CSU California Unmanned Aerial System Competition (C-UASC)

MOJAVE AIR & SPACE PORT

Mojave, California

June 22, 2024

Organized by:

Cal State University – Los Angeles

and

Mojave Air & Space Port

Competition Rules

Rev. 2. 2024-03-25

Contents

About this document

This document contains the official rules for the C-UASC competition. Updates to the document will be released as needed to clarify or augment rules. The chief author of the document is Michael Thorburn; however the rules are established by the organization partners at the California State University and the Mojave Air & Space Port with consultation from our technical advisors. Updates to the rules will be published periodically to clarify items or make necessary corrections.

- Rev 1 of the C-UASC Competition Rules. Dated 2023-10-01

  The initial release of the rules.

- Rev 2. Dated 2024-03-25
  Incorporates errata and a few points for clarification. These are noted in the section below.

Changes in Rev 2.

- In “About the Competition” the name of the Mojave Air & Space Port at Rutan Field (MASP) is spelled out fully.
- In ‘Purpose and Tasks”, the word “small” is added to describe a small Unmanned Aerial System (UAS). Additionally, the sentence “UAS cannot exceed 55 pounds in weight with all packages.” is added.
- In “Use of Mojave Air & Space Port”, a requirement is added to “Provide plans for lost link, loss of control, or loss of communication with the UAS during flight.”
- In “Development Team”, “full-time” is changed to “part-time” to allow for part-time students on the team.
- In “Team Pilots”, the following is added to comply with FAA Part 107. “The competition encourages each team to have a pilot with FAA Part-107 remote pilot certification. The competition operates under these regulations and so if a team does not have a certified pilot, the competition will provide one. The competition’s certified pilot will provide direct supervision of the teams’ remote pilot during their flights.”
- In “UAS Vehicles Type” the phrase “cannot exceed 55 pounds.” is added.
- In “Air Delivery of Package”, the sentence “A detailed description is forthcoming” is changed to “A detailed description is posted on the competition website.” Additionally, the maximum cube side length is reduced from 20cm to 10cm.
- In “Rules Governing Design Team and Design Competition Entries” the phrase “full-time” is eliminated to allow for part-time students as per the modification noted above.

About the Competition

The competition is organized by California State University and by Mojave Air & Space Port at Rutan Field (MASP). It is a student competition, open broadly to teams of students from universities, colleges, and community colleges. All entrants will be required to comply with rules imposed by Mojave Air & Space Port at Rutan Field and by the California State University.

Purpose and Tasks

The competition requires students to design, integrate, and demonstrate a small Unmanned Aerial System (UAS) capable of autonomous flight and navigation, geolocation, remote sensing and the execution of a set of tasks. The competition has three major scored components:

- Technical Design and flight readiness presentation
- Simulation
- Flight evaluation

The mission tasks are:

- Piloted Flight
- Autonomous Flight
- Waypoint Navigation
- Delivery of a Package to a site marked by a target located somewhere within a boundary known in advance.

The UAS aircraft entered can be:

- Rotocopter
- Fixed-Wing UAS
- VTOL

The UAS must include a Ground Control System. UAS cannot exceed 55 pounds in weight with all packages.

To compete in each element of the competition, a UAS will need to:

- Have a piloted mode to demonstrate flight over a defined course, send position data to a ground-control system and deliver a package before landing.
- Have autonomous waypoint navigation capabilities – so that it can follow a programmed course. The waypoints will be available before the competition begins. It needs to be able to send data to a ground control system to monitor its position.
- Have the ability to carry and deliver a package that weighs about 0.25 kg. The package will be provided by the competition. The delivery approach is the choice of the team.
- Sustain flight over one of two courses defined by waypoints. Course 1 is approximately 1 mile (1.6 km) in length. Course 2 is approximately 2 miles (3.2 km) in length.
- Have the ability to locate and identify the target for package delivery within a predefined area, in the presence of decoys.

