Chapter 3. Specific Training Curriculum: Multirotor

3.1 Multirotor Definition

3.1.1 Definition

3.2 Multirotor Uses

3.2.1 Typical uses/missions
3.2.2 Risk associated with multirotor and related missions
3.2.3 Training type flying

3.3 Multirotor Characteristics

3.3.1 General characteristics
3.3.2 Common multirotor components - general information and how they work

- Power - Battery
- Propulsion - Motor
- Electronics
- Frame

3.3.3 UAS axes
3.3.4 Maneuverability

- Ability to change multirotor pitch, yaw, and roll

3.4 Remote Control basics

3.4.1 General concept
3.4.2 Radio wave propagation
3.4.3 Transmitter
3.4.4 Receiver
3.4.5 Multirotor Controllability

- Demonstrate how controller changes an input which effects each axis

3.4.6 Possible RC errors

- Frequency interference
- Antenna placement and propagation

3.5 Introduce the Training Multirotor

3.5.1 Introduce the multirotor used for training
3.5.2 Show storage techniques

- LiPo location and safety
- Folding booms
- Gimbal cover

- Transmitter storage

3.5.3 Demonstrate assembly

- LiPo connections
- Arms and booms
- Gimbal checks
- Transmitter
- Propellers

3.5.4 Describe unique systems

3.5.5 Review UAS checklist

3.5.6 Review maintenance records

3.6 Multirotor Training flight

3.6.1 Prior to training event arrival

- Set and confirm date and location
- Describe training flight plan, objectives, and expectations to student
- Check and review NOTAM with student if applicable
    - 24hrs in advance file backup NOTAM
- Confirm charged battery(s)
- Confirm all UAS components are packed and ready for transport
- Review all student and CFI qualifications and documents

3.6,2 Arrival and preflight preparation

- UAS unpack and assembly
- Checklist usage
    - Explain reason behind important checklist steps
    - Define unfamiliar UAS components
- Controller start and or boot sequence (if applicable)
- Common controller GPS errors (if applicable)
    - Remedies
- FPV connection (if applicable)
- Controller control inputs
- Control review and hands on demonstration
- Camera controls (if applicable)
- Emergency buttons

3.6.3 Initial crew briefing

- Describe flight maneuvers
- Denote safest area to fly
- Denote typical pattern
- List possible safety hazards
- Formulate plan of action for any foreseeable emergencies
- Describe situations which would require exchange of controls
    - State positive exchange of control procedures
- Demonstrate summarized crew briefing

3.6.4 Takeoff

- Describe multirotor takeoff sequence

- Reiterate takeoff technique
- Review checklist
- Commence instructor or student take off

<u>3.6.5 Initial flight familiarity</u>

- Allow student to experience different control inputs at safe altitude
  - Control inputs effecting pitch
  - Control inputs effecting roll
  - Control inputs effecting yaw
- Review and show initial controller features and displays (if applicable)

<u>3.6.6 Introductory flight maneuvers</u>

- Box pattern
  - Flight box pattern with reference to ground
  - Emphasize smoothness of controls
  - Emphasize ground track and even leg distances
  - Describe control lag and system response
- Straight transects
  - Flight in one direction in straight line
  - Describe drone ability to hold altitude with changes in other control inputs like pitch
  - Describe and demonstrate the change in UAS visibility to determine orientation with distance
  - Flight to maximum VLOS to provide coordination between the VLOS definition and the actual sight picture.

<u>3.6.7 Complex flight maneuvers</u>

- Circle around a point
  - Emphasize smoothness and small corrections when using combined control inputs
  - Describe how applying different control inputs can affect drone attitude
  - Gain exposure to flying in the “region of reverse command”
  - Emphasize goal and reason of trying to achieve uniform circle

<u>3.6.8 Emergency procedures</u>

- Lost orientation exercise
  - Flight on limit of VLOS
  - Instructor maneuvers multirotor to induce disorientation
  - Upon student receiving the controls, must regain orientation
    - Teach knowledge of controls and effect on flight
- Lost link / fly away
  - Describe possible situation
    - Demonstrate if applicable
    - Relate responses from student to preflight preparation
- Low fuel or battery scenario
  - Describe scenario requiring emergency landing
  - Have student demonstrate controlled return flight
    - As fast as safe and practical
    - Goals in doing this

    - Describe Multirotor features for returning to home

3.6.8 Normal landing

- Describe typical landing procedure
    - Landing briefing
    - Approach at safe altitude
    - Determining landing zone
    - Clearing the area
    - Vertical decent
    - Final landing stage and touchdown
    - Motor shut down

3.6.10 After landing

- Multirotor shut down
    - Battery change sequence
- Controller shut down
- Multirotor disassembly
- Checklist usage
- Post flight briefing
- Logbook
- Allocate time for student questions

Chapter 10. Airman Certification Standards - Multirotor

10.1 Description

The goal of the airman certification process is to ensure the applicant possesses the knowledge, risk management, and skill consistent with the privileges of the certificate being exercised in order to act as pilot in command (PIC) under this certificate. UCB views the ACS as a more systematic, comprehensive, and standardized approach to airman certification training and testing.

