Submissions for the next academic year accepted through November 1.

Application for Core Curriculum Approval

Click to enter date of submission.
11/12/2021

TABLE #1	General Information		
Course Title:	PHYS 1104 Introduction to Physics for Aviation		
Course Description as listed in the current Fairmont State Catalog:	This course introduces students to principles of mechanics and fluid mechanics (linear and rotational motion, force and torque, work and energy, buoyancy) and their application to flight (including fixed-wing aircraft, rotary-wing aircraft and lighter-than-air flight). The prerequisites are MATH 1540 or MATH 1585 or MATH 2501 or MATH ACT 24 or old MATH SAT 560 or new MATH SAT 580 or College Level Math of ACCUPLACER 65. This course is offered in the spring semester only.		
Prepared by:	Siegfried Bleher		Full-time
Preparer email address:	sbleher@fairmontstate.edu		
Course Coordinator:	Siegfried Bleher		Full-time
Course Coordinator email:	sbleher@fairmontstate.edu		
Core Curriculum Category & Corresponding Outcome:	Category 7 - Natural Science with Critical Thinking	7. Students will demonstrate proficiency with scientific content and data analysis to address real world problems, and recognize the limitations of the scientific process.	
Enter ALL course outcomes: **Note: If there are multiple outcomes this cell may spread onto another page. If that occurs, move Table #2 (page 7) onto a new page.**	The following course outcomes correspond to the sub-attributes of Category 7 – Natural Science with Critical Thinking: 1: Use the vocabulary of basic principles, facts and theories of physics applied to aviation. 2: Demonstrate an understanding of the process and limitations of scientific inquiry as applied to aviation physics. 3: Demonstrate the following skills: analysis; problem solving; quantitative manipulation; and, data interpretation/evaluation in the field of physics of aviation. 4: Apply analysis, problem solving, quantitative manipulation, and data interpretation/evaluation to accomplish meaningful goals in the field of aviation physics.		
Signature of Appropriate Discipline Faculty	Deb Hemler	Outcome 9 - Deb Hemler	10/28/2021
Signature of Unit Chair	Deb Hemler	Natural Sciences	11/11/2021
Signature of Unit Dean	Steven Roof	College of Science & Technology	11/11/2021

PHYSICS 1104

Introduction to Physics for Aviation

Spring 2021

Instructor: Dr. Siegfried Bleher **Tel**: (304) 367-4582

Email: Siegfried.Bleher@fairmontstate.edu

Office: HHH-114 **Office Hours**: M—W, F 2 – 3 pm
R 9 – 10 am

Lectures: HHH-308 MWF 8 am **Lab**: HHH-107 F 10:15 am – 1 pm

Required Textbooks: W. Brian Lane & Paul R. Simony, Introductory Physics with Aviation Applications

Test Schedule

Test One	Feb 14
Test Two	Mar 6
Test Three	Apr 3
Test Four	Apr 29
Final Exam	May 4

Grade Weighting Table

3 tests at 15% each	45%
Homework (online + turned in)	15%
Lab	15%
Attendance + Clickers	5%
Final Exam	20%

Grading Scale

A	90-100%
B	80-89%
C	70-79%
D	60-69%
F	0-59%

Learning Outcomes

Have you ever wondered how heavier-than-air flight is possible? Or how a drone can remain stable while suspended in air? Or what are the physics principles that determine the maximum altitude a Boeing 747 jet can fly? In this course you will not only learn fundamental principles that determine how and why things move, but you will also learn how these principles govern flight of various kinds, including airplanes, helicopters and drones, spaceflight and balloons.

Students will be able to…

- Use the vocabulary of basic principles, facts and theories of physics applied to aviation.
- Demonstrate an understanding of the process and limitations of scientific inquiry as applied to aviation physics.
- Demonstrate the following skills: analysis; problem solving; quantitative manipulation; and, data interpretation/evaluation in the field of physics of aviation.
- Apply analysis, problem solving, quantitative manipulation, and data interpretation/evaluation to accomplish meaningful goals in the field of aviation physics.

Topics

This algebra-based course covers the following topics:

- **Mechanics**: kinematics in 1D, kinematics in 2D, Newton's 3 laws, work-energy theorem, rotational kinematics and dynamics, impulse and momentum
- **Fluid Dynamics**: pressure, Pascal's principle, Archimedes' principle, Bernoulli's equation, Reynolds number
- **Thermodynamics**: Temperature, pressure, volume, equation of state, 3 laws of thermodynamics, gas laws (Boyle's law, Charle's law, Gay-Lussac's law, General Gas Law – equation of state, Avogadro's law, humidity, partial pressure)
- **Flight Kinematics -** Navigation in 3D: Euler angles, Aircraft Body frame, North-East-Down frame, pitch, yaw, roll; aircraft control surfaces
- **Flight Dynamics**: Forces involved in flight (thrust, lift, drag, weight). Planes, helicopters and drones, balloons, spaceflight

Lab Schedule

Week	Lab	Details
1	**Error Analysis**	significant figures, scientific notation, precision, accuracy, random errors, systematic errors, rounding errors, % uncertainty, % difference, standard deviation
2	**Vector Addition**	Force Table
3	**Motion Analysis**	Understanding 1D kinematics—displacement, velocity, acceleration
4	**Projectile Motion**	Kinematics in 2D with constant acceleration
5	**Rocket Flight Simulation; Rocket Build**	Principles of rocket flight: center of pressure, center of gravity, flight path, effect of fin shape and airfoil; build prefabricated model rocket, design and fashion airfoils
6	**Newton's 2nd Law Application**	Measure acceleration due to gravity *g* using Atwood machine
7	**Wind Tunnel**	Bernoulli's principle, navigation, roll, pitch, yaw, effect of shape and orientation of wing, effect of rivets and surface roughness on wing drag
8	**Rocket Launch**	Rocket launch, with altimeter, compare predicted dynamical and kinematic variables with measurements
9	**High Altitude Balloon Launch**	Principles of lighter-than-air flight; organizing launch and recovery; conduct test launch
10	**High Altitude Balloon Launch**	Launch high-altitude balloon from Duvall-Rosier Field; recover balloon; analyze data
11	**Measuring Centripetal Force**	
12	**Drone Flight**	torque, angular velocity, angular acceleration, angular momentum

Tests will be a combination of multiple-choice questions, and problems to be worked out in detail.

Final Exam The final exam is comprehensive and is given Monday May 4th at 8 – 10 am during Final Exam Week.

Labs Students are required to complete all lab sessions in the course, and must turn in a lab report when required to receive a grade for that lab. Each lab report will be due **at the beginning of the next lab session**. You must pass the lab portion of course with a 60% score in order to pass the course. Lab reports that are more than a week late will lose 5 points (out of 25).

Post-Lab Quizzes Many labs will have a post-lab quiz to be taken at the beginning of the following week's lab. Your score on these quizzes are part of overall lab grade (10%).

Homework will be assigned at the end of each class, based on material covered, and will be due the next class. Homework turned in late may have points deducted.

Quizzes A quiz may also be given at the beginning of class which will be similar to one of the homework problems. These are used to determine a student's progress during class, and to prepare students for the homework and tests.

Clickers Clicker sessions may be given periodically. These help a student gauge their comprehension of chapter material, and to prepare for the homework and tests. We will be using personal response system clickers and software from Turning Technology called TurningPoint. You will each be assigned a clicker for the duration of the course. The instructor will bring a box with the clickers from which you will select your assigned clicker. At the end of the class you will return the clicker to the box. Clicker sessions, quizzes, and attendance make up 10% of the grade. Clicker sessions and quizzes cannot be made up.

Content of Tests will reflect what is expected to be learned in class as aided by the homework, not necessarily the homework itself. The aim of the course is for students to be able to do problems like homework problems, but also to learn the fundamental principles of physics well enough to be able to apply them to solve problems with varying circumstances as illustrated by such homework problems.

How to be Successful in Introduction to Physics for Aviation

I consider myself successful when I study a new topic if a) I am able to recall the 'big picture' concepts (and many of the fine points), b) I can explain these concepts clearly to someone who has never heard of them, and c) if I can think about and find solutions to real life problems that require the use of these concepts for their solution. I usually have to not only attend lectures and take notes, but I also have to read the textbook and make notes from that; do homework problems twice—once with the help of classmates or hints or the use of textbook, and once again later, without the aids. My best chance to understand new material is to pre-read before I get to class, and to make sure I understand the lecture as it is happening, not to wait until later. And probably the most important point is to not fall behind. This means two things—not to allow myself to fall behind on homework, but also not to give up on understanding each concept as I go along, since the next one probably depends on the previous concepts, principles or equations. In summary, to be successful in physics:

1) Expect to spend 2 – 3 hours of study and course work (homework, lab report writing) for each hour of lecture
2) Be able to recall and explain each concept to someone who has not heard of it, without using references
3) Go through homework a second time *without* aids (peers or equations or textbook)

4) Pre-read textbook *before* class
5) *Attend* lectures, and understand lecture *during* lecture
6) Keep up with homework
7) *Read* the textbook
8) Ask for help from instructor and/or peer mentor, tutoring center well *before* tests

Academic Integrity

http://www.fscwv.edu/sa/studenthandbook/32-53_regs-policies.html#AcademicDishonesty

Fairmont State values highly the integrity of its student scholars. All students and faculty members are urged to share in the responsibility for removing every situation which might permit or encourage academic dishonesty. Cheating in any form, including plagiarism, must be considered a matter of the gravest concern. Cheating is defined here as the obtaining of information during an examination; the unauthorized use of books, notes, or other sources of information prior to or during an examination; the removal of faculty examination materials; the alteration of documents or records; or actions identifiable as occurring with the intent to defraud or use under false pretense.

