Making newsgathering drones safe near people

White paper

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Introduction and summary

This white paper explains why small drones—those weighing significantly less than 10 pounds—need to be able to fly closer than 500 feet to people in order to fulfill their potential to be new, inexpensive, and flexible tools for newsgathering. It profiles useful newsgathering flight profiles, reviews the results of available analyses of impact energy, and concludes that the risk of injury from the types of mishaps most likely to happen is minimal. It assesses the effectiveness and practicability of specific mitigating measures and urges that any performance standards for newsgathering drone flights proximate to people be implemented through manufacturer self-certification rather than pre-sale approval by the FAA.

On February 24, 2016, the FAA signaled its interest in writing its final small drone rules, expected as early as this summer, to accommodate the needs of the journalism community. While reiterating its reluctance to embrace a simple exclusion for drones below a certain weight, as proposed by the UAS America Fund, the agency formally appointed a new industry advisory committee, and gave it an April 1 deadline to develop recommendations for how flight over people by small drones can be made safe.

This white paper is intended to aid the committee and the FAA in their deliberations.

The output of this advisory committee is but one component of a desirable strategy for regulating UAS: a full set of *incremental* certification, regulatory, and technical requirements to address different levels of risk, as UAS America Fund proposed.

The requirements discussed in this paper focus only on flights close to people, not more generally, where other ways to prevent injuries and loss of control may be desirable requirements, such as built-in GPS data to prevent vehicles from entering pre-determined restricted airspace, or automation built in to drones that would return the vehicle to where it was launched if it loses communication with the operator, senses that it is running low on battery power, or senses interference with its flight controller.

Self-certification

The most important imperative for this initiative is that it not morph into formal airworthiness certification. If newsgathering drones must receive airworthiness certificates before they can fly over people, it will be years before this newsgathering tool will be a reality. The FAA's February, 2015 drone NPRM[1] recognizes the infeasibility of airworthiness certification.

To avoid airworthiness certification, the FAA must allow self-certification by manufacturers and vendors, as occurs with motor vehicles and consumer products under NHTSA and CPSC regulation.[2]

The FAA would articulate performance standards, and manufacturers and vendors would declare that certain models meet those standards.

Utility and mission profiles

The journalism community recognizes that small drones have the potential to supplement helicopters and ground-based units for effective news coverage.[3] The low cost and flexibility of drones make it possible for them to be deployed with reporter and photojournalist teams including freelancers or stringers, significantly increasing the ability of news outlets to obtain aerial imagery, and greatly reducing the cost. A TV station can buy a small drone outright for the cost of one hour of news helicopter time.

Currently, television news stations utilize helicopter crews to shoot aerial imagery of certain newsworthy events. Two common examples of such events include traffic accidents and fires. News organizations could use small drones to cover such events

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[1] 80 Fed. Reg. 9544 (Feb. 23, 2015) [hereinafter "NPRM"].

[2] See Henry H. Perritt, Jr. & Albert J. Plawinski, Making Civilian Drones Safe: Performance Standards, Self-Certification, and Post-Sale Data Collection, 14 Nw. J. Tech. & Intell. Prop. 1 (2016).

[3] "Drones will have an enormous impact on news production," Keith Laing, Feds approve CNN for drone flights, The Hill (Dec. 14, 2015), http://thehill.com/policy/transportation/263103-feds-approve-cnn-for-drone-flights (reporting on grant of section 333 exemption to CNN; quoting CNN petition).

effectively in some scenarios difficult for helicopters. Their low cost and flexibility make it possible for them to be deployed with reporter and photojournalist teams and by freelancers or stringers, significantly expanding the capacity of journalists to obtain aerial imagery. For breaking news, TV stations prefer live imagery that they can include in their over–the–air broadcasts, on their live Internet streams, or on their websites immediately as the story develops. For other, longer form, feature stories, imagery delivered after it is shot is satisfactory. A field team would launch its drone when an aerial perspective adds value to what can be captured from the ground, as in the case of a fire, a large-scale law-enforcement operation, a natural disaster, or any story subject whose scale makes it difficult to represent it photographically with ground–based imagery. In some cases, coverage by drones would be safer and faster than coverage by helicopter. In many other cases, the speed of news helicopters would give them an advantage in getting to the scene.

