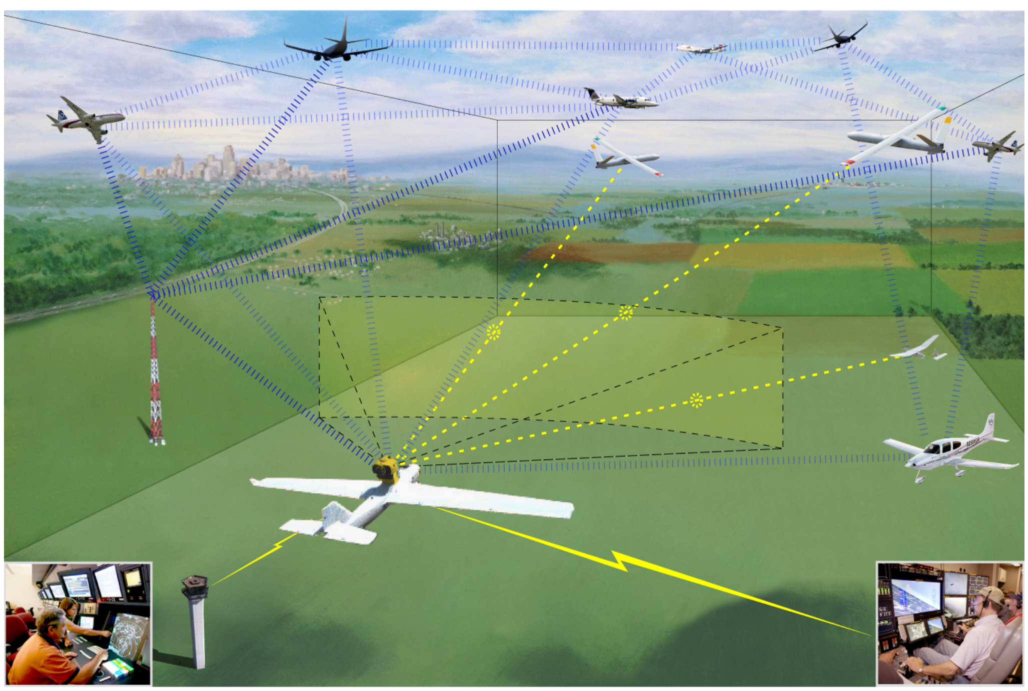
NASA UAS Airspace Operations Challenge
Draft Rules

> *These rules are in draft form and are being released to gather feedback. They have been developed to illustrate the goals of the challenge and give prospective competitors an idea of what may be required to compete in and win this Centennial Challenge.*

UAS AOC BACKGROUND

The NASA Centennial Challenge Program is designed to foster individual, academic, and private sector innovation to solve difficult problems that are important to NASA and the nation. Before unpiloted or remotely piloted aircraft can safely operate in the same airspace as other, piloted aircraft, robotic aircraft and their operators will need to demonstrate a high level of operational robustness as well as the ability to "sense and avoid" other air traffic. The Unmanned Aircraft System Airspace Operations Challenge (UAS AOC) is focused on developing some of the key technologies that will make UAS integration into the National Airspace System possible. This Centennial Challenge will be conducted in two parts: a Level 1 Challenge (L1C) that will be held in 2013 and a Level 2 Challenge (L2C) that will be held roughly 1 year <u>after the L1C has been successfully completed</u>. The earliest that L2C would be competed is 2014:



Artist's Concept of Level 2 Competition (L2C)

The L1C focuses on important aspects of safe airspace operations, robustness to system failures, and seeks to encourage competitors to get an early start on developing some of the skills critical to the L2C. Demonstrating the ability to remain "well clear" of other aircraft and obey the same rules as other air traffic is one of the most important aspects of safely integrating unmanned aircraft into the same airspace as manned aircraft. Unmanned aircraft will also need to be able to reliably and accurately fly 4-Dimensional Trajectories (4DT) to provide a reasonable expectation that they will be where they are supposed to be, when they are scheduled to be there. A third important aspect of safe airspace operations is the ability to interact with Air Traffic Management in a clear, concise, and timely manner, before, during, and after unmanned aircraft operations. This is especially true when operations are hampered by system or component failures. Commonly discussed contingencies include ensuring safe operations in the event that the command and control radio link to the vehicle is lost (Lost Link) and in situations when GPS navigation data becomes unavailable or unreliable.

One goal of the L1C is to prepare competitors for a much more difficult L2C. The L2C will reward competitors who can field a robotic aircraft that can sense and avoid both cooperative and non-cooperative air traffic, can communicate verbally with Air Traffic Controllers under lost link conditions, and can operate safely when GPS is unavailable. One of the most difficult technical challenges of the L2C will be maintaining separation from "uncooperative" air traffic, i.e. aircraft that are not announcing their positions and intentions using Automatic Dependent Surveillance-Broadcast, (ADS-B). Separation assurance for competitors in the L1C is limited to cooperative air traffic that can be detected and tracked by processing ADS-B messages, however the ADS-B data stream received onboard their aircraft will include trajectories for both real and virtual or "ghost" aircraft. Part of the scoring approach developed for the L1C encourages competitors to include sensors onboard their aircraft that will allow them to discriminate between the real aircraft around them and the ghost aircraft that only exist as ADS-B messages. This is an important step toward being able to detect the presence of aircraft independently of the information provided by ADS-B and to operate while staying well clear of this uncooperative traffic. The following capabilities will be the focus of the L1C:

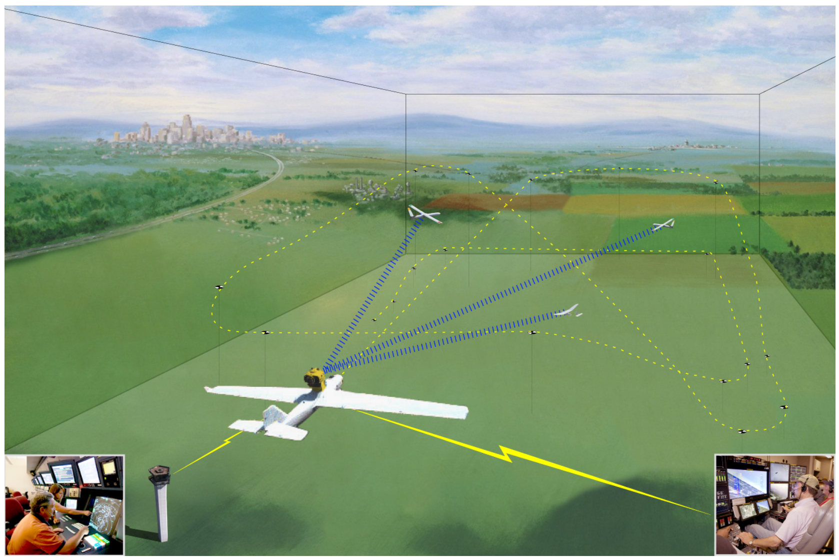
Safe Airspace Operations	Separation Assurance using ADS-B
	4 Dimensional Trajectories
	Ground Control Operations
Robustness to System Failures	Lost Link
	GPS Unavailable
	GPS Unreliable
Preparation for Level 2 Competition	ADS-B Ghost Detection

There are other technical challenges that must be solved to enable the integration of UAS in the NAS, but a competitor that successfully demonstrates all the skills emphasized in the L1C will be able to field a robust UAS that is significantly closer to the goals of UAS-NAS integration embodied in the UAS AOC L2C.

