



LESSON GUIDE

Rocket

SolidWorks Fundamentals Course



Level	Advanced
Academic Connections	Aerodynamics, Engineering, Hands-On Learning, Prototyping
Core Concepts	Computer Aided Design CAD, Engineering Analysis, Engineering Design, Design Optimization, Assembly
Duration	15 weeks

Design and launch a fully functional rocket model, using additive manufacturing and digital fabrication tools to learn and understand physics, aerodynamics, and design as well as material behavior challenges.

Penn State University PrintedRockets.com provides the learning content in this curriculum and includes vast use of 3D printing techniques. It also covers the necessary topics to pass the Certified SolidWorks Associate (CSWA) exam and can accommodate a range of other 3D CAD tools.

Within this course students will explore the importance of fabrication to better understand the behavior of their digital design in physical form and the challenges in the design process.

LEARNING OBJECTIVES

Prepare engineering students to effectively develop, analyze, and communicate mechanical designs using associative solid model authoring and analysis software.

By the end of the 15-week lesson, the student will be able to:

- Proficiently develop, analyze, and communicate designs as solid models.
- Recognize and capture design intent using symmetry and dimension alterations as design rationale is determined
- Virtually test fit, form, and function of assembled components
- Analyze and improve models using the finite element method
- Obtain, edit, and integrate existing non-native file formats
- Prepare models for 3D printing
- Produce and manage part family models
- Prepare technical drawings and illustrations
- Utilize advanced modeling functionality: weldments, sheet metal, photo rendering
- Prepare for SolidWorks CSWA exam

REQUIREMENTS

Educator PC with access to:

- Microsoft PowerPoint
- QuickTime
- Internet connection
- Projector
- 3D printers
- SolidWorks software access (for CSWA exam) or any other advanced 3D CAD tool

ESSENTIAL QUESTIONS

- What is the difference between bottom-up and top-down design?
- How do you properly constrain a sketch?
- Is there another way to sketch a part that would allow for easier design changes (e.g., extrude vs. revolve)?
- What makes your mesh and simulation valid?

LESSON SCOPE AND SEQUENCE

WEEK 1: OPEN DESIGN – ANALYZING

In this unit students will analyze the CAD files and 3D printed rocket files provided by Penn State University. By analyzing other files students will learn about the CAD software environment (navigation, assembly, bodies, components, and features) and how to send files for 3D printing using the GrabCAD Print™ tool.
(<https://grabcad.com/print>)

WEEK 2: OPEN DESIGN – MAKE IT YOUR OWN

Students will review the Penn State University rockets that were prepared and printed the previous week. They will assemble the models and analyze how the parts fit together, present final project goals and assessment criteria. Design Thinking Class Assignment – students learn to follow a Design Thinking approach to structure the project management and focus on subjects for self-study. Start with the analyzed Penn State rocket reference and work on how it can be modified, what to save and what to change in order to make it their own, with new design parameters to meet their project ideation. Then design a rocket based on Penn State new rocket that incorporates the student's version of a design improvement. This week gives students an opportunity to print and test multiple prototypes, understand printing time and changes from virtual design to physical model of their rocket's open design. For this week we recommend to review CAD sketch tools. (See <https://dschool.stanford.edu/resources/collections/a-virtual-crash-course-in-design-thinking>)

TOPICS: Sketch Entities, Sketch Tools, Extrusion Properties, Document Properties, System Properties, Part Templates

WEEK 3: GEOMETRY BASE MODELING

- Students will review their designs from the previous week, check the differences between CAD models and printed models, check joints and tolerances and the material behavior. Students will also: Make a new rocket version by deriving a new geometry from the original part (a new instance that manipulates the original design)
- Redesign the bottom piece of the rocket and apply a pattern to create the bottom fins
- Print out prototypes of the geometry to test various derived and patterned designs.

Once the design is finalized, print out and assemble the rocket.

TOPICS: Reference Geometry, Derived Geometry; Base Features: Revolve, Loft, Swept

WEEK 4: AERODYNAMICS SHAPE

In this unit the students consider the aerodynamics of rocket design. By analyzing geometries from the previous weeks, students will now consider the forces and pressures applied to the rocket. Guide students to explore the relation between geometry and material behavior by creating a more freeform profile using sweeps, lofts and geometry based on mathematical equations. Through exploration, students can create a more optimized design for launch. When creating the rocket profile design, consider the file processing that occurs after the part is exported to the CAD system; for example, the different infills, wall thicknesses and FDM™ structuring techniques that can be used to optimize the design. It is also important to keep in mind while designing in CAD to understand how the model will be sliced and processed in the GrabCAD software.