The UCB DO has published this Airman Certification Standards (ACS) chapter to communicate the aeronautical knowledge and flight proficiency standards pertaining to the certification of pilots flying multirotor category UAS. The certification for this chapter consists of a practical test or checkride in which the DO expects the evaluator to assess the applicant's mastery of the topic in accordance with the level of learning most appropriate for the specified task. This practical test consists of both a ground, sometimes referred to as oral, and flight portion. The ground portions main purpose is to test the applicant's mastery of topics in a discussion format while the flight portion is more tailored to applicant's flight proficiency operational considerations. The oral questioning may continue throughout the entire practical test.

The evaluator is required to test the applicant on all categories listed below during the oral and practical stages of the checkride being conducted for the approval of this certificate. For certification under a different difficulty level decrease, and therefore increase the difficulty, the originally stated tolerance by 20% for level 2 difficulty rated UAS and 40% for level 3 difficulty rated UAS. If a new maneuver is required for certification on a higher difficulty level UAS the task title will have a preceding asterisk after. Two asterisks will indicate a maneuver which is required for certification on a level two difficulty rated UAS. Three asterisks will denote a maneuver which is required for certification on a level three difficulty rated UAS. If no asterisks are present the maneuver is required for the basic level one difficulty rated UAS certification as well as for the level two and three difficulty rated UAS but with increased standards (with increased tolerances by 20 or 40 percent).

10.2 Preflight Preparation

10.2.1 Task A. Pilot Qualifications

- Objective: To determine that the applicant possesses adequate knowledge, risk management, and skills associated with evaluating themselves as PIC.
- References:
  1. FOM sections: 3.15, 2.25, 2.19, 2.19.1, 2.12, 2.22, 2.4, 2.41, 2.42, 2.43, 2.43.1, 2.45, 3.202, 3.21

- Knowledge:
    1. Initial PIC Requirements
    2. Flight Currency
    3. Privileges and Limitations
    4. Medical Qualifications
    5. Documents required to exercise privileges
- Risk management:
    1. Failure to distinguish between currency and proficiency.
    2. Inability to ensure fitness for flight.
    3. Failure to Identifying hazards when piloting unfamiliar UAS or using unfamiliar display or control systems.
- Skills:
    1. When evaluator presents example, applicant can determine requirements to act as PIC under the given flight rules and situational conditions.
    2. Applicant knows and can show evaluator the required documents which need to be on and available when acting as PIC.

10.2.2 Task B. UAS Airworthiness Requirements

- Objective: To determine that the applicant possesses adequate knowledge, risk management, and skills associated with evaluating the UAS intended for flight.
- References:
    1. FOM sections: 2.44, 2.47, 4.14, 4.13, 5.1, 2.37, 7.5
- Knowledge:
    1. UAS flight manual, marking, and placard requirements.
    2. UAS ownership requirements.
    3. Initial airworthiness.
    4. Continuing airworthiness.
    5. LIPO battery storage and use.
    6. UAS discrepancies.
    7. Aircraft Registration.
- Risk management:
    1. Inoperative or nonairworthy equipment may be difficult to recognize and must be dealt with appropriately. This may be a new process for the applicant, so familiarity and practice are important for safety and risk mitigation.
    2. UAS abides by constantly changing FAA, COA, and FOM regulations regarding maintenance, placards, and airworthiness. Rules change over time and the applicant is familiar with where to find new rules and regulations.
- Skills:
    1. Applicant can describe the UAS airworthiness and registration information and process.
    2. In scenario given by the evaluator applicant can determine if the UAS is airworthy.
    3. Applicant can explain continuing airworthiness and its importance.

10.2.3 Task C. Weather

- Objective: To determine that the applicant possesses adequate knowledge, risk management, and skills associated with evaluating UAS weather requirements.
- References:
  1. COA
  2. FOM sections: 2.8, 2.81
  3. Night Flying Training PP
- Knowledge:
  1. Weather minimums
  2. Cloud clearance requirements
  3. METAR
  4. UAS ability and limitations on wind and weather
- Risk management:
  1. Determining possible weather which warrants a flight cancelation.
  2. Changing weather and environment effects on safe operation.
  3. Risks with flights in adverse or diminishing weather.
- Skills:
  1. Using the blanket COA weather minimums and standard cloud clearance requirements the applicant is able to determine if UAS flight is possible.
  2. Given a current METAR applicant has ability to accurately determine location, visibility, height of lowest ceiling.