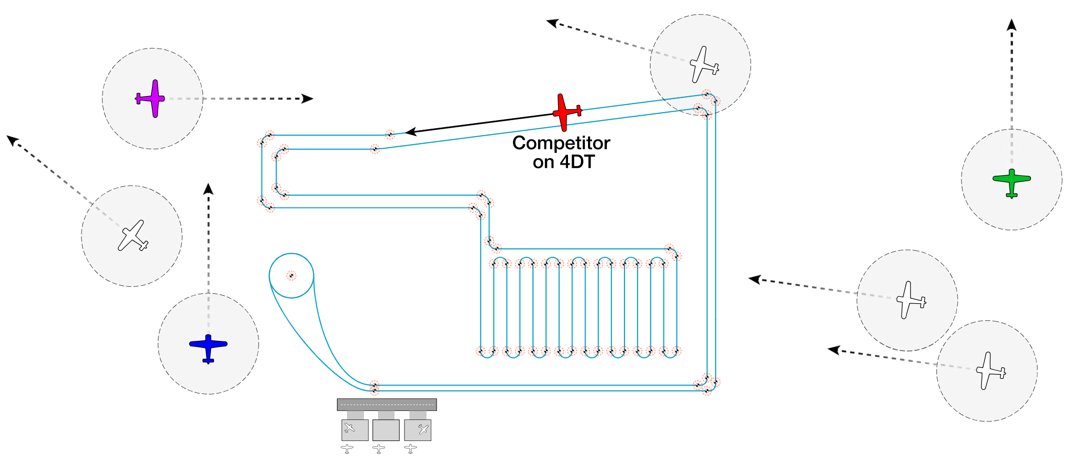
OVERVIEW

The UAS AOC is focused on the technological barriers to the successful integration of Unpiloted Aircraft Systems (UAS) into the National Airspace System (NAS). Competitors will need to field a robust UAS that is capable of successfully flying multiple tightly scheduled missions per day.

While in the air, competing aircraft will have to demonstrate the ability to operate safely in a variety of contingency scenarios and maintain safe separation from other air traffic. Competition missions will be defined by Four-Dimensional Trajectories (4DTs), which will be comprised of a series of three-dimensional waypoints in space and a specific time of arrival for each waypoint. Competition missions will be designed to model future uses of unpiloted aircraft in the NAS, such as aerial mapping surveys, search & rescue operations, disaster response support, or public utility and pipeline inspections.



For the L1C, competitors will be required to implement part of the Automatic Dependent Surveillance - Broadcast (ADS-B) system, specifically ADS-B "in". ADS-B in equipped aircraft are able to receive messages broadcast from other aircraft and the air traffic management system that describe the current position, heading, and speed of nearby air traffic. Competitors will rely on this information to ensure that their aircraft maintains safe separation from other air traffic during their mission.

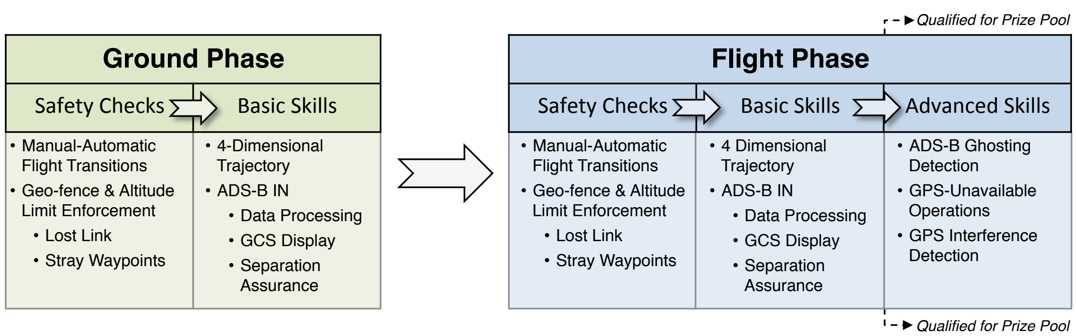


Due to the complexity of the UAS that will be fielded by competitors and the complexity of their interactions with personnel and systems on the ground and in the air, competitors will be required to develop a Hardware-in-the-Loop Simulation (HiLSim) for their aircraft that is capable of demonstrating, prior to flight, that their system conforms to safety rules and competition-related requirements. HiLSim hardware interface requirements and HiLSim test suites used to qualify competitors will be provided to registered contestants at least four months before the L1C.

For competition flights, competitors will be required to use a Competition-Furnished Global Positioning System (CFGPS) unit onboard their vehicle, for navigation. The CFGPS will be provided at no cost to competitors by the Challenge organizer and will perform a number of functions that facilitate this Challenge. It will create a log file that will be the basis of post-mission scoring and evaluation, provide a two-way satellite communication link to the competition judges, and include an additional microprocessor that will allow the judges to control the data output of the CFGPS during competition flights. To minimize integration issues on-site, the design plans for the CFGPS and the software it uses will be provided to registered contestants at least four months before the L1C. Competitors will be able to construct their own copy of the CFGPS to use for testing and integration, prior to their arrival for the competition.

Prior to each competition flight, a competitor will be provided with a data file that defines their upcoming mission. The mission definition will include a 4DT for the mission flight plan and any constraints that must be obeyed during the mission. The constraints will include air traffic separation requirements, minimum speed, maximum speed, and a set of geo-referenced boundary points that define a “geo-fence”. For competition flights, a competitor’s aircraft will be required to stay within this geo-fence at all times. Altitude limits will be provided as part of the geo-fence definition. The competitor’s HiLSim will be used to verify that their aircraft will not exit this geo-fenced volume under any conditions, including lost link conditions and the placement of stray 4DT waypoints outside the geo-fence.

The L1C will be staged in two phases. An initial Ground Phase will include physical inspections of competitor flight and ground systems followed by a series of HiLSim-based tests that will verify that the ground crew operational procedures, flight software, and ground control station meet safety and competition requirements. The Ground Phase will be followed by the Flight Phase of the competition, which will consist of a Qualification Flight followed by a series of scored missions that must be flown by each competitor.