While news helicopters are quite safe, due to the high level of training and professionalism of their pilots and the safety consciousness of their operators, the few mishaps that occur are quite serious: usually fatal to the pilot and photojournalist, and often resulting in fires on the ground from fuel. Drones do not put aircrews in jeopardy and the small multi-copters most likely to be used for newsgathering carry no flammable fuel.

Tethered drones are attractive for covering traffic congestion at major interchanges and for covering special events and breaking news expected to last several hours.

One advantage traditional news helicopters have over small drones is that helicopters can more easily carry cameras with high-power lenses. Small drones such as the DJI Phantom or Inspire cannot carry cameras with long-focal-length zoom lenses and therefore must fly closer to their subjects to obtain good quality video. The problem is not the quality of the camera or gimbal; it is the weight of a telephoto lens and it zooming mechanism, which necessitate larger drone size and weight to carry them and additional complexity to compensate for the shifting center of gravity as the photographer zooms the lens in and out.

In the longer run, news organizations will use larger multicopters capable of carrying larger cameras with zoomable telephoto lenses. In the short run, however, they will begin with smaller drones carrying cameras with fixed lenses.

Experiments conducted by Modovolate Aviation, LLC in 2015 suggest that a newsgathering drone with a fixed lens needs to be no more than 50-75 feet from its subject to capture a reasonable level of detail. News helicopters typically fly more than 500 feet above ground level for safety reasons, mainly to provide sufficient altitude to set up an autorotation if the engine fails. Typically, they cover news events such as fires, traffic accident, or tactical law-enforcement situations by orbiting the scene at a 45° offset, making one orbit every one-and-a-half to two minutes.

Assuming a drone shoots a newsworthy event at an angle of 45 degrees (the angle at which news helicopters shoot) from a horizontal distance[4] of 500 feet, the drone would be about 707 feet away from the newsworthy event. This distance is too far away to shoot news events. A Phantom-class drone could get useable imagery of, for example, a car crash or a fire, by flying at heights of 50 or 75 feet with an the usual offset angle of 45 degrees. At a height of 50 feet, the drone would be about 71 feet from the news event. At a height of 75 feet, the drone would be roughly 106 feet from the news event.

Case	**1**	**2**	**3**	**4**	**5**
Height	1000	353.6	500.0	50	75
Angle (degrees)	63.4	45	45	45	45
Horizontal distance	2000	353.6	500.0	50	75
Slant range	2236.1	500	707.1	70.7	106.1

Table 1 – Newsgathering drone heights, angles, and distance from subject

[4] Section 91.119 is ambiguous as to whether the distance limitations are slant range, horizontal distance, or vertical height.

To complete an orbit in the assumed 90 seconds requires the following speeds at the indicated horizontal distances.

Horizontal distance	Speed
2,000 feet	82.7 knots
500 feet	20.7 knots
75 feet	3.2 knots
50 feet	2.1 knots

To realize their potential, small drones must fly much closer to people, vehicles, and vessels on the ground than the distances now permitted by the FARs, the summary section 333 exemptions granted by the FAA[5] by the NPRM and by 14 C.F.R. §91.119.[6] The FAA needs to find a way to relax the distance-from-people restriction. In considering options for relaxation, the agency must consider safety risks, under its commitment to follow a risk-based regulation strategy.

Risk assessment

The first step in any risk-based performance specification is to identify the risks. If a drone flies over one or more people to gather news, stays in the air and responds to appropriate navigational commands from its drone operator ("DROP"), it poses no risk of injury.

The risks arise from two possibilities: the drone stops flying and falls, or it flies into people. Either may occur because of a "flyaway"—the drone escapes control by the DROP, usually because it loses its lock on the necessary GPS signals. Then the risks fall into two categories: the risk of the rotor blade cutting somebody (the "cutting risk"), and the risk of the impact between the body of the drone and a human body (the "impact risk").

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[5] See Exemption No. 12634A, Regulatory Docket No. FAA-2015-1486, Modovolate Aviation, LLC., page 6, at paragraph 26 (operations must remain at least 500 feet from non-participating persons, vehicles, vessels, and structures).