RESOURCES: Please refer to documents: FDM Post Processing and FDM Assemblies. Both documents are located in the Advanced Applications section at <http://www.stratasys.com/3DLC>.

TOPICS: Advanced Sweeps, Controlling Splines, Advanced Lofts, Equations and Linked Variables

WEEK 5: 3D PRINTING TECHNOLOGIES

Present the 3D Printing Technologies PowerPoint presentation. Students will learn the differences between technologies and different material behaviors.

Students take a closer look at the material properties, tolerances, orientation, and the various infills. Print out the material properties data sheets for PLA, ABS, and ASA. What are the differences in the materials? Use the aerodynamic models from last week and print the rocket with the following changes:

- Print in another material and explain the differences between the materials before the next class meeting.
- Print the model in another slice height with the same infill.
- Print the model in the same slice height with a different infill or orientation.

As multiple parts are printed, look at the nesting lesson (see: Nesting lesson) to make sure optimal trays are being prepared.

Once all parts have been printed and assembled, analyze the differences between the various prints and discuss as a class. After discussion, apply post-processing to the models to gain a better surface finish on each model. Make sure students take note of which models were easier to finish and why.

RESOURCES: 3D Printing Technologies PowerPoint, FDM Best Practices: Post-Processing, Nesting Lesson. Located in Advanced Applications section at <http://www.stratasys.com/3DLC>.

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WEEK 6: WATER TIGHT MODELING

Present “What is Mesh” PowerPoint.

Students will gain knowledge beyond basic freeform functions of sweeps and lofts and make a true freeform sculpted rocket. An important characteristic of many printed models is to ensure that it is watertight. Refer to the FDM Best Practice on water tight models when printing. Before importing the model into the GrabCAD Print software, ensure the model is completely closed and water tight in the CAD software.

In this unit, students will create two new models of a rocket:

- One rocket will be completely sculpted (single piece or assembly) in the software and printed.
- The second rocket will be a mix of sculpted parts and constructed parts or constructed parts that have been manipulated using sculpting functions on the constructed model.

This is a great week to paint both freeform rockets in the paint colors of the student’s choice.

RESOURCES: What is Mesh PowerPoint, FDM Best Practices: Water Tight Models, Painting FDM parts. Located in Advanced Applications section at <http://www.stratasys.com/3DLC>.

TOPICS: Techniques - Constructed vs. Sculptured, 3D Sketch Applications, Helix, Splines, Weldments

WEEK 7: INTRODUCTION TO THE FINITE ELEMENT METHOD FOR ROCKET MODELS

In this unit students get an introduction to stress analysis of models. Building upon the material knowledge gained from previous weeks, students analyze previously printed models and build upon their material and design knowledge. Students will design a new part with complex geometry (an open design, can be rocket-related or not) and make prints in a minimum of four orientations. If material testing equipment is available, students can print test samples in multiple orientations and see the material behavior in live engineering tests.

TOPICS: Part Configurations, Feature Tree Properties, Split Line, Combine, Cut with Surface

WEEK 8: BOTTOM-UP DESIGN: ADDING EXISTING PARTS TO AN ASSEMBLY

Starting from a sketch, redesign the rocket using the bottom-up design approach. This approach is favored when designing for off-the-shelf components that are integrated into the final product assembly. Even when off-the-shelf components are not used, the bottom-up approach is used often by designers and engineers. Each part of the assembly can be designed separately while still keeping clearance values and tolerances in mind. Once the parts are finished they can be organized using the CAD program to get the final product completely printed and assembled. Stress

prototyping and testing of assemblies by experimenting with different tolerances and a variety of connections. Print multiple rockets based on the design built using the bottom-up approach, striving for an easy-to-assemble rocket that stays together.

TOPICS: Multibody Techniques: Merge, Combine, Copy Body, Save Bodies; Bottom-Up Techniques I: Fixed Part, Mates, Selection Filters, Exploded View

WEEK 9: TOP-DOWN DESIGN: PARTS DESIGNED IN THE CONTEXT OF THE ASSEMBLY

After learning the basic features involved in top-down design, students will take the design from last week (bottom-up design) and recreate a similar rocket using the top-down design approach. The top-down approach focuses on creating parts in context to other bodies, components, and features. As students create their new rockets using the top-down approach, remember to stress the importance of aerodynamics for their design. Since the top-down approach designs in context to the other bodies, components, and features, ensure this custom design considers the various forces that will be encountered by the rocket. Students will print the new design and compare with their bottom-up design from last week.

