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The Essential Guide to Drone Show Safety

Maximising Drone Show Safety by following Aviation Best Practices

By Nils Thorjussen, Chris Franzwa, Anthony Merlino, and Tony Samaritano

Introduction

Seeing a drone show should be an awesome experience.

Drone shows are a fabulous addition to live entertainment events. After a period of rapid adoption, they have become an essential part of any high-profile production—along with lighting, lasers, and fireworks—but with the power to surprise and amaze even audiences who've "seen it all".

Unfortunately, like with many new technologies, rapid growth has caused some companies to prioritize profit over safety. Some new industry participants have limited experience and don't yet know how to fully evaluate their purchasing options. Many decisions are based on price, with problems only becoming apparent when it's too late. *Safety* is an afterthought.

Verge Aero's safety commitment.

Recently, high-profile accidents have underscored the critical importance of safety. As drone shows become more ambitious and widely adopted, ensuring the highest standards of safety should not be just a regulatory requirement, but a fundamental responsibility. This white paper illustrates what Verge Aero considers to be essential tenets of a safe drone show, and offers insights to potential light show customers on what to look for when weighing their purchasing options.

What Makes A Safe Drone Show System?

Verge Aero believes a safe drone show system **must** incorporate these five major elements:

1. *Navigation Redundancy*
2. *Appropriate and Up-to-Date Software*
3. *Multiple and Independent Geofence Systems*
4. *Reliable, Long-Range Communication*
5. *Training and Safety Management*

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1. Navigation Redundancy

This is hands-down the #1 safety feature for drones and drone fleets.

Redundancy is essential in all of aviation. Multiple sets of avionics (aircraft electronic navigation systems) provide redundancy for manned aircraft. Any drone operating close to people should have the same.

Most drones use something called an EKF (Extended Kalman Filter)[1] estimator to navigate with precision. This algorithm calculates position, velocity, and orientation by combining inputs from data sensors such as GPS (Global Positioning System) and IMU (Inertial Measurement Unit) sensors.

Unfortunately, many drone show systems in operation today have only a single estimator, and some use more primitive implementations. This has resulted in drones repeatedly flying out of designated flight areas, causing several high-profile accidents.

Estimators can stop working properly in the event of collision or sensor failure, resulting in out-of-control drones that may breach a show's safety perimeter and quickly fly long distances. **Therefore, drones with only a single estimator lack redundancy and are inherently less safe.**

It's crucial to note the difference between estimators and sensors and why it's important to have multiples of each. An array of sensors provides measurements of the drone's position, velocity, and orientation. EKF estimators are designed to evaluate these measurements (as well as non-linear, real-world factors such as wind gusts), reject faulty data, and estimate the most accurate measurements for the drone's position, velocity, and orientation. The official guide to the world's leading drone autopilot software, PX4, states that multiple EKF estimators provide "protection against a wider range of sensor errors".[2]

Many systems claim to have appropriate redundancy by using multiple sensors, but without multiple estimators. A configuration like this gives a false sense of security. These systems are problematic because, as stated in the *PX4 Guide*, **a single estimator can only accommodate "a limited number of sensor faults" and cannot identify inaccurate sensor data,** which is the bigger problem. A system with redundant sensors, but without redundant estimators, only

[1] Learn more about how the Kalman Filter works: https://www.kalmanfilter.net
[2] PX4 Guide: https://docs.px4.io/main/en/advanced_config/tuning_the_ecl_ekf.html

protects for sensor data loss and not sensor inaccuracy, which is far more common and important.

The Verge Aero® drone show platform has embraced navigation redundancy from inception. The flagship X7™ drone has two independent sets of navigation sensors, enabling four estimators. The workhorse X1™ drone has three sets of navigational sensors, enabling six estimators. The X1's additional redundancy makes it ideal for more demanding operations, such as deploying pyrotechnic devices.

2. Appropriate and Up-to-Date Software

To work properly, a drone's estimators need to be supported by appropriate autopilot software. Most drones use PX4, which has undergone significant updates to its safety features over the years. Only recent versions (1.15 onwards) make full use of multiple estimators. Just as it's important to keep computers safe with operating system updates, it's essential to incorporate the latest safety autopilot enhancements on drones.

