to Tell Clients that Want to Use Drones in Their Business*, BUS. L. TODAY, Oct. 2014, at 1.

[16] *See generally* ITHIEL DE SOLA POOL, TECHNOLOGIES OF FREEDOM (Belknap Press) (1983).

¶14 The Federal Aviation Act says that a "person may not . . . operate a civil aircraft in air commerce without an airworthiness certificate in effect or in violation of a term of the certificate . . . ."[17]

¶15 An "aircraft" is "any contrivance invented, used, or designed to navigate, or fly in, the air."[18] A "civil aircraft" is "an aircraft except a public aircraft."[19] A "public aircraft" is an aircraft owned or operated for a federal, state, or local governmental entity.[20] "Air commerce" is "foreign air commerce, interstate air commerce, the transportation of mail by aircraft, the operation of aircraft within the limits of a Federal airway, or the operation of aircraft that directly affects, or may endanger safety in, foreign or interstate air commerce."[21]

¶16 Under these definitions, drones are aircraft, because they are contrivances that are used and designed to navigate, or fly in, the air.

¶17 The statute obligates the FAA Administrator to prescribe aircraft airworthiness rules: "minimum standards required in the interest of safety for appliances and for the design, material, construction, quality of work, and performance of aircraft, aircraft engines, and propellers . . . ."[22]

¶18 The Administrator may grant an exemption from the requirements if he finds that the exemption is in the public interest.[23]

¶19 The FAA has promulgated extensive rules for aircraft airworthiness and type certification.[24] Part 27 of the FARs, for example, prescribes airworthiness standards for normal category helicopters.[25] Among many other things, an applicant for an airworthiness certificate must determine the minimum rate of descent, the airspeed, and the best angle of glide airspeed at maximum weight at rotor speeds determined by the applicant.[26] An applicant must also construct a height-speed envelope portraying combinations of height and forward speed from which a safe landing cannot be made in autorotation after an engine failure.[27]

¶20 The applicant must show compliance with the following standards:

> (a) By tests upon a rotorcraft of the type for which certification is requested, or by calculations based on, and equal in accuracy to, the results of testing; and
>
> (b) By systematic investigation of each required combination of weight and center of gravity if compliance cannot be reasonably inferred from combinations investigated.[28]

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[17] 49 U.S.C. § 44711(a)(1) (2015).
[18] *Id.* § 40102(a).
[19] *Id.*
[20] *Id.*
[21] *Id.*
[22] *Id.* § 44701(a)(1).
[23] *Id.* § 44701(f).
[24] 14 C.F.R. §§ 21–50 (2015).
[25] *Id.* § 27.
[26] *Id.* § 27.71.
[27] *Id.* § 27.87.
[28] *Id.* § 27.21.

The applicant must "make all flight tests that the FAA finds necessary to determine compliance with the applicable [airworthiness standards]."[29]

¶21 The FAA has published a 1023-page advisory circular explaining how to meet the airworthiness certification requirements for normal category rotorcraft.[30] The circular explains that the applicant conducts the flight tests, with follow-up "verification tests" conducted by the FAA itself.[31] Further, it prescribes the order in which the applicant should conduct flight tests for specific requirements.[32] It explains that a 150-hour flight-test program must be conducted, unless the aircraft incorporates new engine types, in which case 300 hours are required.[33] During the tests, "all components of the rotorcraft should be periodically operated in sequences and combinations likely to occur in service."[34] A range of representative ambient operating conditions and sites should be part of the tests.[35] It prescribes how flight test results, including parameter values, should be captured and recorded.[36]

¶22 The result of these certification rules is a process that takes years and costs millions of dollars.[37]

¶23 Despite decades-long efforts to simplify the process for experimental and homebuilt aircraft, the airworthiness and type certification process remains burdensome. During this process, the FAA evaluates the plan for amateur-built aircraft.[38] Builders must submit applications for registration 60-120 days before contemplated completion of assembly.[39] Before granting an airworthiness certificate, the FAA inspects amateur-built aircraft,[40] including "an onsite, visual, general airworthiness certification inspection of the aircraft,"[41] and recommends involvement of designated airworthiness representatives (DAR's) before the inspection occurs.[42] The inspection may require some disassembly.[43] The FAA

[29] *Id.* § 21.35.

[30] FED. AVIATION ADMIN., U.S. DEP'T OF TRANSP., AC NO. 27-1B, CERTIFICATION OF NORMAL CATEGORY ROTORCRAFT (2014),http://www.faa.gov/documentLibrary/media/Advisory_Circular/AC_27-1B_thru_Chg_6.pdf [http://perma.cc/9J7F-YRDN]

[31] *Id.* at FAR 21-2.

[32] *Id.* at FAR 21-2-3.

[33] *Id.* at FAR 21-3 (referring to 14 C.F.R. § 21.35(f)(1) and (2)).

[34] *Id*. at 21-5(iii).

[35] *Id*. at 21-5(vi).

[36] *Id*. at 21-5 to 21-6.

[37] *See generally What Does It Cost to Certify a New Aircraft?*, AIRLINERS.NET, http://www.airliners.net/aviation-forums/general_aviation/read.main/2666549/ (last visited Oct. 21, 2015) [http://perma.cc/HG7V-5ZWM] (estimating cost of certifying A380 as exceeding 100 million Euros); *Changing the World for General Aviation Airplane Manufacturing*, GAMA, http://www.gama.aero/node/12004 (last visited Oct. 21, 2015) [http://perma.cc/FF42-HH8F] (asserting that the cost of airworthiness certification can be cut by half); *Aircraft Certification Process Review and Reform*, GAMA, http://www.gama.aero/files/downloads/FAA-ACPRR-Report-to-Congress-2012-08.pdf [https://perma.cc/HVA5-R2XR?type=source] (last visited Oct. 21, 2015) (reviewing decades-long pressure for FAA to reform airworthiness certification process).

[38] *See* FED. AVIATION ADMIN., U.S. DEP'T OF TRANSP., AC 20-27G, CERTIFICATION AND OPERATION OF AMATEUR-BUILT AIRCRAFT ¶ 8(j)(3) (2009), http://www.faa.gov/documentLibrary/media/Advisory_Circular/AC 20-27G.pdf [http://perma.cc/64NC-M5YM].

[39] *Id.* ¶ 9(a).

[40] *Id.* ¶ 12.

[41] *Id.* ¶ 12(b).

[42] *Id.* ¶ 12(a)(2).

[43] *See id.* at 24 (Figure 3).

inspection includes review of inspections by certificated mechanics or other builders/commercial assistance providers, builders' construction log entries, logbooks and maintenance covering the aircraft, engine, and propeller or rotor blade(s), and Experimental Aircraft Association ("EAA") technical counselors' visit report cards. [44] Builders often must provide photographs documenting construction details. The inspection and records review substantiates sound workmanship methods, techniques, and practices.[45]

¶24 The inspection is followed by a flight test "appropriate for the applicant to show the aircraft is controllable throughout its normal range of speeds and maneuvers and that the aircraft has no hazardous operating characteristics or design features."[46] Flight tests must span twenty-five to forty hours[47] and follow recommended flight test procedures.[48] The FAA may require additional flight test hours.[49]

IV. AVOIDING THE SLIPPERY SLOPE

¶25 Point-of-sale requirements specifying technological capabilities easily morph into traditional airworthiness and type certification requirements. The question is how to avoid that slippery slope. The answers are to prescribe performance, rather than design standards, to allow self-certification of compliance and to minimize the cost of testing. To avoid that slippery slope, it is also useful to review the basic thinking surrounding regulatory reform from the mid-1970s. The foundational choice for policymakers is between self-regulation (essentially the market) and some kind of governmental requirements.[50] But even if the government imposes standards or requirements, they can be enforced in various ways. For example, regulatory regimes can require preapproval of new systems before they can be put into use, they can rely on reports by the regulatees and they can rely on inspections and audits.

A. Reliance on markets

¶26 Government regulation is not necessary in all cases. In fact, most goods and services in the economy are not regulated.

¶27 If a particular seller's drones consistently do not perform as advertised, word will spread, and demand for that seller's products will decline. Larger enterprises, both those selling drones and those operating them, usually have insurance to protect them against loss. Insurance coverage depends upon compliance with limitations imposed by the insurer. Those limitations often represent greater restrictions on flight than would be imposed by government regulators. A prime example is the requirement for a certain number of turbine

[44] *Id.* ¶ 12(c)(1). EAA technical counselors are experienced mechanics and experimental aircraft builders who volunteer to assist other builders. EAA Technical Counselors, http://www.eaa.org/en/eaa/aviation-communities-and-interests/homebuilt-aircraft-and-homebuilt-aircraft-kits/eaa-homebuilt-airplane-programs-and-resources/eaa-technical-counselor-program.

[45] *Id.* ¶ 12(c).

[46] *See id.* at 26 (Figure 4).

[47] *Id.* at 27.

[48] *Id.* (referring to AC 90-89).

[49] *Id.* ¶ 14(b).

[50] *See* Douglas C. Michael, *Federal Agency Use of Audited Self-Regulation as a Regulatory Technique*, 47 ADMIN. L. REV. 171, 185–186 (1995) (reviewing history of regulatory reform and criticism of command-and-control regulation; advocating greater use of "audited self-regulation").

hours for turbine helicopter pilots to be covered under commercial insurance policies. The FARs impose no such requirement.

¶28 Relying on markets does not promise a return to the Wild West; markets impose constraints on participants. Sellers sell only what buyers demand, or they do not stay in business for long. If there is no market for 16-rotor drones with an endurance of only five minutes, sellers will not try to sell them. Buyers' activities are limited by what is available from sellers. If one can only buy a drone with geofencess that exclude them from prohibited airspace in Washington, buyers will not fly drones in those areas. If a seller programs a drone so that it will not take off unless it has GPS lock and a functioning return-to-home feature, buyers will not be able to fly without return-to-home capability.

¶29 The law, of course, is never entirely absent from commerce. If a drone seller promises certain safety features or other capabilities, and they do not work as advertised, the buyer always can bring a breach of warranty claim against the seller. The common law of contracts imposes an obligation on sellers to deliver what they have promised. Sellers can disclaim warranties under the Uniform Commercial Code, but only up to a point.

¶30 The common law of torts protects third parties. If the drone experiences a flyaway and hits someone on the head, the victim may recover damages in a negligence action – assuming she can prove some kind of injury or loss. If the DROP deliberately flies a drone into a person or a thing, the common law of battery and trespass provides for damages.

¶31 Gradations exist in the balance between market reliance and government regulation. A market for a particular product, say very small drones, might be completely unregulated by any government agency, or it might be subjected to fairly detailed regulation. In most cases, the constraints will be a mixture of supply and demand and regulatory mandates.

¶32 As this article proposes, the FAA could set performance standards for autonomous safety features and let the market take care of enforcement. A buyer who discovers that the safety features of her drone do not meet the requirements of the performance standard could bring a breach of warranty claim against the seller. A third-party injured by a drone that does not satisfy the performance standard would use that violation of the standard to establish liability in a tort action. The FAA would not play any role in the common-law enforcement process; instead, enforcement would be a matter for buyers and sellers, private lawyers, and the regular courts.