TOPICS: Design Tables & Coordinate Systems Bottom-up Techniques II: Sub-assemblies, Collision Detection, Editing Assemblies; Top-Down Techniques I: Creating In-Context Features

WEEK 10: ASSEMBLY FEATURES AND PHYSICAL ANALYSIS TOOLS

Students gain more depth this week by learning additional top-down design techniques and applying them to a new rocket design. As with last week’s unit, it is important to focus on the aerodynamics and engineering references while creating the new rocket. Before the student creates the first part, ensure they are knowledgeable about how it connects to the next body, component, or feature that will reference the geometry being built.

The rocket being built this week will be the reference model for launch week. In the following units, students will utilize additional tools to refine this model for launch. Students should have all of their prints in class during the first meeting of the week so they can see how designs have progressed. From here students make a decision on how to create the top-down design for the week that will be the main reference geometry for launch day. Stressing aerodynamics is extremely important and they should apply these concepts to their custom top-down design geometry.

TOPICS: Top-Down Techniques II: In-Context Design, Assembly Sketch, Hole Series, Interference, Collision, Physical Dynamics, Animation, Exploded Views

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WEEK 11: 2D ENGINEERING DRAWINGS

In this unit students create 2D drawings to explain design decisions and the challenges faced. Using the top-down design technique from two weeks ago, create the 2D drawings for the rocket and explain the engineering decisions that drove their designs. Errors and other insights are likely to be encountered, and the student should be encouraged to make changes to their main reference geometry (Week 9; top-down design) and test new prototypes and assemblies.

Discuss with the students and provide feedback on designs and engineering drawings (feedback will be used next week to refine design.)

TOPICS: Drawing preparation, Drawing environment, Drawings sheets & Sheet formats, Views palette, Views: Standard, Section, Detail; Dimensions: Drawing & reference

WEEK 12: ASSEMBLY CONFIGURATION, DISPLAY STATES

Students will create an Assembly Guide (step-by-step instructions) to focus on communication, user experience, 2D CAD skills (drawing/creating the assembly configuration). Don't forget to add isometric sketches with dimensions. Pay attention to line thickness, line type, coloring system, legend (if necessary) and positions.

Students should optimize designs based on feedback from the previous week—make sure that changes are being made to the top-down design from Week 9. The optimized files from the Week 9 design will be used on launch day. As students are making changes to their designs, ensure they print new prototype models. These models should be used to test the Assembly Guide being prepared during the week. At the end of the week, students exchange the model and guidebook with another student, and provide feedback on the assembly and overall design communication.

TOPICS: Using Part Annotations: Feature vs. Reference Dims, Assembly Configurations, Display States, Isolate; Layers: Line thickness, Line style, Move; Views: Alternate position, Exploded, Cutaway; Export Options: .dxf, .pdf; System Options & Document Properties

WEEK 13: PHOTO RENDERING AND ADVANCED:

SHEET METAL TOOLS

Continuing from the previous week's assignment, teach how to render for SolidWorks. Students can use PhotoView 360, add those renders to the guidebook, and pay attention to view positions, light and how to focus the viewer's eye on the important part in the scene.

Encourage students to optimize the main reference rocket geometry from Week 9 by testing additional prototype rockets. Launch date is only two weeks away!

TOPICS: Introduction to Sheet Metal Flange Types: Base, Miter, Edge, Tab; Flat Pattern, Drawing Views, Closed Corner, Design Library, Lofted Bends

WEEK 14: FINITE ELEMENT ANALYSIS OF ASSEMBLIES AND SECOND-TO-LAST PRINT

In this unit students perform stress analysis on their near-final rocket models. Students will learn about valid meshes and various types of analysis. Based on the finite element results, how might the rocket design be improved? Use the results of the simulation to redesign the main rocket reference geometry. Print the new prototype rockets and assemble.

TOPICS: Design Cycle, Finite Element Method, Types of Analyses, Analysis Steps, Mesh Tuning, Results Presentation

WEEK 15: PREPARE FOR LAUNCH!

The final week that everyone has been waiting for — the true challenge of the rocket launch! Which student's rocket will launch the highest? Make final tweaks to model design from the information learned on last week's FEA analysis. Print final prototypes and then assemble the final rockets for the launch competition.

