**Cover Page**

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| Lesson Title | Net Forces with Drones |
| Context Key Words | Net Force, Drone, Lift, Physics Applications |
| Grade Level | 9-12 |
| Next Generation Science Standards | HS-PS2-1 Analyze data to support the claim that Newton’s second law of motion describes the mathematical relationship among the net force on a macroscopic object, its mass, and its acceleration. |
| Science and Engineering Practices | * Planning and carrying out investigations * Analyzing and interpreting data * Using mathematics and computational thinking |
| Supplies Needed | * One drone per group (preferably one of the inexpensive drones that operates without a speed regulator) * Scale for finding masses * Timers (ideally three per group) * Washers or coins suitable for adding mass to drones * Point of known height, such as a field goal pole |
| Lesson Outline | * Students begin with a background understanding of standard instruction in types of forces, net forces, and acceleration. * Help students to visualize the system of forces involved when a drone lifts in the vertical dimension: weight, lift (or “applied force”), and net force. * Provide students with the task description: Determine the lifting force provided by the drone’s rotors working at three or more different settings. To do this, students must find the acceleration, net force, and weight of the drone. To begin, students must collect data on the mass of the drone as weight is added, and the time it takes for the drone to reach a pre-determined height. * If desired, provide students with the attached worksheet. Alternatively, have students decide on their own what data they will need to collect, and then decide on a path to calculate the lifting force applied by the drone’s rotors. * Conclude the lesson by having students write a summary of their work (procedure, results, conclusions), including force diagrams and a graph of some results. |
| Time Needed | 90 minutes |

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| **Activity Context** |

Newton’s second law states that the net force (Fnet)acting on an object equals mass (m) times acceleration (a).

Equation 1: Fnet = ma.

In the case of a drone flying vertically, the net force is also equal to the sum of two forces acting in the opposite direction: the drone’s weight (Fw) and the lift provided by the drone’s rotors (FL).

Equation 2: Fnet = Fw + FL.

Students can determine the weight and mass of the drone using a scale (and converting weight into mass using Fw = mg).

Equation 3: Fw = mg

The lift force of the drone’s rotors is what remains from the net force according to Equation 2. Students can calculate the acceleration of the drone using any of several standard acceleration equations. One way is to record time and distance data, starting from rest and timing the drone to reach a known height.

Equation 4: d = vit + 1/2at2

Another option is to use data from the drone control interface to record the initial and final velocities while timing the drone’s rise.

Equation 5: vf2 = vi2 + 2ad

Once the acceleration of the drone has been found, students can determine the net force acting on the drone, using equation 1.

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| **Student Directions**   1. Have students consider the task and the system of equations. Ask them to consider what data they will need to record. 2. Specifically note that time is a critical variable for determining acceleration, and suggest that students might want to employ three timers for each trial, taking the middle number. 3. Inform students that the drone’s flight is very sensitive to weight distribution, so it will be important to attach weights carefully. 4. Remind students that adding weights to the drone not only alters the value of Fw (from Equations 2 and 3), but also the value of m (from equations 1 and 3). (Failing to recognize this is a common error in this type of problem.) 5. Conclude by informing students the drone is a sensitive piece of equipment, and that you will be available to trouble-shoot problems and to answer questions. 6. Divide students into groups based in part on the available number of drones per student. | | | |
| **Making the Math Explicit** | | | |
| **Activity** | **Teaching Approach** | | **Estimated Time** |
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| Teacher Guidance/Questioning | | Anticipated Student Responses/Misconceptions | |
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| **Revisiting Context** | | | |
| **Activity** | **Teaching Approach** | | **Estimated Time** |
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|  | | Anticipated Student Responses/Misconceptions | |
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