10.2.4 Task D. National Airspace System, COA, and Flight Planning

- Objective: To determine that the applicant exhibits satisfactory knowledge, risk management, and skills associated with operating in the national airspace system (NAS) under the current UCB blanket COA.
- References:
  1. FOM sections: 1.3
  2. COA
  3. An Introductory Guide to Airspace and Use of a VFR Sectional Chart
- Knowledge:
  1. Types of airspace and associated requirements.
  2. Chart symbology.
  3. SUA.
  4. TFR.
  5. Airport proximity.
  6. Sectional chart time reversions.
- Risk management:
  1. Applicant has familiarity with different UCB approved resources pertaining to airspace.
  2. Various classes of airspace have different regulations, look similar, and can be difficult to decipher which could cause confusion to a new applicant.
- Skills:

1. Applicant can determine the airspace in a certain location from a scenario given by the evaluator.
2. Applicant understands airspace reversions and can correctly navigate the different websites and sources to find the correct information.

10.3 Preflight Procedures

10.3.1 Task A. NOTAM Submission

- Objective: To determine that the applicant possesses adequate knowledge, risk management, and skills associated with UAS NOTAM submission.
- References:
  1. FOM sections: 2.22, 2.22.1 → Update with updated FOM
  2. COA
  3. NOTAM Submission Guide
- Knowledge:
  1. Familiarity with filing database
  2. Location format: determination, size, documentation, and verification
  3. Valid time format: length and correct time zone
- Risk Management:
  1. Unfamiliarity with location designation submission format thus providing unclear or unusable information.
  2. Inability to make realistic submissions could cause confusion to other NAS users.
- Skills:
  1. Applicant can file a NOTAM which accurately covers and corresponds to the location and time of proposed flight, which is consistent with all FOM, COA, and FAA regulations.

10.3.2 Task B. Preflight Assessment

- Objective: To determine that the applicant possesses adequate knowledge, risk management, and skills associated with evaluating the UAS as airworthy before flight.
- References:
  1. FOM sections: 2.22 → update with updated FOM
  2. UAS manufacture documents
  3. UAS Checklist
- Knowledge:
  1. Pilot self-assessment
  2. UAS specific preflight actions
     - What items must be inspected
     - The reason for checking each item
     - How to detect possible defects
  3. Checklist usage
  4. Initial crew briefing

- Risk Management
    1. Inoperative or nonairworthy equipment may be difficult to recognize and must be dealt with appropriately. This may be a new process for the applicant, so familiarity and practice are important for safety and risk mitigation.
    2. Decision making to terminate the flight early or upon receipt of unairworthy information when external pressures exist may be very difficult for a first-time applicant.
- Skills:
    1. Applicant can inspect UAS with reference to appropriate checklist.
    2. Applicant can verify UAS is airworthy and in condition for safe flight.
    3. Applicant can give detailed and accurate crew briefing encompassing all important aspects of proposed flight.
    4. Applicant can prove all crew members are legal and safe to conduct the operation.

10.3.3 Task C. Engine Starting

- Objective: To determine that the applicant possesses adequate knowledge, risk management, and skills associated with recommended engine starting procedures.
- References:
    1. UAS Checklist
    2. UAS Manufacturer Documents (if applicable)
- Knowledge:
    1. Normal engine start
    2. Safe locations for start
- Risk Management:
    1. Propeller safety at all times.
    2. Battery safety at all times.
- Skills:
    1. Position UAS properly, considering structures, other UAS, wind, and safety of nearby persons and property.
    2. Proper UAS engine start procedures.

10.4 Takeoff and Landings

10.4.1 Task A. Normal Takeoff and Climb

- Objective: To determine that the applicant exhibits satisfactory knowledge, risk management, and skills associated with normal takeoff and climb procedures.
- References:
    1. UAS Checklist
    2. UAS Manufacturer Documents (if applicable)
- Knowledge:
    1. Effects of atmospheric conditions on takeoff
    2. Appropriate power settings
    3. Minimum altitude safe altitude

- Risk Management:
    1. Selection of acceptable takeoff area and risks associated with it.
    2. Collision hazards, to include other UAS and obstacles during takeoff phase.
    3. Distractions, loss of directional control, improper task management during critical phase of flight.
    4. Assessment and avoidance of excessive control and ground induced instability.
- Skills:
    1. Ability to clear takeoff area.
    2. Lift off in stable and safe manner before initiating climb.
    3. Maintain directional control and proper wind drift correction throughout climb.
    4. Initial climb altitude is suitable for VLOS and safe from obstacles.