Introduction to Rules

Use of Mojave Air & Space Port

Teams shall comply with all operational requirements of the Mojave Air & Space Port. These requirements will be posted separately on the competition website. They will include:

- Operation within FAA Part 107 guidelines
- Operation at or below 400 feet above ground level (AGL)
- Always Remaining within Line of Sight (LOS) of the UAS Pilot
- No photos or video taken of personnel or property belonging to entities that are non-participating in this competition.
- Provide plans for lost link, loss of control, or loss of communication with the UAS during flight.

The agreement with Mojave Air & Space Port, describing the rules of operation, will be posted on the competition website.

Composition of Teams

Teams are composed of students from colleges or universities.

Teams will be organized into three categories:

- Development Team
- Competition Team
- Competition Guests

Development Team

The development team must consist of undergraduate students who attend school part-time for at least one semester during the academic year. The team may have at most 2 graduate students participate during the academic year. The team must have at least 1 student from the school being represented and may have students from other schools. A school may have multiple teams, but a student may only be on 1 team. There are no limits to the number of students on the Development Team.

Competition Team

The team of students which participate in the Mission Flight Demonstration. The competition team must be at most a 12-person subset of the development team. Members of the competition team may participate onsite or participate remotely (e.g. over the internet), but remote members cannot hold safety-critical roles or perform safety-critical functions.

Key Competition Team Members

Team Captain

One member of the competition team will fill the role of team captain during the competition year. This student will be the primary point of contact for the judges. All questions, comments, statements, and deliverables must be submitted by the team captain. The judges must be immediately notified of any team captain change.

Advisor

Each team must have a school faculty member/advisor or official point of contact (POC) from the team's school. Teams whose entire team is age 18 years or above are not required to have the advisor or school official travel with the team, otherwise at least two adults shall travel with the team and shall take full responsibility for the students. The advisor will be permitted to observe the team at the flight line but is forbidden from communicating or otherwise assisting the team during setup, mission, or tear down. While the advisor may teach concepts, answer questions, provide high-level guidance, and review deliverables before submission, the students must design, manufacture, and operate the system on their own and must produce all deliverables on their own.

Safety Pilot

The Safety Pilot used during the year can be a student, the advisor, or non-student. The Safety Pilot must complete The Recreational UAS Safety Test (TRUST) and present the certificate of completion at safety inspection and at the flight line. While the UAS occupies the runway or airspace, the Safety Pilot must not have any other roles and must maintain continuous unaided visual line of sight with the vehicle (no FPV). If the Safety Pilot performs any other tasks during mission time, the mission will be terminated. The Safety Pilot counts as one of the members of the competition team. If the pilot is not a member of the development team, then the pilot is limited to safety related functions and communication and must not advise or participate in other roles.

GCS Operator

The Ground Control Station (GCS) operator is responsible for operating the autopilot including setting parameters, uploading mission objectives like waypoints, monitoring for performance and compliance, and intervening as necessary. While the UAS occupies the runway or airspace, the GCS Operator must not have any other roles and must maintain situational awareness of the UAS, the autopilot subsystem, and the ground control station. For example, the GCS Operator cannot operate payloads. If the GCS Operator performs any other tasks during mission time, the mission will be terminated. The GCS Operator counts as one of the members of the competition team and is classified as a Team Pilot.

Team Pilots

The GCS Operator and any member of the Competition team that will control a UAS flight, for test or for competition, at the competition site will be deemed a UAS pilot.

- UAS pilots must be members of the Academy of Model Aeronautics. https://www.modelaircraft.org/membership/enroll
- UAS pilots must have completed the FAA Trust Course and have a Certificate. The Recreational UAS Safety Test (TRUST) | Federal Aviation Administration (faa.gov)

The competition encourages each team to have a pilot with FAA Part-107 remote pilot certification. The competition operates under these regulations and so if a team does not have a certified pilot, the competition will provide one. The competition's certified pilot will provide direct supervision of the teams' remote pilot during their flights.

Competition Guests

Each team will be allowed to bring additional guests to the competition. If desired, these guests may be development team members, but they cannot assist with the mission demonstration.