[6] (no closer than 500 feet in uncongested areas; no lower than 1,000 feet above the highest obstacle within 2,000 feet in congested areas).

The cutting risk is significant but not catastrophic. The rotor blades of the most popular drones now on the market are not heavy enough, long enough, strong enough, or sharp enough to cut anybody's head or hand off. They can, however, inflict serious lacerations, and, if the stars align in an unlucky way, put someone's eye out.

While credible data on the subject is scarce, some risk-analysis models evaluate injuries to third parties caused by impacts from a small drone, or Unmanned Aerial Vehicle ("UAV"). The U.S. Department of the Navy issued a report in June 2012 that aimed to create a UAV "crash lethality model."[7] Although much of the report focuses on large drones and fixed-wing drones—drones that would not be used in any newsgathering process—the report's conclusions are nonetheless instructive.

The report sought to predict the lethal crash area ("LCA") for a variety of drones used or manufactured by the U.S. government. The lethal crash area is defined as the region in which a human death could occur during a UAV crash. The study modeled four different flight terminations: fixed-wing dive, fixed-wing glide, rotary-wing dive, and rotary-wing glide.

The study's findings for the LCA of a RQ-11 and a Desert Hawk are most relevant, since their gross weight is similar to that of the DJI Phantom 3 Professional and the DJI Inspire Professional respectively, two small drones that could be used in newsgathering. For a dive flight termination, the study found the LCA for the RQ-11 to be 25 ft^2 and found the LCA for the Desert Hawk to be 22 ft^2 [8]

Based on data from a variety of other studies, including automobile accident analysis, and the analysis of accidents involving baseballs, the Navy study concluded that 54 foot-pounds is the critical energy value below which the probability of lethal injury is less than 10%. This figure assumes the accident vehicle makes contact with an individual. Other parts of the Navy study calculate the likelihood of vehicle impact with an individual based on aircraft profiles, including glides and vertical descents of

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[7] Ball, J. et al, Crash Lethality Model, U.S. Department of Navy Naval Air Warfare Center, Aircraft Division; Patuxent River, Maryland (2012), http://oai.dtic.mil/oai/oai?verb=getRecord&metadataPrefix=html&identifier=ADB382358 [hereinafter "Navy Study"].

[8] Navy Study at p. 67.

airplanes and helicopters. The 54 foot-pound 10% limit applies only if the aircraft actually hits someone. Intuitively, a drone experiencing a catastrophic failure and crash may nevertheless not hit people within any specified radius. So even at the 54 foot-pound level of kinetic energy, the probability of lethal injury is considerably less than 10%.

As the table below shows, the kinetic energy of a small drone in newsgathering operations is far less than the Navy Study's 54 foot-pound threshold.

Another study, authored by Monash University and the Australian Civil Aviation Safety Authority,[9] developed a model to predict injury to a third party on the ground from a small UAV. The 2013 study used the UAV's mass and impact velocity to predict the severity of injury.

The study evaluated the maximum mass/impact velocity that would lead to the "highest acceptable injury severity," which the study defined as rib fractures, broken sternum, or skull fracture. The study states the probability of death from these injuries is less than 10 percent. The study notes that the diameter of the object that makes contact with the third party affects the severity of injury. In general, the larger the diameter of the object is the less severe the injury will be. Assuming a diameter of 10 cm for a 2 kg UAV, the study found the highest velocity for a head impact that does not result in serious injury is 15 kts. At roughly 20 kts, the study predicts contact with a third party's head will cause skull fracture.

Some of the study's assumptions differ materially from the figures used in this white paper. For example, the Australian Study assumes free-fall velocities from 10-15 meters per second. Such assumptions are unwarranted. For example, the Australian study calculates uncontrolled descent speeds at 30% over stall speed.[10] Multi-rotor drones such as the DJI Phantom do not stall. Accordingly, they have no stall speed. They can remain aloft even at zero airspeed.

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[9] Civil Aviation Safety Authority, Human Injury Model for Small Unmanned Aircraft Impacts (2013), https://www.casa.gov.au/sites/g/files/net351/f/_assets/main/airworth/papers/human-injury-model-small-unmanned-aircraft-impacts.pdf [hereinafter "Australian Study"].