Plagiarism is defined here as the submission of the ideas, words (written or oral), or artistic productions of another, falsely represented as one's original effort or without giving due credit. Students and faculty should examine proper citation forms to avoid inadvertent plagiarism.

Disability Services

http://www.fscwv.edu/sa/studenthandbook/11-17_studentservices.html#DisabilityServices

Services are available to any student, full or part-time, who has a need because of a [documented] disability. It is the student's responsibility to register for services with the coordinator of students with disabilities and to provide any necessary documentation to verify a disability or the need for accommodations. The Coordinator of Disability Services is located in the Turley Center, room 310a. The office phone is (304) 367-4686 or (800) 641-5678 Ext. 8. TDD# is 304-367-4200. Check the web site at http://www.fscwv.edu/sa/disability/disability.shtml

Attendance

http://www.fscwv.edu/sa/studenthandbook/54-62_aca-policies.html#StudentAbsences

Students are expected to attend regularly the class and laboratory session of courses in which they are registered. Regular attendance is necessary to the successful completion of a course of study and is an integral part of a student's educational experience. Although a student may jeopardize his/her grade by nonattendance, the final grade is performance-based.

Copyright Notice

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Information Required for Creating Assessment Plan in Watermark

- Complete one copy of Table #2 for each course outcome which addresses the Core Curriculum category outcome.
- Copy Table #2 to create a separate table for additional course outcomes as many times as needed. Place only one table per page.
- Cells expand.

Table #2	Course Outcome Information
Course Outcome:	1. Use the vocabulary of basic principles, facts and theories of physics applied to aviation.
Method to Measure Course Outcome	Direct - Exam
Details/ Description:	Final Exam – combination of multiple-choice questions and word problems
Satisfactory Performance Standard (based on rubric):	70% mean score on items corresponding to course outcome 1 and fewer than 30% of students score less than 60% on Final Exam
Ideal Target (based on rubric):	80% mean score on items corresponding to course outcome 1 and fewer than 20% of students score less than 60% on Final Exam
Implementation Plan (timeline):	Once per year (course is taught only in Spring semester)
Key/Responsible Personnel:	Siegfried Bleher
Supporting Attachments: These attachments are to be placed immediately after the associated Table #2 in the proposal.	*Attachment 1:* Sample Test *Attachment 2:* Type here to enter description. *Attachment 3:* Type here to enter description.

Attachment 1: Final Exam 2019 Note: Each question maps to one or more of the Course Outcomes, the rubric is a weighted score based on the number of questions answered correctly that correspond to each outcome. It is the same attachment for course outcomes 1 - 3, and is therefore attached only once.

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Dr. Siegfried Bleher

Final Exam

Name ____________________________ Score _______/ 100

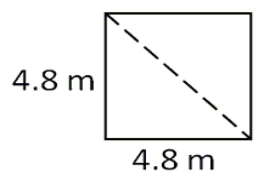
1. In a diving competition, a woman dives from a platform that is ten meters above the surface of the water. What is the height, expressed in feet, of the platform?

A) 13 feet
B) 18 feet
C) 24 feet
D) 33 feet
E) 47 feet

2. Complete the following statement: The ratio $\frac{\text{1 milligram}}{\text{1 kilogram}}$ is equal to

A) 10^2.
B) 10^3.
C) 10^6.
D) 10^{-3}.
E) 10^{-6}.

3. The length of each side of a square is 4.8 m. What is the length of the diagonal of the square (shown as a dashed line in the figure)?



A) 2.8 m
B) 8.0 m
C) 5.7 m
D) 6.8 m
E) 16 m

4. What is the angle between the vectors $\vec{\mathbf{A}}$ and $-\vec{\mathbf{A}}$ when they are drawn from a common origin?

A) 0°
B) 90°
C) 180°
D) 270°
E) 360°

5. Town A lies 20 km north of town B. Town C lies 13 km west of town A. A small plane flies directly from town B to town C. What is the displacement of the plane?

A) 33 km, 33° north of west
B) 19 km, 33° north of west
C) 24 km, 57° north of west
D) 31 km, 57° north of west
E) 6.6 km, 40° north of west

6. A displacement vector has a magnitude of 810 m and points at an angle of 18° above the positive *x* axis. What are the *x* and *y* scalar components of this vector?

	x scalar component	*y scalar component*
A)	770 m	250 m
B)	560 m	585 m
C)	585 m	560 m

D) 250 m 750 m
E) 713 m 385 m

7. Which one of the following statements concerning vectors and scalars is *false*?
A) In calculations, the vector components of a vector may be used in place of the vector itself.
B) It is possible to use vector components that are not perpendicular.
C) A scalar component may be either positive or negative.
D) A vector that is zero may have components other than zero.
E) Two vectors are equal only if they have the same magnitude and direction.

8. For which one of the following situations will the path length equal the magnitude of the displacement?
A) A toy train is traveling around a circular track.
B) A ball is rolling down an inclined plane.
C) A train travels 5 miles east before it stops. It then travels 2 miles west.
D) A ball rises and falls after being thrown straight up from the earth's surface.
E) A ball on the end of a string is moving in a vertical circle.

Peter noticed a bug crawling along a meter stick and decided to record the bug's position in five-second intervals. After the bug crawled off the meter stick, Peter created the table shown.

time (s)	position (cm)
0.00	49.6
5.00	39.2
10.0	42.5
15.0	41.0
20.0	65.7

9. What is the displacement of the bug between t = 0.00 s and t = 20.0 s?
A) +39.9 cm
B) –39.9 cm
C) +65.7 cm
D) –16.1 cm
E) +16.1 cm

10. An object moving along a straight line is accelerating (speeding up). Which one of the following statements concerning the object's acceleration is *necessarily* true?
A) The value of the acceleration is positive.
B) The direction of the acceleration is in the same direction as the displacement.
C) The acceleration changes as the object moves along the line.
D) The direction of the acceleration is in the direction opposite to that of the velocity.
E) The direction of the acceleration is in the same direction as that of the velocity.

11. A landing airplane makes contact with the runway with a speed of 75.0 m/s and moves toward the south. After 18.5 seconds, the airplane comes to rest. What is the average acceleration of the airplane during the landing?
A) 2.11 m/s^2, north
B) 2.11 m/s^2, south
C) 4.05 m/s^2, north
D) 4.05 m/s^2, south
E) 14.3 m/s^2, north

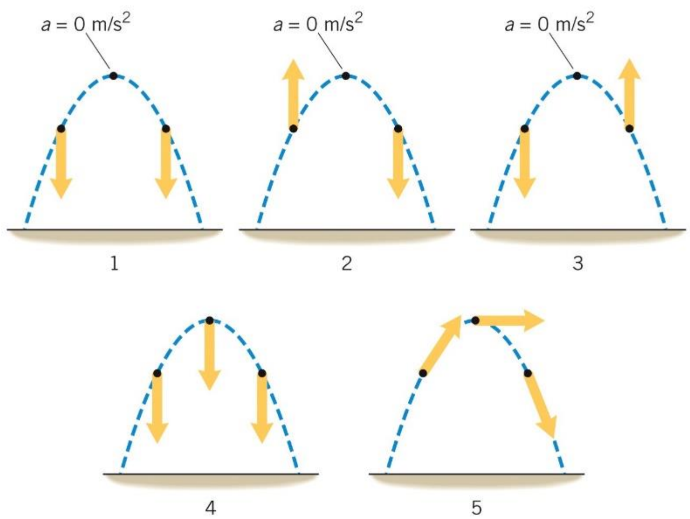
12. A ball is dropped from rest from a tower and strikes the ground 120 m below. Approximately how many seconds does it take the ball to strike the ground after being dropped? Neglect air resistance.
A) 24.5 s
B) 3.50 s
C) 22.5 s

D) 4.95 s
E) 4.74 s

13. A wheel with a 0.10-m radius is rotating at 35 rev/s. It then slows uniformly to 15 rev/s over a 3.0-s interval. What is the angular acceleration of a point on the wheel?
A) –2.0 rev/s^2
B) 0.67 rev/s^2
C) –6.7 rev/s^2
D) 42 rev/s^2
E) –17 rev/s^2

14. Each drawing shows three points along the path of a projectile, one on its way up, one at the top, and one on its way down. The launch point is on the left in each drawing. Which drawing correctly represents the acceleration *a* of the projectile at these three points?

a. 5
b. 4
c. 3
d. 2
e. 1

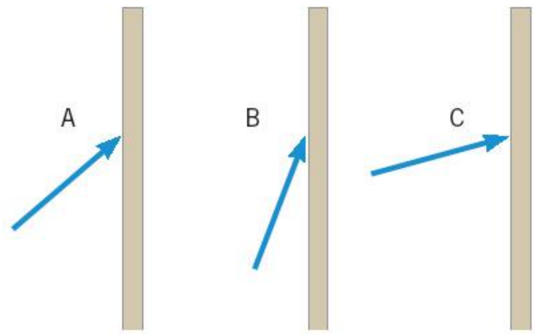


15. A car travels due north at 21 m/s. It makes a turn due east and continues to travel at 21 m/s. What is the change in velocity of the car?
A) 21 m/s, due south
B) 21 m/s, due east
C) 30 m/s, 45° north of east
D) 30 m/s, 45° south of east
E) There is no change in velocity, as it is still moving at 27 m/s

16. Two forces act on a 16-kg object. The first force has a magnitude of 68 N and is directed 24° north of east. The second force is 32 N, 48° north of west. What is the acceleration of the object resulting from the application of these two forces to the object?
A) 1.6 m/s^2, 5.5° north of east
B) 1.9 m/s^2, 18° north of west
C) 2.4 m/s^2, 34° north of east
D) 3.6 m/s^2, 5.5° north of west
E) 4.1 m/s^2, 52° north of east

17. The drawings show three examples of the force with which someone pushes against a vertical wall. In each case the magnitude of the pushing force is the same. Rank the normal forces that the wall applies to the pusher in ascending order (smallest first).