To qualify to win a portion of the prize pool, a competitor must demonstrate proficiency at a set of Basic Skills. The Basic Skills include accurately flying 4DTs, processing ADS-B messages onboard the aircraft for transmission to the vehicle’s Ground Control Station (GCS), where they must be displayed graphically, and maintaining required horizontal separation from other ADS-B equipped air traffic while there is a valid command link between the flight vehicle and its GCS.

Competitors who successfully demonstrate all of the Basic Skills in the Flight Phase of the competition qualify for the prize pool. Their cumulative scores across all of their competition flights will be used to determine their share of the prizes.

While the Basic Skills have been selected to emphasize some of the basic capabilities that will be needed for UAS to interact safely with other aircraft in the NAS, the Advanced Skills have been selected to promote additional system robustness and encourage competitors to begin developing the capabilities that will be needed to succeed in the L2C.

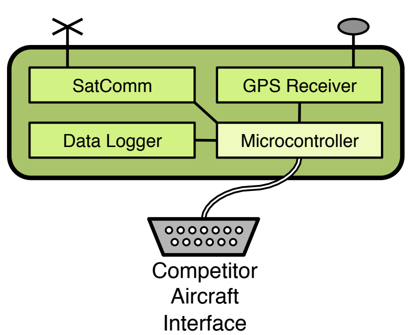
The Advanced Skills are aimed at promoting additional UAS robustness include demonstrating safe flight operations during periods when GPS is not available, and demonstrating the ability to detect incorrect or unreliable GPS data, based upon comparisons with the output of other (non-GPS) onboard sensors. These GPS-related difficulties will be simulated by the CFGPS. The CFGPS will, however, supply the competition judges and safety personnel with accurate GPS data from the competitor's aircraft at all times.

The Advanced Skill chosen to encourage the early development of a L2C skill is the ability to determine which nearby aircraft are real aircraft and which are "ghost" aircraft, which exist only as ADS-B messages. While proficiency at this Advanced Skill could provide robustness to inaccurate ADS-B messages in real-world operations, it is included in the UAS AOC to promote the inclusion of onboard sensors that will eventually enable successful Detect, Sense, and Avoid (DSA) interactions with non-ADS-B-equipped aircraft. Instead of scanning a broad swath of sky to "detect" the presence of other aircraft and "sense" their speed and direction of flight, Level 1 competitors who choose to attempt this skill will be able to concentrate their detection capabilities on specific areas of the sky where ADS-B information indicates that there is an aircraft. Competitors will be required to "avoid" all aircraft indicated by ADS-B, whether real or not.

Competitors are not required to demonstrate proficiency at all three Advanced Skills, but the cumulative scores across all skills will be used to determine the winner. The first place competitor will earn 60% of the available prize money, second place will win 20% of the available prize money, and the remaining 20% of the available prize money will be distributed evenly among the remaining prize-qualifying competitors. A total Prize Purse of $500,000 is offered.

CFGPS DESCRIPTION

The CFGPS (Competition Furnished Global Positioning System) unit serves several functions that enable this competition. The CFGPS will be provided at the time of the competition as a single unit that competitors will install and use. To avoid on-site integration problems, a reference design and parts list will be published for the CFGPS that will allow competitors to construct their own, identical CFGPS to use as they prepare for the competition. The CFGPS will include a low-cost, commercial GPS receiver, a microcontroller, a data logger, and a transceiver to provide a Satellite Communication (SatComm) data link to the AOC judges and safety personnel.



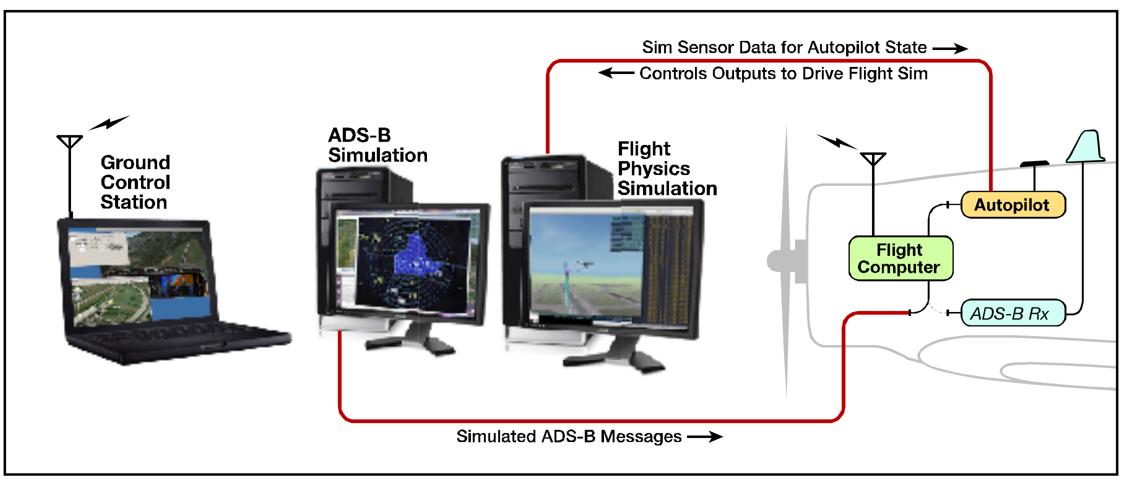
The microcontroller and SatComm link provide the judges with the capability to create different situations that mimic real world system faults. This link will also provide the capability for the judges to command a pause in the competition or command flight termination, independent of the competitor's command and control link. The CFGPS data logger will capture the trajectory and timing information that will be used to score each flight.

CFGPS mockup showing external SatComm antenna and external GPS antenna.

In addition to providing GPS data for navigation, the CFGPS will include a data port that will allow competitors to indicate flight events that impact scoring for the competition. This includes indicating when a conflict avoidance maneuver is being performed, when unreliable GPS data has been detected, or when an actual flight emergency has occurred. The data port will allow judges to provide the start signal for the 4DT mission (see Example Mission), send a signal that the mission should be aborted, or send a command for flight termination.

HILSIM DESCRIPTION

The use of a Hardware-in-the-Loop Simulation (HiLSim) is a common practice when complex flight software is being tested. The name comes from the use of actual flight hardware in ground testing and an effective HiLSim will allow realistic testing of almost all flight modes in a controlled and repeatable manner.