Flight Competition and Demonstration

UAS Vehicles Type

- The UAS may be:
  - Rotocopters or Fixed-Wing Vehicles
  - Vertical Takeoff and Landing (VTOL), able to use a runway of approximately 70ft x 75ft (20 m x 23 m)
  - Horizontal Takeoff and Landing (HTOL), able to use a runway of approximately 70ft x 600ft (20 m x 180 m)

The Fully loaded weight includes the weight of the UAS and the Delivery Package cannot exceed 55 pounds.

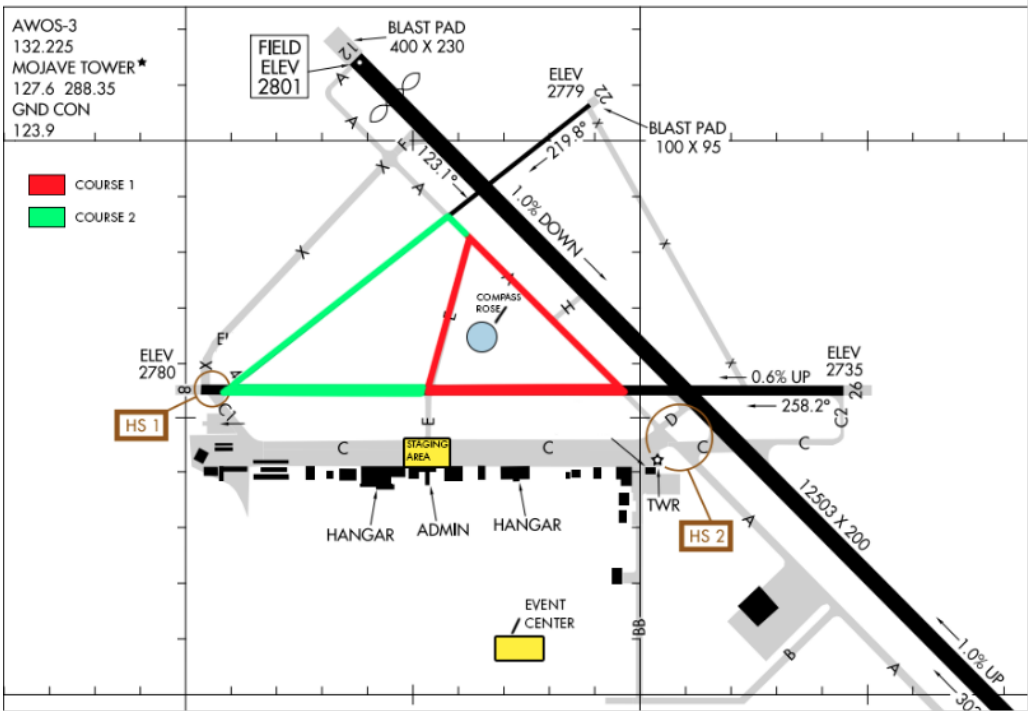
Minimum UAS Capability

- The UAS must have the ability to:
  - Fly the course defined by the waypoints at fully loaded weight in a single flight.
  - Fly through the waypoints with a max error of 23 ft. (7 m). The threshold must be configured in the autopilot.
  - Be able to turn in a radius not larger than 150 ft (46 m)

Facilities Infrastructure, Flight Boundaries and Environment

Course Map

The course if at the Mojave Air & Space Port in Mojave, California. There are two courses identified. Course 1 is in RED and Course 2 includes the eastern side of Course 1 and adds the additional space on the west denoted in GREEN. Course 1 is approximately 1 mile (1.6 km) and Course 2 is approximately 2 miles (3.2 km).



Flight Boundaries

- Mission flight boundaries are defined by a set of GPS points and altitude restrictions. They will be provided before the competition. These will incorporate restrictions associated with the neighboring airport and runways. The UAS must comply with these requirements. The UAS is out of bounds if it's outside of the specified area, at which point the mission will be terminated.
- Package delivery target boundaries are defined by large red X contained within a set of GPS points. The package delivery target will be somewhere within this boundary. The boundary in which the package-delivery target is placed is approximately 10-20 meters in diameter. It will be within the portion of the field which is in the interior of Course 2 but exterior to Course 1.