A) C, A, B
B) A, C, B
C) C,B,A
D) B, C, A
E) B,A,C



A student pushes a cart full of physics books along the floor. Consider the following four forces that arise in this situation.

(*1*) the force of the student pushing on the cart
(*2*) the force of the student pushing against the floor
(*3*) the force of the cart pushing on the student
(*4*) the force of the floor pushing against the student

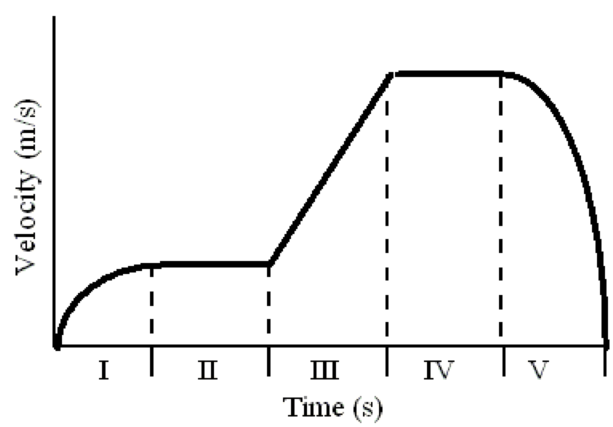
18. Which two forces form an "action-reaction" pair that obeys Newton's third law?
A) *1* and *4* B) *1* and *3* C) *1* and *2* D) *3* and *4* E) *2* and *3*

19. Suppose that the student and cart have started from rest; and as time goes on, their speed increases in the same direction. Which one of the following conclusions is correct concerning the magnitudes of the forces mentioned above?
A) Force *1* exceeds force *3*.
B) Force *3* is less than force *2*.
C) Force *3* exceeds force *4*.
D) Force *2* exceeds force *4*.
E) Forces *1* and *3* cannot have equal magnitudes.

The graph shows the velocity of the object as a function of time. The various equal time intervals are labeled using Roman numerals: I, II, III, IV, and V.

The net force on the object always acts along the line of motion of the object.

20. Which section(s) of the graph corresponds to a condition of *zero net force*?
A) V only
B) II and IV
C) II, III, and IV
D) III only
E) I, III, and V

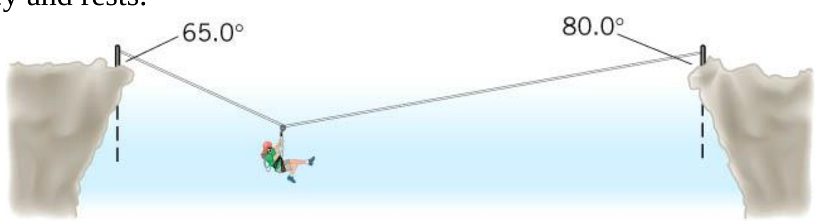


21. (10 points) A 145 g baseball, traveling at +60 mph, is in contact with a bat for a time of 0.5 ms. The baseball is moving at -50 mph after being hit by the bat.

A) What is the impulse delivered by the bat to the ball?
B) What is the change in kinetic energy of the ball before and after being hit by the bat?

22. (10 points) An 8000-kg plane has two propellers, each of which takes in air at a rate of 50 kg/s, imparting a change in velocity of the air of 63 m/s. If, as the plane taxies down the runway, it accelerates forward at a rate of 0.15 m/s^2, how much total drag force plus friction are acting on the plane?

23. (20 points) A 75 kg climber is making his way from one cliff to another along a rope, using a pulley and friction clamp. When he is at a point where the angles the rope makes with each supporting post are as shown, he clamps down on the pulley and rests.



A) (4 points) Draw two Free Body Diagrams: one for the pulley the climber is hanging from, and for the climber.
B) (6 points) Based on the FBDs, fill in two tables of components of the forces acting on the pulley and the climber.
C) (4 points) Write the Newton's 2nd law equations from the FBDs
D) (2 points) Solve the equations in part C) for tension in the rope directly attached to the climber
E) (4 points) Solve the equations in part C) for the tensions in the two sides of the rope the pulley is rolling on.

24. (10 points) A plane weighs 8000. lb and is traveling at 352 ft/s with $\alpha = 0$. While the plane is in cruising flight, an accident occurs, causing the plane to lose 1000. lb of fuel. If the plane is to maintain cruising flight with the same lift coefficient, at what speed should it now travel? With this new speed, the drag force will change; if the drag coefficient remains constant, by what percentage must the thrust change to maintain cruising flight?

25. (10 points) A space laboratory is rotating to create artificial gravity, as the figure indicates. Its period of rotation is chosen so that the outer ring (r_O = 2170 m) simulates the acceleration due to gravity on earth (9.80 m/s^2).

A) What is the tangential velocity of someone standing on the inside surface of the outer ring?
B) What should the radius r_i of the inner ring be so it simulates the acceleration due to gravity on the surface of the Moon ($1.62\,\text{m/s}^2$)?
C) What is the rotational period T of the space laboratory?

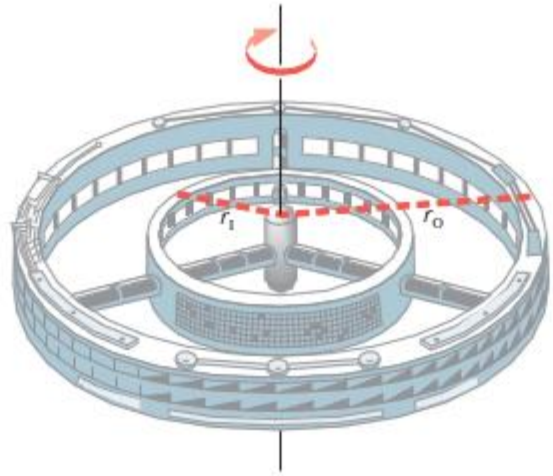

r_I
r_O

Table #2	Course Outcome Information
Course Outcome:	2. Demonstrate an understanding of the process and limitations of scientific inquiry as applied to aviation physics
Method to Measure Course Outcome	Direct - Student Artifact
Details/ Description:	Lab 5: Projectile Motion with questions specific to assess Core Curriculum Attribute 7: attached lab includes questions and rubric in green font
Satisfactory Performance Standard (based on rubric):	70% mean score on items corresponding to course outcome 2 and fewer than 30% of students score less than 60% on lab assessment
Ideal Target (based on rubric):	80% mean score on items corresponding to course outcome 2 and fewer than 20% of students score less than 60% on lab assessment
Implementation Plan (timeline):	Once per year (course is taught only in Spring semester)
Key/Responsible Personnel:	Siegfried Bleher
Supporting Attachments: These attachments are to be placed immediately after the associated Table #2 in the proposal.	*Attachment 1:* Lab 5 with questions and rubric *Attachment 2:* Type here to enter description. *Attachment 3:* Type here to enter description.

Experiment 5 Projectile Motion

Equipment

Pasco launcher, 1 metal ball, 1 metal stand, 1 metal ring, 2 brackets, one 2-meter stick, plumb bob (with string)

Introduction

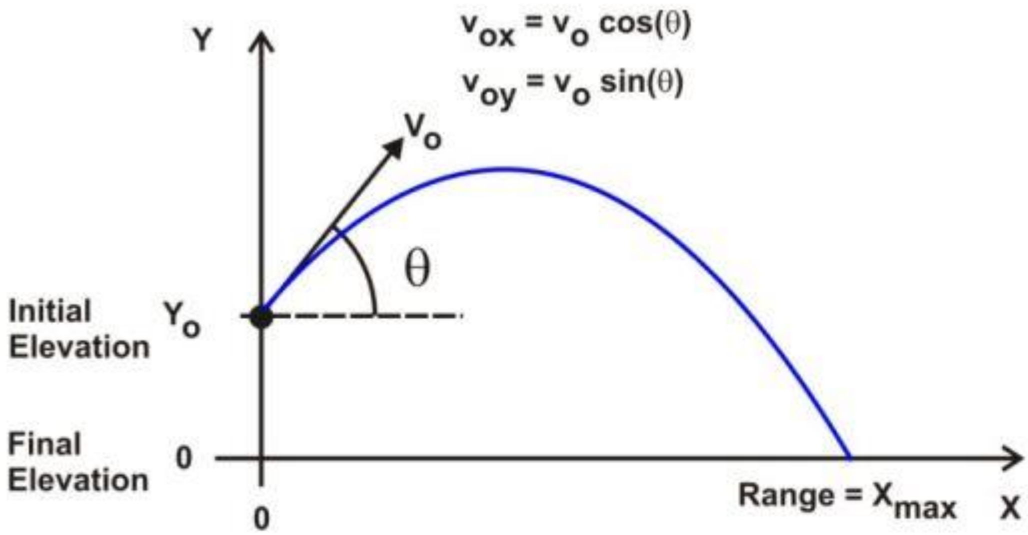
If we ignore air friction, then the equations of motion for a projectile near Earth's surface are given by

$$x = x_0 + v_{0x}t \quad \& \quad y = y_0 + v_{0y}t - \frac{1}{2}gt^2 \qquad (1)$$

where the initial velocities v_{0x} and v_{0y} are given in terms of the initial launch angle (measured from the horizontal direction) θ_0 by

$$v_{0x} = v_0 \cos\theta_0 \quad \& \quad v_{0y} = v_0 \sin\theta_0 \qquad (2)$$

These are the same as the usual equations of kinematics for motion in two dimensions at constant acceleration. In the case of projectile motion there is no acceleration in the $x-$ direction, and acceleration in the $y-$ direction is the acceleration due to gravity $g = 9.80\,\text{m/s}^2$, here considered to be a constant. In this lab we use equations (6) and (7) to determine where to place a ring attached to a stand such that a steel ball launched from a v_0 certain distance will go through the ring.