Most importantly this week, besides having a rocket to launch, is to have fun on the launch date! Happy Launchings!

Essential Launch Day Question:

- How was design research and design thinking used and applied to the final design?
- How did the student decide upon the final design?
- Did the stress analysis influence the design?
- Did the rocket go as high as expected?
- What was learned from the launch? Would additional changes be made based on the results of the launch?

ADDITIONAL RESOURCES

Course information:

Visit <http://www.printedrockets.com> for more helpful information from Penn State faculty.

Lessons and Labs for weeks 1-3 available at: <https://stratasys.box.com/s/umsdgpb1mnlq77v5aocx11oiiuuko4g>

For more information regarding the CSWE exam visit: <https://www.solidworks.com/sw/support/CSWE.htm>

For SolidWorks tutorials visit: SolidProfessor.com or Lynda.com

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ASSESSMENT

Student evaluation and individual grades are based on a combination of lab assignments, quizzes, projects and the CSWA Exam.

1. Lab Assignments	35%
2. Quizzes	20%
3. Project: Phase 1	20%
4. Project: Phase 2	15%
5. CSWA Exam	10%

Student learning is applied in two project phases. See PrintedRockets.com for rubric and timing. See below for examples of Phase 1 and 2 scoring breakdown.

DESIGN COMPETITION

Scoring Rubric: 1300 points max, Metric Units

PHASE 1: DUE (MARCH OR DATE OF YOUR CHOICE)

1. 500 points – Build CAD Model Using SolidWorks
 - Submit assembly model of a 3-component rocket design suitable for 3D printing on a single-head extruder with minimal support. (i.e., zero support = highest score)
 - Assembly: Nose, Body, Base, Motor Mount (please provide to student)
 - Design should accept provided motor mount sub-assembly
 - Design integral launch lug
 - Design integral exhaust gas baffle
 - Design integral shock cord attachment points on nose and body
 - Nose cone must be hollow to accept ballast
 - Fins must have airfoil profile (not simply flat)

2. 100 points – Analyze Stability Using OpenRocket:
 - Calculate stability caliber (1.0 minimum) for D12 engine
 - Submit OpenRocket analysis report (File>Print/Export PDF)

PHASE 2: DUE (MAY OR DATE OF YOUR CHOICE)

3. 200 points – Attend the Prelaunch Build Event
 - Assemble all rocket components for flight

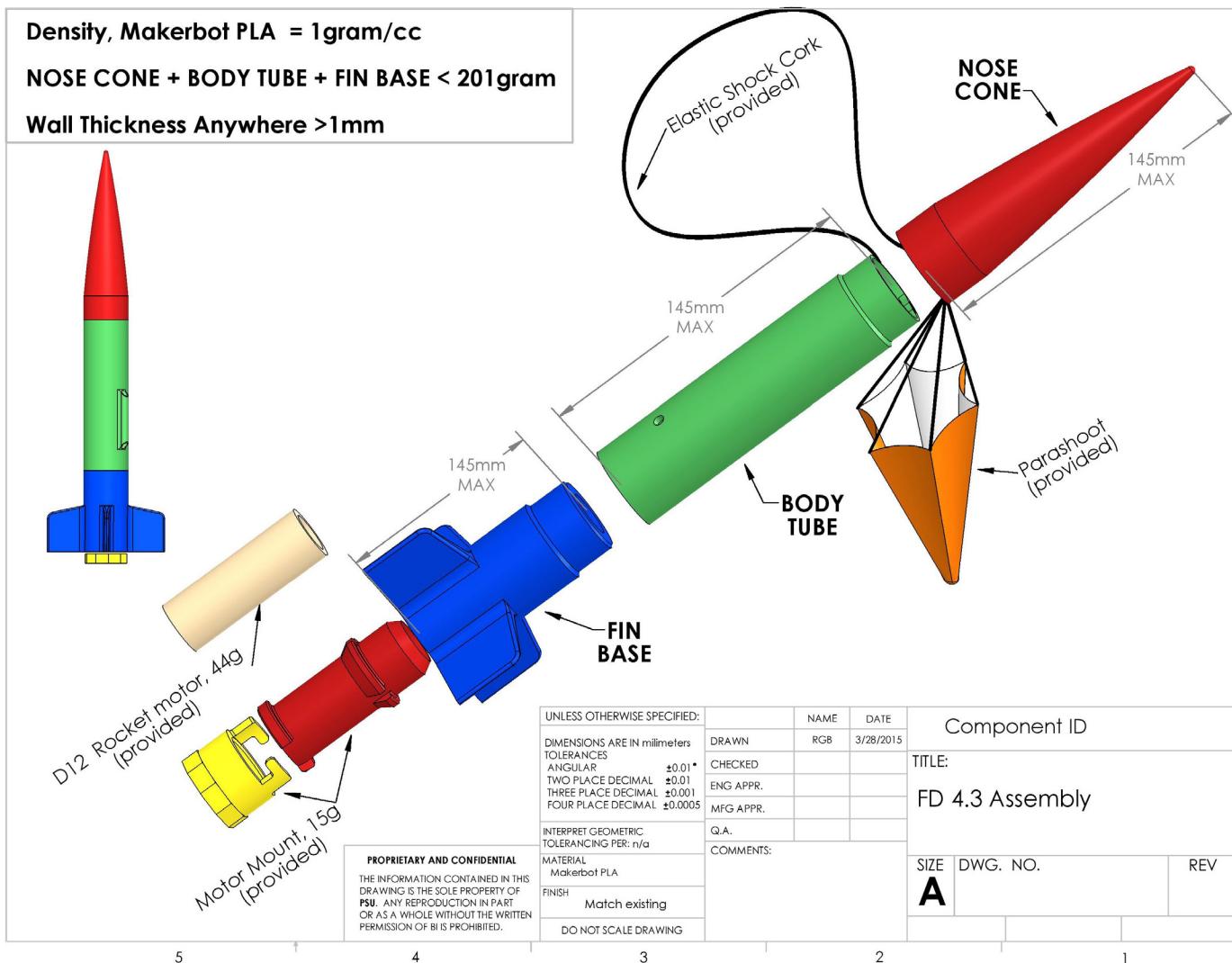
4. 200 points – Attend the Launch Event
 - Preflight inspection (i.e., rocket determined flight worthy by instructor)
 - Rocket flight stable
 - Rocket recovered without damage