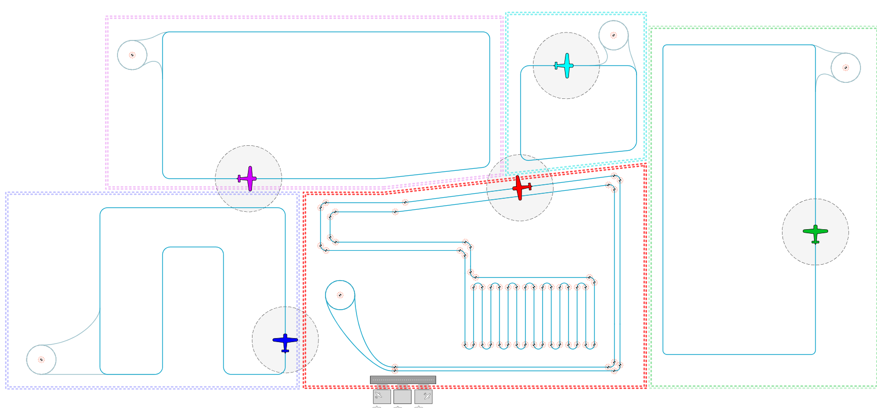


HiLSim incorporating actual Ground Control Station and simulated ADS-B traffic.

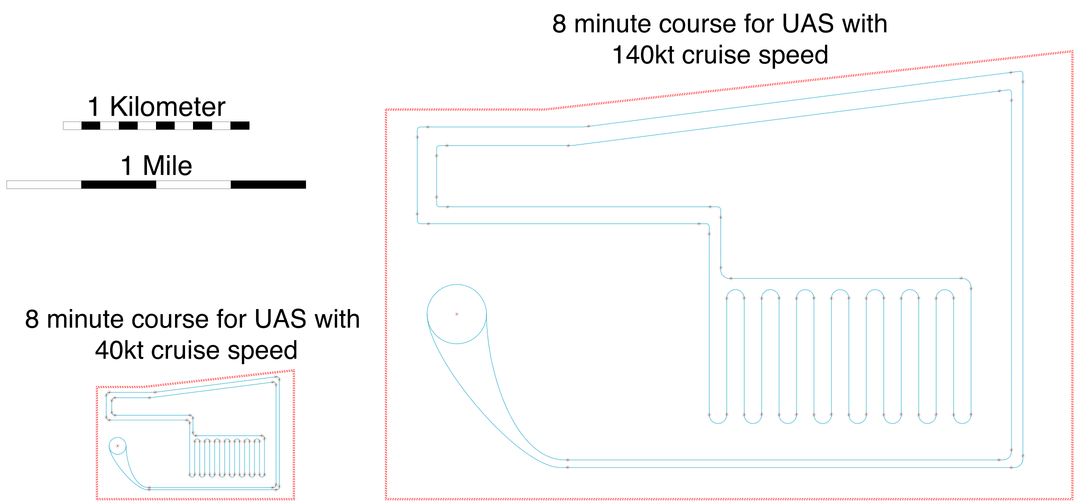
The Ground Phase of the L1C will be accomplished using a HiLSim that the competitor will develop and bring to the competition. The HiLSim configuration shown above is typical of one that might be used in preparation for the L1C. The aircraft autopilot is connected to a flight physics simulation that could be a simple commercial or open source flight simulator. The data link between the autopilot and the simulation carries simulated sensor data to the autopilot that it interprets as real data from its onboard sensors. It also transmits control outputs from the autopilot in a way that allows them to drive the aircraft simulation, closing the loop and allowing the onboard autopilot and flight software to control the simulated vehicle. An ADS-B traffic simulator is also shown, feeding traffic information to the flight computer onboard the aircraft. To successfully complete the Ground Phase and Flight Phase of the L1C, the Flight Computer would be connected to the onboard ADS-B receiver and acquire traffic information from ADS-B radio transmissions, just as they would during the Flight Phase of the L1C. Using the configuration shown before arrival at the L1C would allow testing with a wide variety of traffic scenarios without the need to broadcast fake ADS-B messages using a radio. Test suites comprised of an ADS-B data stream, 4DT mission definition, and expected outcomes will be provided to all registered contestants at least four months prior to the L1C.

CONCEPT OF OPERATIONS

Each competitor will be required to deploy and operate their UAS on a relatively tight schedule to avoid disrupting the UAS AOC schedule and negatively impacting other challenge competitors. Every event that requires a competitor to fly their aircraft for scoring is called a “mission”. The five distinct segments of a mission are: aircraft launch, pre-4DT loiter, 4DT flight, post-4DT loiter, and aircraft recovery (see Example Mission section). This structure enables surrounding air traffic to be created using a combination of real and virtual aircraft working synchronously to create specific scenarios for the competitors.



Prior to each mission, competitors must declare several details about their aircraft and how they intend to operate it. Chief among these is their preferred cruise speed for their aircraft. This cruise speed is used to establish the overall size of the geo-fence, the waypoint hit radius, and other characteristics of the 4DT that will define the missions assigned to them. Tailoring the size of the course to the capabilities of each competing UAV, while keeping event timing for the sometimes-complex mission scenarios constant, will enable fair competition between UAS that vary significantly in size and performance. Required air traffic separation distances will be chosen to capture important scale effects inherent in operating different classes of aircraft.



Course scaling will permit fair competition, independent of UAS performance.

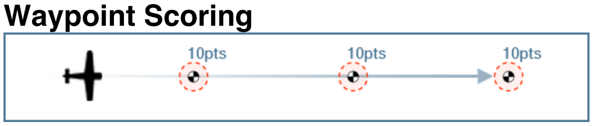
Competitors must, however, provide other UAS performance related information, such as their stall speed, maximum speed, endurance, and maximum range for command and control links, so that safety checks can be made to ensure that the generated 4DTs will not drive their UAS into unsafe flight conditions. Specific limits on many of these parameters will be driven by several factors, including final site selection, and will be stated clearly in the final competition rules.

How a competitor is scored during contingency operations will depend upon their operational response to certain events, such as the temporary loss of reliable GPS information. Thus, the information submitted prior to each mission would include their intended response to GPS loss, lost link, etc. Acceptable mitigation strategies for this competition are to loiter in place, to return to the Loiter Point, or to continue the 4DT for that mission. Increasing system sophistication and robustness in ways that allow a UAS to continue to navigate accurately and maintain safe separation in these situations is encouraged and rewarded through higher scores.

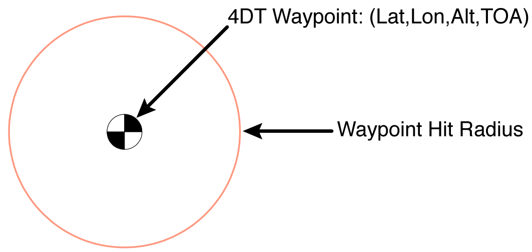
SCORING

Competitors will fly a series of missions that will require them to safely address many of the technical issues important to integrating UAS in the NAS. Several different types of scoring may apply during a single mission, depending upon the mission goals and the types of contingency situations that occur. Competitors will not have advance knowledge of the scenarios they will encounter and different teams will encounter scenarios in different orders.