Likewise, unified design and control software created specifically for drone shows is generally safer than using a patchwork of software applications subject to incompatibilities and unintended errors. **Appropriate drone show software automatically calculates flight paths for every drone throughout the *entire* flight sequence and mathematically validates them to prevent collisions.**

Proper software also helps people avoid mistakes. In manned aviation, the pilot is focused on flying the plane and not on carrying out tasks that can easily be automated. Modern avionics have streamlined operations to automate processes prone to human error and thereby increase safety. The FAA has long recognized the benefits of automation to reduce pilot workload and the risk of accidents.[3]

The same is true for drone shows. The pilot must be able to trust that the system will safely perform the show so they can focus on their safety role. Critical safety vulnerabilities—like flight path deconfliction—should not be handled manually or with third party software. **There must be no room for human error in validating if a drone show can fly safely.**

Verge Aero continuously invests in R&D to deploy state-of-the-art technology. Automation is a major component of the Verge Aero system. Our underlying software calculates flight paths for

[3] Refer to page 2-25 of the Pilot's Handbook of Aeronautical Knowledge https://www.faa.gov/sites/faa.gov/files/04_phak_ch2.pdf

the entire flight sequence—from props spinning to aircraft landing—and mathematically validates the flight paths to ensure that they do not intersect before the show is ever flown. Having this in a completely integrated technology package maximizes both safety and efficiency while making the show creation process simple and user-friendly.

3. Multiple, Independent Geofence Systems

A geofence is a virtual boundary surrounding a drone show's display area. When working correctly, it prevents drones from leaving the designated flight area. **Multiple geofences powered by independent processors increase redundancy and safety.**

Most drone show systems use both a **"**soft" and a "hard" geofence:

- A **soft geofence** is a virtual boundary that triggers a "return to home" or "land" command when a drone breaches it.
- A **hard geofence** encompasses the entire show airspace and causes the drone's motors to turn off immediately and the drone to freefall to the ground if the drone breaches it (having first ignored the soft geofence)

The Verge Aero drone show platform uses a **triple redundant geofence system** that consists of a "dynamic bubble" soft geofence, a hard geofence, and a predictive trajectory hard geofence. These three geofences ensure that drones stay within the safe operational area, preventing accidents caused by out-of-control drones. (For an additional level of redundancy, two of the three geofences are powered by independent onboard computers.)

Soft Geofences vs. "Dynamic Bubble" Geofencing

A standard soft geofence lies within the hard geofence and essentially acts as a secondary hard geofence. A drone should immediately terminate its mission upon reaching this boundary, executing a "return to home" or controlled land function.

Uniquely, Verge Aero's soft geofence is multiple "dynamic bubbles" that provide each drone with their own independent, moving geofences. See Image 1 for an illustration of the dynamic bubble geofence contrasted with the standard soft geofence concept.