10.4.2 Task B. Normal Decent and Landing

- Objective: To determine that the applicant exhibits satisfactory knowledge, risk management, and skills associated with normal decent and landing procedures.
- References:
    1. UAS Checklist
    2. FOM sections: 2.26
    3. UAS Manufacturer Documents (if applicable)
- Knowledge:
    1. Effects of atmospheric conditions on landing
    2. Stabilized approaches
    3. Autoland or final stage landing procedures
    4. Landing briefing
- Risk Management:
    1. Selecting suitable landing area and risks associated with it.
    2. Collision hazards, to include, other UAS and obstacles.
    3. Distractions, loss of directional control, improper task management during critical phase of flight.
- Skills:
    1. Proper landing briefing.
    2. Maintain safe altitude before final decent to LZ.
    3. Maintain directional control and proper wind drift correction throughout decent.
    4. Stable approach down to minimum hovering altitude right before touchdown.
    5. Correct controller inputs used to land UAS on ground.

10.5 Performance and Ground Reference Maneuvers

10.5.1 Task A. Box Pattern

- Objective: To determine that the applicant exhibits satisfactory knowledge, risk management, and skills associated with a flying the box pattern maneuver.
- References:
    1. FOTM Training Sections
- Knowledge:
    1. Control input and UAS response
    2. Power output changes with varying control inputs
    3. Orientation determination
    4. Wind effect on UAS and needed control to hold location
- Risk Management:
    1. Collision hazards, to include UAS, terrain, and obstacles. The area selected for this maneuver considers these factors.
- Skills:
    1. Clear the area.
    2. Select altitude sufficient for VLOS and obstacle avoidance.
    3. Fly even box pattern with reference to ground track. Each leg should be the same length to within 25 ft.
    4. Each turning corner is well defined.

10.5.2 Task B. Straight Transects

- Objective: To determine that the applicant exhibits satisfactory knowledge, risk management, and skills associated with the straight transect flight maneuver.
- References:
    1. FOTM Training Sections
- Knowledge:
    1. Control input and UAS response
    2. Power output changes with varying control inputs
    3. Wind effect on UAS and needed control to hold straight ground track
    4. Change in control inputs when flying backwards
- Risk Management:
    1. Collision hazards, to include UAS, terrain, and obstacles.
- Skills:
    1. Clear the area.
    2. Select altitude sufficient for VLOS and obstacle avoidance.
    3. Fly to predetermined point within 50feet without reference to any instruments or displays.
    4. Then fly backward, with forward facing to original starting point within 50 feet without reference to any instruments or displays.
    5. Ability to hold a flight path along the center line of the transect to within +/-15 feet.

10.5.3 Task C. Circles Around a Point

- Objective: To determine that the applicant exhibits satisfactory knowledge, risk management, and skills associated with turns around a point.
- References:

1. FOTM Training Sections

- Knowledge:
    1. Control input and UAS response
    2. Power output changes with varying control inputs
    3. Flying in the region of reverse command
- Risk Management:
    1. Collision hazards, to include UAS, terrain, and obstacles.
    2. Effects of quick reactions when UAS is in “region of reverse command”.
- Skills:
    1. Clear the area.
    2. Select altitude sufficient for VLOS and obstacle avoidance.
    3. Select suitable ground reference area for maneuver.
    4. Complete one 360-degree orbiting turn around a prespecified point with the longitudinal axis of the UAS pointing towards the center point for the entirety of the turn.
    5. Radius of turn is prespecified and held within 15 feet.

10.6 Emergency Operations

10.6.1 Task A. Loss of Orientation

- Objective: To determine that the applicant exhibits satisfactory knowledge, risk management, and skills associated with a UAS loss of orientation scenario.
- References:
    1. FOM Sections: 2.18, 2.19, 2.34
    2. FOTM Training Section
- Knowledge:
    1. VLOS rules and regulations
    2. Control inputs effect on UAS movement
    3. Autolevel and inherent stability of UAS
- Risk Management:
    1. Altitude awareness at extended distances.
    2. Effects of quick reactions when UAS is in “region of reverse command”.
- Skills:
    1. Ability to determine orientation and return UAS into VLOS in timely manner.

10.6.2 Task B. Lost Link Scenario

- Objective: To determine that the applicant exhibits satisfactory knowledge, risk management, and skills associated with a possible lost link scenario while flying the UAS.
- References:
    1. FOTM Training Sections
    2. FOM Sections: 2.18, 2.19, 2.34
    3. UAS checklist

- Knowledge:
    1. Preflight preparation on the variety of hazards in the flight area with a possibility of effecting that UAS flight
    2. Actions available to recapture a lost link signal
    3. UAS range and flight time
    4. Controller and UAS emergency switches
- Risk Management:
    1. Known risks in and around flight area.
    2. Inappropriate or nonstandard actions may cause added unnecessary confusion and panic.
- Skills:
    1. Applicant can determine appropriate actions to take during a simulated lost link scenario including knowledge of required information to communicate to nearest airport or possible at-risk facility if applicable.