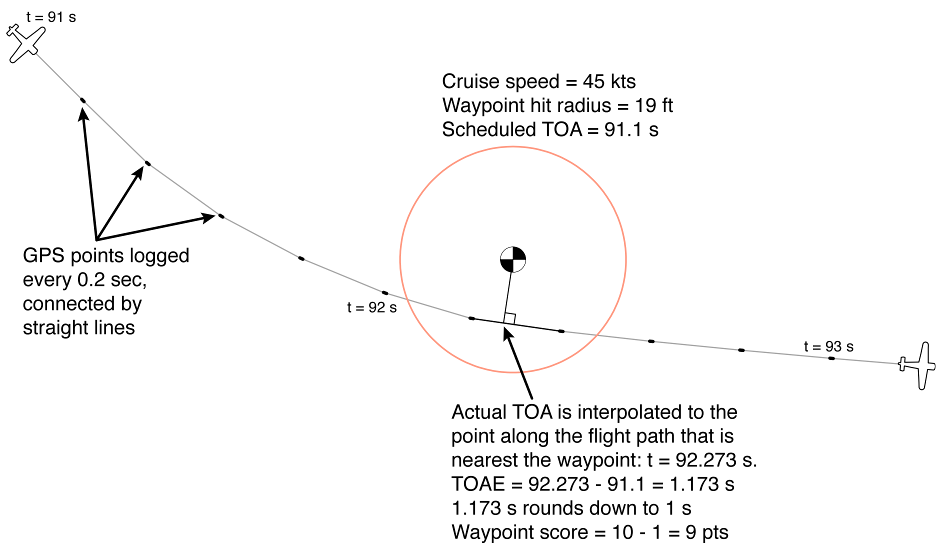
Waypoint Scoring



Waypoint Scoring is used during every scored flight in the UAS AOC to provide a base score and to ensure that competitors are focused on accomplishing their specific mission. A single 4DT waypoint is defined by a three-dimensional location in space and the required Time Of Arrival (TOA) at that waypoint. “Hitting” a waypoint requires a competitor’s aircraft to fly within a specified radius of the waypoint. The waypoint radius is calculated to be the distance the aircraft would travel in 0.25 seconds at its declared cruise speed.



For scoring purposes, all distances to waypoints will use the time and position history logged by the CFGPS. The difference between the scheduled TOA and the actual TOA is defined as the Time Of Arrival Error (TOAE) for each waypoint. The actual TOA of the aircraft at a waypoint is defined as the time at which the aircraft is closest to the 4DT waypoint. Competitors can receive a maximum of 10 points for hitting a waypoint, but the TOAE, in seconds, will be subtracted from the 10 point score if the TOAE is 10 seconds or less. Zero points will be awarded for hitting waypoints more than 10 seconds early or more than 10 seconds late. For TOAE calculations, the number of seconds will be rounded down to an integer before subtraction, so that a TOAE of 3.76 seconds will result in a waypoint score of 7 points and a TOAE of 0.999 seconds will result in a full score of 10 points for a waypoint.

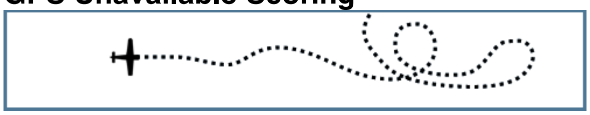


Scale diagram illustrating Waypoint Scoring for a UAS with an average speed of 45kts.

Separation Scoring

Whenever a competitor is flying a 4DT mission, safe separation must be maintained between their aircraft and other air traffic. Competitors will discover and monitor other air traffic by interpreting ADS-B messages received onboard the aircraft. Competitors will forward-project the trajectories of all observed traffic and attempt to identify traffic conflicts that would result in their aircraft violating the separation requirement. If an evasive maneuver is required to remain well clear of other air traffic, the competitor may find it necessary to interrupt their 4DT mission to execute the evasive maneuver. To get credit for maintaining safe separation, the vehicle must indicate that it is making an evasive maneuver by sending the appropriate electronic signals to the onboard CFGPS, where it will be recognized and logged. When it is safe to do so, the aircraft can resume its 4DT mission and attempt to earn more points according to rules of Waypoint Scoring. A successful evasive maneuver that prevents a violation of the separation requirement will be worth 200 points. An unneeded evasive maneuver that does not prevent a violation of the separation requirement will not receive any Separation Scoring points, but Waypoint Scoring will still be in effect. Separation distance violations will result in a score of zero points for the entire mission.

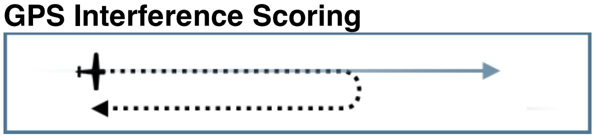
GPS Unavailable Scoring



Scoring for successfully responding to a loss of GPS data in-flight is designed to encourage robust UAS designs that are not completely dependent on the integrity of the GPS system for safe operation. Competitors will have identified their chosen mitigation strategy for a GPS Loss contingency, prior to the initiation of each flight. The three mitigation strategies allowed are: loiter in place (50 points), return to Loiter Point (100 points), or complete the mission (200). GPS loss will be simulated by the CFGPS, which will halt GPS data output to the UAS on command from the judges. During this period, the microcontroller that is integrated inside the CFGPS will monitor the vehicle's location and will resume the output of valid GPS data if the vehicle approaches a geo-fence boundary or if the judges command it to. The CFGPS will also continue providing a valid GPS solution to the competition judges and safety personnel through its two-way satellite communication data link.

Aircraft that elect to enter a safe loiter mode upon the loss of GPS data and remain within the allowable flight area until valid GPS data is reacquired will earn 50 points. Valid GPS data will always become available again before the end of a mission. If a vehicle can successfully navigate back to the Loiter Point without valid GPS data and establish a stable orbit around that point, it will earn 100 points. Once valid GPS data is reacquired, the UAS can continue with its mission. UAS that can navigate with sufficient precision in a GPS-unavailable environment can elect to continue their mission after the loss of valid GPS data. The UAS will continue to earn points under the rules of Waypoint Scoring and, if it earns points at 50% or more of the 4DT waypoints scheduled during the GPS outage, it will earn an additional 200 points. Once valid GPS data is restored, the UAS can continue to earn points according to the rules of Waypoint Scoring while it completes its mission.