Image 1: Standard Soft Geofence v. Dynamic Bubble Soft Geofence

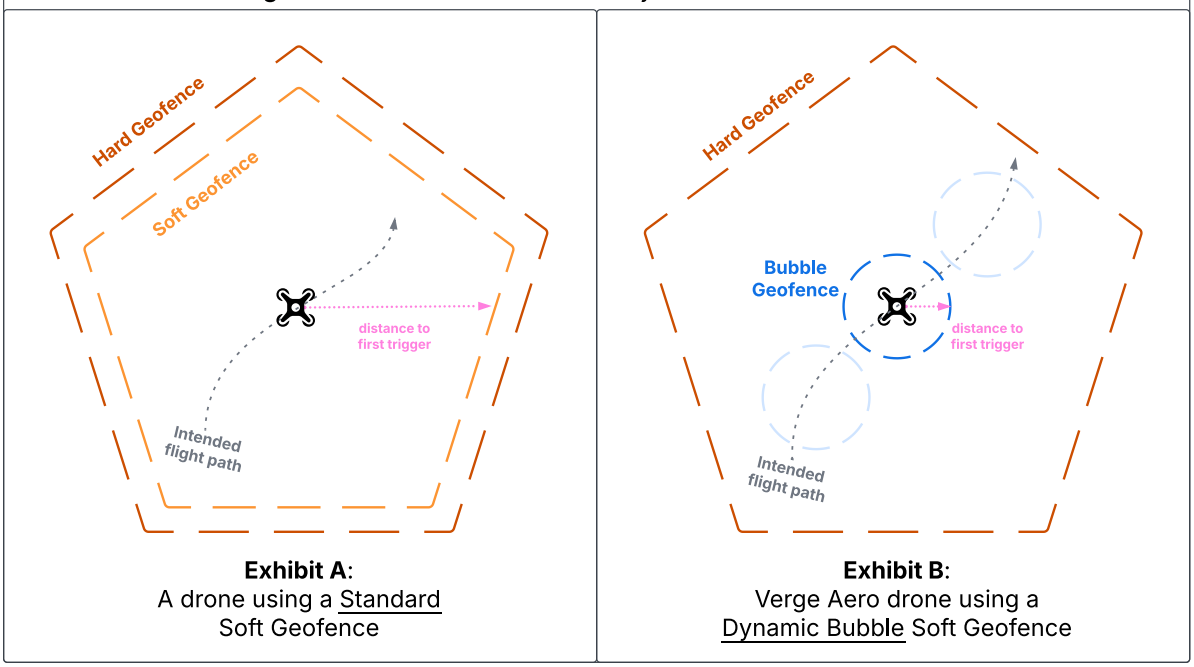


Exhibit A:
A drone using a Standard Soft Geofence

Exhibit B:
Verge Aero drone using a Dynamic Bubble Soft Geofence

Verge Aero's dynamic bubble soft geofence keeps a drone within a few meters of its target position, rather than allowing it to potentially veer far off course before a mission is terminated. If an individual drone deviates from its flightpath enough to breach its “bubble” radius, it lands immediately by descending vertically in a controlled manner until it reaches the ground and the motors turn off.

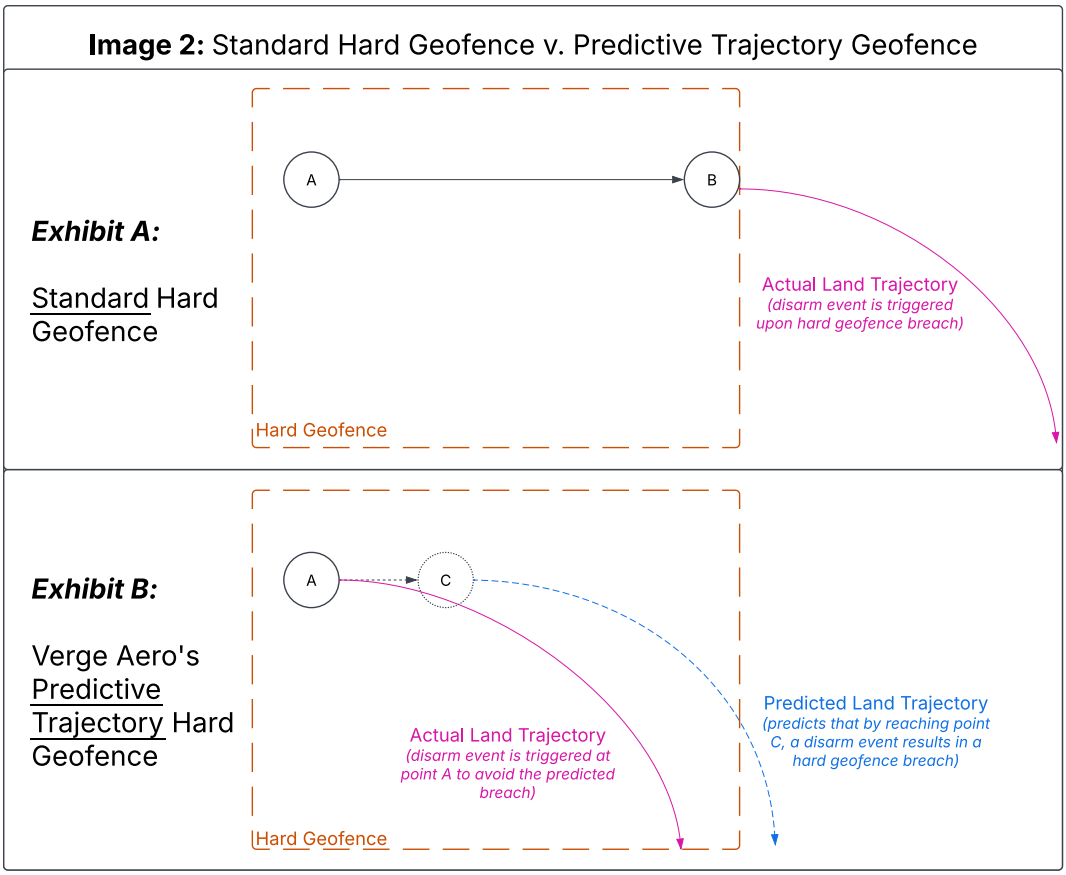
In contrast, standard soft geofences only trigger a “return to home” command upon reaching a boundary that is essentially slightly smaller than the show’s entire airspace. By the time a drone reaches this point, it may be a significant distance from its intended flightpath. Verge Aero has found that the “dynamic bubble” approach is a far more effective way to maintain a safe drone show than a standard soft geofence.