Procedure

A. Measure launch velocity v_0.

1. Orient launcher vertically and place it on the floor. Place the metal ball into launcher. Record the initial height of the top of the ball y_0 before you compress the spring. Using the rod, compress the spring to its highest setting.
2. Hold the 2-meter stick vertically close to launcher and launch the ball, recording the highest point y reached by the top of ball.
3. Initial launch velocity v_0 is the ball's velocity just as it exits the launcher when the spring is fully decompressed. Calculate this velocity from the projectile equation for vertical projectile. Solve for v_0 from

$$v^2 - v_0^2 = 2a_y(y - y_0) = -2g(y - y_0) \qquad (3)$$

(Make use of the fact that $v = 0$ when the ball reaches the peak of its trajectory to find v_0.)

B. Predict where to place ring.

1. Set up the launcher to launch at the angle 30° from horizontal from atop the lab table. Attach the metal ring to the stand using a bracket and place the stand on the floor. Your setup should look similar to the figure below.

2. Apply equations (1) and (2) to the case shown in the figure to find the time of flight t of metal ball from launcher to ring. The initial and final heights y_0 and y_f of the projectile are set by the height of the center of the ball as it is leaving launcher and the height (from the floor) of the center of the ring, respectively. Use these heights to determine the time of flight t from launcher to the ring. The quadratic equation to be solved for t is

$$y_f - y_0 = v_{0y}t - \frac{1}{2}gt^2. \tag{4}$$

We can rewrite this in the common form of a quadratic equation, as

$$\frac{1}{2}gt^2 - v_{0y}t + y_f - y_0 = 0 \tag{5}$$

The solution to the quadratic equation $at^2 + bt + c = 0$ is given by $t = \frac{1}{2a}\left(-b \pm \sqrt{b^2 - 4ac}\right)$, where in this case we have $a = \frac{1}{2}g$; $b = -v_{0y}$; and $c = y_f - y_0$. Applying this solution to equation (5) gives

$$t_\pm = \frac{1}{g}\left[v_{0y} \pm \sqrt{v_{0y}^2 - 2g(y_f - y_0)}\right], \tag{6}$$

where $v_{0y} = v_0 \sin\theta_0$ and $\theta_0 = 30°$. Determine which of the two times t_+ or t_- is the correct time of flight t.

3. Use the time of flight t in the first of equations (1) to determine the range R of the projectile:

$$R = x_f - x_0 = v_{0x}t, \tag{7}$$

where $v_{0x} = v_0 \cos\theta_0$.

4. Place the ring with stand at the horizontal distance R away from launcher as follows. Use the compass on launcher to set the angle of launcher at 30°. Use the plumb bob to mark the horizontal location on the floor of the center of the ball when placed in launcher. Use 2-meter stick to measure the distance R to place the ring with stand. Sight along the barrel of the launcher to determine the location to place the ring in a direction perpendicular to the direction of flight.

C. Test Your Prediction (25 points)

1. Launch projectile to see if it goes through the ring.

   i. If it goes through the first time, you will get full credit for the launch portion of the lab.

ii. If the ball over or undershoots, then double-check a) your calculations, and b) your measurements to see if your prediction was in error. If you find an error, then re-measure the predicted location of the ring and repeat the launch.

iii. One point will be taken off for each additional corrected launch. Please do not simply adjust launch distance by trial and error, although you may adjust direction of launch by trial and error if the ball achieves the correct distance but overshoots laterally.

D. Questions (20 points): number of points = number of items from rubric or equally valid alternatives that are included in answer.

1. (2 points) What is the meaning of the negative time solution you found? The negative time solution is the time prior to the launch it would take the ball to reach the height of the launcher from a position behind the launcher at the height of the ring on the floor.

2. (3 points) What physical factors or influences did you have to ignore that may have affected your prediction? We ignored: a) air resistance, b) the different amount of friction the ball experiences inside the barrel of the launcher as a function of the tilt of the barrel, c) the differing amount of gravitation force the ball experiences inside the barrel as a function of the angle of tilt. These may all have affected our assumption that the initial velocity for a vertical launch is the same as the initial velocity of tilted launch.

3. (5 points) What physical factors or influences may have affected your test launch(es)? a) Precision of plumb bob that determines angle of launch; b) precision of meter sticks used to position ring and stand the predicted distance from launcher; c) air resistance; d) variability in spring force exerted on ball during launch; e) tilt of ring; f) visual estimate of horizontal alignment of ring.

4. (5 points) If you were asked to devise a plan to deliver a package to a town by releasing a package from an airplane, list and explain what information you would need to know in order release the package at the right time for it to land in a designated target area. a) height of package drop; b) airplane velocity; c) wind; d) air resistance; e) whether parachute is to be used

5. (5 points) What are the limitations of the method you learned in Lab 5? In other words, what might prevent you from correctly estimating the time to drop the package so that it lands on target? a) is g really to be regarded as constant for the displacement considered; b) model ignores air resistance; c) no way to account for wind; d) size and shape of package will affect its trajectory whereas our experiment was performed with dense metal balls that is likely not affected much by air resistance, e) launcher is not moving.

Table #2	Course Outcome Information
Course Outcome:	3. Demonstrate the following skills: analysis; problem solving; quantitative manipulation; and, data interpretation/evaluation in the field of aviation physics
Method to Measure Course Outcome	Direct - Student Artifact
Details/ Description:	Lab 8 Rocket Launch with questions specific to assess Core Curriculum Attribute 7: attached lab includes questions and rubric in green font.
Satisfactory Performance Standard (based on rubric):	70% mean score on items corresponding to course outcome 3 and fewer than 30% of students score less than 60% on lab assessment
Ideal Target (based on rubric):	80% mean score on items corresponding to course outcome 3 and fewer than 20% of students score less than 60% on lab assessment
Implementation Plan (timeline):	Once per year (course is taught only in Spring semester)
Key/Responsible Personnel:	Siegfried Bleher
Supporting Attachments: These attachments are to be placed immediately after the associated Table #2 in the proposal.	*Attachment 1:* Lab 8 with rubric *Attachment 2:* Type here to enter description. *Attachment 3:* Type here to enter description.

Experiment 8 Rocket Launch

Equipment

Research Express Rocket from Apogee Rockets, AltimeterThree from Jolly Logic, Rocket Launcher

Introduction

In this experiment a model rocket is launched that was built in a previous lab. Altitude, velocity and acceleration data collected from the launch are compared with predictions based on Newton's laws, and with predictions made with the RockSim rocket flight simulation software. We also calculate coefficient of drag (C_D), which is compared with predictions based on theory and rocket flight simulation software (RockSim). Note: It is also possible to define and measure center of gravity (y_{CG}) and center of pressure (y_{CP}) for the model rocket, but these numbers are not used in the present experiment. These numbers, specifically their relative positions $y_{CP} - y_{CG}$ determines stability of the rocket during its flight.

Stages of Model Rocket Flight

There are six stages in the flight of a model rocket: a) launch, b) powered ascent, during which the engine fuel burns, c) coasting flight, after the fuel is exhausted, d) ejection charge, e) slow parachute-assisted descent, f) recovery. It is possible to predict the flight path in stages b), c) and d) to estimate the rocket's maximum velocity and altitude. Let's consider the powered ascent first.

Powered Ascent

We can analyze the motion of the rocket during powered ascent by using a Free Body Diagram, as shown below in figure 2a. Assuming the rocket is launched vertically (zero angle of attack), the forces acting on the rocket are thrust force F_T, drag force F_D, and weight $W = mg$. Newton's second law equation for the FBD in the y—direction is

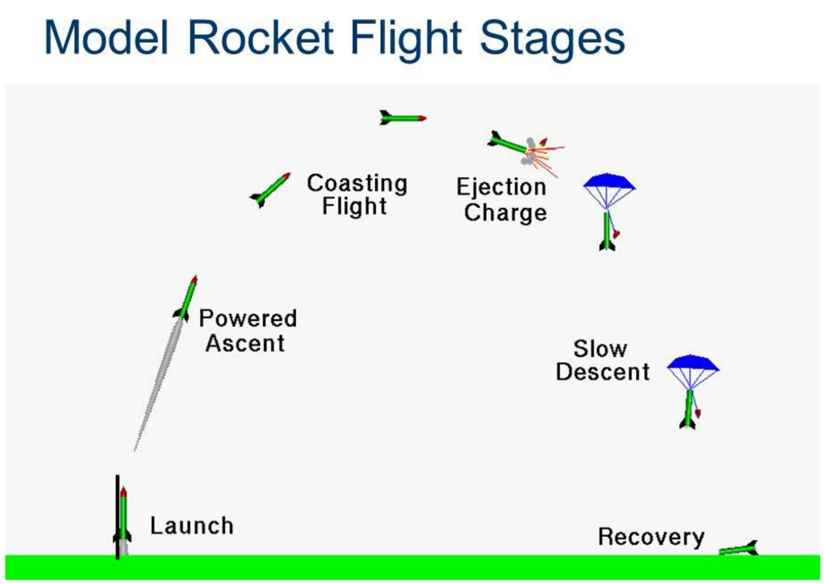
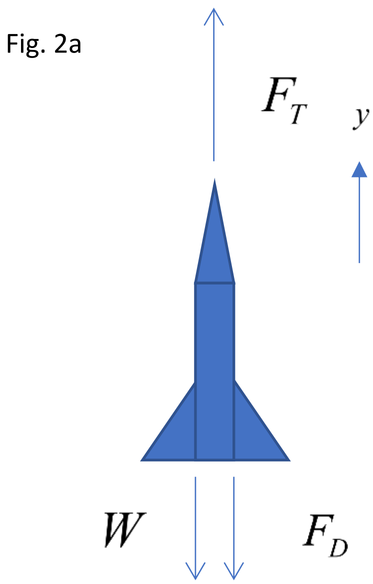


Figure 1 Flight Stages for Model Rocket

$$F_{\text{net},y} = F_T - F_D - mg = ma_y \quad (1)$$

Note that F_T, F_D, and m (the rocket's mass), are all changing as the rocket fuel burns. This means that, unless we use calculus, we must find the altitude and velocity at the end of the burn time t_b by using averaged values for F_T, F_D, and m.