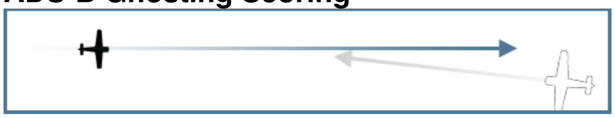
GPS Interference Scoring



During the 4DT section of a mission, the judges may command the CFGPS to begin to provide inaccurate GPS data to the aircraft. The amount of GPS error will increase over time, resulting in a significant directional offset from the correct 4DT or, in some cases, a significant heading change from the path defined by the 4DT. The score for successful detection of inaccurate GPS data will be calculated by subtracting the number of seconds that elapse between initiation and detection from 200. For example, if a competitor was able to signal their detection of inaccurate GPS data 45 seconds after the erroneous data stream had been initiated, they would earn an additional 155 points.

At the point in a mission when GPS Interference is detected, the UAS must isolate the inaccurate GPS data from its guidance, navigation and control processes, implement its mitigation strategy for GPS Loss, and can begin to earn points under the rules of GPS Loss Scoring. At the end of the mission timeline, defined by the TOA for the last 4DT mission waypoint, the CFGPS data stream can be treated as trustworthy and used to safely navigate to the Loiter Point. If a competitor signals the detection of unreliable GPS data when it has not, in fact, been initiated, their Waypoint Scoring total for the mission will likely suffer as they implement their GPS Loss mitigation strategy.

ADS-B Ghosting Scoring



For each 4DT mission flown, competitors will be able to earn points by generating a list of nearby aircraft, identified by processing ADS-B signals received onboard the aircraft, and indicating which aircraft on the list are real and which are virtual or “ghost” air traffic. This classification must be based upon data from sensors onboard the aircraft and the data used for classification should be stored in such a way that it can be reviewed by judges, post-flight. The competition will be staged such that half the aircraft represented in the ADS-B data stream received by a competitor’s aircraft will be real aircraft and half will be ghost aircraft. 20 points will be added to a competitor’s score for each correct classification and 20 points will be subtracted from their score for each incorrect classification. Contestants who do not attempt to classify surrounding air traffic will not have points added to or subtracted from their score.

Waypoint Scoring	From 0 to +10 pts per waypoint, depending on accuracy
ADS-B Ghost Scoring	+20 pts per correct ID; -20 pts per incorrect ID
Separation Scoring	+200 pts for a successful conflict avoidance maneuver
GPS Unavailable Scoring	+50, +100, or +200 pts, depending on mitigation strategy
GPS Incorrect Scoring	+200 pts minus number of seconds to detect deception

EXAMPLE MISSION

The following example mission illustrates some of the different types of scoring. This specific mission begins and ends with 4.2km traverses, which have been folded to fit inside a more compact geo-fence. The middle of the mission includes flying a raster pattern that is typical of real-world aerial mapping missions.

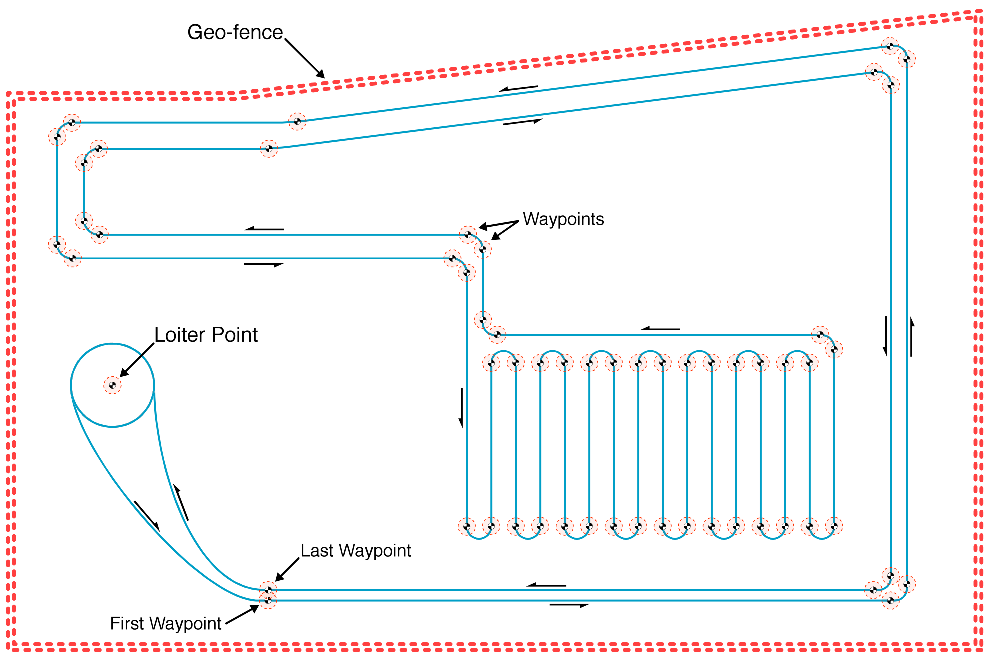


Figure 1. The major features that define a mission are the geo-fence boundary, the location of the Loiter Point (LP), the maximum orbit distance from the loiter point, and the 4DT. The mission shown is comprised of 58 waypoints. Competitors will not be informed as to whether a mission will be assessing their skill at maintaining safe separation, navigating after loss of GPS data, or detecting and mitigating the effects of incorrect GPS data.