5. 300 points – PowerPoint-Based Design Review
 - Submit PowerPoint
 - Introduction
 - Design Intent
 - Analysis Results: OpenRocket
 - Rocket Shop Drawings (use design intent prints as your guide)
 - Discussion

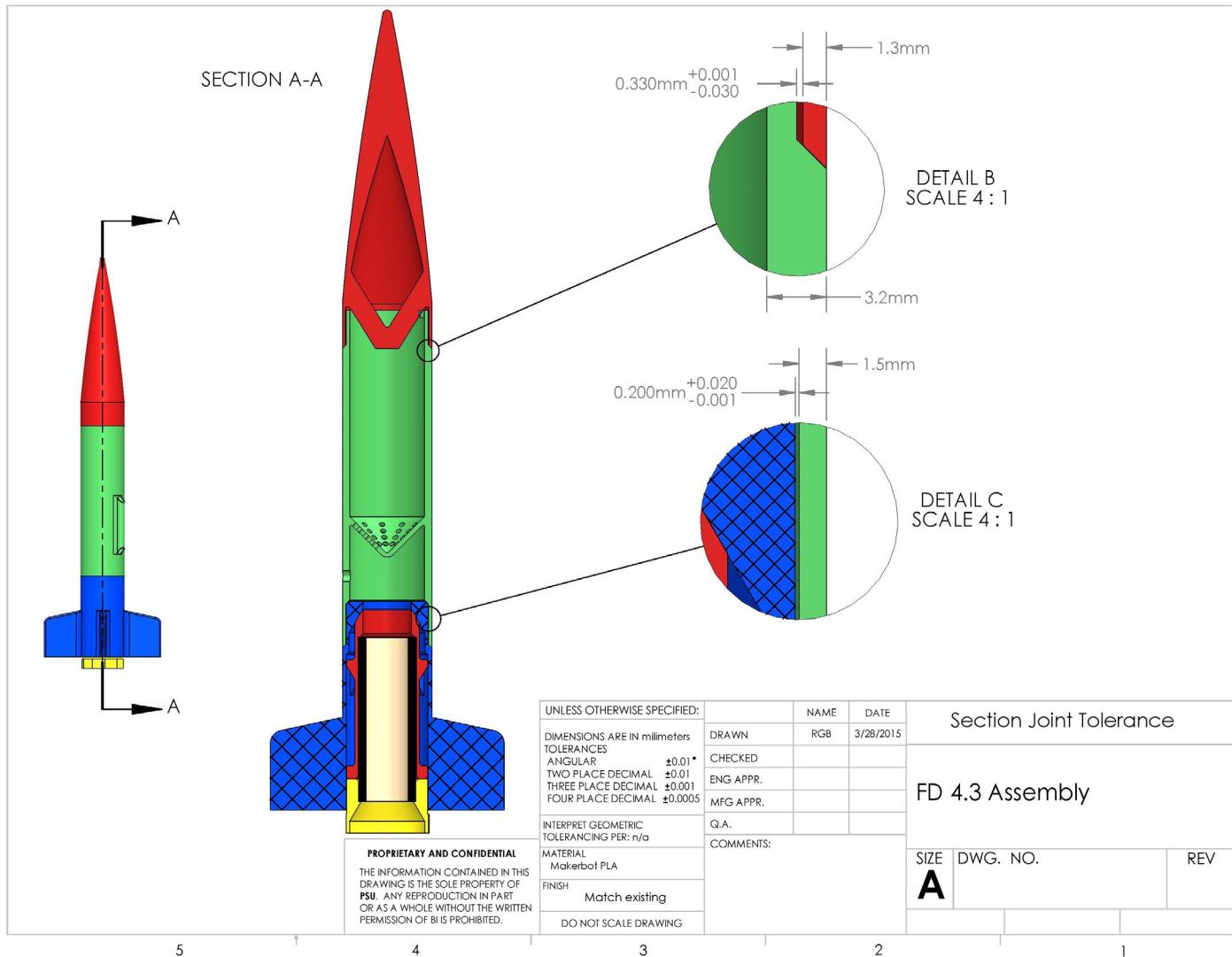
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EXAMPLES OF DESIGNS