[10] Australian Study at 17.

One can apply the study's findings specifically to two popular UAV models that could be used by news organizations: the DJI Phantom 3 Professional and the DJI Inspire Professional. According to the study, a DJI Phantom striking a person at 15 kts would not even cross the Australian Study's "dangerous injury" threshold. At 20 kts, a Phantom could cause dangerous injury but could not cause "severe damage;" i.e., damage that could result in death, as outlined by the study. Applying the study's model to the DJI Inspire, the UAV could cause dangerous injury if it struck a person at 10 kts. The DJI Inspire could cause damage that would result in death somewhere between 15 and 20 kts.[11]

The following table shows the kinetic energy associated with different speeds of a DJI Phantom 3 Professional and a DJI Inspire Professional. Various speeds are shown along the top, with 5 kts representing orbit speed at an offset angle of 45%, higher speeds shown in the middle columns, and terminal velocity from a free-fall shown in the last column.

Drone kinetic energy

Model	**Gross weight**	**Kinetic energy Speed=5kts (2.572 m/sec)**	**Kinetic energy Speed=10kts (5.144 m/sec)**	**Kinetic energy Speed=15 kts (7.717 m/sec)**	**Kinetic energy Speed=20kts (10.289 m/sec)**	**Kinetic energy Speed= 3 kts (1.56 m/sec)***
DJI Phantom 3 Professional	1280 g (2.82 pounds)	4.233 joules (3.12 foot-lbs)	16.935 joules (12.49 ft-lbs)	38.113 joules (28.11 ft-lbs)	67.753 joules (49.97 ft-lbs)	1.558 joules (1.149 ft-lbs)
DJI Inspire Professional	3400 g (7.5 pounds)	11.246 joules (8.29 ft-lbs)	44.983 joules (33.18 ft-lbs)	101.239 joules (74.7 ft-lbs)	179.968 joules (132.74 ft-lbs)	

11 Navy Study Figure 10, p. 17.

* Terminal velocity in free fall

At orbit speeds, the kinetic energy of either the Phantom or the Inspire is well below the 54 foot-pound threshold of the Navy Study. Only at speeds greater than 20 knots for the Phantom and 15 knots for the Inspire is the threshold approached.

One must note that the Australian Study does not take into account a UAV's frangibility. The study assumes a rigid body and thus predicts the "highest possible deformation energies."[13] Mitigating measures discussed below—increased frangibility of materials and possible incorporation of a parachute for the UAV—would decrease the risk of injury to a third party struck by the UAV.[14]

Anecdotal evidence of a handful of reported drone crashes that involved injuries to people show that the injuries were generally minor lacerations or bruising.

One exception is noted by the U.S. Navy's "Crash Lethality Model" report. The report refers to a 2003 incident outside Houston, Texas, in which a 41-year-old man died after he was struck on the neck by a model helicopter's rotor blades. News reports state that the man was instructing the model helicopter's operator when the operator lost control. Reports indicated the helicopter's blades, which were two inches wide, struck the 41-year-old man's throat. Paramedics did not arrive for more than 30 minutes, and the man died. This isolated accident should be distinguished from foreseeable crashes involving newsgathering drones. The incident was reported as "bizarre" or "freak." Further, while reports did not include the exact model of helicopter used—described by witnesses as a "size 60" model helicopter—it made clear the model helicopter did not have prop guards (mentioned below). The Model 60 model helicopter was considerably larger and had heavier, longer, and stiffer blades than the small drones likely to be flown by news organizations—exemplified by the DJI Phantom.[15] The DJI Phantom's blades pose a smaller risk than those posed by such a model helicopter.

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[13] Navy Study at 23.

[14] See Navy Study, Recommendations 1-7, at 25.

[15] "Size 60" model helicopters are generally understood to weigh up to 6 kg (13.2 pounds) and have a 200 cm (78 inch) rotor diameter. A Phantom 3 weighs 2.7 pounds and has rotor diameters of 9 inches.

