**Measuring Rocket Impulse**

**Introduction**

The impulse data for model rocket engines is stated and shown graphically for Estes engines. This lesson will allow you to compare the manufacturer’s specifications with experimental data and compare apogee with several classes of engine.

**Learning Outcomes**

Upon completion of this lesson plan, students will be able to:

* Derive the impulse equation from Newton’s Second Law
* Graph impulse data from experimental launches and compare to engine manufacturer specifications.
* Conclude that the area under the curve of a force/time graph is the impulse
* Compare impulse data for several classes of rocket engines

**Curriculum Alignment**

Phy.1.2 Analyze systems of forces and their interaction with matter

Phy.1.2.3 Explain forces using Newton’s Laws of Motion as well as the universal law of gravitation.

Phy.1.3 Analyze the motion of objects based on the principles of conservation of momentum, conservation of energy and impulse.

Phy.1.3.2 Analyze the motion of objects based on the relationship between momentum and impulse.

**Critical Vocabulary**

* Momentum
* Impulse
* Apogee
* Altimeter
* Unbalanced Force
* Ignition
* Propellant
* Tolerance
* Thrust

**Classroom Time**

The equivalent of five 90 minute blocks (less 2 blocks of time if rocket construction can be done at home)

**Materials Needed**

* One model rocket for each student group
* One class launch pad
* One class launch controller
* Access to an electrical outlet and a large open field. This is best done with long extension cords.
* One spark timer with altered tape. (You must line the back side of the spark timer tape with masking tape to strengthen it and stop the timer tape from breaking while under force.)
* Graph paper and/or graphing software (like Excel)
* For first time rocket builders, I suggest using a low level skill classroom bulk pack kit sold at most hobby stores and made by Estes Rockets. <http://www.estesrockets.com/rockets/educator>
* For teachers and/or students with rocket building experience, higher level skill kits can be ordered from a model rocket supplier such as Apogee <http://www.apogeerockets.com/Rocket_Kits?zenid=lmt4dvkd790ia2eed4hf742ol3>
* And for those wishing to push the envelope, individual parts can be ordered <http://www.apogeerockets.com/Building_Supplies>
* Students can work individually or in pairs, groups of threes or fours, depending on budget constraints.
* You will need a launch pad and a launch controller (batteries are needed). <http://www.estesrockets.com/rockets/accessories/launch-systems>
* The rocket engine manufacturer Estes provides the following specifications for its rocket engines:
	+ [http://www.spaar.org/Downloads/Libra HYPERLINK](http://www.spaar.org/Downloads/Libra%20HYPERLINK%5C%22http%3A//www.spaar.org/Downloads/Library/EstesEngineSpecs.pdf%5C%22r%20HYPERLINK%5C%22http%3A//www.spaar.org/Downloads/Library/EstesEngineSpecs.pdf%5C%22y/EstesEngineSpecs.pdf)
	+ ["http://www.spaar.org/Downloads/Library/EstesEngineSpecs.pdf"r HYPERLINK](http://www.spaar.org/Downloads/Libra%20HYPERLINK%5C%22http%3A//www.spaar.org/Downloads/Library/EstesEngineSpecs.pdf%5C%22r%20HYPERLINK%5C%22http%3A//www.spaar.org/Downloads/Library/EstesEngineSpecs.pdf%5C%22y/EstesEngineSpecs.pdf)
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**Technology Resources**

* Spark Timer purchased from Fisher Scientific – catalog number S434172
* Spark Timer Tape purchased from Fisher Scientific – catalog number S434175
* Computer with Microsoft Excel
* Printer
* Video recorder and/or camera
* Altimeter

**Pre-activities**

1. Students should already have covered Newton’s Laws of Motion and should be familiar with Critical Vocabulary, listed in an above section. Students should also be able to apply the concepts of average velocity, displacement, acceleration and use data collected to calculate average velocity for a rocket in flight.

2. Students should be familiar with the operation of a spark timer.

3. The following excerpt is from the physicsclassroom.com website. Students must read this before coming to class:

**Momentum** is a commonly used term in sports. A team that has the momentum is on *the move* and is going to take some effort to stop. A team that has a lot of momentum is really *on the move* and is going to be *hard to stop*. Momentum is a physics term; it refers to the quantity of motion that an object has. A sports team that is *on the move* has the momentum. If an object is in motion (*on the move*) then it has momentum.