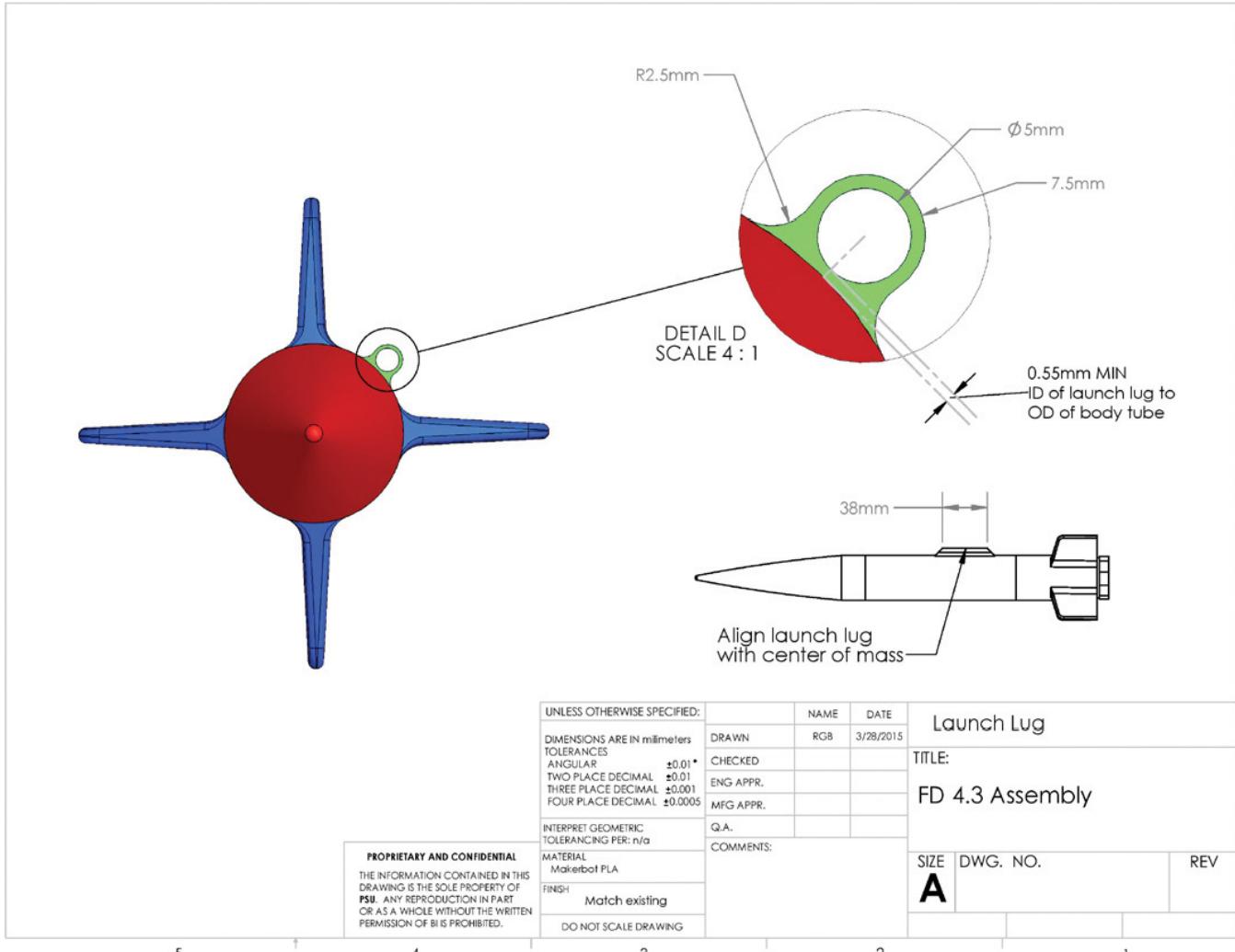
The following are examples from students at Penn State University.