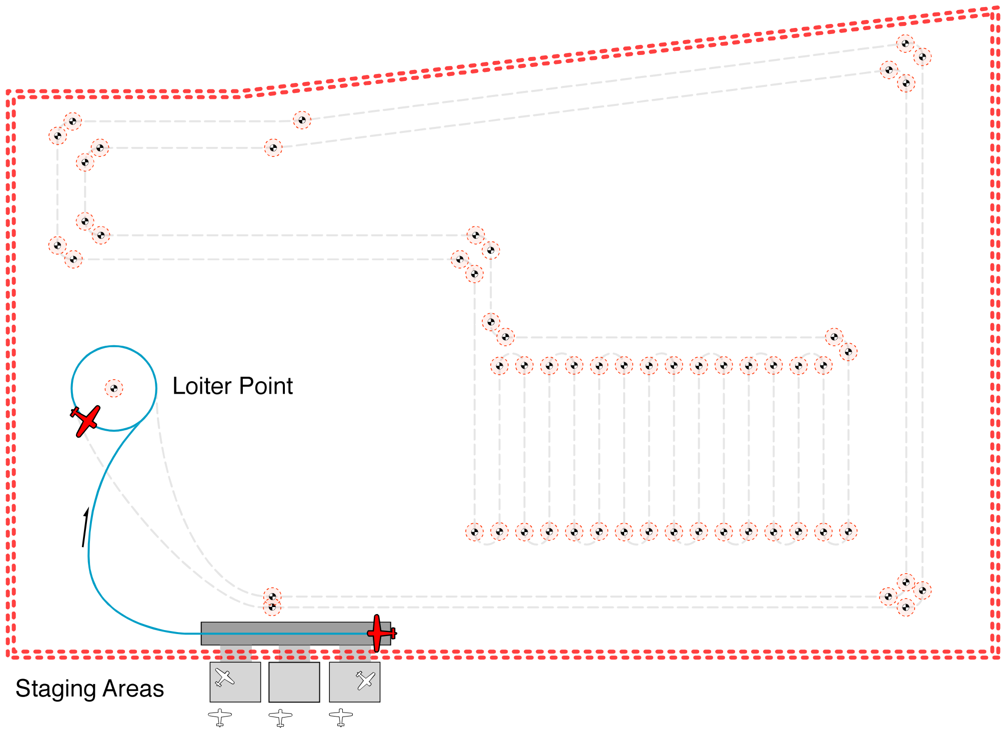


Figure 2. The mission begins with the launch of the competitor's aircraft, which must establish a stable orbit around the designated LP, within the maximum allowed radius. This initial loiter provides several minutes for the judges and safety personnel to verify that other aircraft are in position and that all systems are "go".

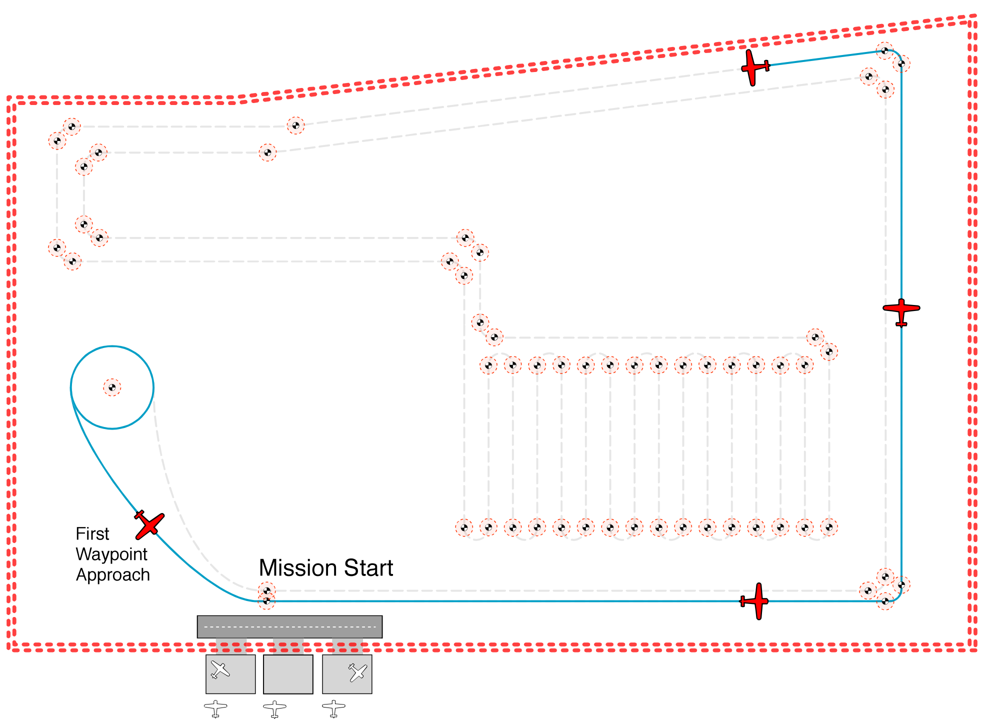


Figure 3. All range systems will synchronize on GPS time and, once the judges give the signal to initiate the 4DT, the TOA for the first 4DT waypoint is set to be the beginning of the next whole minute. Subsequent waypoints' TOA will be defined in seconds, relative to the TOA of the first waypoint. The

competitor would have earned 50 points, so far, if they were able to hit each waypoint and zero their Time Of Arrival Errors (TOAEs).

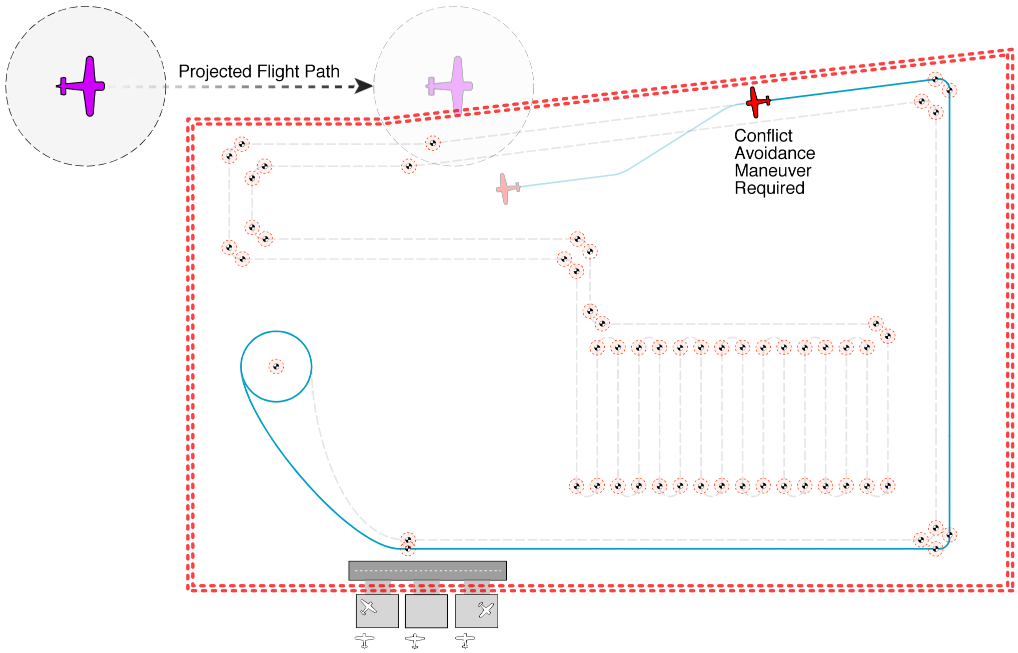


Figure 4. Based upon ADS-B information, the competitor identifies an impending conflict with the purple aircraft and executes a conflict avoidance maneuver. This competitor chooses to offset their flight path so that their vehicle stays well inside the geo-fence and well clear of the flight path of the other aircraft. Under the rules of Separation Scoring, this successful conflict avoidance maneuver earns an additional 200 points.