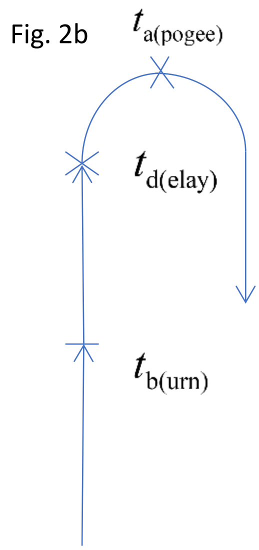


Figure 2a Free Body Diagram - Powered Ascent

Figure 2b Duration of Stages

Before we do this, we can ask what is the origin of the thrust force? In the case of airplanes, thrust force is due to the displacement of air by propellers in a direction opposite the plane's velocity; in a rocket the fuel is displaced opposite the rocket's velocity. In both cases Newton's third law of motion explains that the thrust force is a reaction force to the acceleration of air or fuel toward the rear of the aircraft. Consider the diagram below, which shows a rocket at two times: at time t the rocket has mass M, which includes the fuel mass, and velocity v.

At time $t+\Delta t$ the rocket has expelled a small amount of fuel of mass Δm with exhaust velocity v_e, and its velocity has increased to $v+\Delta v$. Since the forces involved in thrust are internal to the system of rocket + fuel, total linear momentum is conserved, and we have

$$p_{\text{total}}(t) = p_{\text{total}}(t+\Delta t) \quad (2)$$

where

$$p_{\text{total}}(t) = Mv \quad \& \quad p_{\text{total}}(t+\Delta t) = \underbrace{(M-\Delta m)\cdot(v+\Delta v)}_{p_{\text{rocket}}} - \underbrace{\Delta m\cdot(v_e - v)}_{p_{\text{fuel}}} \quad (3)$$

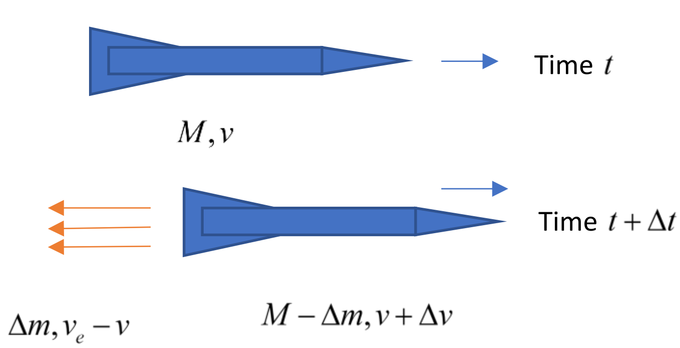


Figure 3 Rocket Propulsion

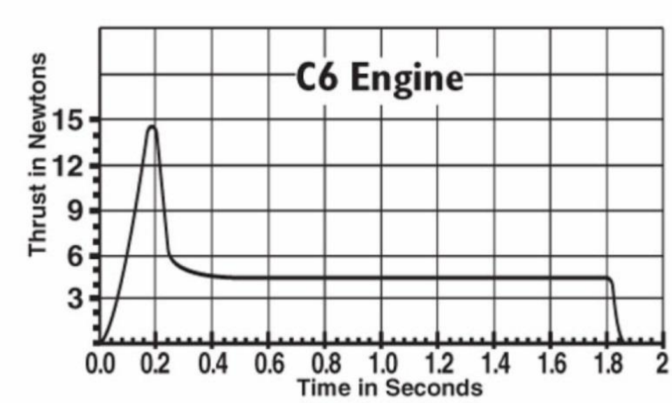
The last term has the form it has because we are measuring rocket fuel velocity in the frame of an observer on the ground, and v_e is the exhaust velocity of the fuel relative to the rocket. If we set the momenta at t and $t+\Delta t$ equal to each other, $p(t) = p(t+\Delta t)$, we can cancel some terms and simplify as follows:

$$\begin{aligned} Mv &= Mv + M\Delta v - \Delta m \cdot v - \Delta m \cdot \Delta v - \Delta m \cdot v_e + \Delta m \cdot v \\ 0 &= M\Delta v - \Delta m \cdot v_e \\ M\Delta v &= \Delta m \cdot v_e \end{aligned} \qquad (4)$$

In the second line, we discarded the term $\Delta m \cdot \Delta v$, which is exceedingly small if each of the individual terms is small. The thrust force at time t is, therefore, given by

$$F_T = M\frac{\Delta v}{\Delta t} = \frac{\Delta m}{\Delta t} v_e \qquad (5)$$

Here $\frac{\Delta m}{\Delta t}$ is the burn rate. If we know the burn rate and exhaust speed, we can calculate thrust; if we know the thrust and burn rate, we can calculate burn rate, and so on. Let us use available characteristics of the Estes motors.



The burn characteristics of the model rocket motor C6-5 are shown in Figure 4, and additional data in Table I. Clearly F_T is variable.

The area under this curve, however is equal to the total impulse, which is related to average thrust and burn time as follows:

$$J = \text{area under } F_T \text{ vs } t \text{ curve} = \bar{F}_T \cdot \Delta t \qquad (6)$$

The total impulse J is given by the letter in the motor designation C6-5. The letter 'C' means the total impulse is between 5.01 N.s – 10.00 N.s. The average thrust $\bar{F}_T$ is given by the first number, in this case 6 N. (The second number—5 is the delay time before the ejection charge goes off, in this case 5 seconds.) In eq. (6), $\Delta t = t_b$, the burn time:

$$\Delta t = \frac{J}{\bar{F}_T} = \frac{10.0\ \text{N}\cdot\text{s}}{6\ \text{N}} = 1.67\ \text{s} = t_b \qquad (7)$$

Table I Estes Motor Specifications

Engine Type	Total Impulse (N.sec)	Time Delay (Sec.)	Max. Lift Wt (g)	Max. Thrust (N)	Thrust Duration (Sec.)	Initial Weight (g)	Propellant Weight (g)
C6-5	10.00	5	113	15.3	1.6	25.8	12.48

If acceleration is due only to thrust, and we can ignore gravity and drag force, then from eq. (5) we can calculate the rocket's velocity at the end of the burn:

$$\Delta v = v_f - v_i = \frac{F_T}{M}\Delta t. \tag{8}$$

Use $v_i = 0$, and take average values for thrust force and the rocket's total mass: $\bar{F}_T = 6.0\text{ N}$, $\bar{M} = m_r + \bar{m}_e + m_a = 28.35\text{ g} + 19.56\text{ g} + 10.5\text{ g} = 58.41\text{ g}$. To get the average mass of the motor $\bar{m}_e = m_{e0} - \frac{1}{2}m_p$, we use its initial mass $m_{e0} = 28.35\text{ g}$ and the mass of the propellant $m_p = 12.48\text{ g}$, as shown in Table I. $m_r = 28.35\text{ g}$ is the mass of the Research Express rocket, and $m_a = 10.5\text{ g}$ is the AltimeterThree mass, as given by the manufacturer. Finally, we have

$$v_f = \frac{\bar{F}_T}{\bar{M}}t_b = \underbrace{\frac{6\text{ N}}{0.05841\text{ kg}}}_{\bar{a}=102.7\text{m/s}^2=10.48g} \times 1.67\text{ s} = 171.5\text{ m/s} \tag{9}$$

[Note: if we use calculus, we arrive at the expression $v_f = v_i + v_e \ln\frac{M_i}{M_f}$, where v_e is propellant exhaust velocity, M_i is the total rocket mass before the burn, and M_f is the total rocket mass after the burn.] We can also estimate the altitude at burn-out:

$$\begin{aligned} y_b &= v_i t + \frac{1}{2}\bar{a}t^2 = 0 + \frac{1}{2}\frac{\bar{F}_T}{\bar{M}}t_b^2 \\ &= \frac{1}{2}\cdot 102.7\text{ m/s}^2 \cdot (1.67\text{ s})^2 = 143.2\text{ m (470 ft)} \end{aligned} \tag{10}$$

What happens if we include drag and weight, the full eq. (1)? First, find drag force from

$$F_D = \frac{1}{2}\rho v^2 C_D A, \tag{11}$$

where $\rho = 1.225\,\text{kg/m}^3$ is air density, v is average velocity of the rocket during the burn phase, A is the cross sectional area of the rocket (πr^2), and C_D is the *drag coefficient*. The most accurate way to estimate C_D is with a wind tunnel. In this discussion we rely on published data, according to which the nosecone shape of the Research Express rocket has a drag coefficient between 0.2 and 0.34 (see figure 5). If we use $C_D = 0.34$, $\bar{v} = \frac{1}{2}(v_i + v_f)$, and $r = \frac{1}{2}(0.0249\,\text{m})$, we can estimate drag force:

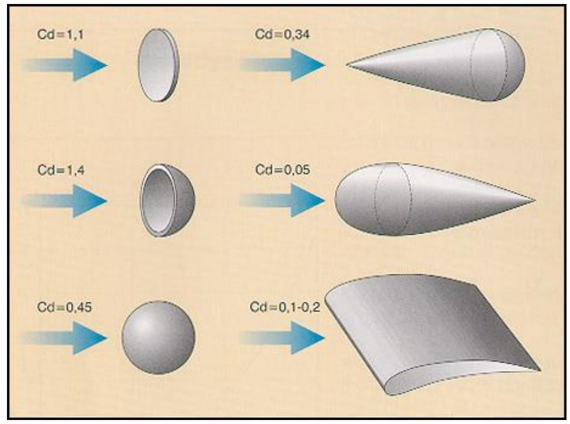


Figure 5 Drag Coefficients for various shapes

$$F_D = \tfrac{1}{2}(1.225\,\text{kg/m}^3)(0.5 \cdot 171.5\,\text{m/s})^2 \cdot 0.34 \cdot \pi(0.01245)^2$$
$$= 0.746\,\text{N}$$

The contribution of the rocket's weight to the net force, and to final velocity is given by $W = \bar{M}g = 0.05841\,\text{kg} \cdot 9.8\,\text{m/s}^2 = 0.57\,\text{N}$. So the net force on the rocket during the powered stage is

$$F_{\text{net},y} = \bar{F}_T - \bar{F}_D - \bar{M}g = 6.0\,\text{N} - 0.75\,\text{N} - 0.57\,\text{N} = 4.68\,\text{N} \qquad (12)$$

The value for $F_{\text{net},y}$ that accounts for drag force and weight of the rocket yields the following new predictions [using equations (9) and (10)]:

$$\bar{a} = 80.12\,\text{m/s}^2 = 8.18g, \quad v_f = 133.8\,\text{m/s}, \quad y_{\max} = 111.7\,\text{m}. \qquad (13)$$

Coasting Flight

After the burn-out, the rocket continues to climb, until it reaches apogee, its maximum altitude. We can treat this phase of its flight as a projectile, as long as we ignore drag force. The initial velocity for the coasting flight is the final velocity of the powered ascent phase. Note that the ejection charge ignites during the coast flight stage. Estimate the apogee (maximum altitude) as follows. Assume result (13), which includes wind resistance and the weight of the rocket. For initial velocity we assume the final velocity after the burn, 133.8 m/s, and we take the time for projectile motion to be 5 seconds, the time before the ejection charge:

$$\begin{aligned} y_{\text{max,coasting}} - y_{\text{max,burn}} &= v_0 t - \frac{1}{2}gt^2 \\ &= 133.8\,\text{m/s} \cdot 5.0\,\text{s} - \frac{1}{2}9.8\,\text{m/s}^2\,(5.0\,\text{s})^2 \qquad (14) \\ &= 669\,\text{m} - 122.5\,\text{m} = 546.5\,\text{m} \end{aligned}$$

The apogee is calculated by adding the altitude at burn-out $y_b = 111.7\text{m}$ to the vertical displacement before ejection charge $y_{\text{max,coasting}} - y_{\text{max,burn}} = 546.5\,\text{m}$:

$$y_{apogee} = 111.7\,\text{m} + 546.5\,\text{m} = 658.2\,\text{m} \simeq 658\,\text{m} \qquad (15)$$

Procedure

1. Measure the following masses:

    a. mass of the rocket without the engine m_r

    b. the mass of the Estes C6-5 engine m_e

    c. the mass of the Jolly Logic AltimeterThree m_a

    d. the total mass of the rocket once the engine and altimeter are added, $m_0 = m_r + m_e + m_a$.

    * Note that the engine mass will decrease during the flight by the amount $m_p = 12.48\,\text{g}$, which is the mass of the propellant, according to the specifications for the Estes C6-5 engine.

2. Mount the C6-5 engine, and load the altimeter into the nosecone of the rocket. Use a string to fasten the altimeter to the nosecone shoulder. Use masking tape around the base of the nosecone shoulder so that the nosecone has a snug fit around the shoulder. Make sure the nosecone shoulder is securely fastened to the payload bay.

3. Measure the center of gravity, y_{CG} of the rocket from the bottom of the engine once it is mounted and the payload (altimeter) is inserted into the nosecone. Record this data in Table II.

4. Assemble the rocket launcher, and place it on hard ground, away from dried vegetation. Mount the rocket on the launcher rod using the two lugs fastened to the long tube. Wrap masking tape around the rod above the blast plate so that the rocket does not rest against the plate. Insert a starter and starter plug into the engine. Attach the ignition wires to the starter using alligator clips, and make sure the wires do not touch. Insert the ignition key into the ignition box until the light comes on. Current is now available from the batteries. Press the ignition button to ignite the motor fuel. Remove the key when the rocket launches.

5. Recover the rocket.

6. Download rocket flight data from iPad AltimeterThree app.

Data Analysis (Record in Table III) (Total Points = 30 points)

1. Repeat the predictions in (9) - (15) above for your rocket: using the masses you measured for the rocket, motor and altimeter in step 1. of Procedure, the specs for the C6-5 motor listed in Table I, and eqs. (8), (10) and (11), predict the following (include drag force and weight):

    a. The rocket's average acceleration in the powered stage of the rocket's flight;

2 points (0 = no attempt to calculate, 1 = incorrect calculation based on equations (9) – (15), 2 = correct calculation based on equations (9) – (15))

b. the rocket's velocity at the end of the burn stage v_f in m/s and ft/s.

2 points (0 = no attempt to calculate, 1 = incorrect calculation based on equations (9) – (15), 2 = correct calculation based on equations (9) – (15))

2. Using the result of step 1, and the discussion under "Coasting Flight" above, predict the maximum altitude of the rocket (apogee), in meters.

2 points (0 = no attempt to calculate, 1 = incorrect calculation based on equations (9) – (15), 2 = correct calculation based on equations (9) – (15))

3. Compare the predictions in steps 1 and 2 with the results from your rocket's flight data. That is, find the % error between prediction and actual results for $v_f, \bar{a}, y_{\max}$.

6 points: 2 points for each of three quantities $v_f, \bar{a}, y_{\max}$ (0 = no attempt to calculate, 1 = incorrect calculation based on results from steps 1 and 2, 2 = correct calculation based on results from steps 1 and 2)

4. Compare the predictions in steps 1 and 2 with those from RockSim. That is, find the % error between prediction in steps 1 and 2 and RockSim simulation.

6 points: 2 points for each of three quantities $v_f, \bar{a}, y_{\max}$ (0 = no attempt to calculate, 1 = incorrect calculation based on results from steps 1 and 2 and flight simulation, 2 = correct calculation based on results from steps 1 and 2 and flight simulation)

5. Compare the predictions from the RockSim software flight simulations with results from your rocket's flight data. That is, find the % difference between the simulation and actual results for $v_f, \bar{a}, y_{\max}$.

6 points: 2 points for each of three quantities $v_f, \bar{a}, y_{\max}$ (0 = no attempt to calculate, 1 = incorrect calculation based on results of flight data and flight simulation, 2 = correct calculation based on results of flight data and flight simulation)

6. Discuss reasons for the differences between theoretical calculations and experiment, and between RockSim and experiment. For example,

a. How large an impact on the prediction would there be for v_f if your estimate for C_D is off by 25%? Hint: use $C_D = 0.2$ instead of 0.34 to see what the prediction for v_f is.

2 points (0 = no attempt to calculate, 1 = incorrect calculation, 2 = correct calculation)

b. What do you expect is the impact on the airfoiling of the fins, or their shape?

3 points (there are 6 observations: airfoiling reduces induced drag; choice of shape can also reduce induced drag; airfoiling increases lift from fins; airfoiling increases stability due to increase in lift; optimal shape of fin is elliptical; airfoiling has a larger effect than shape of fin): 0 = none of these or other valid points mentioned; 1 = any one or two of these or other valid points mentioned; 2 = any three or four of these or other valid points mentioned; 3 = 5 or 6 of these or other valid points mentioned)

c. What does RockSim take into account that we did not in the calculations above?

1 points (shape and airfoiling of fins, wind speed, shape of nose cone: 0 = no valid points mentioned, 1 = 1 or more item mentioned)

Table II Mass Data & Center of Gravity

m_e (g)	m_r (g)	m_a (g)	m_0 (g)	y_{CG} (cm)

Table III Rocket Flight Data

	Calculated	RockSim	Measured	% error calculated/ Rocksim	% error calculated/ measured	% diff RockSim/ measured
y_{max} (m)						
$v_{max} = v_f$ (m/s)						
a_{max} (m/s^2)						
a_{ave} (m/s^2)						

Table #2	Course Outcome Information
Course Outcome:	4: Apply analysis, problem solving, quantitative manipulation, and data interpretation/evaluation to accomplish meaningful goals in the field of aviation physics.
Method to Measure Course Outcome	Direct - Student Artifact
Details/ Description:	Lab 7 Wind Tunnel with questions specific to assess Core Curriculum Attribute 7: attached lab includes questions plus rubric.
Satisfactory Performance Standard (based on rubric):	70% mean score on items corresponding to course outcome 4 and fewer than 30% of students score less than 60% on lab assessment
Ideal Target (based on rubric):	80% mean score on items corresponding to course outcome 4 and fewer than 20% of students score less than 60% on lab assessment
Implementation Plan (timeline):	Once per year (course is taught only in Spring semester)
Key/Responsible Personnel:	Siegfried Bleher
Supporting Attachments: These attachments are to be placed immediately after the associated Table #2 in the proposal.	*Attachment 1:* Lab 7 Wind Tunnel including rubric *Attachment 2:* Type here to enter description. *Attachment 3:* Type here to enter description.