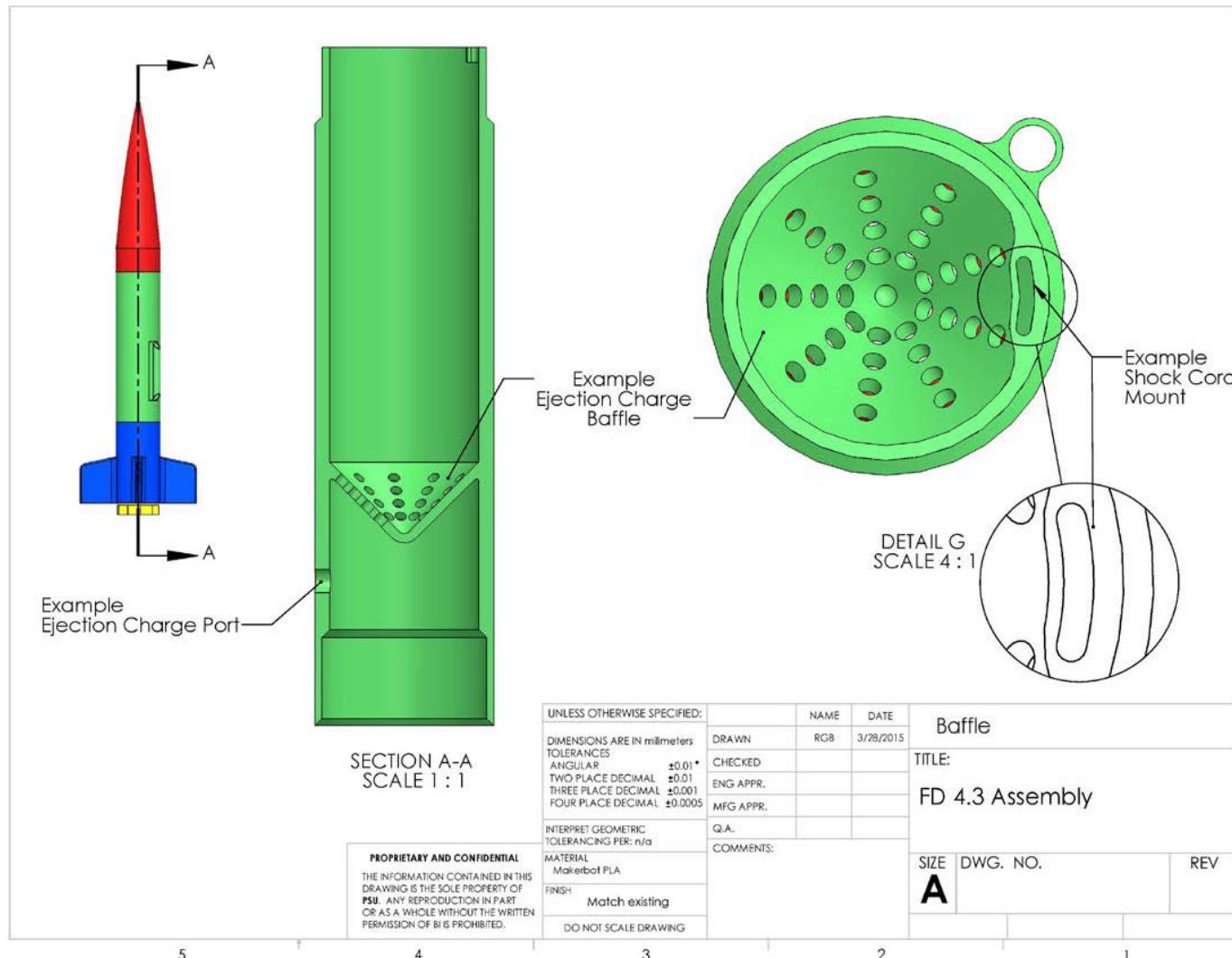
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