Momentum can be defined as "mass in motion." All objects have mass; so if an object is moving, then it has momentum - it has its mass in motion. The amount of momentum that an object has is dependent upon two variables: how much *stuff* is moving and how fast the *stuff* is moving. Momentum depends upon the variables [mass](http://www.physicsclassroom.com/Class/newtlaws/u2l2b.cfm) and [velocity](http://www.physicsclassroom.com/Class/1DKin/U1L1d.cfm). In terms of an equation, the momentum of an object is equal to the mass of the object times the velocity of the object.

**Momentum = mass • velocity**

In physics, the symbol for the quantity momentum is the lower case "p". Thus, the above equation can be rewritten as

**p = m • v**

where **m** is the mass and **v** is the velocity. The equation illustrates that momentum is directly proportional to an object's mass and directly proportional to the object's velocity.

The units for momentum would be mass units times velocity units. The standard metric unit of momentum is the kg•m/s. While the kg•m/s is the standard metric unit of momentum, there are a variety of other units that are acceptable (though not conventional) units of momentum. Examples include kg•mi/hr, kg•km/hr, and g•cm/s. In each of these examples, a mass unit is multiplied by a velocity unit to provide a momentum unit. This is consistent with the equation for momentum.

Momentum is a **vector quantity**. As discussed in an earlier unit, [a vector quantity](http://www.physicsclassroom.com/Class/1DKin/U1L1b.cfm) is a quantity that is fully described by both magnitude and direction. To fully describe the momentum of a 5-kg bowling ball moving westward at 2 m/s, you must include information about both the magnitude and the direction of the bowling ball. It is not enough to say that the ball has 10 kg•m/s of momentum; the momentum of the ball is not fully described until information about its direction is given. The direction of the momentum vector is the same as the direction of the velocity of the ball. In a previous unit, it was said that [the direction of the velocity vector](http://www.physicsclassroom.com/Class/1DKin/U1L1d.cfm) is the same as the direction that an object is moving. If the bowling ball is moving westward, then its momentum can be fully described by saying that it is 10 kg•m/s, westward. As a vector quantity, the momentum of an object is fully described by both magnitude and direction.

From the definition of momentum, it becomes obvious that an object has a large momentum if either its mass or its velocity is large. Both variables are of equal importance in determining the momentum of an object. Consider a Mack truck and a roller skate moving down the street at the same speed. The considerably greater mass of the Mack truck gives it a considerably greater momentum. Yet if the Mack truck were at rest, then the momentum of the least massive roller skate would be the greatest. The momentum of any object that is at rest is 0. Objects at rest do not have momentum - they do not have any "[mass in motion](http://www.physicsclassroom.com/Class/momentum/U4L1a.cfm)." Both variables - mass and velocity - are important in comparing the momentum of two objects.

The [momentum equation](http://www.physicsclassroom.com/Class/momentum/U4L1a.cfm) can help us to think about how a change in one of the two variables might affect the momentum of an object. Consider a 0.5-kg physics cart loaded with one 0.5-kg brick and moving with a speed of 2.0 m/s. The total mass of *loaded* cart is 1.0 kg and its momentum is 2.0 kg•m/s. If the cart was instead loaded with three 0.5-kg bricks, then the total mass of the *loaded* cart would be 2.0 kg and its momentum would be 4.0 kg•m/s. A doubling of the mass results in a doubling of the momentum.

**Momentum and Impulse Connection**

Momentum is a commonly used term in sports. When a sports announcer says that a team has the momentum they mean that the team is *really on the move* and is going to be *hard to stop*. The term *momentum* is a physics concept. Any object with momentum is going to be hard to stop. To stop such an object, it is necessary to apply a [force](http://www.physicsclassroom.com/Class/newtlaws/u2l2a.cfm) *against* its motion for a given period of time. The more momentum that an object has, the harder that it is to stop. Thus, it would require a greater amount of force or a longer amount of time or both to bring such an object to a halt. As the force acts upon the object for a given amount of time, the object's velocity is changed; and hence, the object's momentum is changed.