10.6.3 Task C. Low Fuel / Low battery

- Objective: To determine that the applicant exhibits satisfactory knowledge, risk management, and skills associated with a low fuel or low battery emergency while flying the UAS.
- References:
    1. FOM Sections: 2.18, 2.19, 2.34
    2. UAS checklist
- Knowledge:
    1. UAS battery and fuel limitations
    2. UAS response to low fuel or battery situation
    3. Possible actions to extend UAS fuel life
- Risk Management:
    1. Added risk with aggressive control inputs and flying faster when trying to execute a quick maneuvers or landings.
- Skills:
    1. Determine suitable landing area.
    2. Preform emergency or precautionary emergency landing.

10.6.4 Task D. Emergency Landing

- Objective: To determine that the applicant exhibits satisfactory knowledge, risk management, and skills associated with an emergency landing.
- References:
    1. FOM Sections: 2.18, 2.19, 2.34
    2. UAS checklist
- Knowledge:
    1. Immediate action items and emergency procedures
    2. Landing briefing
    3. Safe landing zone
    4. Safe altitude
    5. Situations that require an emergency landing
- Risk Management:

    1. Added risk with aggressive control inputs and flying faster when trying to execute quick maneuvers or landings.
    2. The original landing zone may pose more hazards then desired and a new landing zone should be selected.
- Skills:
    1. Determine if UAS has ability to safely land in originally planned LZ.
    2. Execute stabilized but timely emergency approach and landing.

10.7 Shutdown and Securing UAS

10.7.1 Task A. Shut down and securing UAS

- Objective: To determine that the applicant exhibits satisfactory knowledge, risk management, and skills associated with a shut down and securing operations for the UAS.
- References:
    1. FOM Sections: 2.46,2.46.1
    2. UAS Checklist
- Knowledge:
    1. UAS shutdown, securing, and postflight inspection
    2. UAS disassembly and storage procedures
    3. UAS required documentation
    4. Required logbook entries
- Risk Management:
    1. Inappropriate activities and distractions.
    2. PIC professional and proper decision making until completion of *entire* flight.
    3. Towards end of flight it is crucial to avoid rushing and unsafe practices.
- Skills:
    1. Complete appropriate checklist.
    2. Shutdown and power down of all applicable components.
    3. Proper disassemble and storage UAS.
    4. Correct and complete logbook entries.

Descriptions- Specific Training Curriculum: Multirotor

Definition: The definition of a multirotor is a helicopter type UAS having more than two lift generating rotors.
Typical uses/missions: Typical uses for multirotor vary but common multirotor uses include flights involved in photography, filming, racing, data collecting, etc.
Risk associated with multirotor and missions: Multirotor relay heavily on electronics and control boards for stability. A malfunction of these control boards could be catastrophic. Multirotor have multiple engines which need to produce a predetermined required amount power in order to stabilize and control the drone. If one of these motors fails completely or partially a crash is imminent. Most drones have complex software with presets that can be hard to understand. Although it is rare, it is possible for the software to malfunction, control the UAS in undesirable ways, and take control away from the pilot. A large amount of multirotor mission involve filming and photography. Some desired photograph places are in commonly visited areas and the risk of flying over people and in congested airspace poses added risk.
Training type flying: The multirotor training that UCB provides is done in coordinates with FOTM related documents. This type of training includes the operation of a well-known and common multirotor in the industry. The training covers everything from preflight inspections, drone set up, controller settings, camera settings, takeoffs, landings, common maneuvers, emergency procedures, postflight inspections, and packing or storage. The majority of the training flights take place at model airports or designated flying areas away from additional distractions.
General characteristics: Multirotor are unique in the fact that they operate similar to a helicopter but with added inherent stability. Although some multirotor have three, six, eight, or ten motors the most common multirotor types have four motors. For this reason, in this training we will primarily refer to the “quadcopter”, four motor, multirotor type UAS. This drone has four motors located on all four corners of the UAS. The motors are connected to booms which connect to the main “fuselage” of the drone. The fuselage on most quadcopter type multirotors house the electrical components, the battery, and any camera(s) or additional equipment.
Motor: Most electronic motors on quadcopter category multirotors are brushless outrunners. These motors operate on the principle of electromagnetism. You will notice that if you spin the shaft of brushless outrunner the outside of the motor spins. The outer portion of the brushless out runner is called the bell portion of the motor and it consists of a motor shell and magnets lined on the inside. The stator part of the motor is the inner part of the motor which is fix with relation to motor rotation. The stator has electromagnets which are all wired in parallel in a slightly different way, normally opposite magnets change at the same time to cause rotation of the outer portion of the motor. When power is given to the motor electricity flows through these wires, charges up the magnets, which causes rotation. Motors have naming conventions which typically include the total length and diameter along with a KV rating. There are a wide variety of different motor ratings, sizes, and types so its important to know what type your motors are and how your motors work.
Electronics: In order to get the motors to run properly the DC battery voltage from your battery is converted and controlled though what is called an ESC (or electronic speed