Experiment 7 Wind Tunnel

Equipment

Interactive Instruments Jet Stream 500 Wind Tunnel, metal ball, plastic ball, foam ball, rubber ball, airfoils, fins

Introduction

In this experiment, we use the Jet Stream 500 Wind Tunnel to measure lift and drag forces on several airfoil shapes, and how these forces vary with angle of attack. Lift force is the force perpendicular to the relative wind direction that arises from the pressure difference between the upper and lower surfaces of an airfoil. Drag force arises from frictional forces between air and surface, and is directed parallel to the flow direction. Angle of attack is the angle between flow direction and the chord line. As illustrated in Figure 1, the chord line is a line connecting the leading edge and the trailing edge of an airfoil. In Part I, we measure lift and drag forces for different with angles of attack. Part II tests several spherical balls with different surfaces, to see how surface smoothness affects drag. The latter is also in support of a high-altitude balloon launch.

I. Four Forces of Flight

There are generally four forces acting on the wing of an aircraft during flight, as shown in the figure: thrust, drag, weight (mg) and lift. **Thrust** is the forward force F_T provided by the engines and propeller(s), and is directed forward in the relative wind direction. A propeller or jet turbine displaces a pocket of air whose mass is Δm from the front of the propeller, where it has relative velocity to the plane v, to the back of the plane, where it has velocity v'. This implies a change in momentum $\Delta p = \Delta m \cdot \Delta v = \Delta m \cdot (v' - v)$. The mass flow rate, $\frac{\Delta m}{\Delta t}$, is the rate at which air is displaced from the front of a turbine or propeller to its rear.

The thrust force is equal to the net change of momentum of the displaced air mass per unit time, given by

$$F_T = \frac{\Delta p}{\Delta t} = \frac{\Delta m \cdot v' - \Delta m \cdot v}{\Delta t} = \frac{\Delta m}{\Delta t}(v' - v), \quad (1)$$

where v is the relative velocity of the pocket of air in front of the propeller, and v' is the new relative velocity of the pocket of air behind the propeller.

According to Newton's third law of motion, the displacement of the pocket of air toward the back of the aircraft creates a forward reaction force exerted on the aircraft by the displaced air.

Lift force F_L can be calculated from Bernoulli's principle:

$$p_1 + \frac{1}{2}\rho v_1^2 + \rho g y_1 = p_2 + \frac{1}{2}\rho v_2^2 + \rho g y_2 \quad (2)$$

This equation states that the sum of the three quantities at one point along a streamline in a fluid is the same at another point along that streamline. The first term p is the fluid pressure, which is related the work performed by fluid pressure along a streamline on a small portion of fluid; the second term $\frac{1}{2}\rho v^2$ is called 'dynamic pressure', and is essentially the kinetic energy carried by the portion of fluid along the streamline, ρ is the air density (in kg/m^3) and v_1, v_2 are the air velocities at the two points along the streamline; the last term is the potential energy of the portion of fluid at the given height y. Bernoulli's principle states that mechanical energy is conserved along the streamline. A wing is shaped in such a way that the air above the wing moves faster than the air below, so that the pressure above the wing is less than that below. From eq. (2) we have

$$\Delta p = p_l - p_u = \frac{1}{2}\rho v_u^2 - \frac{1}{2}\rho v_l^2 > 0, \quad (3)$$

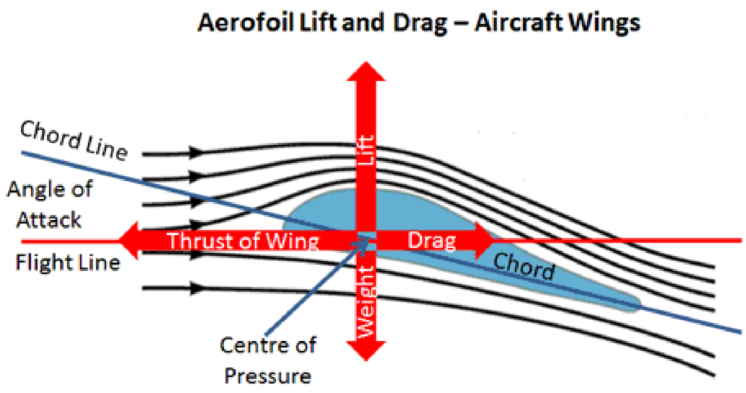


Figure 6: Forces on an airfoil

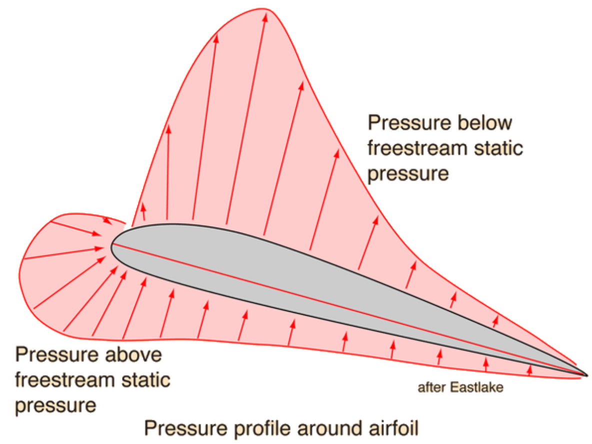


Figure 7 Pressure profile around an airfoil

where we have assumed the height difference $y_u - y_l$ is negligible. Figure 2 shows the pressure above the wing is lower than the free stream static pressure by an amount proportional to the arrows, and similarly the pressure below the wing is above the free stream static pressure. The net upward force on the wing, or the lift force F_L, is given by

$$F_L = \Delta p \cdot A, \tag{4}$$

Where A is the surface area of the wing. We can rewrite the expression for the pressure difference in terms of the *lift coefficient* C_L, defined as

$$C_L = \left(\frac{v_u}{v}\right)^2 - \left(\frac{v_l}{v}\right)^2. \tag{5}$$

In eq. (5) v is the relative wind speed away from the wing. Using eq. (5) we can rewrite eq. (4) as

$$F_L = \frac{1}{2}\rho v^2 C_L A. \tag{6}$$

Note that lift coefficient C_L is dimensionless, and depends on the wing's shape, material and angle of attack, but does not depend on its size or weight. Lift force acts in a direction that is perpendicular to the direction of oncoming air. Figure 3 shows how C_L depends on angle of attack α. Note that C_L increases linearly with angle of attack, until it reaches a critical (stalling) angle. Beyond this critical angle, lift coefficient and lift force drop sharply.

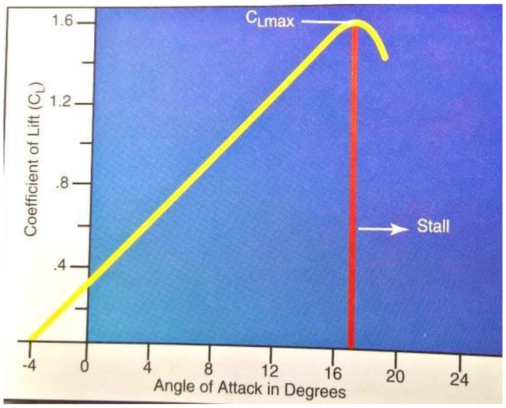
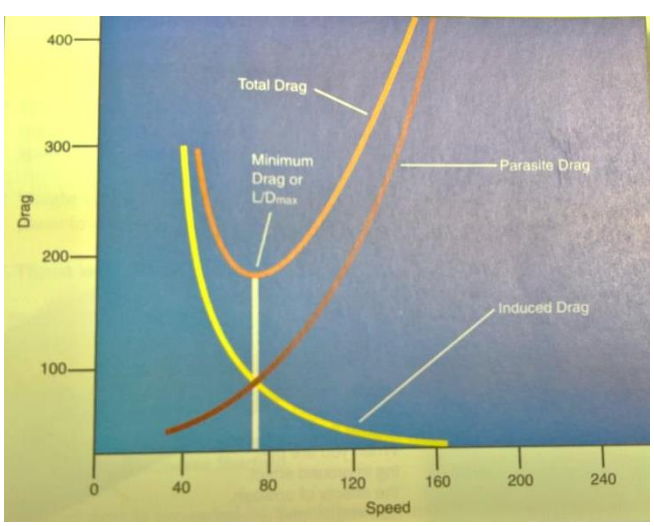


Figure 8 Lift coefficient as a function of angle of attack
(Figure 3-7 in Private Pilot)

Drag force is primarily due to sticking of air molecules to the surface of an airfoil, and acts in a direction opposite to the direction of oncoming air. Types of drag include *parasitic drag*, where an aircraft surface interferes with the smooth flow airflow around the airplane, and induced drag, which arises when wing tip vortices redirect airflow by increasing downwash behind the airfoil. Parasitic drag includes form drag, due to air turbulence caused by separation of airflow from the surface of a structure; interference drag, to the interaction of air currents from different structures (like wing brace struts and landing gear struts); and skin friction drag (see Private Pilot, by Jeppesen). Drag force can be calculated with an equation similar to that for lift, eq. (6) :

$$F_D = \frac{1}{2}\rho v^2 C_D A, \qquad (7)$$

where ρ is air density, v is the relative wind speed before the air interacts with the airfoil, A is the surface area of the wing, and C_D is the *drag coefficient*. Note that, like the lift coefficient C_L, C_D is dimensionless, it depends on the shape of the wing and the angle of attack α, and it does not depend on the wing's size or weight. For small angles C_D increases as the square of α. Induced drag force is inversely proportional to the square of the relative wind speed, $F_{D,\mathrm{ind}} \propto 1/v^2$, whereas parasitic drag force is proportional to the square of the relative wind speed, $F_{D,\mathrm{par}} \propto v^2$. The total drag has a parabolic shape, as shown in Figure 4. Note the point of minimum drag, where the lift-to-drag ratio is greatest.