Hard Geofences and “Predictive Trajectory” Geofencing

In many respects, traditional geofences are not ideal for drone shows. Unlike other modes of aviation, where aircraft may fly *anywhere* within a given space, drone shows are precisely choreographed. Drones are programmed to fly a specific, predetermined route. The control system always knows where a drone is and where it should be. Otherwise, flight should be terminated immediately.

It's usually clear that something has gone wrong long before a drone ever reaches the hard geofence. That's why Verge Aero has found a predictive trajectory geofence to be quite useful. If an out-of-control drone reaches the hard geofence, momentum will propel it beyond this boundary even if its motors are cut immediately. It's better to ground a drone as soon as anomalies are detected to prevent any breach of the hard geofence, which is the concept behind Verge Aero's "predictive trajectory" geofence. This system *predicts* if a drone will breach the hard geofence in the future by accounting for its momentum and cuts the drone's motors in time for it to land within the hard geofence, as illustrated in image 2 below.

Image 2: Standard Hard Geofence v. Predictive Trajectory Geofence



Geofence Type Overview		
	Verge Aero	**Other Systems**
Soft Geofence	A "dynamic bubble" soft geofence moves with the drone's flight path in time and space. Triggers land event (a controlled flight to the ground) if breached.	A basic geofence that is slightly smaller than the hard geofence. Triggers land event (a controlled flight to the ground) if breached.
Hard Geofence	Encompasses the entire show airspace, acting as a last resort boundary. Triggers a disarm event (power to the motors is cut, resulting in a freefall) at the boundary of the safe zone.	
Predictive Trajectory Geofence	Predicts a drone's breach of the hard geofence ahead of time, allowing the operator to turn off the drone's motors while its trajectory is such that the drone will land within the geofence boundary.	N/A. Without a predictive geofence, the system waits for a drone to breach the hard geofence before its motors turn off, causing it to land outside the safe perimeter of the geofence.

4. Reliable, Long-Range Communication

Imagine you're a drone show pilot operating a show and have just been notified that a manned aircraft is fast approaching. You need to stop the show immediately, but the fleet is a few hundred meters away from the launchpad. Thanks to the reliable long-range communication link you have with each drone, you're able to immediately and safely land the fleet.

Long-range emergency communication is another crucial safety element of a drone show system. Its concept is straightforward: if you can't communicate with every drone at any given time, you can't land your fleet safely in the event of an emergency. If communication is not guaranteed, there's an increased risk of accidents.

Many drone show systems use WiFi for their primary communication. However, **WiFi is not always reliable when flying in urban or congested environments** as there are so many possible sources of interference and frequency congestion. WiFi also doesn't offer long-range point-to-point communication without the placement of additional ground hardware to boost the signal—introducing yet another potential point of failure.

Without a reliable, long-range communication link with each drone, safety procedures cannot be guaranteed to work. The more robust communication the operator has, the more information they have to monitor the health of the entire system—and to take fast preventative action if necessary.

Verge Aero's approach to long-range emergency communication embraces reliability and redundancy. Our system uses three communication links (all intended for long range point-to-point communication) that operate in two bands. It has both a dual-band telemetry radio system and a long-range radio:

- The **Telemetry Radio** is a dual-band radio with medium range (500+ meters) and higher bandwidth (2.4GHz and Sub-1GHz).
- The **Long-Range Radio** has a theoretical range of 15km and a practical range of 5-10km, and is used for all safety-critical messaging.

5. Training and Safety Management

Much of what has created an incredibly safe commercial aviation industry is equally relevant to drones. Rigorous training, safety management systems, and aeronautical decision-making guidelines are all part of safe aviation—whether manned or unmanned. Seemingly insignificant details often have a dramatic impact on show execution, which is why it is essential to always operate at the highest levels of professionalism.