Other incidents resulted in minor injuries or no injuries at all. In one such instance involving an ill-advised holiday promotional event, a drone carrying “mistletoe” inside a TGI Fridays restaurant cut a bystander’s nose. Another incident involved a bystander being struck by a DJI Phantom in a parking lot near Bryant-Denny Stadium during a University of Alabama football game; news reports indicated the bystander was uninjured in the collision. In the most serious non-lethal case, a 25-year-old woman watching a parade in Seattle was knocked unconscious by a drone that fell on her after striking a building. Seattle police described the woman’s injury as a concussion. Thus, with the exception of the 2003 incident, anecdotal evidence shows that collisions between small UAVs and people are non-fatal and tend to involve minor injuries.

These data support relaxation of the 500 horizontal distance bar for small drones operating in the vicinity of people. A limit of no closer than 75 feet slant-range, at speeds no greater than 5 knots from people would ensure safety. Such a modification in flight restrictions would be accompanied by no significant increased risk of injury to people on the ground.

For closer flights, heavier vehicles, or higher speeds, a variety of mitigating measures are available.

Mitigating measures

The preceding sections of this paper show that small newsgathering drones do not imperil the safety of persons on the ground when they travel at low speeds. They do not need additional mitigating measures, beyond speed and orbit-offset limitations.

In the longer run, however, journalists will need to fly larger drones to accommodate heavier cameras and lenses. They may orbit at greater distances from the subject and thus fly faster to complete the orbit. Their weight and speed will give them a kinetic energy that approaches or exceeds the 54 foot-pound threshold of the Navy Study. For them, additional mitigating measures may be necessary.

The best and simplest mitigation of the cutting risk is to install blade guards—"prop guards”—a widely available accessory for most popular models of drones. A straightforward way to deal with the cutting risk is to have an FAA rule that says, "No one may fly a drone over people unless it has prop guards.”

The impact risk is more complicated, although the physics are straightforward: injury in the form of concussions, fractures, or other tissue damage is proportional to the kinetic energy that must be absorbed by the body in a collision. When a collision occurs between a drone and a human being, some of the kinetic energy is absorbed by the drone, and some by the human. The more kinetic energy absorbed by the vehicle, the less that must be absorbed by the human. That approach was used by the Navy Study, the Australian Study and in this paper.

Evaluation of mitigating measures must proceed from quantifying and limiting the kinetic energy and understanding and increasing the mechanisms through which a drone hitting a person can absorb much of it.

Kinetic energy of a moving object is equal to half the mass (weight) of the object, multiplied by the square of its velocity. A lighter-weight drone moving more slowly has less kinetic energy than a heavier one moving faster. Low kinetic energy can be assured by operating rules that restrict flights over people to drones below a certain weight threshold, moving below a certain speed threshold.

That, however, addresses only the horizontal component of kinetic energy, relevant if a drone hits someone from the front, side, or back. What if a drone falls from the sky onto someone because it loses a rotor, exhausts its batteries, or one or more of its motors stop functioning?

Then, the drone will fall at a vertical speed equal to or less than its terminal velocity. Terminal velocity depends on the shape of the drone and the ratio between its surface area and its weight. A balloon or a blimp has a much lower terminal velocity than a steel rod. The Navy Study includes detailed aerodynamic and Newtonian-mechanics calculations to compute the terminal velocity of a helicopter falling without any rotor lift.[16] It provides a formula for computing terminal velocity as a function of weight and cross-sectional area. Applying that formula to the specifications of a Phantom 3

[16] Navy Study, equation #21 at p. 26. The Study estimates a drag coefficient of 0.5 for a helicopter in free fall. Id., page 27.

Professional[17] yields an estimated terminal velocity of 3 knots. The kinetic energy is 1.558 joules or 1.149 foot-pounds.

The most logical approach to mitigate the impact risk from a falling drone is to require that it have a relatively low terminal velocity. The calculations shown in the table show that the Phantom class has terminal velocity and associated kinetic energy well below any reasonable risk threshold. For heavier drones flown directly over people, as opposed to the 45-degree offset, the most straightforward way to do this is to require the drone to be equipped with parachute that would automatically deploy under appropriate emergency circumstances. It is feasible to equip even small drones with emergency parachutes, although there is a weight and complexity penalty.