¶33 To be sure, there would be disputes in both types of cases as to the relationship among the performance standard, the drone's equipment and capabilities, and whatever incident triggered the dispute. The drone manufacturer would be expected to defend on the grounds that the incident was caused by operator error and not by any defect in the drone systems; the claimant would argue that a deficiency in the systems was the primary or sole cause of the incident. Both sides would present evidence, and a fact finder – judge or jury—would decide, based on the evidence, what the actual facts were.

¶34 But there is nothing unusual about that. Factual controversies are the core of any enforcement action, whether it is taken by a government agency enforcing its own rules or whether it crops up in a private lawsuit. Constitutional due process guarantees require that the disputants have adequate procedures to resolve contested facts before government agencies or courts can impose any kind of penalty or economic burden on them.

B. Exempting small drones from regulation

¶35 The most fundamental regulatory policy question for FAA regulation of drones is whether government regulation is necessary at all. No apparent reason exists, for example, to subject very small toy drones to FAA regulation, because they pose minimal risk.

¶36 The Hubsan X4 (H107C) is a good example. It weighs 1.75 ounces and costs $47. It is extremely unlikely to cause damage or injury regardless of how it flies, because of its low kinetic energy.

¶37 In its NPRM, the FAA explicitly invited comment on UAS American Fund's proposal to exempt drone weighing less than three pounds from regulation altogether, except for the most basic flight envelope limitations.

¶38 The question is: what constitutes a toy? Is a toy anything below a certain weight? What should that weight be?

¶39 If the lower boundary of regulation is defined in terms of weight, it is not clear why regulation should depend on the purpose of use. Why should a particular vehicle be unregulated when it is used as a toy and regulated when the same vehicle is used to earn compensation? The classification is made more difficult because even the smallest microdrones, like the Hubsan, have some kind of camera capability, which will tempt some users to use it for commercial photography.

C. Impose performance standards rather than design standards

¶40 The Office of Management and Budget requires federal agencies to prefer performance standards:[51] "To the extent feasible, agencies should specify performance objectives, rather than specifying the behavior or manner of compliance that regulated entities must adopt."[52]

¶41 The final report of the Clinton Administration's White House Commission on Aviation Safety and Security White House Commission on Aviation Safety and Security said, "all new rules should be rewritten as performance-based regulations."[53]

¶42 The FAA recognizes the superiority of performance standards over design standards, particularly in the drone context:

> It is well understood that regulations that are articulated in terms of the desired outcomes (i.e., "performance standards") are generally preferable to those that specify the means to achieve the desired outcomes (i.e., "design" standards). According to Office of Management and Budget Circular A–4 ("Regulatory Analysis"), performance standards "give the regulated parties the flexibility to achieve the regulatory objectives in the most cost-effective way.

[51] *See* Jay P. Kesan & Rajiv C. Shah, *Shaping Code*, 18 HARV. J.L. & TECH. 319, 340–41 (2005) (distinguishing performance standards, design standards, and best-available-technology standards and briefly summarizing criticisms of each).

[52] OFFICE OF INFO. & REGULATORY AFFAIRS, REGULATORY IMPACT ANALYSIS: A PRIMER 2, https://www.whitehouse.gov/sites/default/files/omb/inforeg/regpol/circular-a-4_regulatory-impact-analysis-a-primer.pdf [https://perma.cc/LQT6-GBPU].

[53] White House Commission on Aviation Safety and Security, *Final Report to President Clinton* (1997), http://fas.org/irp/threat/212fin~1.html [http://perma.cc/8DYQ-4QW8]. The Commission was established by Executive Order 13015 on August 22, 1996.

> Design standards have a tendency to lock in certain approaches that limit the incentives to innovate and may effectively prohibit new technologies altogether. The distinction between design and performance standards is particularly important where technology is evolving rapidly, as is the case with small UAS.[54]

¶43 In the air and water pollution contexts, for example, a performance standard can be set at the effluent levels achievable by the best available technology, while leaving the choice of the particular technology to be used to the regulated entity. [55]

¶44 This preference for performance standards does not, however, steer the FAA away from certification of compliance by an administrative agency, as opposed to self-certification. And FAA involvement in certifying compliance with performance standards can be extensive.

¶45 FAA regulations for flight simulators provide an example of performance standards. For example, 14 C.F.R. § 60.1 requires persons using simulators to meet airman qualification requirements to comply with performance standards set forth in appendices to the rule.[56] Some of the language sets forth straightforward performance requirements: "A flight dynamics model that accounts for various combinations of air speed and power normally encountered in flight must correspond to actual flight conditions, including the effect of change in helicopter attitude, aerodynamic and propulsive forces and moments, altitude, temperature, mass, center of gravity location, and configuration."[57]

¶46 But this performance-oriented language is buried in a multipage set of detailed specifications which include requirements to submit to FAA inspector oversight of factory test runs and to submit extensive QTG[58]data. Before the data even can be collected:

> [T]he sponsor should submit to the NSPM for approval, a descriptive document (see Table C2D, Sample Validation Data Roadmap for Helicopters) containing the plan for acquiring the validation data, including data sources. This document should clearly identify sources of data for all required tests, a description of the validity of these data for a specific engine type and thrust rating configuration, and the revision levels of all avionics affecting the performance or flying qualities of the aircraft. Additionally, this document should provide other information, such as the rationale or explanation for cases where data or data parameters are missing, instances where engineering simulation data are used or where flight test methods require further explanations. It should also provide a brief narrative describing the cause and effect of any deviation from data requirements. The aircraft manufacturer may provide this document.[59]

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[54] Operation and Certification of Small Unmanned Aircraft Systems, 80 Fed. Reg. 9552 (Feb. 23, 2015).

[55] Richard L. Revesz & Allison L. Westfahl Kong, *Regulatory Change and Optimal Transition Relief*, 105 NW. U. L. REV. 1581, 1597 (2011) (explaining that performance standards allow for technological innovation, while design standards do not, in the context of water-pollution regulation); *see also* Timothy V. Malloy, *The Social Construction of Regulation: Lessons From the War Against Command and Control*, 58 BUFF. L. REV. 267, 310–19 (2010) (arguing superiority of performance standards, and evaluating how they are used by EPA in regulating air pollution).

[56] 14 C.F.R. § 60.4 (2008).

[57] *Id.* pt. 60 app. C tbl.C1A Item 2.a. (Minimum Simulator Requirements).

[58] Qualification Test Guide ("QTG") is a document containing test results and statements of compliance with standards).

[59] *Id.* pt. 60 app. C sec. 9(g) (FFS Objective Data Requirements).

Performance standards similarly could be used for airworthiness and type certification of droness, but that does not answer the question of how the certification process can be designed so that it does not take years and cost millions of dollars.

¶47 Environmental regulators set performance standards based on the level of performance a particular technology can deliver. The ultimate standard does not require use of that technology, but the link between them ensures that there is at least one way to comply with the performance standard. The same approach is useful in developing performance standards for drone return-to-home systems. The problem with deriving a performance standard from the performance of an actual technology is that it can have the effect—intended or unintended—of locking in proprietary technology. Much of the law of standard-setting has evolved from deliberate attempts to set a standard to confer a proprietary advantage.[60] Many of the controversies in contemporary standard-setting relate to designers' reluctance to give up their intellectual property, and their competitors' opposing unwillingness to pay their competitors to license its intellectual property in order to comply with the standard.[61]

¶48 An approach more hospitable to competition would involve someone—either the FAA itself, NASA, or a private association—sponsoring a competition among competing return-to-home subsystems, collecting data, and the FAA setting the performance standard based on the data collected. That kind of laboratory/experimental approach is widely used when any new technologies enter the marketplace, but the effort takes time and does not immediately generate revenue and return on investment.

¶49 One disadvantage of any performance-based regulatory standard is unpredictability. A regulatee has flexibility to choose how to meet the performance standard, but he has no guarantee that the regulator or a court hearing a civil claim may not reach a different conclusion, after the fact, about the most appropriate way to meet the standard. Uncertainty can be reduced by publication of a non-exclusive safe harbor. A regulatee may apply different standards at its discretion, but if it seeks more certainty, it can apply the published, safe harbor standard. By proving that it followed the published standard, it has protection against being found in violation or being held liable. Antitrust guidelines published by the Department of Justice[62] are a good example of this approach.

D. Allow self-certification

¶50 Preapproval represents the greatest burden on the regulatees and the greatest barrier to innovation. That approach is what the FAA mostly relies on to certificate aircraft, operators, and airman. So a fundamental question in crafting a simple approach to drone regulation is whether the preapproval strategy can be replaced by self-certification. It can;

[60] *See* Radiant Burners, Inc. v. Peoples Gas Light & Coke Co., 364 U.S. 656, 658 (1961) (holding that complaint alleging refusal to give seal of approval to plaintiff's gas burner for anti-competitive reasons stated antitrust claim); Cryptography Research Inc. v. Visa Intern. Serv. Ass'n, No. C 04–04143 JW, 2008 WL 5560873, at *3 (N.D. Cal. Aug. 13, 2008) (citing *Radiant Burners* in support of denial of motion to dismiss claim that standard setting organization denied certification for reasons unrelated to objective merits of technology).

[61] *See* Martin Campbell-Kelly, *Not All Bad: An Historical Perspective on Software Patents*, 11 MICH. TELECOMM. & TECH. L. REV. 191, 229 (2005) (discussing controversy over public key encryption and RSA software patent).

[62] ANTITRUST DIV., U.S. DEP'T OF JUSTICE, ANTITRUST DIVISION MANUAL CH. VII (5th ed. 2015) http://www.justice.gov/sites/default/files/atr/legacy/2015/05/13/chapter7.pdf [http://perma.cc/8STB-A42R].

in fact, self-certification is the prevailing way to assure compliance with safety standards in non-aviation industries, such as motor vehicles, consumer products, and consumer electronics.