controller). This speed controller takes a DC input voltage and converts it to three phase alternating current which is outputted to the motors. This AC voltage is what is sent to the motor and is the main sources which causes the motors to spin. The speed controller also varies the amount of voltage and amperage output to control the power output of each motor.

Most quadcopters also have a power distribution board which takes power from the DC battery and distributes it to each motor's electronic speed controller (ESC). The power distribution bord could be part of the frame of the multirotor or could be a mounted printed circuit board.

Lastly, all multirotors have flight controllers. Flight controllers are needed to provide stability and control response. This is the brain of the multirotor and depending on the type of controller, may be programmed to include features like automatic stabilization, return to home, level hover, etc.

Battery: Most multirotors operate using LiPo batteries. Lithium polymer batteries, LiPo batteries for short, use lithium ion technology with polymer electrolytes. They are very energy dense batteries and are commonly used in devices which have weight restrictions. LiPo batteries are used commonly in UAS's but are also very common in smart phones. There is no real inherent danger with LiPos but proper storage and damage evaluation is critical for safety. Some batteries which are used to power UASs include smart technology which transmits battery data from the battery to and onboard control system which may give pass along data to the user. These batteries are more complex and must be compatible with the all communication systems.

UAS Axes: In order to better describe the drone controls, it is important to describe the different axes of a drone. There are three axes: the longitudinal axis, the lateral axis, and the vertical axis. To define these axes, lets imagine the front and back of a drone as viewed from the pilot's common flying perspective. With the multirotor laying on the ground, the axis that points from the front to the back of the drone is considered the longitudinal axis. The lateral axis runs 90 degrees to the longitudinal axis, in a plane which is level to all the motors propellers. The lateral axis can be thought of as the axis you look down when looking left and right if sitting in the multirotor. Finally, the vertical axis is the axis that points through the top and bottom of the multi rotor and can be thought of as the axis which you look through when looking directly up and down if "sitting" in the multirotor. This axis is the axis of the cross product of the lateral and longitudinal axis. The normal direction of this axis is down.

Maneuverability: Control for quadcopter type multirotors comes from varying the power of specific motors to get a desired effect. Varying all motors thrust evenly allows for the UAS to climb and descend. Varying all motors to the left or right side of the longitudinal axis creates a moment which induces roll. Varying all motors behind or in front of the lateral axis creates forward or backward pitch. Finally, yaw is controlled by keeping net thrust the same but varying the thrust of the counter rotating and non-counter rotating motors to increase the angular momentum in one direction or another.

General concept: Control of the multirotor is achieved through wireless communication and the use of a transmitter in the controller sending signals to "talk to" a receiver receiving signals on the drone.

Radio wave propagation: Signals sent from the transmitter to the receiver are electromagnetic waves which propagate through the atmosphere at roughly the speed of light. These electromagnetic waves are signals which are modulated to carry specific information which can be interpreted and use once received. When you move a control on the controller a signal is measured then modulated and sent from the transmitter to the receiver, which receives this signal, demodulates it to gather the desired sent information.

Transmitter: The transmitter is normally a built-in component in the controller. The transmitter sends desired control input data through the air via the antenna(s) mounted on the controller. It's common for controllers to have one antenna but occasionally multiple are installed. It is important to note that antenna wave propagation comes out the side of the antenna and not through one point at the top (this is a common misconception).

Receiver: The receiver on most multirotors is built into the control board/ flight computer, but could be a completely separate piece of hardware. It works in a similar principal to the transmitter, but its goal is on receiving the information sent from the transmitter. Typically having two antennas for receiving, normally positioned at ninety degrees to each other, the data can be received in almost any orientation. Because receivers can differ is important to become familiar with the specific type of receiver on the multirotor being used for training.

On some DJI products there are actually transmitter and receivers on both the multirotor and the controller and this allows for multirotor data to be sent and displayed on the controller screen but typically a transmitter is used for UAS control and receiver is what is on the UAS and receives the desired signals inputted into the transmitter.