Ground Control Station (GCS)

- The GCS Operator and GCS Judge will sit together and must have continuous uninterrupted access to the GCS display throughout the Mission Demonstration.
- The GCS Display must
    - Show a map showing the flight boundaries and the UAS position.
    - Indicate the UAS speed and altitude.

Radio Frequency (RF)

- The competition management will not provide any RF Spectrum Management
- Each team should expect other teams to be using similar equipment (e.g. same autopilot) and teams must ensure that they don't allow invalid connections (e.g. connecting to another team's autopilot).
- Teams found intentionally jamming or interfering with another team's communications will be eliminated from the competition.

Flight Qualification and Proof of Safe Flight

- All UAS and pilots must qualify for the competition – this is done before the event.
- To qualify, each team will videorecord safe flight demonstrations with the following characteristics:
    - There must be videos for each instance of the aircraft (e.g., primary and backup), and every Safety Pilot that may be used in competition.
    - Each flight video must be visually labeled with the Safety Pilot's name and the aircraft's identifier.
- Required flights per aircraft instance and Safety Pilot:
    - Manual flight showing takeoff, flying 1000 ft (0.3 km) from the Safety Pilot, and landing.
    - Autonomous flight, showing takeoff, flying 200 ft (60 m) from the Safety Pilot, a transition to manual mode, and manual landing.
    - Autonomous package delivery, showing the system can deliver package autonomously, with takeoff and landing that is either autonomous or manual.
- Prior to the Mission Demonstration, the team must show the safe flights video recordings.
    - Teams may only attempt those portions of the competition for which they have qualified.
    - Insufficient Proof of Safe Flight will immediately yield disqualification.

Flight Demonstration

Mission Time and Order of Tasking

- Teams will be provided 30 minutes to complete the mission. Mission time stops once the UAS has landed, the UAS has cleared the runway and the team relinquishes the airspace.
- Teams must follow this order of mission tasks:
    - UAS must successfully take off.
    - UAS must immediately fly the waypoint path before attempting other tasks.
    - After the waypoints, teams may decide the order of all other tasks. These tasks include:
        - Object Detection, classification, and localization
        - Air Delivery of Package to target
    - UAS must successfully land and be cleared from the runway.

Tasks Definitions

- Piloted Mode
    - The UAS aircraft will be directly controlled by one of the pilots on the team. This is to demonstrate aircraft capabilities and safe flight.
- Autonomous Mode
    - The UAS is to navigate the waypoints and deliver the package without a pilot. (A pilot may be used to land the UAV after the package is delivered.) There are two system architectures permitted for autonomous mode:
        - Fully autonomous aircraft. All flight control and package delivery control is carried out by the aircraft alone. Telemetry of aircraft data, including position data, is sent to the ground control station.
        - Autonomous UAS system. The flight control and package-delivery control is carried out by the aircraft with assistance from the ground control system. (for example, computer vision algorithms may be running on the ground control system.) There is both telemetry from the aircraft to the ground control system and commands from the ground control system to the aircraft.
    - A fully autonomous aircraft will be awarded more points than an autonomous UAS system.
- Waypoint Navigation
    - Within the region defined by the flight boundaries, there will be as many as 7 waypoints defined. The UAS shall fly a path of its own determination passing each of the waypoints.
- Air Delivery of Package
    - The UAS will be required to deliver a package to a well-marked target.
    - The delivery package will be provided. A detailed description is posted on the competition website. It will weigh not more than 0.25 kg and be smaller than a cube defined by a side length of 10 cm.
    - The delivery package will have four attachment eye-hooks on the top side for the teams to use if they wish.

- The delivery package will be equipped with a device to measure the intensity of the impact upon delivery.
- The target will be approximately 5 m in diameter. The target will be identified by a large red bullseye.
  - Example:

- There may be decoys, such as red X's and blue circles in the vicinity of the target.

- Landing
  - The UAS will be required to land safely and be removed from the runway.

- Waypoint Navigation
- Course Selection
- Teams choose whether to follow Course 1 or Course 2.

- Number of Waypoints
- There will be four waypoints on Course 1 and seven waypoints on Course 2.