1. Self-certification of compliance with motor vehicle safety standards

¶51 Anyone is prohibited from selling or distributing a motor vehicle unless it complies with federal safety standards.[63] The Secretary of Transportation is authorized to prescribe standards.[64]

> The Secretary of Transportation reasonably may require a manufacturer of a motor vehicle or motor vehicle equipment to keep records, and a manufacturer, distributor, or dealer to make reports, to enable the Secretary to decide whether the manufacturer, distributor, or dealer has complied or is complying with this chapter or a regulation prescribed or order issued under this chapter.[65]

Manufacturers must certify compliance to the next entity in the stream of commerce—for example, to dealers[66]—and must also affix a certificate of compliance to the vehicle.[67]

¶52 Manufacturers are responsible for doing whatever they deem necessary to certify compliance with Federal Motor Vehicle Safety Standards (FMVSSs). "This is a self-certification process as opposed to the type of approval process which is used in some other countries such as Japan. The National Highway Traffic Safety Administration ("NHTSA") does not issue approval tags, stickers or labels for vehicles or equipment items before or after the first sale."[68] NHTSA does not specify test procedures or quality control programs. Those are decisions left to the manufacturer.[69]

2. Self-certification of compliance with Consumer Product Safety requirements (CV)

¶53 The Consumer Product Safety Act[70] establishes an independent regulatory commission, the Consumer Products Safety Commission ("CPSC"), authorized to develop "uniform standards for consumer products" and to reduce conflict between federal regulation and state and local regulation.[71] The CPSC may promulgate a consumer safety rule[72] so long as it prepares a description, based on findings, of the "potential benefits and

[63] 49 U.S.C. § 30112 (2012) (prohibition on selling noncompliant vehicles).
[64] *Id.* § 30111.
[65] *Id.* §30166(e).
[66] *Id.* § 30115 (requiring certification of compliance).
[67] 49 C.F.R § 567.4 (2013) (requiring certification placard).
[68] NAT'L HIGHWAY TRAFFIC SAFETY ADMIN., U.S. DEP'T OF TRANSP., COMPLIANCE TESTING PROGRAM (Aug. 18, 1998), http://www.nhtsa.gov/cars/testing/comply/Mission/1_ovsc_1.html [http://perma.cc/DS3M-MT4F]. *Accord*, Stephen P. Wood, et al., *The Potential Regulatory Challenges of Increasingly Autonomous Motor Vehicles*, 52 SANTA CLARA L. REV. 1423, 1435 (2012) (asserting that "NHTSA does not certify or approve products"; self-certification is the regulatory approach).
[69] NAT'L HIGHWAY TRAFFIC SAFETY ADMIN., *supra* note 68.
[70] 15 U.S.C. § 2053 (2012).
[71] *Id.* § 2051.
[72] *Id.* § 2058.

potential costs"[73] and alternatives to the rule.[74] Additionally, the consumer safety rule must be "reasonably necessary"[75] and in the "public interest."[76] The consumer safety rules must be expressed as performance standards.[77] It is unlawful to "sell, offer for sale, manufacture for sale, distribute in commerce, or import into the United States any consumer product" not in conformity with the applicable consumer safety rule.[78]

¶54 *a) Product certification in general.*—A consumer product subject to the applicable safety rule requires certification.[79] The certification includes testing of the product to ensure conformity with the safety regulations.[80] Specific consumer safety rules define certification procedures for the products they cover.

¶55 *b) Children's products.*—The Consumer Products Safety Improvement Act (CPSIA)[81] sets regulations for "children's products" and rules for compliance by the manufacturers or importers into the United States.[82] The product must comply with children's product safety rules, be tested for compliance by an accredited laboratory, provide evidence through a certificate of the product's compliance, and have a tracking number that contains information about the manufacturer, location of production, and details about the manufacturing process.[83]

¶56 Full-size baby cribs are an example of a children's product that must comply with the CPSC's regulations. The regulation defines full-size baby cribs as beds for infants within a range of inner dimensions.[84] "[F]ull-size baby crib[s] shall comply with all applicable provisions of ASTM F1169-13, Standard Consumer Safety Specification for Full-Size Baby Cribs."[85] Manufacturers must obtain a copy of the specifications from ASTM International, the American Society for Testing and Materials.[86] Current revisions of the ASTM for full-size cribs include: limit to movable sections, slat joint construction in lieu of finger or lateral joints, and warning label visibility.[87]

¶57 *c) Lawn mowers.*—Walk-behind lawn mower manufacturers and importers must certify their safety compliance by labeling their products accordingly.[88] The manufacturer or importer must issue certificates of safety based on a "reasonable testing program."[89] Unlike children's products, such as cribs, walk-behind lawn mowers do not require certification at an accredited laboratory.[90] A manufacturer can establish a "reasonable

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[73] *Id.* § 2058(f)(2)(A).
[74] *Id.* § 2058(f)(2)(B).
[75] *Id.* § 2058(f)(3)(A).
[76] *Id.* § 2058(f)(3)(B).
[77] *Id.* § 2056(1)(1).
[78] *Id.* § 2068(a)(1).
[79] *Id.* § 2063(a)(1).
[80] *Id.*
[81] Consumer Products Safety Improvement Act of 2008, Pub. L. 110-314, 122 Stat. 3016 (2008).
[82] *See The Consumer Product Safety Improvement Act*, CONSUMER PRODUCT SAFETY COMMISSION, http://www.cpsc.gov/cpsia [http://perma.cc/SN4V-3YJ5].
[83] *Id.*; 15 U.S.C. § 2063(5)(A).
[84] 16 C.F.R. § 1219.1.
[85] 16 C.F.R. § 1219.2.
[86] *Id.*
[87] *Standard Consumer Safety Specification for Full-Size Baby Cribs*, ASTM http://www.astm.org/Standards/F1169.htm [http://perma.cc/4SHD-6J4E].
[88] 16 C.F.R. § 1205.30.
[89] *Id.*
[90] *Id.* § 1205.33.

testing program" through which testing "provides reasonable assurance" of the safety standards.[91] A manufacturer can divide products into production lots and certify an entire lot by only testing a sample.[92] If the product fails the testing, the manufacturer cannot certify any member of the production lot unless the manufacturer makes necessary adjustments for safety conformity.[93]

¶58 The CPSC standards for walk-behind lawn mowers require the manufacturer to conform to specifications for rotor shields,[94] mower controls,[95] and warning labels.[96] Each specification includes technical drawings and testing procedures, including areas of inspection and testing conditions. Rotor shields, for example, require testing on a smooth, level surface, with inflated pneumatic tires, the highest level setting, and the rotor blade set to the lowest position.[97] Conformity with these standards allow manufacturers to self-certify their product.

¶59 This self-certification scheme mirrors verification and declaration of conformity procedures of electronic consumer devices described in subsequent sections. Self-certification of products requires recordkeeping by the manufacturer. For lawn mowers, the manufacturer must keep certification records, including test results and lot information, for three years.[98] This allows the CPSC to inspect manufacturer test records and ensure that the manufacturer complies with safety standards.

3. Certification of compliance by consumer electronics devices

¶60 The FAA's expressed interest in special treatment for micro UAS draws support from other areas of regulation, such as the FCC's regulation of consumer electronics devices.. The argument for subjecting them to a lighter regulatory touch proceeds from their limited capacity to cause damage and injury. Likewise, unintentional radio frequency ("RF") radiators pose some risk of RF interference, but not nearly as much as intentional radiators. Accordingly the FCC's regulatory regime, aimed at reducing the risks of RF interference, allows self-certification of compliance by the vendors of low-risk unintentional radiators. The FCC does, however, prescribe default testing procedures even for these vendors. Intentional radiators, posing a higher risk, must be certified by the FFC in advance of sale.

¶61 The FCC regulations[99] define classes of electronics for the purpose of certification. A consumer device can be an intentional, an unintentional, or an incidental radiator; an intentional radiator emits radio frequencies through induction or radiation, an unintentional radiator emits internal radio frequencies, and an incidental radiator emits radio frequencies but was not designed for that purpose.[100] An electronic manufacturer can self-certify its

[91] *Id.* § 1205.33(b)(1).
[92] *Id.* § 1205.33(b).
[93] *Id.* § 1205.33(b)(4).
[94] *Id.* § 1205.4.
[95] *Id.* § 1205.5.
[96] *Id.* § 1205.6.
[97] *Id.* § 1205.4(b).
[98] *Id.* § 1205.34.
[99] *See* 47 C.F.R. §§ 0.1 *et seq.* (2014).
[100] *Id.* § 15.3.

product through Verification[101] or a Declaration of Conformity,[102] or it can seek Certification[103] prior to marketing, pursuant to FCC requirements. All methods require manufacturers to test their products and take the necessary measurements to "ensure that the equipment complies with the appropriate technical standards."[104] Certification, however, requires the applicant to submit measurements and test data for approval.[105] The FCC does not require manufacturers to send their product for approval unless specifically requested,[106] but the FCC requests test measurements for Certification. Whether a manufacturer requires a Declaration of Conformity ("DoC") or Certification depends on the class of radiator and type of electronic device—discussed in a subsequent paragraph.

¶62 The level of burden depends on the type of spectrum occupied. The devices that require Verification simply receive signals and do not transmit. The devices that require a DoC transmit signals but occupy unlicensed spectrums. The devices that require Certification occupy licensed and congested spectrum. The following types of electronic equipment authorizations are listed in ascending order by their level of compliance burden:

¶63 *a) Verification.*—Devices like FM and Television broadcast receivers can self-certify through verification. By verification, the manufacturer determines that the product complies with FCC technical standards.[107]

¶64 Unlike DoC and Certification, Verification requires testing at any laboratory—the laboratory need not be accredited. Manufacturers must design products to comply with FCC regulations that govern radio frequency emissions. For devices that connect to the public utility power lines, the product shall not exceed limits of radio frequency voltage introduced back into the AC power lines.[108] Products also have limits on radio frequency emissions measured from various distances.[109]

¶65 The FCC requires the responsible party to maintain documents with technical drawings and specifications, records and procedures of product testing, and record of measurements taken at the test site.[110] Upon the FCC's "reasonable" request, the manufacturer must submit "one or more sample units for measurements at the Commission's Laboratory."[111] Failure to comply within fourteen (14) days will lead to forfeiture or other administrative sanctions.[112]

¶66 *b) Declaration of Conformity (DoC).*—The Declaration of Conformity by a manufacturer signifies that the product complies with FCC regulations.[113] DoC does not differ from Verification except that a DoC requires testing by an accredited laboratory.[114]

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[101] *Id.* § 2.902.
[102] *Id.* § 2.906.
[103] *Id.* § 2.907.
[104] *Id.* §§ 2.906–2.907.
[105] *Id.* § 2.907.
[106] *Id.*
[107] *Id.* § 2.952.
[108] *Id.* § 15.107.
[109] *Id.* § 15.109.
[110] *Id.* § 2.955.
[111] *Id.* § 2.956.
[112] *Id.* § 2.946.
[113] *Id.* § 2.906.
[114] *See Equipment Authorization Procedures*, FED. COMMC'NS COMM'N, https://www.fcc.gov/oet/ea/procedures.html [https://perma.cc/WV6F-9XKT].

The FCC requires the same document maintenance[115] and may request a sample product for testing.[116]

¶67 A Declaration of Conformity is sufficient for Consumer Industrial, Scientific, and Medical ("ISM") devices like WiFi Access Points ("APs").[117] Access points operate in unlicensed frequency bands, meaning that the FCC did not reserve and allocate specific frequencies for specific licensees. WiFi APs operate on the 2.4 GHz spectrum, 5 GHz spectrum, or both unlicensed spectrums. Manufacturers must test their products in an accredited laboratory equipped with an anechoic chamber to take measurements of their devices. One of these measurements is antenna power.[118]

¶68 *c) Certification.*—Certification of a product requires the manufacturer to submit the product test results and measurements and seek authorization by the FCC or the Telecommunication Certification Body (TCB).[119] The manufacturer must submit an FCC Form 731 including technical measurements that show compliance with the FCC requirements.[120] Rules govern the measurements required for particular devices. Devices that use authorized radio services, like cell phones, require the following measurements: RF power output, modulation characteristics, occupied bandwidth, spurious emissions at antenna terminals, field strength of spurious radiation, and frequency stability.[121] Cell phones must conform to the specifications under 47 C.F.R. pt. 22 subpart H, which outlines permissible channel usage, radiation limits, and frequency band operation by cellular devices.