II. Wind Tunnel

This lab makes use of Jet Stream 500 wind tunnel by Interactive Instruments, shown in Figure 5. The wind tunnel uses a 1 HP motor to generate winds with velocities up to 80 mph (129 kph), with a precision of 0.1 mph. The wind velocity is continuously measured and adjusted by using a pitot tube placed at one end of the test area. The pitot tube is connected to a differential pressure transducer that calculates air speed from Bernoulli's equation (eq. (2)). The 5.25"x5.25"x16" test area can be accessed by removing two support screws below the test bed. Inside the test area there is a platform on which the sample airfoil is fastened.

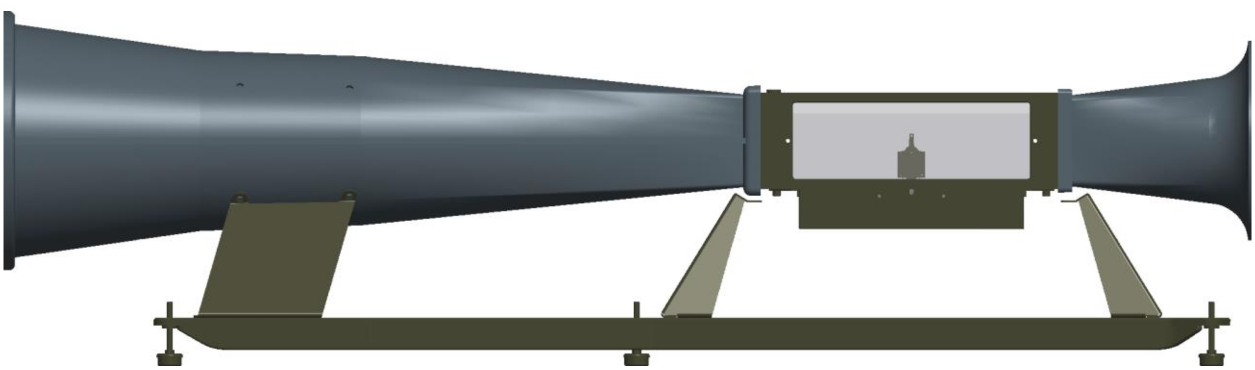


Figure 10 Jet Stream 500 wind tunnel

The front of the test area has a control button that can adjust the angle of attack +/- 30° with a precision of 5°.

Instrumentation beneath the test bed measures lift and drag forces, as well as the ratio C_L/C_D. A 12 bit A/D converter converts the signal from the instrument to a 20 character by 4 line digital readout that gives air speed v, lift force F_L, drag force F_D, and the ratio of lift coefficient to drag coefficient C_L/C_D. Force gauges in the test bed instrumentation are automatically zeroed so the unit remains calibrated before every test.

Procedure

I. Dependence of Drag and Lift on Angle of Attack

1. Airfoil 1 (symmetric profile). Remove the test bed from the wind tunnel. Fasten airfoil 1 to the platform using Velcro, and replace the test bed.

2. Set the angle of attack to -15°. Turn on the power on the control panel. Slowly turn the velocity control knob clockwise until the measured velocity shows 60 km/h. Record this value in Table 1 (or whatever value you are able to set, to within 0.1 km/h). Also record values shown on control panel for lift force F_L, drag force F_D, and the ratio of lift to drag F_L / F_D. Note that, from eq. (6) and eq. (7), the ratio of lift force to drag force is the same as the ratio of lift coefficient to drag coefficient: $F_L / F_D = C_L / C_D$.

3. Repeat step 2 for angles of attack from -10° to +30° in 5° intervals and complete the first four columns of Table 1.

4. Measure the dimensions (chord length c and span l) of Airfoil 1 and calculate its cross section area A_1. Using the value $\rho = 1.225\,\text{kg/m}^3$ for the density of air at sea level and at the standard temperature of 15°C, and the measured values of wind speed v, calculate the lift and drag coefficients C_L, C_D and complete the last two columns of Table 1. (Use eqs. (6) and (7).)

5. Repeat steps 1 – 4 for Airfoil 2, which has an asymmetric profile, and enter data in Table 2.

II. Dependence of Lift and Drag on Wind Speed

1. Fasten Airfoil 2 to platform and attach test bed to wind tunnel. Set the angle of attack to 0°.

2. Gradually increase the wind speed to 100 km/h in 10 km/h intervals, and record the lift force F_L, drag force F_D, and the ratio of lift to drag F_L / F_D in Table 3.

3. Using eqs. (6) and (7), and the dimensions of Airfoil 1, calculate C_L and C_D and complete the last two columns of Table 3.

III. Lift and Drag for Spherical Balls

1. Fasten the smooth plastic ball to the test platform and place test bed inside wind tunnel. Set the angle of attack to 0°.
2. Gradually turn the wind speed up to 100 km/h in intervals of 10 km/h, and record $v, F_L, F_D, \dfrac{C_L}{C_D}$ in Table 4.
3. Repeat step 4. Part I and complete the entries of Table 4 for C_L and C_D.
4. Repeat steps 1 and 2 for golf ball and enter the data in Table 5.

Data Analysis

I. Graphs for Tables 1 & 2 (7 points)

1. (2 points) Open a new spreadsheet in Excel, and enter the angle of attack in one column. In the next two columns, enter the lift coefficients from Airfoil 1 and Airfoil 2 (Tables 1 & 2). Using all three columns, plot α vs C_L for both airfoils on a single graph. (0 = no plot, 1 = correct plot of data for single airfoil, 2 = correct plot of both airfoils)
2. (2 points) Repeat step 1 for drag coefficients: plot α vs C_D on a single graph for both airfoils. (0 = no plot, 1 = correct plot of data for single airfoil, 2 = correct plot of both airfoils)
3. (1 points) What is the critical angle for each airfoil? (0 = no valid answer, 1 = correct determination of critical angle, or absence of a critical angle)
4. (2 points) What difference(s) do you notice in the graphs for the airfoils? (0 = no valid answer, 1 = correct assessment of difference in one or the other of two graphs, 2 = correct assessment of difference in both graphs)
5. Label and print graphs.

II. Graph for Table 3 (4 points)

1. (2 points) Open a new spreadsheet in Excel, and enter the wind speed in one column. In the next two columns, enter the lift and drag coefficients for Airfoil 2. Using all three columns, plot v vs C_L and v vs C_D for Airfoil 2 on a single graph. (0 = no plot, 1 = correct plot of data for v vs C_L or v vs C_D, 2 = correct plot of data for v vs C_L and v vs C_D)
2. (2 points) Are there specific velocities at which the curve of v vs C_D or v vs C_L changes sharply? Explain such changes in terms of the flow of air on the leeward side of the airfoil. (0 = no valid answer, 1 = correct assessment and identification of critical velocity (or velocities) at which one or the other curve changes sharply, 2 = correct assessment and identification of critical velocity (or velocities) at which each curve changes sharply. Correct assessment includes observing that no such changes are present in one or both curves.)
3. Label and then print graph.

III. Graphs for Tables 4 & 5 (11 points)

1. (2 points) Open a new spreadsheet in Excel, and enter the wind speed in one column. In the next two columns, enter the lift coefficients from plastic ball and golf ball. (Tables 4 & 5). Using all three columns, plot v vs C_L for both balls on a single graph. (0 = no plot, 1 = correct plot of v vs C_L for one or the other ball, 2 = correct plot of data v vs C_L for both balls.)
2. (2 points) Repeat step 1 for drag coefficients: plot v vs C_D on a single graph for both balls. (0 = no plot, 1 = correct plot of v vs C_D for one or the other ball, 2 = correct plot of v vs C_D for both balls.)
4. (3 points) Are there specific velocities at which the curves of v vs C_D change sharply? Explain such changes in terms of the flow of air on the leeward side of each ball. (0 = no

valid answer, 1 = correct assessment and identification of critical velocity (or velocities) at which curve of v vs C_D changes sharply for one ball, 2 = correct assessment and identification of critical velocity (or velocities) at which curve of v vs C_D changes sharply for both balls, 3 = correct assessment and identification of critical velocity (or velocities) at which curve of v vs C_D changes sharply for both balls and correct explanation of sharp change in curve of v vs C_D in terms of flow of air on leeward side of ball. Correct assessment includes observing that no such changes are present in one or both curves.)

3. (2 points) What difference(s) do you notice in the v vs C_D graphs for the airfoils? (0 = no valid answer, 1 = correct assessment of difference in one or the other of two graphs, 2 = correct assessment of difference in both graphs)
4. (2 points) What difference(s) do you notice in the v vs C_L graphs for the airfoils? (0 = no valid answer, 1 = correct assessment of difference in one or the other of two graphs, 2 = correct assessment of difference in both graphs)

Table 1 Lift and drag versus angle of attack: Airfoil 1

α(deg)	v(km/h)	F_L(N)	F_D(N)	$\frac{C_L}{C_D}$	C_L	C_D

Table 2 Lift and drag versus angle of attack: Airfoil 2

α(deg)	v(km/h)	F_L(N)	F_D(N)	$\frac{C_L}{C_D}$	C_L	C_D

Table 3 Lift and drag vs wind speed for Airfoil 2

v(km/h)	F_L(N)	F_D(N)	$\frac{C_L}{C_D}$	C_L	C_D

Table 4 Lift and drag versus wind speed for smooth sphere

v(km/h)	F_L(N)	F_D(N)	$\frac{C_L}{C_D}$	C_L	C_D

Table 5 Lift and drag versus wind speed for golf ball

v(km/h)	F_L(N)	F_D(N)	$\frac{C_L}{C_D}$	C_L	C_D