- Data Collection
- Teams must stream GPS data to the Ground Control Station (GCS) and the GCS must record it.

Flight Demonstration Scoring

- The UAS flight demonstration will be scored in the following way:For both piloted and autonomous flights
  - The total time of flight, from take off to landing and removal from runway.
  - The successful completion of each of the tasks
    - Waypoint Navigation
    - Obstacle Avoidance
    - Delivery of Package to the targeted position
- The formula for the evaluation of the score will be provided in a subsequent revision of the rules document.

Score for Flight Evaluation

The score for the flight evaluation event will be composed of scores measuring the accuracy of which the UAS navigates the course defined by a set of waypoints, the accuracy of which the UAS delivers a small

package to a target marked so that it can be identified, and the time the UAS takes to do complete these tasks and return to the home base.

In the following section, details for each of the tasks, and how the UAS performance will be scored, are provided.

Scoring for Waypoint Navigation (350 points possible)

The maximum score for waypoint navigation is 500 points. The metrics are the number of waypoints attempted, the precision with which the waypoints are navigated, and the degree of autonomy use by the UAS. The score will be calculated based on the table below.

Waypoint Navigation Score Table.

Piloted Flight			
Course	**Points per Waypoint**	**Reduction for Missing a Waypoint**	**Total Possible Points**
Course 1	25 points per waypoint	For each waypoint Error < 5 m 0 pts Error > 5 m -5 pts/m for each meter of error beyond 5	100 points possible
Course 2	25 points per waypoint	For each waypoint Error < 5 m 0 pts Error > 5 m -5 pts/m for each meter of error beyond 5	175 points possible
Autonomous Flight			
Course	**Points per Waypoint**	**Reduction for Missing a Waypoint**	**Total Possible Points**
Course 1	25 points per waypoint	For each waypoint Error < 5 m 0 pts Error > 5 m -5 pts/m for each meter of error beyond 5	100 points possible
Course 2	25 points per waypoint	For each waypoint Error < 5 m 0 pts Error > 5 m -5 pts/m for each meter of error beyond 5	175 points possible

The total score for Waypoint Navigation is a combination of piloted and autonomous scores.

$$P_{waypoint} = P_{waypoint,piloted} + P_{waypoint,autonomous}$$

Scoring for Time of Flight (200 points possible)

The score for the Time of Flight is based on a relative measure of the best score of the teams that completed the event. The Time of Flight will be recorded for both the piloted flight and the autonomous flight. The maximum combined score for Time of Flight will be 200 points.

The scores for those teams that choose Course 1 will be normalized to those that choose Course 2.

Definitions of Top Time

- TS1 = Top Time for Course 1 (measured in seconds)
- TS2 = Top Time for Course 2 (measured in seconds)
- TS = minimum of 2*TS1 and TS2 (This is the official Top Time)

The TS may change with each subsequent flight as the teams compete.

The maximum score for time of flight is 100 points for the piloted flight and 100 points for the autonomous flight. The minimum score is 0, for each, regardless of the time of flight.

Time of Flight Score Table

Piloted Flight			
Course	**Total Possible Number of Points**	**Reduction based on Top Time**	**Total Score**
Course 1	100	For time of T seconds reduction of points is $P_r = 40\left(\frac{2T}{TS} - 1\right)$	$P_{TOF} = 100 - 40\left(\frac{2T}{TS} - 1\right)$
Course 2	100	For time of T seconds reduction of points is $P_r = 40\left(\frac{T}{TS} - 1\right)$	$P_{TOF} = 100 - 40\left(\frac{T}{TS} - 1\right)$
Autonomous Flight			
Course	**Total Possible Number of Points**	**Reduction based on Top Time**	**Total Score**
Course 1	100	For time of T seconds reduction of points is $P_r = 40\left(\frac{2T}{TS} - 1\right)$	$P_{TOF} = 100 - 40\left(\frac{2T}{TS} - 1\right)$
Course 2	100	For time of T seconds reduction of points is $P_r = 40\left(\frac{T}{TS} - 1\right)$	$P_{TOF} = 100 - 40\left(\frac{T}{TS} - 1\right)$

The total score for Time of Flight (TOF) is a combination of piloted and autonomous scores.

$$P_{TOF} = P_{TOF,piloted} + P_{TOF,autonomous}$$

Scoring for Package Delivery (450 points possible)

The maximum score for package delivery is 450 points. The score for the Package Deliver is based on the accuracy of the delivery as measured from the center of the bullseye. The package delivery scores are computed the same way, regardless of whether the team chooses to fly Course 1 or Course 2.