E. Minimize pre-sale testing requirements

¶69 Applying safety standards, whether they are performance or design-based, whether a government agency must approve a product before it is sold, or whether a vendor can self-certify compliance with the standards, almost always involves some form of testing. To reduce the cost of drone-vendor compliance with FAA safety standards, vendors must be in a position to decide how much pre-sale safety testing they want to do, as compared with post-sale data collection to verify compliance.

1. Fault analysis

¶70 Requiring autonomous return-to-home capability is a good example of the challenge, and it is almost certain to be included in any conceivable set of vehicle requirements.[122]

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[115] 47 C.F.R. § 2.1075 (2014).

[116] *Id.* § 2.1076.

[117] An access point (AP) is not what is commonly referred to as a router. What consumers generally consider a router includes a device that directs traffic between the local area network (LAN) and the wide area network (WAN) called the router, a network switch that allows multiple physical connections into the device, and a wireless access point (AP) that allows wireless connection with the network.

[118] 47 C.F.R. § 15.247 (2014) (limiting antenna power to 1 watt). *See also FCC Rules Dictate Antenna Use*, BITSTORM, http://www.bitstorm.com/fcc-regulations/ [http://perma.cc/K75S-6Y8Y] (last visited Sept. 24, 2014).

[119] 47 C.F.R. § 2.907 (2014).

[120] *Id.* § 2.1033.

[121] *Id.* § 2.1041; *see also id*. §§ 2.1046–2.1057.

[122] This return-to-home function applies in local drone missions within the line of sight. The drone can travel a maximum distance equivalent to half the maximum charge of the battery from the launch position; the battery must have sufficient charge to support a journey back. When the FAA lifts the limit on line of

Stating the general performance requirement is straightforward. For example, proposed language for such a requirement would state: "the aircraft must have a return-to-home mode that, when triggered, causes it to return to the launching point and land without DROP intervention."

¶71 It is similarly straightforward to impose tolerances for the landing point, such as, "within 2 feet of the launching point."

¶72 The reliability of the return-to-home function presents difficulties if the return-to-home system works only some of the time. Then it will have only limited safety benefits. A pure performance-based approach to reliability would add a proviso that the return-to-home feature must work a certain percentage of the time, say 99.5%. But why 99.5% as opposed to 85% or 92% or 99.6%? The most appropriate figure, theoretically, should be based on a balancing of the magnitude of the cost of a failure weighed against the cost of compliance, but that requires data, and there is not much data yet for microdrone return-to-home system functionality. There is even less data on the cost of drone accidents.

¶73 Beginning with the components of the system, fault analysis can create a failure rate estimate. Additionally, fault analysis can begin quantifying the cost of improving the failure rate from the cost of an additional component or a more reliable component. Redundancy almost always improves reliability, and it is not difficult to determine the cost of a backup system, which also would reduce endurance because of power consumption and weight.

¶74 Analytically, aviation reliability engineering requires: (1) inventorying every fault that can occur in every aircraft component, (2) quantifying the probability of that fault occurring, and (3) assessing the risk of failure.

¶75 An example of reliability engineering would be the failure of a pitch link on a helicopter rotor blade. The probability of this occurring depends on the design of the link and the properties from which it is made. A failure in the pitch link would be catastrophic. Asymmetries left between the two rotor blades would probably cause the rotor blade to separate from the rotor hub.

¶76 In a microdrone, a fault might occur in the power supply to one rotor because the soldered connection of one of the motors that leads to the power distribution board has failed, resulting in an open circuit to that motor. The probability of failure of soldered connections is relatively high because wire connections, in which the only strength is provided by the solder itself, are brittle and weak. The consequences of failure of a soldered connection would not likely be catastrophic in a multi-rotor design because the thrust of the rotors still in operation can be ramped up to ensure stable flight or at least a controlled landing.

¶77 Another fault could be a capacitor failure on an integrated semiconductor circuit board, rendering a microdrone's GPS navigation system inoperative. The consequences of an inoperative GPS navigation system depends upon the drone's alternative navigation capabilities.

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sight operation of drones and drones become truly autonomous (not requiring a DROP to intervene), drones should have pre-programmed coordinates of safe landing zones along the travel route. In R&D scenarios, a package traveling from point A to point B should include coordinates of landing zones to avoid traveling back to the starting position. This also increases the drone's effective travel distance because the furthest a drone can travel is equivalent to requisite battery charge left and the nearest safe landing point.

¶78 The three-step process—inventorying possible faults, assessing probability, and quantifying risk— is known as *fault analysis,* which also recognizes that multiple faults can occur at more or less the same time. Thorough fault analysis must consider all of the possible permutations of faults.

¶79 A *fault tree* quantifies the results of a fault analysis. From there, probability analysis multiplies and adds the probabilities to determine the joint probability of various combinations of multiple faults.

¶80 After the complete fault analysis process identifies faults, estimates their probabilities, and assesses their consequences, then the designers and regulators decide what should be done to reduce the risk of failure. One possibility is to redesign the failing component to reduce the probability of failure occurring. Depending on the way in which the failure such as that of the pitch link occurred, the component link could be redesigned to be made of stronger material, to be larger in dimension, or to attach the link to the pitch horn of the blade or to the upper swashplate in a different way.

¶81 Going back to the example of a broken solder connection, assembly procedures could be modified to require that the wire be mechanically connected before it is soldered, as by wrapping the wire around or hooking it through a terminal, or twisting two wires together before the connection is soldered.

¶82 If redesign is not likely to be cost-effective, redundancy is another corrective action. Each rotor blade could be equipped with two pitch links, either one strong enough to adjust the pitch of the rotor blade throughout its operating range. Two power connections for each leg of the electrical circuit could be provided for each motor.

¶83 Another mitigating strategy is to revise component specifications so as to narrow operating limits in terms of speed, temperature, or turbulence.

¶84 Increasing automation means that more of the critical aircraft systems are implemented by computer software rather than by mechanical structures, assemblies, connections, and movements. Faults in software are far more likely to be due to mistakes in coding logic than due to physical failure, such as failure of a disk drive or a solid state storage device containing the software. In the world of computer programming, fault analysis and mitigation is known as *debugging*. The more complex the program, the more difficult it is to debug. A programming fault may manifest itself in the overall failure of the system of which it is a part. A program may cease execution or produce wrong values, but isolating the exact cause of the program anomaly is a challenge. Advancing the frontier of reliability engineering for aircraft requires better techniques for fault analysis of computer software and automating them.

¶85 In many cases, the best solution for a programming error is some means of indicating failure of a system or of a component, allowing a backup system to take over, or alerting the pilot or DROP. Triggering an alarm system allows the pilot to utilize training, human instincts, and ingenuity to take appropriate corrective action, which is not programmed into any of the systems in advance.

¶86 When the engine of a single-engine helicopter fails, it is less important for the pilot to know whether it was a tooth on the bevel gear in the main transmission that failed than it is for him to know that the propulsion system as a whole has failed. To make sure the pilot recognizes such a failure immediately, helicopters are equipped with both an annunciator light and an aural alarm for low rotor RPM, an immediate manifestation of an engine failure.

¶87 Engineering science permits the designers of physical components to determine the component's strength and other properties and thus to determine the conditions under which they will break, bend, or suffer fatigue processes likely to resolve into eventual fatigue fractures.

¶88 But mechanical parts often behave differently under real-world conditions than theory can predict. Data on actual behavior is essential for adequate failure analysis, and data is often unavailable in sufficient quantities to complete feasible fault analysis before an aircraft enters operation.

¶89 Usually, a full fault analysis is not possible until after an aircraft system is in service for many months or years. Before that, averages of test results can be used, but averages such as mean time between failure (MTBF) are not enough. Failures often exhibit wide deviations around the average. A particular fault may have such a catastrophic consequence that it may jeopardize safety even if it occurs only at the 10%, 5% or 1% probability level, even though the average failure rate suggests adequate reliability.

¶90 Several vulnerabilities exist in drone safety systems. A power lead from a microdrone motor might detach from a poorly soldered connection. Wiring connections on or between integrated circuit boards can develop faults because of vibration or impacts encountered in use or because of manufacturing defects. Electronics hardware can malfunction because of overheating, moisture, or dust.

¶91 Far more likely, points of failure involve the three different RF links involved in drone missions: the control link, the GPS link, and the Internet connection. Control link failure is the most basic of these, but when that happens, well functioning autonomous safety protocols can resolve the situation safely. Almost all of the autonomous safety protocols depend upon GPS lock. Complete loss of control requires the loss of the control link and GPS lock. Live Internet connectivity is not essential for safe flight, but it is necessary to provide live telemetry to customers and vendors and to provide moving map displays to DROP and photog.[123]

¶92 On the microdrone systems marketed in 2015, control links are implemented by spread spectrum modulation[124] of frequencies in the unlicensed 2.4 GHz band,[125] with some vendors selecting the 5.7 GHz band instead.[126] Sometimes the control link piggybacks on top of a Wi-Fi connection;[127] in other cases, the control link uses coding

[123] in newsgathering-helicopter and drone parlance, a "photog" is the camera operator.

[124] Spread-spectrum modulation is a system for splitting information into tiny slices of content that are transmitted separately on each of a hundred or more frequencies in a band of RF spectrum. *See* K. H. Torvmark, *Frequency Hopping Systems*, TEX. INSTRUMENTS, http://www.ti.com/lit/an/swra077/swra077.pdf [http://perma.cc/76Z5-9NQ6] (last visited Sept. 24, 2015) (explaining spread spectrum); *see generally* U. S. Patent No. 7,990,874 (granted Aug. 2, 2011) (reviewing history and characteristics of spread spectrum technologies). WiFi uses spread spectrum modulation. Syed Masud Mahmud, *Spread Spectrum and Wi-Fi Basics*, WAYNE ST. U. http://ece.eng.wayne.edu/~smahmud/ECECourses/ECE5620/Notes/Wi-Fi-Lecture.pdf [http://perma.cc/G6K5-PBDB] (last visited Sept. 24, 2015) (explaining how WiFi uses spread spectrum modulation).

[125] *Phantom 3 Professional & Advanced*, DJI, http://www.dji.com/product/phantom-3/spec [http://perma.cc/N63J-HHVV] (last visited Sept. 24, 2015).

[126] Craigi, *Basics of Radio Frequencies for FPV Quadcopter Drones*, DRONEFLYERS (Nov. 17, 2014), http://www.droneflyers.com/2014/11/basics-radio-frequencies-fpv-quadcopter-drones/ [http://perma.cc/YP2H-F6WJ] (reviewing frequencies used by popular drones).