Drone pilots must undergo the same kind of initial and recurring training programs that are standard practice for other commercial pilots. As they gain experience, they're ready to take on increasingly complex shows. It's essential for equipment manufacturers to support pilots with comprehensive and ongoing training programs to build proficiency. Pilots must know their technology inside-out to quickly respond to unforeseen events. Training and hands-on experience are essential to developing world-class pilots.

In addition, pilots must be supported by operations focused on quality control to deliver well-maintained drones. Companies with a comprehensive safety management system are best positioned evaluate and mitigate risk in all aspects of their business. A healthy safety culture should be nurtured to ensure potential issues are identified and addressed.

Finally, pilots must be well-rested and able to think clearly in order to make good decisions. Pilots don't just press Go and then sit back and relax! They need to be 100% involved and operating at full strength. Fatigue, complacency and stress all impact a pilot's ability to manage risk and maintain situational awareness. Adherence to established principles of aeronautical decision-making help keep drones shows safe.

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Verge Aero's Commitment to Safety

Every commercial airline passenger expects air travel to be a safe and uneventful experience—and rightfully so. A century of manned aviation has resulted in an industry with an incredible safety record. Fewer than one in a million flights involve an accident: those resulting in fatalities are far fewer still. This extraordinary record is the result of decades of strict regulations, technological advancement, redundant safety systems, extensive training, and a commitment to improving the safety of the future by continuously learning from the failures of the past.

Drones are airborne vehicles and must be operated as professionally and responsibly as any other aircraft.

A spectator's experience of a drone show should be no different. By leveraging best practices from mainstream aviation, drone shows can be made equally safe. Verge Aero has taken this approach from its inception, designing systems from the core with redundancy and safety in mind while continuously updating them to take full advantage of new technologies.

Moving forward, we encourage the industry to adopt best practices to maximize and prioritize safety. A single failure can result in reputational damage, financial loss, and—most importantly—potential harm to spectators. Drone shows have so much potential. Let's not blow it by cutting corners on safety.

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Some Questions to Ask When Evaluating a Drone Show System

Does the system have true navigation redundancy by using multiple estimators?

- Multiple independent estimators and sensors are necessary. A properly redundant system has at least two sets of IMUs (sensors), running four independent EKFs (estimators).

Is the control software up to date?

- If the PX4 autopilot is used by the drones, is it version 1.15 or newer? This version of the PX4 autopilot incorporates multiple safety enhancements.

How does the geofencing system work?

- Having multiple geofences maximizes safety and redundancy. Do separate processors power each one?

How many long-range emergency communication links are used? Are they dual- or single-band? Is WiFi the primary link?

- Three point-to-point communication links, including a dual-band radio system, is ideal.
- WiFi is likely to be unreliable in congested areas.

What software is used to create and fly the show? Is it fully integrated?

- Ideally, the launch sequence is generated automatically by the same software that controls the rest of the show.

What is the safety record of the company and pilots operating the show?

- How are their pilots trained? What is their Safety Management System?
- How often have they experienced flyaway / out-of-control drones?

What is the safety record of the drone technology used in the show?

- Has the same type of drone been involved in accidents with other operators?

How much experience does the pilot have?

- How many shows have they flown? How much training have they received? Are they a full-time employee?

About the Authors

Nils Thorjussen, Anthony Merlino, Christopher Franzwa, and Tony Samaritano have over forty years' combined experience in the development and advancement of drone show technologies. They've helped pioneer the field of drone show entertainment with their creation of the Verge Aero all-in-one drone show system. Their efforts, combined with those of Verge Aero team members since its founding in 2016, have pushed drone shows into the mainstream of global events and helped solidify the medium as a staple in live entertainment.

Today, the Verge Aero system is used by professional production teams globally. It has been used to fly shows for high-profile events including President-Elect Biden's victory celebration, America's Got Talent: Extreme, Macy's Fourth of July celebrations in New York City, festivals such as Lollapalooza, the celebratory demolition display of the Tropicana Hotel and Casino in Las Vegas, and many more.

Verge Aero is recognized globally by airspace authorities, such as the Federal Aviation Administration (FAA) and the European Aviation Safety Agency (EASA). Learn more about Verge Aero's safety advantage at verge.aero/safety.

For further information, contact media@vergeaero.com.