Package delivery score will be computed by the following equation.

Definition of Package Delivery Error

- Package Delivery Error X = distance in meters from center of package delivery target
- M = average error of package delivery across all teams

Package Delivery Point Formula

The score for the package delivery accuracy is given:

$$P_{package\ delivery,event} = 150\ e^{-\frac{(X/M)^2}{6}}$$

Teams receive a package delivery accuracy score for both the piloted and the autonomous flights, each worth as much as 150 points.

Impact on Package during Delivery

The package will be equipped to measure the intensity of the impact. Details are forthcoming. There will be a reduction to the score of the delivery if the impact exceeds a threshold.

$$P_{package\ delivery} = P_{package\ delivery,event} - P_{impact\ penalty}$$

Autonomy Bonus for Package Delivery

A fully autonomous aircraft, as compared to an autonomous UAS system will receive a 150 point bonus.

Combined Package Delivery Score

The package delivery score is a sum of the scores for the piloted flight, the autonomous flight and the autonomy bonus.

$$P_{package\ delivery} = P_{package\ delivery,piloted} + P_{package\ delivery,autonomous} + P_{autonomy\ bonus}$$

Total Score for Flight Evaluation (1000 points possible)

The total score for the competition is a combination of Waypoint Navigation, Time of Flight, and Package Delivery Scores. The total score is:

$$P_{piloted} = P_{waypoint} + P_{TOF} + P_{package\ delivery}$$

Impact of Wind on Score

It can be windy at Mojave Air & Space Port. The competition is evaluating options to account for the wind in the score, to some extent. Details will be forthcoming in a later revision.

Design Competition

In addition to the documentation required from each to for purposes of demonstrating flight qualification, teams are encouraged to submit more design documentation to demonstrate the quality and creativity of the work they have performed. There will be a design and innovation prize awarded based on this documentation.

Rules Governing Design Team and Design Competition Entries

- All Design Team Members shall be members of the Development Team.
- All design competition entries must also be entries in the Flight Competition.
- All design, analysis, and fabrication of the competition entry is the sole responsibility of the student team members.
- All design work must be performed by undergraduate or graduate students enrolled during at least one of the preceding Fall, Spring, or Summer terms at an accredited college or university.
- Designs may include commercial off-the-shelf parts but the integration of these parts and the design of the overall system, including hardware and software, must be done by the design team.
- Students may only participate on a single team. Faculty advisors may advise more than one team.

Score for Design Competition

The score for the Design Competition will be based on a number of factors and evaluated by a panel of judges from industrial and academic partners.

Judges will evaluate:

- Well formulated engineering processes, analysis, and methodology
- Well described engineering design features
- Well described manufacturing processes
- Innovation in processes or materials
- Innovation in aircraft configuration, aerodynamics or structure
- Innovation in control systems, autonomy or computer vision
- Innovation in package-delivery system

Design Simulation Competition

To promote the use of modern model-based design tools and digital simulations, a prize will be awarded for the best use of simulation as part of the design process.

Score for Design Simulation Competition

Judges will evaluate:

- Well formulated use of modern simulation tools, including:
  - Computational Fluid Dynamics
  - Computer Vision and Target Identification
  - UAS Control and Flight Dynamics

Awards/Prizes

Awards and recognition will be given to the winners of the competition.

- Prizes will be awarded to the teams in each of three categories:
  - Flight Demonstration
  - Design Competition
  - Design Simulation
- A team has to compete in the Flight Demonstration to be eligible for prizes in either of the other competitions.
- A Grand Prize will be awarded to the team with the highest weighted-average composite score of the three competitions.