[127] *Drone and UAV Tech.*, 3DR, http://3drobotics.com [http://perma.cc/Q2MY-75A2] (last visited Sept. 24, 2015).

and modulation schemes similar to those used by Wi-Fi but independent of it.[128] The range of control link signals is limited to a half-mile or so.[129]

¶93 Interference from the other strong sources of RF energy, such as high tension power lines or broadcast radio and television antennas, can disrupt the control link, as can congestion on the relevant frequency band from other Wi-Fi users. Heavy cellphone usage is unlikely to interfere, because the frequencies are different.[130] Dense materials such as structures and hills attenuate these frequencies and can result in loss of the control link when they come between the DROP and the drone.

¶94 GPS operates by means of a receiver and associated processing software that triangulate RF signals received from a multiplicity of GPS satellites. The receiver is passive; it is not a transmitter, and no handshake is involved with the GPS satellite. All the receiver needs to do is to be able to see and hear the requisite number of satellites. The satellites transmit on two frequencies: 1575.42 MHz (L1) and 1227.60 MHz (L2).[131] Typical drone GPS implementations require anywhere from 6 to 12 satellite signals to perform the necessary computations.[132] When this occurs, a state known as "GPS lock" exists. The frequencies involved suffer significant attenuation from physical objects such as foliage, structures, and precipitation, and so it is not unusual for the requisite signals to be unavailable or intermittent in particular circumstances.

¶95 Internet connectivity in the field usually depends on a data connection through a cellphone provider; WiFi-based Internet links rarely are available where drone missions are flown. In the typical DJI, 3DRobotics, or Parrot AR configuration, Internet connectivity is provided by the user's cellphone or tablet computer, operating in the 869–894 MHz and 1850–1990 MHz bands,[133] while the drone and DROPCON limit themselves to providing GPS and control links on other frequencies.

¶96 A cellular data connection is not required, however, to realize the basic flight and video functionality of cellphone or tablet computers in these configurations; the cellphone or tablet communicates with the drone and the DROPCON via Wi-Fi, Bluetooth, or both. If the user wants Internet connectivity, he must have a cellular data subscription. In the absence of Internet connectivity during missions, the user can upload recorded data later, when Internet connectivity is available, after the flight.

¶97 Of the three kinds of RF connectivity, cellular data is the most reliable; although, cellular coverage is limited in some places and in some circumstances, as when congestion is high during music concerts or athletic events.

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[128] A drone vendor could design and deploy its own control link hardware that would use some or all of the 802.11 standard without relying on off-the-shelf WiFi products.

[129] *Phantom 3 Professional & Advanced*, *supra* note 127.

[130] U.S. cellphones operate on the 800 MHz and 1.9 GHz frequency bands; WiFi operated in the 2.4 and 5.8 GHz bands. *Cellular Frequencies and Bands in Use Today*, CRITERION CELLULAR, http://www.criterioncellular.com/tutorials/bandsandfrequencies.html [http://perma.cc/P8WW-JNTS] (last visited Sept. 24, 2015) (summarizing cellphone frequencies).

[131] *GPS Signals*, WIKIPEDIA https://en.wikipedia.org/wiki/GPS_signals [https://perma.cc/3PPW-WBFC] (last visited Sept. 24, 2015).

[132] Tom Clark, *How a GPS Receiver Gets a Lock*, GPSINFORMATION.NET http://gpsinformation.net/main/gpslock.htm [http://perma.cc/7RHT-5WQ4] (last visited Sept. 24, 2015) (explanation by amateur radio operator of how a device gets a GPS lock).

[133] *Cellular Frequencies*, WIKIPEDIA https://en.wikipedia.org/wiki/Cellular_frequencies [https://perma.cc/3BJJ-FHRQ] (last visited Sept. 24, 2015).

¶98 The most important thing to understand in terms of safety systems failure analysis is how joint failures of the control link and the GPS system could occur.

2. Test protocols

¶99 Test protocols specify how a system or subsystem should be tested to ensure that it meets its design goals. Control surfaces such as ailerons can be tested in a wind tunnel, by measuring the relationship between degrees of aileron deflection and the resulting moment at the wing root at various air speeds. Structural strength can be tested destructively by applying steadily increasing loads at the wingtip and measuring the load at which the wing root attachment fractures. Crash resistance, say of a LiPo battery container can be tested by subjecting the battery casing to various kinds of puncture loads to determine the puncture force at which the battery case is penetrated.

¶100 All of these examples can be accomplished fairly quickly, given the right test equipment. Other kinds of tests, however, require much more data and sufficient time to collect the data. Testing for fatigue tolerance of a structural component requires repeatedly loading and unloading the structure until failure occurs or a crack can be detected. Testing for system reliability requires the application of enough use cycles to derive a statistically valid measure of mean time between failures. Tens of thousands of use cycles often are required to collect the necessary data.

¶101 In any test protocol, failure, e.g. the fracture of a wing root in testing wing strength, must be defined. Additionally, the event or phenomenon whose relationship of failure is being tested must be defined – loading and unloading the wing in the fatigue-tolerance example.

¶102 Microdrones are exceedingly unlikely to suffer structural failure in ordinary use, in the sense that the booms would separate or the central bay for the electronics would collapse. Certain components may experience physical failure; however, a rotor blade could come off in flight or a battery attachment could fail in flight, resulting in separation of the battery. Testing for these kinds of physical failures requires application of traditional techniques for measuring component attachment reliability. Additionally, the tester must determine the kinds of flight profiles or phenomena likely to cause the fault to be manifest: perhaps sudden changes in torque for the rotor blade, turbulence, or other causes of abrupt, extreme acceleration in the case of the battery attachment.

¶103 The greatest concern for microdrone safety, however, is not failure of structural components; it is the reliability of safety systems. A drone with automatic take off, automatic landing, automatic hover, geo-fencing, and automatic return-to-home poses little risk. The concern is the behavior of the vehicle when one or more of these autonomous safety features fails to operate as intended. Return-to-home is the most basic autonomous safety feature. When it works properly, the DROP can trigger the feature when he is about to lose control or is otherwise uneasy with the drone behavior. The vehicle's onboard safety systems can trigger it when the battery reaches a certain level of discharge, when the drone flies outside a defined height and distance envelope, or when the control link is lost.

¶104 Understanding the potential for failure starts with understanding how the feature works. Almost all microdrone return-to-home systems start with calculation of GPS coordinates, at least twice, when the drone is launched, to determine the home position and again to calculate present position when return-to-home is triggered. Calculation of a vector that connects two sets of coordinates is a straightforward application of trigonometry, but the return-to-home subsystem must have an algorithm that performs the calculation. The control subsystem must be able to fly the path with some means of detecting deviation, probably requiring additional GPS-coordinate input from the GPS subsystem. Calculation of GPS coordinates depends on the availability of signals from enough GPS satellite signals to achieve "GPS lock."

¶105 Conceptually, the design of a test protocol for return-to-home subsystem reliability is straightforward. The tester performs a large number of flights to different radii from the DROP in different directions and different proximities to obstacles and triggers the return-to-home at least once on each test flight. Each success and failure is recorded, along with all the flight parameters and profiles.

¶106 The challenge, and the main driver of cost and duration, is not only that many—probably thousands—of flights are necessary to collect the necessary data, but also that multiple causes of return-to-home failure exist – even as a theoretical matter; never mind real-world complications. To function successfully, any return-to-home subsystem must (1) know where the vehicle is when the feature is triggered; (2) it must know where home is; (3) it must be able to calculate a path from its present position to home; (4) it must communicate that path to a navigation system capable of causing the drone to fly the path; (5) the path must be one that the drone's thrust, climb and descent capabilities permit it to fly; (6) the path must not be interrupted by obstacles; (7) the drone's return speed must be greater than opposing wind; and (8) and the remaining battery charge must be sufficient to fly to the launching point.

¶107 Failure of steps (1) and (2) results from not having GPS lock at the points when coordinates are recorded. Failure of step (3) can result from a mis-designed algorithm, data errors in the coordinates input to it or a hardware fault as the algorithm is being executed. Failure of step (4) can result from a poor physical connection, data errors, or misalignment of data-structure frames. Failure of step (5) could result from the commanded path requiring altitudes, speeds, or turn rates exceeding the drone's performance capabilities. Failure of step (6) results if the drop has flown around or above a tree, pole or building on the outbound flight. Failure at step (7) can result if the drone flew downwind on its outbound flight, or if the wind speed has increased during the flight or is greater at a higher altitude at which the drone is flying. Failure at step (8) results from the battery's exhausting its charge.

¶108 A comprehensive test protocol must collect failure rate data under each of these conditions, many of which must be simulated for the test. Room for argument always exists as to whether a simulation adequately models reality. Some of the testing, such as that for steps (3) and (5), may not require actual flight, however. Programmers can create "test cases" where they input several coordinates and inspect the algorithm's output. Requirements for any kind of compliance testing are controversial, even among engineers skilled on the subject matter.[134] The same room for argument exists with respect to drone autonomous safety system testing.

[134] NHTSA's recent standard for electronic stability control on busses and trucks is a good example. The final rule published in the federal register has more than a dozen pages devoted to arguments over test standards in the proposed rule. Federal Motor Vehicle Safety Standards; Electronic Stability Control Systems for Heavy Vehicles, 80 Fed. Reg. 36,049 (final rule June 23, 2015) (to be codified at 49 C.F.R. pt. 571).

¶109 The cost of all this is considerable. Suppose 1,000 flights or other test cycles for each condition are necessary to collect the data needed for statistical robustness. The actual number may be much larger. Suppose a DROP, a reliability engineer, and a data analyst are necessary for each series of tests. Suppose further that the replacement cost of the test vehicle is $1,200, and that the vehicle loss rate during the tests is 10%. Finally, suppose that the duration of each test flight is 20 minutes and that return-to-home can be triggered every 5 minutes on each flight.

¶110 Those assumptions result in total test-flight time of 416.6 hours.[135] Assuming personnel compensation of $30,000 annually for the DROP, $50,000 annually for the reliability engineer, and $25,000 annually for the data analysis, labor cost for the testing totals $21,872.[136]

¶111 This is just one part of a comprehensive test protocol. Tests also must be designed to determine how much return-to-home capability is achievable without a GPS lock by reliance on the onboard IMU, or with onboard magnetometer and altimeter alone. An IMU can record spatial movements from the launch point and therefore enable the drone to retrace the path to return-to-home. A magnetometer and altimeter alone can allow a drone to fly directly toward the launching point—assuming it knows where it is—but are incapable of compensating for wind. Current devices also drift quickly, making them more suitable for maintaining vehicle orientation than for navigation.

¶112 On the other hand, not every component has to be subjected to reliability testing if the return-to-home subsystem includes particular component designs or off-the-shelf components that have passed reliability testing with specified failure rates. A rotor blade rated at 1,000 hours will not decrease the reliability of a system in which other critical components have lives of 100 hours.

3. Data collection and analysis

¶113 Verifying flight characteristics and functionality of automated emergency protocols requires data. One possibility is to require vendors to collect certain data and evaluate the data according to certain criteria and algorithms.[137] This approach, however, steers the drone certification process in the direction of traditional certification.