Multirotor controllability: This section relates similarly to the maneuverability section described above. In this section we will discuss what is done when certain controls are moved on the controller and what effect they have on the multirotor. The left stick of the controller controls throttle and yaw. When the stick is moved up or down the power on all motors speeds up or slows down. This causes the multirotor to climb and descend vertically. Moving the left stick right and left causes clockwise rotating motors to speed up and counterclockwise rotating motors to slow down. This change in angular momentum cause the multirotor to yaw left or right. Looking at the right stick. If you move the right stick up and down this controls pitch. Pushing the stick full forward causes the rear motors to spin up and raising the tail of the multirotor up and pushing the nose forward. Pulling the right stick down causes the front motors to speed up and the back motors to slow down. If held in the respective positions these actions will cause the multirotor to move forward and back. If you move the right stick right, the left motors will speed up causing a roll to the right. If you move the right stick left the right motors will speed up causing a roll to the left. If held in the respective positions these actions will cause the multirotor to move left and right. Some control boards have preprogrammed constraints to limit deflection of the multirotor and some have mixing technology which compensates for the change in lift when varying different motor speeds as the effect of some control inputs in order to hold a constant altitude. Familiarity with your multirotor control board is key in order to successfully fly some of the required training maneuvers.

Possible RC errors: When operating wirelessly there is always a possibility for errors. Although its rare it is important to know what error possibilities exist and how to mitigate the risk. There are two main reasons for RC errors, frequency interference and antenna placement. Frequency interference could come from a lot of different sources or environmental factors like signals operating on the same frequency without preceded messages, some type of conductive shielding in the way of the signal, power losses over great distances or through different environments or weather conditions, and antenna placement could cause signals to be received out of phase or with less power than required.

Prior to arrival: A training briefing should be conducted to determine what is the main objective for the day. The student NOTAM submission should be checked for accuracy and detail before conducting the flight. It might be advantageous for the instructor to file a backup NOTAM. Before leaving for the training area in which the training flight will be conducted, confirm that all required batteries are charged and undamaged. A flight kit or UAS transportation kit should be checked for all the correct parts or components (including propellers, spare parts, buddy box cables).

Preflight preparation: The mandatory use of checklist should be one of the first lessons implemented on a training flight. This use of checklist in the preflight steps of the flight sets the mentality for the use of checklists through the rest of the flight. The checklists can be used in a call and response format or a check but verify format. The call and response technique would be reading line by line the correct call, followed by that action, and the correct response. The do and verify or check and verify method is doing all of a phases action (preflight, landing, etc) then checking your actions for completeness based on the correct checklist section. The checklist will cover the majority of the other steps discussed in the paragraph but if need the instructor should go into a more in depth explanation on certain checklist section, for example the controller boot section (keep in mind that this is most likely the students first time using a control of that type). If the controller connects to a GPS satellite review all applicable messages when the control is achieving a GPS fix. If the drone is equipped with an FPV or camera set up review all connections and applicable controller inputs. If the controller has any emergency switches review those as well and describe the scenarios in which they should be used. Finally, one final demonstration or explanation should cover the normal controls for operating that UAS.

Initial crew briefing: This briefing should follow the standard initial crew briefing with a training-oriented twist. Go over location safety hazards, a plan for any foreseeable emergencies, and describe all the flight maneuvers to be performed. Typical flight maneuvers for the initial drone training event will include those which are identical to what needs to be performed on a checkride: box pattern, straight transects, turns around a point, loss of orientation, lost link scenario, low battery emergency with emergency landing, normal landing, and normal takeoff. Describe the procedure for who will fly and when and if any instructor demonstrations will be performed.

Takeoff: Follow the checklist for a normal takeoff but explain the typical procedure in more of a discussion format to the student. For most multirotor takeoffs, the drone will be positioned in a suitable takeoff location with the motors off and the area clear. After that the controller sequence to start the motors is initiated and the motors turn on to a low power setting. When takeoff is desired the student should slowly advance the throttle stick until the drone begins lift off. Once lift off occurs the throttle can be used to increase the rate of ascent. A stable ascent is desired for safety and control ability.

Initial flight familiarity: Once at a suitable altitude the student should play with different the controls by moving the controllers sticks around and observing the effect of the drone. Ideally varying one control to see the effect on each axis at a time is important. This initial familiarity is crucial as it is typically the first exposure a student has to hand eye coordination when flying a drone and will be the basis on what the student uses to build his or her knowledge.