The concepts in the above paragraph should not seem like abstract information to you. You have observed this a number of times if you have watched the sport of football. In football, the defensive players apply a force for a given amount of time to stop the momentum of the offensive player who has the ball. You have also experienced this a multitude of times while driving. As you bring your car to a halt when approaching a stop sign or stoplight, the brakes serve to apply a force to the car for a given amount of time to change the car's momentum. An object with momentum can be stopped if a force is applied *against* it for a given amount of time*.*

A force acting for a given amount of time will change an object's momentum. Put another way, [an unbalanced force always accelerates an object - either speeding it up or slowing it down](http://www.physicsclassroom.com/Class/newtlaws/u2l2a.cfm). If the force acts opposite the object's motion, it slows the object down. If a force acts in the same direction as the object's motion, then the force speeds the object up. Either way, a force will change the velocity of an object. And if the velocity of the object is changed, then the momentum of the object is changed.

These concepts are merely an outgrowth of [Newton's second law](http://www.physicsclassroom.com/Class/newtlaws/u2l2a.cfm) as discussed in an earlier unit. Newton's second law (Fnet = m • a) stated that the acceleration of an object is directly proportional to the net force acting upon the object and inversely proportional to the mass of the object. When combined with the definition of acceleration (a = change in velocity / time), the following equalities result.



If both sides of the above equation are multiplied by the quantity t, a new equation results.



To truly understand the equation, it is important to understand its meaning in words. In words, it could be said that the force times the time equals the mass times the change in velocity. In physics, the quantity Force • time is known as **impulse**. And since the quantity m•v is the momentum, the quantity m•Δv must be the **change in momentum**. The equation really says that the

**Impulse = Change in momentum**

**Activities**

* Students need to assemble a model rocket. There are various kits (described in materials needed) that cover various skill levels. If built at school, this will take approximately one class day if not painted; two days if painted. We typically use colorful spray paint to help in rocket recovery. Immediately before flight, record the total mass of the rocket system.
* The students need to make modifications to the spark timer tape to increase strength - the tape will break off prematurely if it is not reinforced.
* Take 15 meter lengths of spark timer tape and place 15 meters of masking tape on the back side of the spark timer tape, running the entire length. Only the top side of the tape will make spark marks. The top is the shiny side.
* Cut and trim to fit. The opening in the spark timer is sufficient to fit this thicker tape piece.
* Thread the tape with the top side facing the marker of the spark timer.
* Use masking tape to connect the threaded spark timer tape to one fin on the rocket. The tape should be running along the slanted edge of the rocket fin.
* Aligning the rocket and tape to the spark timer will reduce interference from friction which can be substantial. I remind my students that the act of taking measurements always alters the experiment but we need to minimize effects whenever possible.
* Put in the spark timer and fix it to the ground. A bent coat hanger or two works well. Set the spark timer to 60 Hz.
* Have students step back behind the launch controller for safety purposes and launch rocket. Smaller engines will increase recovery rate, particularly if a very large field is not convenient to an electrical outlet.
* Once recovered, the tape needs to have all intervals measured. Since the timer was set to 60 HZ or 60 cycles per second, each interval has a constant time of 1/60th of a second. Velocities can be calculated at each interval, dx/dt, and then the change in momentum (Impulse) can be calculated, dv \* m. I have the students create a spreadsheet computing all values.

**Assessment**

Students will then compare their experimental impulse values with the manufacturer’s specifications. They will have to account for all discrepancies - both observed and potential sources. A formal Laboratory Report will also be completed including Objective, Materials, Procedures, Data, Data Analysis, Conclusion and Sources of Error.

**Community Engagement**

The American Association of Physics Teachers (AAPT) has been an extremely valuable resource for my students to present their original research using rocketry. Local University professors have taken great interest in helping my high school students by providing mentorship and resources not normally accessible to K-12 education. My students have presented twice to the AAPT – once at the local North Carolina chapter meeting and also at the National meeting in Portland, OR where they gave a contributed talk and a poster session on Green Physics: Developing a Model Rocket System to Measure Air Quality. <http://aapt.org/Resources/pre-college.cfm>

Team America Rocketry Challenge has provided us with mentors to assist with our custom rocket builds by providing guest speakers and lesson plan resources.

**Supplemental Information**

Resources from Team America Rocketry Challenge including everything from building rockets, Newton’s Laws and Aerodynamics (PDF): <http://rocketcontest.org/>

**Websites**

* NASA's Adventures in Rocket Science Educator's Guide (website): <http://www.nasa.gov/audience/foreducators/topnav/materials/listbytype/Adventures_in_Rocket_Science.html>
* Estes Educator’s Guide (website): <http://www2.estesrockets.com/cgi-bin/wedu001P.pgm?p=educator>
* National Association of Rocketry website has many teacher resources

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