¶114 A less burdensome, performance-oriented approach would be to require the vendor to collect "appropriate data" to allow it to evaluate system reliability.

¶115 All of the necessary data can be collected as a part of a presale flight-test program, as it usually is for conventional airworthiness certification. But this is not necessary. Thousands of vehicles with their relevant safety subsystems are already flying.

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[135] 1,000 test flights, divided by 4 cycles per flight, multiplied by 20 minutes per flight, multiplied by 5 scenarios (excluding tests for steps (3) and (5)).

[136] Total test time of 416.6 hours, divided by annual work hours of 2,000, multiplied by the sum of the annual salaries for the three test professionals.

[137] *See* NAT'L HIGHWAY TRAFFIC SAFETY ADMIN., U.S. DEP'T OF TRANSP., LARGE SCHOOL BUS SAFETY RESTRAINT EVALUATION, http://www.nhtsa.gov/DOT/NHTSA/NRD/Multimedia/PDFs/ESV/18/Files/18ESV-000313.pdf (illustrating test data evaluation methodology); FED. AVIATION ADIM., U.S. DEPT. OF TRANSP., AC 150/5370-11B, USE OF NONDESTRUCTIVE TESTING IN THE EVALUATION OF AIRPORT PAVEMENTS 37-69 (2011), http://www.faa.gov/documentLibrary/media/Advisory_Circular/150_5370_11b.pdf %5Bhttps://perma.cc/CR84-E4YC?type=source] (illustrating evaluation of test data).

¶116 *a) Having operational drones collect the data.*—Most of the microdrones on the market collect data on flight profiles and parameter values so that they can be fed down to the DROP through a telemetry link (usually a channel on the control link). Many also provide the option of uploading the data to a website so that one can review flight profiles graphically or otherwise. Parrot was a pioneer in this with its first AR model, marketed in early 2014. As more of these vehicles are sold and flown, an enormous stockpile of data is collected. Determining the reliability of existing systems can make use of these data. It is not clear that the data are being used effectively for this purpose, however.

¶117 Various regulatory options are conceivable to assure exploitation of the collected data, enabling evaluation of existing systems, and targeting opportunities for improved functionality and reliability. A mandatory data collection requirement is not necessary to achieve this result. Any drone vendor has a self-interest in satisfying itself and its customers—as well as regulators—that its vehicles are safe. The FAA could, following the example of the FCC, prohibit sale of any drone for which the vendor has not issued a certificate of conformity, certifying that the vendor has done whatever is necessary to assure safety and the reliable operation of certain failsafe features. It would be left entirely up to the vendor to determine the basis for such self-certification.

¶118 Then, either on a random spot check basis or only when the agency has reason to believe that the certification is unwarranted, the vendor could be required to submit to the FAA documentation of the basis for its self-certification. If the documentation shows that the basis was inadequate, the FAA could impose remedial measures or prohibit sale of the vehicle.

¶119 The advantage of this approach is that it does not interpose delays and unwarranted costs before vendors market new technology. It aligns regulatory requirements with market forces. Drone vendors already advertise product safety features, and this would enable them to brag about data-based indicia of safety.

¶120 Using the safe-harbor approach suggested in Part V would allow vendors to work out some tricky implementation issues. Under present systems, selection of data to be included in downloadable telemetry is optional for the user. Similarly, whether a flight profile is uploaded to the vendor or elsewhere is optional. Downlinking is necessary for uploading to be possible; the vehicle is unlikely to have a direct Internet connection. Does that mean that a drone must have an Internet connection before it will take off? That would radically change the architecture and circumscribe available missions significantly. One way to deal with this is to collect the captured data, not in real time, but periodically – whenever the user does have an Internet connection.

¶121 Exactly how this should work is not ripe for regulatory prescriptions; the market should allow experimentation in order to crystallize the best approach or approaches.

¶122 *b) Mandatory data collection.*—The suggested approach presents two challenges: first, to make sure the data is captured; second, to make sure that it is recorded or transmitted to the ground. The first challenge is easier to meet than the second. The *capability* to capture the relevant data is not a problem: most microdrones on the market capable of carrying cameras and performing commercial work capture data on position and state of the GPS system. Typically, they allow the DROP to specify that some or all of these data be downlinked to the DROPCON as telemetry. Many also record the data by writing it to an onboard memory chip such as an SD card in the form of log files.

¶123 DJI allows outsiders to develop applications with its SDK API.[138] The API provides functionality similar to the 3Drobotics API. The DJI Matrice 100 is a developer kit to experiment with code, sensors, and accessories on a specially designed quadrotor UAV intended to interface with user application software.

¶124 Examining the 3D Robotics API reveals the capability for programmers to capture and analyze data from the microdrone. (DJI's programming language and API have similar capabilities).

¶125 For example the class *droneapi.lib.Attitude(pitch, yaw, roll)* contains three Parameters:

pitch – Pitch in radians
yaw – Yaw in radians
roll – Roll in radians

¶126 The class *droneapi.lib.Battery(voltage, current, level)* contains three other Parameters:

voltage – Battery voltage in millivolts
current – Battery current, in 10 * milliamperes
level – Remaining battery energy

¶127 The class *droneapi.lib.GPSInfo(eph, epv, fix_type, satellites_visible)* provides information available about GPS.

¶128 If there is no GPS lock the parameters are set to None; otherwise the parameters are:

eph (IntType) – GPS horizontal dilution of position (HDOP) in cm (m*100)
epv (IntType) – GPS horizontal dilution of position (VDOP) in cm (m*100)
fix_type (IntType) – 0-1: no fix, 2: 2D fix, 3: 3D fix
satellites_visible (IntType) – Number of satellites visible

¶129 The class *droneapi.lib.Location(lat, lon, alt=None, is_relative=True)* contains latitude, longitude and altitude. The altitude is relative to either the home position or "mean sea-level," depending on the value of the *is_relative*.

¶130 For example, a location object might be defined as:
Location(41.879100, -87.642350, 30, is_relative=True)

¶131 Parameters:
lat – Latitude
lon – Longitude
alt – Altitude in meters (either relative or absolute)
is_relative – True if the specified altitude is relative to a 'home' location (this is usually desirable). False to set altitude relative to "mean sea-level"

¶132 The API allows commands in the form of functions. The function *takeoff(altitude)* causes the vehicle to take off and fly to the specified altitude (in meters) and then wait for another command.[139]

[138] *Guidance SDK: Empower Your Device with Vision*, DJI, http://dev.dji.com/en/products/sdk/onboard-sdk [https://perma.cc/RDY2-UP7G?type=source] (last visited Sept. 24, 2015).
[139] *DroneKit-Python API Reference*, 3DR, http://python.dronekit.io/automodule.html

¶133 3Drobotics provides programming code examples to do things such as following the DROP.[140]

¶134 The point is not that this kind of programming would take place after sale; rather the code examples show the capability of existing software to perform the data capture and recording proposed in the section. Moreover, evolution of the API will give access to more values that make IMU calculations possible.

¶135 The present state of the market is far from what it should be. For example, DIY Drones, an association of drone developers supported by 3DRobotics, offers an app called *droneshare*, which enables a drone to upload flight path data and other parameters to an Internet cloud maintained by a remote server.[141] Alternatively, it permits data to be collected and transmitted to the cloud as soon as the DROPCON has an Internet connection. Parrot offers *AR.Drone Academy*, which maintains a gallery of user-uploaded flight profiles.[142] Archiving and sharing flight profiles and imagery is part of the overall experience. DJI drones collect the data but make it difficult for a user to access or upload them. DJI does not get the data unless the user figures out how to access the data files and sends them to DJI.[143]

¶136 But all of this is optional and—with respect to the most popular microdrones, those from DJI—difficult. The DROP can choose whether to record or transmit the data. So meeting the first challenge requires automatically generating log files. A vendor could make data collection automatic, beyond the control of the user. It is difficult to *ensure* data recording, however. Even if it is automatically programmed to occur, the DROP may simply fail to insert an SD card. Designers can nullify this barrier to recording by programming the drone not to take off unless a memory chip is installed.

¶137 Eventual uploading of data through the Internet is easier to assure. Because both DJI and 3DR require firmware updates before the drone will fly, users must establish an Internet connection. Uploading log data easily can be made an invisible prerequisite for downloading the software update.

¶138 The proposed approach would capture and record data, not only about position and state of the GPS system, but also flight path data from the IMU, and magnetometer and barometric altimeter values. The frequency of data capture might be once per second—the same as that transmitted by ADS-B out.[144]

[http://perma.cc/8MYB-PD8Z] (last visited Sept. 24, 2015).

[140] The above example, *id*., causes the vehicle to take off and fly to the specified altitude (in meters) and then wait for another command.

[141] Kevin Hester, *Introducing Droneshare, the 3DR Cloud Flight and Fleet Management Service*, DIY DRONES BLOG (June 2, 2014, 4:40 PM), http://diydrones.com/profiles/blogs/new-droneshare-com-released [http://perma.cc/VAN6-XFE8].

[142] *Parrot AR. Drone Academy*, PARROT, http://ardrone2.parrot.com/ar-drone-academy/ [http://perma.cc/ZA93-KV2K] (last visited Sept. 13, 2015).

[143] *Compare* Inspire 1 Flight Data Logs, DJI FORUM (Jan. 19, 2015, 10:50 AM), http://forum.dji.com/thread-5269-1-1.html [http://perma.cc/GH8E-MJXC] (reporting difficulties accessing flight logs) *and* Pro/Adv Discussion, PHANTOM PILOTS, http://www.phantompilots.com/threads/telemetry-data-and-videos.38922/page-2 - post-368084 [http://perma.cc/WR9N-FTF2] (describing hex files generated by Naza flight controller) *with* Tips to See Your Flight Records in App! Great!, DJI FORUM (Apr. 24, 2015, 1:16 AM), http://forum.dji.com/thread-12989-1-1.html[http://perma.cc/C38Q-THQS] (summarizing steps to access flight records and to upload them to the cloud).

[144] *See Equip ADS-B – The Ins and Outs of ADS-B*, FAA (June 29, 2015), https://www.faa.gov/nextgen/equipadsb/ins_and_outs/ [http://perma.cc/TJE5-N7XT].

¶139 The second challenge, ensuring the transmission of the data to the vendor, is more difficult. Relying on DROPs to transmit flight data afterwards is insufficient. Some data will and will not be transmitted, and the database thus would not contain a statistically reliable sample of actual flight experience because it would contain only self-selected samples. The system must automatically transmit the data to a repository. That could occur in real time or automatically whenever a user connects to the vendor for such things as for software updates. Real-time or near-real-time transmission is better. Such transmission cannot occur in real time, however, unless the drone system has an Internet connection. Internet connections may be active for other reasons: to enable moving-map displays of GPS-determined position, or to support archives of flight profiles and imagery. Such archives are part of the sales pitch by some vendors,[145] and feeding data to the archives is attractive to some users. The same mechanisms for doing this can be required as part of the performance standards for microdrone sale and distribution. Then, data would be recorded whenever wireless Internet connectivity is available to the drone or the DROPCON.