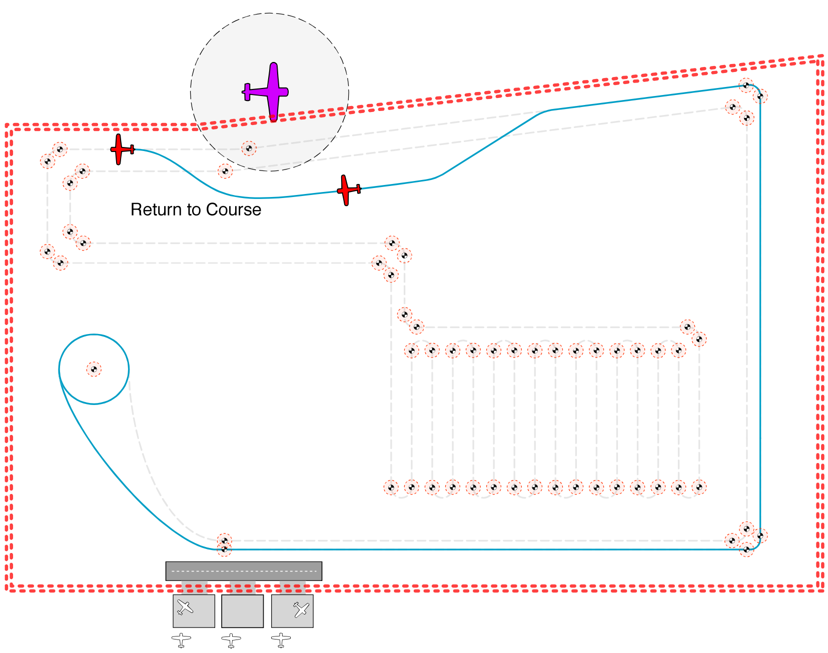


Figure 5. Once the other aircraft has passed and there are no other impending conflicts that would further impact the mission, the competitor's UAS can return to the 4DT and continue earning points under the rules of Waypoint Scoring.

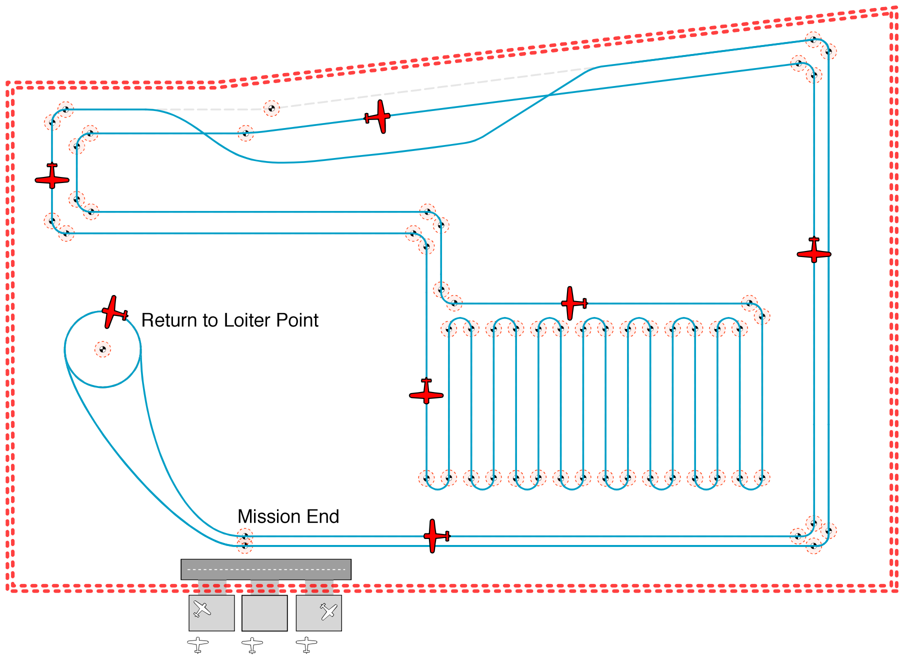


Figure 6. Completing the remaining waypoints with no errors would add an additional 520 points. After completing the mission, the UAV orbits the Final Loiter Point, until cleared to land. If this mission included GPS Interference that went undetected, this final loiter period provides several minutes for the CFGPS to gradually transition to providing true GPS data to the UAS. ADS-B messages during this mission would have indicated eight other aircraft nearby, even though only one flew close enough to the competing UAS to create a conflict. If the competitor correctly identifies which of the eight other aircraft were real and which were ghosts, they would earn an additional 160 points under ADS-B Ghost Scoring, for a maximum score of 930 points for this mission. The timing and geometry of the conflict ensured that the sixth 4DT waypoint would be missed. Since the maximum score can be determined prior to flight, judges can generate unique missions for each competitor while ensuring that missions are directly comparable in terms of complexity and maximum score.

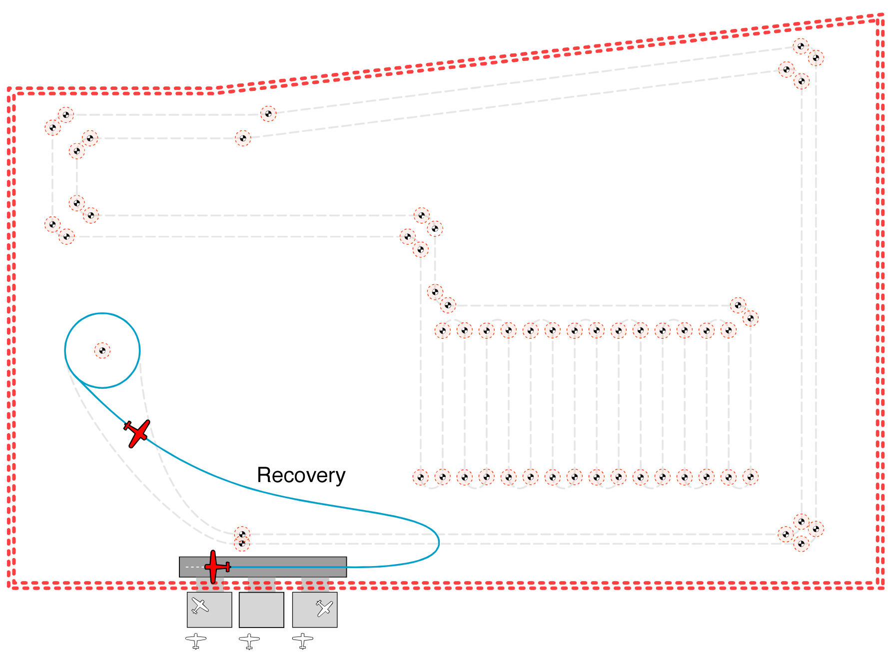


Figure 7. Once the aircraft has been recovered, a competitor will have a fixed amount of time to clear the staging area.