Requiring that newsgathering drones flying over people absorb a high fraction of the kinetic energy involved in a collision is more challenging. The NPRM mentions frangibility, which addresses this issue. But frangibility is a better solution when two hard objects collide than when a hard object collides with a person. Soft and elastic are better characteristics for a drone impacting a person. But it is hard to envision a drone design that would incorporate soft and elastic surfaces without sacrificing aerodynamic characteristics necessary to make it useful. Small airbags are one possibility. Light helicopters that fly over water often are equipped with emergency floats that inflate quickly just before a helicopter making a forced landing touches the water. These floats are basically elongated airbags. The challenge for drone application is designing the appropriate triggering mechanism. Emergency floats on helicopters are inflated by a switch on the pilot's cyclic or collective stick or by contact with water. Airbags on automobiles inflate at a certain level of deceleration ("G force"). On a drone, airbags could be inflated manually by the DROP, which would depend on the integrity of the control link at the moment inflation is necessary, or by contact with any surface.

Soft and elastic are less necessary features, however, when the kinetic energy is less. Accordingly, more restrictive speed and weight limitations reduce the need for energy-absorption requirements. Larger parachutes can reduce terminal velocity almost to zero.

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[17] The Phantom 3 has a gross weight of 1280 grams (2.82 pounds). Its planform cross-sectional area is 57 square inches and side-view cross sectional area is 24 square inches. Assuming that it tumbles in free fall, it would present its planform area half the time and its side-view area half the time, for an average cross sectional area of 40.5 square inches.

In any event, genuine performance standards would let the manufacturer decide how it chooses to meet the standards and to certify its compliance.

Part of the solution is more hospitable treatment of tethered drones. They do not flyaway; they do not need GPS lock, and their batteries never run down. The FAA has granted some 333 exemptions that cover tethered drones, and has inserted a paragraph on tethered drones some of its more recent standard section 333 exemptions.

Data collection

Robust risk-based safety regulation depends on data about accident incidence and severity. Unfortunately, small drone technology has been in the market for such a short period of time that such data is lacking for most useful drone operations. The FAA's six test sites have not yet generated such data.

The most relevant data, however, reflects actual operation rather than data generated from test scenarios. Operational data is widely available for the hundreds of thousands of small drones now being flown on a regular basis, but it not being collected and analyzed systematically. Drone manufacturers are capable of collecting flight data from the vehicles they sell, and in many cases do it automatically in conjunction with software upgrades. A self-certification process for safety performance standards should include a mandate to collect such data, to use it to validate engineering design assumptions, and to make it available in conjunction with any accident investigations.

Proposed regulatory language

Subpart E – Special rules for flights near people

§ 107.90. A tethered UAS may be flown, notwithstanding § 107.39, so long as it is not flown closer horizontally to people than the length of its tether above the ground.

§ 107.91. A drone may be flown directly over people, notwithstanding § 107.39, so long as it is equipped with:

(a) a parachute that deploys automatically if the drone propulsion system malfunctions or the operator loses control of it. It must be flown no lower than a height above the people that permits the parachute to deploy and to reduce the vertical velocity to no greater than 5 feet per second before the drone reaches a height of 10 feet over the tallest of the people;

(b) an airbag that deploys before or as soon as the drone makes contact with a person, designed to absorb sufficient energy from the contact to avoid significant injury; or

(c) both.

§ 107.92. A drone may be flown near people, but not directly overhead, notwithstanding section § 107.39, so long as it is flown at an angle no less than 45° to the people with a speed and weight combination ensuring that its kinetic energy is no greater than 50 foot-pounds.

§ 107.93. (a) No one may operate a drone under §§ 107.90 to 107.92 unless:

(a) the manufacturer has certified its compliance with the performance standards set forth in those sections. Such certification may be based on engineering calculations, test data, or both. The manufacturer must disclose the basis for it certification to the FAA on its request.

(b) the manufacturer has certified that the UAS automatically records flight data and malfunction indications to non-volatile memory permanently installed on the vehicle and the operator's console as it is collected; and

(c) the manufacturer has certified that it automatically uploads flight data and malfunction reports to the vendor or to an Internet server accessible by the vendor.

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About the authors

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