¶140 If data transmission is not completely automatic, it could be the default, reinforced by incentives to leave it enabled. Other consumer electronic vendors provide for uploading of data in conjunction with operating system and application software performance.[146] Users could block the uploads because of privacy concerns until Windows 10, in which users cannot turn off the data collection and uploads.[147]

¶141 It is not hard to articulate such a requirement as part of the set of performance requirements that microdrones must meet in order to be sold or distributed: "The vehicle and its control systems must collect flight profile data and transmit it to a repository controlled by the vendor. This collection and transmission must be beyond the control of the operator."

¶142 Several likely objections to such a requirement can be anticipated. First, a number of commercial users and operators—especially in the agriculture industry—have already expressed opposition to governmental or third-party access to their data, which they consider to be proprietary.[148]

¶143 Second, the amount of data collected and stored would be large, and could tax any processing and analytical capability.[149] This second objection could be mitigated by database algorithms that would screen incoming data for anomalies and discard everything that appears fairly routine, or record only anomalies rather than all the data. An example of such an algorithm is shown below.

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[145] *See* 3D ROBOTICS, http://3DRobotics.com[http://perma.cc/BCC4-H7XX] (last visited Sept. 13 2015).

[146] Examples include Microsoft OneDrive, Apple's iCloud, and DropBox.

[147] Gregg Keizer, *Windows 10 Makes Diagnostic Data Collection Compulsory*, COMPUTER WORLD (Apr. 10, 2015, 11:52 AM), http://www.computerworld.com/article/2968288/microsoft-windows/windows-10-makes-diagnostic-data-collection-compulsory.html [http://perma.cc/LW29-TW84] (contrasting optional data collection in previous versions of Windows with always-on data collection in Windows 10).

[148] Gary Truitt, *Farm Bureau Addresses Data and Technology Privacy Concerns of Farmers*, HOOSIER AG TODAY (Feb. 11, 2014), http://www.hoosieragtoday.com/farm-bureau-addresses-data-and-technology-privacy-concerns-of-farmers/ [http://perma.cc/7B44-L6NK].

[149] If 50,000 drones are flown for five hours per week, and twenty 4-byte parameters are collected each second, seventy-two gigabytes of data per week would be collected. Processing time, given a particular speed of the processor, is proportional to the amount of data to be processed. Storage requirements are proportional to the amount of data to be stored.

```
If (problem) {
INSERT INTO table_name (column 1, column 2) VALUES (x,y);
}
```

¶144 The kind of accident data recording required of certain helicopter and airplane operators is not suitable for drones. Black boxes—flight data recorders and cockpit voice recorders—are useful only if they are recovered after a mishap. That is possible only if the recorders are hardened to withstand a crash, which considerably increases their weight, and if personnel are available to recover them. NTSB "Go-Teams"[150] are not going to be investigating every drone flyaway and looking for black boxes—the hardened SD card on the crashed drone.

F. Provide for product recalls

¶145 Federal agencies responsible for safety of consumer products,[151] motor vehicles,[152] pharmaceuticals, food,[153] motor homes,[154] marine vehicles,[155] and aircraft[156]can compel product recalls.[157]

¶146 Authorizing the FAA to order recalls of drones that do not meet performance standards could be a powerful incentive for vendors to do a better job of assuring compliance before sale.[158]

V. ADAPTING DRONE REQUIREMENTS

A. Setting the standard

¶147 Two alternatives exist. One is to let the market develop the data. The other is to develop performance standards purely from theory. The difficulty with the theoretical

[150] *The Investigative Process*, NAT'L TRANSP. SAFETY BOARD (last visited Sept. 13, 2015), http://www.ntsb.gov/investigations/process/pages/default.aspx [http://perma.cc/C9JL-CEXR] (explaining "Go Team" concept).

[151] 15 U.S.C. § 2064 (2012) (authorizing recalls). *But see* United States v. Zen Magnets, LLC, No. 15-cv-00955, 2015 WL 2265385 (D. Colo. May 14, 2015) (granting injunction against sale of small magnets, but expressing doubt about power to order recall of products already sold).

[152] 49 U.S.C. § 30118 (2012) (authorizing NHTSA to order recalls for noncompliant motor vehicles); 49 U.S.C. § 30120 (2012) (requiring manufacturers of vehicles to repair, replace, or refund purchase price); Ctr. for Auto. Safety, Inc. v. NHTSA, 342 F. Supp. 2d 1 (D.D.C. 2004) (summarizing statutory authority of NHTSA to order recalls).

[153] 21 U.S.C. § 350l (2012) (granting mandatory recall authority to FDA).

[154] 24 C.F.R. § 3282.407 (2015).

[155] 46 U.S.C. § 4310(f) (2012).

[156] *See* FAA, Airworthiness Directive 2000-15-15, Docket No. 2000-NM-89-AD; Amendment 39-11847; AD 2000-15-15, 65 Fed. Reg. 48355 (Aug. 8, 2000) (requiring inspection and, under some circumstances, replacement of jack screw assembly on DC-9 aircraft). The FAA airworthiness directive process is not generally referred to in terms of "product recall," but that is the effect in many cases when an AD prohibits flight until a system is replaced.

[157] Anita Bernstein, *Voluntary Recalls*, U. CHI. LEGAL F. 359, 363–366 (2013) (summarizing recall authority).

[158] Tavor White & Renata Pomponi, ¶ *54,363 "Best Practices" Net Lower Recall Rates, Study Finds*, CCH-CPSGD P 54363 (C.C.H.), 2009 WL 3626105 (2015) (reporting on statistical study that showed lower consumer product recall rates and costs for enterprises that did a better job of pre-sale design and testing and noting high cost of recalls, often resulting in bankruptcy).

approaches is obvious: there is no assurance that the resulting standard will be achievable with any technology now available or likely to become available.

¶148 The market-based approach is reality: vendors deliver the kind of autonomous safety features they think there is a demand for—almost all of them now include return-to-home. Actual experience in the air teaches what is feasible, highlights the most common failures, and shows what the costs of failure are. For example, Modovolate Aviation, LLC has lost two microdrones because of flyaways. One was a DJI Phantom 2 Vision; the other was a Parrot AR+. The Phantom had six hours total flight time before the flyaway occurred; the AR+ had three hours. The cost of the Phantom was $1,200 while the AR+ was $700. Neither vehicle was ever recovered, and to the best of the LLC's knowledge, no damage to persons or property on the ground occurred. The vehicles, however, were lost. So an appropriate value to place on the malfunction is the cost of the lost vehicle, plus the value of any attached accessories.

¶149 As § IV.D explains, a less burdensome approach involves self-certification, backed up by periodic audits or inspections. That is the way much regulation in the United States works, beginning with income taxation.

¶150 But how should a prudent self-certifier proceed? Can he rely wholly on engineering estimates? Probably not; he probably should do some testing. But what test protocol should he use? How much data is enough? How important is it to get some kind of independent verification?

¶151 These are not novel questions. Anyone who designs and sells a new product must consider them.

B. Proposed standard

¶152 Under existing law, an aircraft, including a drone, cannot be flown by anyone unless it meets FAA airworthiness requirements or unless the FAA, under the authority of Section 333 of the 2012 Act, determines that airworthiness certification is unnecessary, as it has in the Section 333 exemptions and as it proposes to do in the NPRM.

¶153 The FAA could implement this article's proposal by issuing a blanket determination under the authority of Section 333 that small UAS outside the micro UAS category are airworthy if, and only if, they meet the following requirements:

14 C.F.R. Part 107

Subpart E—Small Unmanned Aircraft Autonomous Safety Systems

§ 107.90

a. *Small unmanned aircraft systems are deemed airworthy under Part 21 if, and only if, they are equipped with the following autonomous safety features:*
b. *GPS-enabled automatic land-immediately and return-to-home capability;*
c. *Backup land-immediately and return-to-home capability not dependent on GPS lock;*[159]
d. *Live collection of flight data and malfunction indications, automatically recorded to non-volatile memory permanently installed on the vehicle and the operator's console as it is collected;*[160]
e. *The capability to upload flight data and malfunction reports to the vendor or to an Internet server accessible by the vendor; and*
f. *Vendor certification of compliance with these requirements.*

¶154 It does not make any sense either to distinguishing between hobbyist and commercial flight as the fundamental organizing principle for drone regulation or to regulate commercial operations more heavily than hobbyist use. While commercial incentives may draw more drone operations into the airspace, the commercial operators will be safer than hobbyist operators because of their concerns about liability, their compliance with insurance coverage limitations, and their unwillingness to jeopardize their certificates.

¶155 Traditional hobbyists may fly safely because they are embedded in the social matrix of a model aircraft club. This is not the case with hobbyists who fly on their own, unassociated with any club. A safe harbor strictly limited to hobbyist community events is sound. Exempting those solo hobbyists who remain unassociated with any club, is not.

¶156 Reliance on advisory committees to develop a standard may seem like a good idea. It is not. . [161] Relying on a consensus hammered out through a committee process that reconciles conflicting views of stakeholders shields the FAA from political buffeting. It takes considerable time, however, to develop a consensus, especially when participants have limited time, and many are indifferent to delays occasioned by the committee process. Reliance on committees is not working for drone regulation. The pace of the FAA' drone advisory committees has been excruciatingly slow, and the output modest in quantity and

[159] This requirement would be satisfied by software that collects the necessary data from an onboard IMU, magnetometer, and barometric altimeter so as to enable the drone to retrace its outbound flight path, as explained in § IV.E.2.

[160] The proposed rule requires recording on *both* the vehicle and on the operator's console, because if the control link is lost, the console will not receive what may be the most critical data about the malfunction in the autonomous safety features. Alternatively, the vehicle may be lost in the mishap, in which case the only recorded data would be on the operator's console.

[161] *Advisory and Rulemaking Committees*, FAA http://www.faa.gov/regulations_policies/rulemaking/committees/documents/ [http://perma.cc/JKK3-MQAZ] (last visited Sept. 13, 2015) (noting reliance on advisory committees for development of regulations); *NPRM*, *supra* note 3, at 9545, 9551 (noting reliance on Aviation Rulemaking Committee since 2008 for recommendations on drone regulation).

quality. Standard setting by committee is cursed by process worshippers, who care far less about timely results than whether detailed rules for committee deliberation are followed.

¶157 Decision-making by private committees is often worse than governmental decision-making; the FAA's drone advisory committee process is an example. The RTCA Special Committee 228, Minimum Operational Performance Standards for Unmanned Aircraft Systems, has issued only two white papers: one on command and control data links and the other on detection and avoidance. Both of these papers were released in 2013, and are available only if one pays $150.[162] Waiting for committee results to craft regulatory standards would defer realization of drone potential by a decade or more.