Introductory flight maneuvers: For the initial flight training there are two introductory flight maneuvers which are normally taught to students. One is the box pattern and other is straight transects. The box pattern maneuver is a simple ground reference maneuver in which the pilot attempts to make an even box across the ground. Goals of this maneuver are to determine even lengths across the ground without reference to any on board camera or telemetry and based on the skill of the pilot and his/her ability to determine distance based on multirotors size and relative location. The next goal is to understand the response of the flight controls. Not over shooting corners but anticipating response of flight controls to stick movements in order to make smooth transitions at each corner. The box maneuver is completed with the drones orientation facing the same direction throughout the entirety of the maneuver. The transient flight maneuver is used to test the students ability to determine UAS distance with respect to UAS size and to demonstrate the effect of altitude loss on pitch controls (if applicable). This maneuver will start with the instructor asking the student to fly to some predetermined desired point on a straight-line path and stop whenever he or she believes to be over that point. If the drone does not have features which compensate for loss of vertical thrust with changes in pitch the drone will descend when a forward pitch control is applied, thus additional throttle is needed to maintain altitude. This maneuver is also difficult because as the drone gets farther and farther away it appears to lose altitude as well so exposure to these phenomena will be beneficial to the students understanding. This is why it is important to understand the specific tuning of the drone to determine what actions will be required to make a constant altitude straight line flight.

Complex flight maneuvers: The complex flight maneuver section is for testing the skill of the pilot when flying the drone through a ground reference maneuver which requires constant changing of control inputs to continuously change the movement of the drone when in different orientations. In the circle around a point maneuver it is important to have the “center” axis, longitudinal axis, or camera view to be fixed at one point all throughout the circle. This maneuver requires finesse and constantly changing control inputs. The goal of this maneuver is to test to smooth inputs of the pilot and show/introduce the pilot to the region of reverse command. In this region the controls are essentially reversed as the front of the drone is facing the pilot where it normally the complete opposite direction. Before starting this maneuver it may be beneficial to let the student experiment with flying the drone in a backwards orientation first.

Normal landing: A normal landing should be done in coordination with the checklist. A more in-depth teaching of the process from the instructor is desired before the student completes a normal landing for the first time. A brief overview of the importance of flying over the landing zone at an appropriate altitude should be discussed. The major reasons are for safety and obstacle avoidance. The actual altitude should not be drastically high but high enough to avoid obstacles and low enough to reasonably predict when the drone will be right over the desired landing zone. After the area is clear a stable approach should be used all the way down to landing height. Depending on the drone type some may hover at an altitude right over the ground, landing height, until a certain control input is used to "force" the drone to land. If this is applicable to the drone used in training, that feature should be discussed.

Emergency procedures: There are three typical emergency procedures that are taught on a training event. One is a loss of orientation exercise. In this exercise the instructor will fly the drone out to the edge of VLOS and maneuver it in a way to disorient the student. When the student regains control it is up to them to determine the orientation and return the drone back to a more visible location. This should be done without the help of any onboard camera or additional sighting device. The goal in this exercise is to test the student's ability to use control inputs to coordinate the movement of the drone to what the student is seeing in order to determine its orientation. This exercise also provides a lesson on the VLOS requirements and what constitutes the max VLOS for that specific multirotor. The next emergency exercise is a lost link exercise. This is not a flight maneuver but a scenario presented in oral fashion from the flight instructor to the student. This is best done while the student is flying to simulated the stress of the actual situation and to show the student the importance of proper flight training. The lost link or fly away scenario should include a scenario in which the drone is flying in a certain direction away from the flight area. It will be up to the student to describe the course of action which he or she will take in order to prevent hazards to surroundings. The use of an emergency checklist is encouraged in the situation but the overall knowledge of the area and preflight preparation should be tested. The last emergency procedure which is done in multirotor training is the low fuel or battery exercise. In this case the instructor will tell the student to conduct and emergency landing because of low battery annunciation. The student will need to use proper judgement, checklists, and memory items to quickly but safely get the drone on the ground as quickly as possible. The goal of this exercise is to test the students ability to make sound decisions in a time of stress with the main emphasis on safety all while controlling the UAS.

After landing: The after-landing training should consist of proper checklist usage, postflight inspections, and a thorough postflight briefing. Motor shutdown should be one of the first action items after landing. Depending on the drone type the shutdown sequence can differ. It is important to explain the proper way in which the motors should be shut off. After proper motor shutdown is reviewed and completed, retrieval of the UAS should commence. It is important to make sure the student know that the propellers of the UAS should be treated with great respect until the battery is removed. While following the checklist, battery removal and multirotor disassembly should be described in detail. Although some checklists may be concise in this section, detailed explanations allow the student to make mental connections to actions which will help in future multirotor use. The post flight briefing should follow, the correct format with an example debrief or explanation of the typical debrief should be explained by the instructor to the student. A time for questions should be allowed so the student can clarify any confusing areas.