¶158 Similarly, the ICAO is moving at a glacial pace. Its 2011 circular asserted the need for international harmonization, but it did little more than review existing standards for manned aircraft and speculate how they might apply to drones.[163]

VI. TORT LAW ENFORCEMENT OF PERFORMANCE STANDARDS

¶159 Tort liability backs up any set of standards for drone design. Failure to satisfy governmental safety standards is a powerful way for a plaintiff to show breach of the duty of care. Indeed, the doctrine of negligence *per se* may make any violation of governmental standards sufficient to establish that a defendant's conduct fell below the reasonable standard of care.[164] Even if the FAA does not promulgate a standard for vehicle and system design, designers of vendors nevertheless are liable if a plaintiff can show negligent design, negligent manufacture, or failure to warn.[165] Under the familiar elements of a negligence cause of action, the plaintiff must establish a duty owed by the defendant to the plaintiff,[166] that the defendant should have foreseen the risks of the injury that the plaintiff suffered,[167] that the defendant failed to take reasonable measures that could have prevented that injury,[168] that his failure to do so was the proximate cause of the injury,[169] and damages.[170] Products liability operates within the same general framework but adjusts the standards of proof for some of the elements.[171]

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[162] *SC-228 Minimum Operational Performance Standards for Unmanned Aircraft System*s, RTCA, http://www.rtca.org/content.asp?contentid=178 [http://perma.cc/A5YF-QUN3] (last visited Sept. 9, 2015).

[163] *See ICAO Circular 328 AN/190 Unmanned Aircraft Systems (UAS)*, International Civil Aviation Organization (ICAO), http://www.icao.int/Meetings/UAS/Documents/Circular 328_en.pdf [http://perma.cc/S3F2-33K5] (last visited Sept. 11, 2015).

[164] RESTATEMENT (THIRD) OF TORTS: PHYS. & EMOT. HARM § 14 (2010) ("An actor is negligent if, without excuse, the actor violates a statute that is designed to protect against the type of accident the actor's conduct causes, and if the accident victim is within the class of persons the statute is designed to protect."); RESTATEMENT (SECOND) OF TORTS § 285 (1965) ("The standard of conduct of a reasonable man may be…established by a legislative enactment or administrative regulation"); *see* Sibert-Dean v. Washington Metro. Area Transit Auth., 721 F.3d 699, 701 (D.C. Cir. 2013) (ruling that a bus driver's failure to follow regulations constituted negligence *per se*).

[165] Merrell Dow Pharm. Inc. v. Thompson, 478 U.S. 804, 805–806, 817 n.15 (1986) (distinguishing ordinary negligence theories from *per-se* negligence theories and explaining how plaintiff can recover by proof of negligence, without relying on negligence *per se*).

[166] RESTATEMENT (THIRD) OF TORTS: PHYS. & EMOT. HARM § 7 (2010).

[167] *Id.*

[168] RESTATEMENT (SECOND) OF TORTS § 328A BURDEN OF PROOF (1965) (detailing elements plaintiff must prove); RESTATEMENT (SECOND) OF TORTS § 282 NEGLIGENCE DEFINED (1965).

[169] *Id.* § 328A(c) (requiring proof of proximate cause).

[170] *Id.* § 328A(d) (requiring proof of damages).

[171] *See* RESTATEMENT (THIRD) OF TORTS: PROD. LIAB. § 1 cmt (1998).

¶160 To assure coherence with the example used in the rest of this article, assume that the return-to-home function on a microdrone has malfunctioned, causing a flyaway and an injury to a person on the ground. The victim sues the operator and the drone vendor. To simplify the analysis, assume that the vendor designed, manufactured, and sold the drone directly to the operator.

¶161 Two scenarios are plausible: the plaintiff may be the drone customer or a third-party victim. Either type of victim claims that the vendor owed a duty of care to the victim. That will not be hard to establish for the customer: following *MacPherson v. Buick Motor Co.*,[172] negligence law has imposed duties on manufacturers running to customers in the chain of distribution, even if they have no privity of contract with the manufacturer.[173] Manufacturers also have duties to third parties who foreseeably may be injured by product malfunction.[174]

¶162 Then, the victim—of whichever type—must establish the applicable standard of care and that the vendor breached it. It is at that stage of the analysis that FAA's standards come into play. Suppose the FAA issues a rule requiring all microdrones to have automatic return-to-home systems that the DROP can trigger and that activate automatically when the drone loses the control link or there are other signs of loss of control. The vendor will argue that the vehicle in litigation had a return-to-home system and therefore complied with the FAA standard. The defendant will further argue that states are preempted from establishing, through their common law, standards that differ from those established by the FAA. The preemption argument is compelling.[175]

¶163 So then the battle will be over the FAA's performance standard. Subsequent sections in this analysis explore the implications of a more detailed performance standard, but initially, suppose it just says that the drone must have automatic return-to-home capability. What does that mean? Some extreme interpretations can be ruled out. Surely the drone would not satisfy the standard if the drone vendor argued only that it was possible for a DROP to fly the drone back manually. The standard says "automatic." Some automation, surely, is required. At the other extreme, the standard is not likely to be a source of absolute liability—one that the vendor breaches if the drone is struck by lightning or flies inside of a tunnel that blocks the GPS signal. Both of these risks are arguably foreseeable, but no feasible design would reduce them significantly. That would leave open, however, the question of whether the vendor has satisfied its duty to warn.[176]

¶164 Under what range of conditions and with what level of reliability must a compliant return-to-home system function correctly? That is the main issue in this factual and legal

[172] MacPherson v. Buick Motor Co., 111 N.E. 1050 (N.Y. 1916).

[173] *Id.*; Minton v. Krish, 642 A.2d 18, 21 (Conn. Ct. App. 1994) (applying *MacPherson* to hold that contractor could be held liable for injuries to third party resulting from door although door had been accepted by owner of premises).

[174] RESTATEMENT (SECOND) OF TORTS § 303 (1965) ("An act is negligent if the actor intends it to affect, or realizes or should realize that it is likely to affect, the conduct of another, a third person, or an animal in such a manner as to create an unreasonable risk of harm to the other.").

[175] Henry H. Perritt Jr. & Albert J. Plawinski, *One Centimeter Over My Back Yard: Where Does Federal Preemption of State Drone Regulation Start?*, 17 N.C.J.L. & TECH. (forthcoming Dec. 2015).

[176] *See* Elsworth v. Beech Aircraft Corp., 208 Cal. Rptr. 874, 877 n.4 (Cal. 1984) (affirming judgment for damages against aircraft manufacturer on negligence *per se* and failure to warn theories; state tort damages for violation of FAA standard not preempted); Rehler v. Beech Aircraft Corp., 777 F.2d 1072 (5th Cir. 1985) (affirming judgment on jury verdict for manufacturer; reviewing proof and jury instructions of negligent design, failure to warn, and misrepresentation of flat-spin danger).

battle. In fighting it, the plaintiff has an advantage if the defendant did little, if any, testing, or if the defendant's tests did not cover a reasonable range of likely flight conditions. Expert witnesses from both sides will help establish what a reasonable flight test program comprises, likely—at least on the plaintiff's side—using traditional airworthiness flight-test standards as a benchmark. One expert will explain why the manufacturer cannot design against GPS signal loss in tunnels, while the other side will introduce evidence of *alternatives* that are easy to design to avoid signal drop out.

¶165 Because a drone can lose—or fail to acquire—a GPS lock in the first place, under many operational circumstances, a defendant may be persuasive in arguing that the particular risk that caused the flyaway could not have been prevented by any reasonable measure. The plaintiff will respond that the vendor could have designed a vehicle so that it would not take off without a GPS lock that could not be overridden by the DROP. He will also argue that a variety of autonomous safety modes would have prevented the accident if they had been triggered automatically by a lost GPS lock in-flight, such as relying on IMU, magnetometer, and altimeter data to fly back to the launching position.

¶166 If the vendor self-certifies compliance with the standard without much basis for doing so, a customer-plaintiff has an additional claim for negligent misrepresentation (assuming that legal theory is recognized under the applicable state law).[177] Likewise, such a well-represented plaintiff will claim failure to warn in addition to negligent design and manufacture because weakness of one strengthens the other. Whatever risks the defendant establishes as reasonable under the negligent design theory, the plaintiff can challenge the inadequacy of the warning about them.

¶167 Third party plaintiffs, however, are unlikely to have either misrepresentation or failure to warn claims; any representations would not have been made to them, and any warning would not have been communicated to them.

¶168 The result is an enforcement mechanism that does not require any FAA or local law enforcement resources to back up a performance standard for drone safety. The more detailed the performance standard, the more powerful adherence to it will be as a defense in the negligence action. The more the vendor has deviated from the performance standard, the greater the likelihood of liability.

¶169 This approach does not require any kind of agency preapproval for sale, and it leaves how many resources to invest in presale compliance testing and validation entirely up to the vendor. The vendor is perfectly free to get a new technology on the market and *hope* it works reliably. Victims of errant drones are free to decide what is worth fighting about; only a handful will file lawsuits. Public resources embedded in the judicial system are targeted on mishaps that actually have consequences.

¶170 This approach represents a way to embrace enforceable performance standards without imposing additional prescriptive burdens for testing and pre-approval. And it is already there, embedded in the common law.

¶171 In litigation over a drone mishap, the plaintiff should have the burden of proof with respect to the cause of any mishap. In the case of a customer-plaintiff, if the plaintiff's vehicle had the ability to send telemetry to the vendor or the cloud and the plaintiff did not

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[177] RESTATEMENT (THIRD) OF TORTS: PROD. LIAB. § 9 (1998) (describing liability for fraudulent, negligent, and innocent misrepresentations of products).

activate it, the plaintiff's position is weak. The theory is not exactly *last clear chance*[178]or *assumption of the risk*;[179] collecting data would not have prevented the mishap. Data from the flight merely enables proof, and the defendant has the burden of proof once the plaintiff proves causation.[180]

¶172 If the plaintiff is a third-party and the vendor did not take reasonable action to ensure collection and preservation of flight data, *res ipsa loquitor* should operate against the vendor, creating a presumption that flight anomalies resulted from the vendor's fault.[181] If the vendor did collect data, it is, of course, discoverable by the third-party plaintiff.

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[178] RESTATEMENT (SECOND) OF TORTS § 480 (1965) (allowing the plaintiff to recover when the plaintiff perceived the danger but did not have the opportunity to avoid own peril).

[179] *Id.* § 496A (barring plaintiff's recovery when he perceives the risk and proceeds).

[180] *See* Galanek v. Wismar, 81 Cal. Rptr. 2d 236, 243 (Cal. Ct. App. 1999) (restating general rule that burden shifts to defendant to show product is not defective when plaintiff proves causation; reversing nonsuit against plaintiff).

[181] *Compare* Newing v. Cheatham, 540 P.2d 33, 40–41 (Cal. 1975) (affirming directed verdict for plaintiff on *res ipsa loquitur* theory establishing pilot fault) *and* Abbott v. Page Airways, Inc., 245 N.E.2d 388, 391–392 (N.Y. 1969) (affirming judgment on jury verdict for plaintiff against helicopter pilot on *res ipsa loquitur* theory) *with* Sievers v. Beechcraft Mfg. Co., 497 F. Supp. 197, 202–203 (E.D. La. 1980) (explaining that *res ipsa* not available against manufacturer when negligence by pilot or other factors besides manufacturer fault could have caused accident).