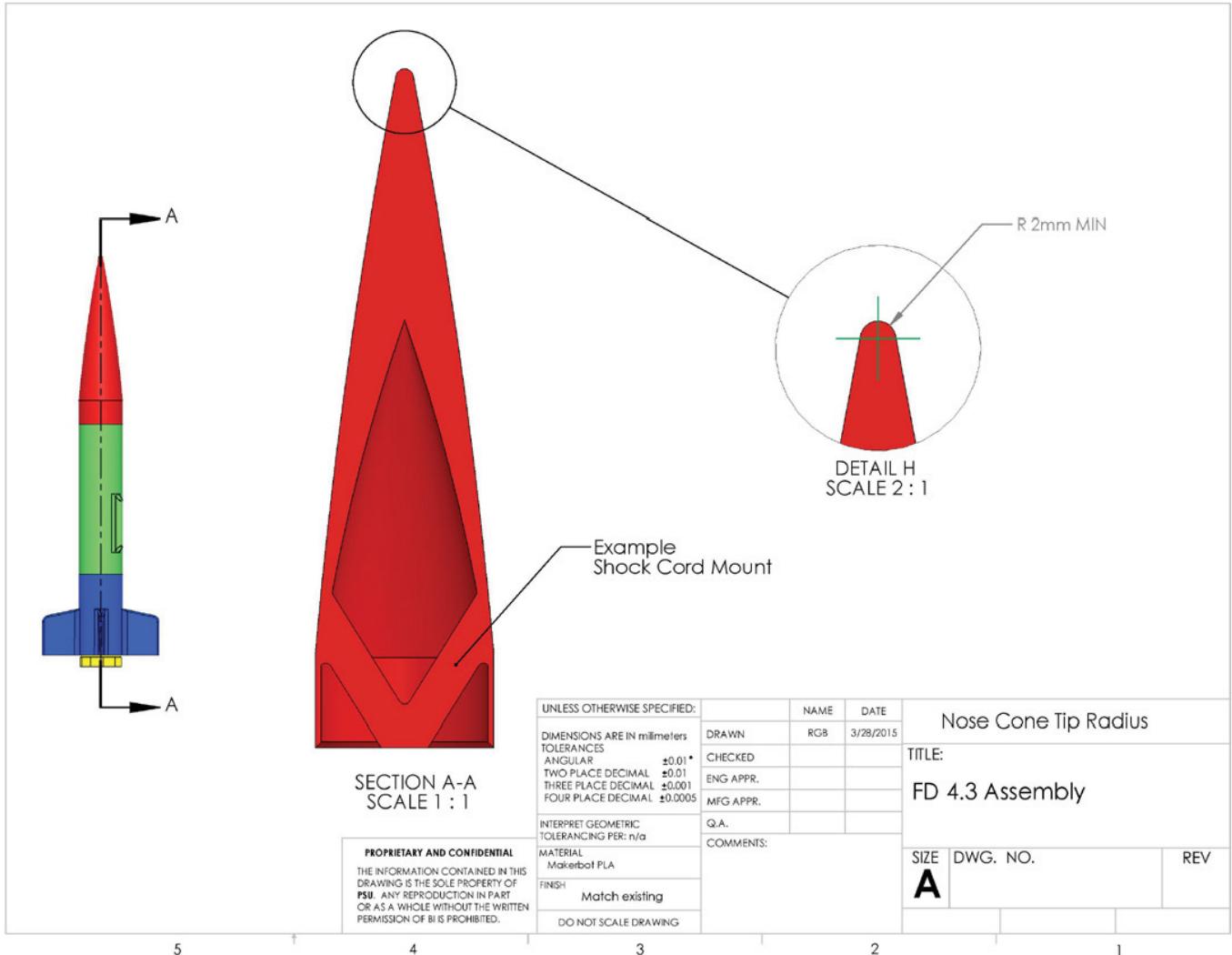
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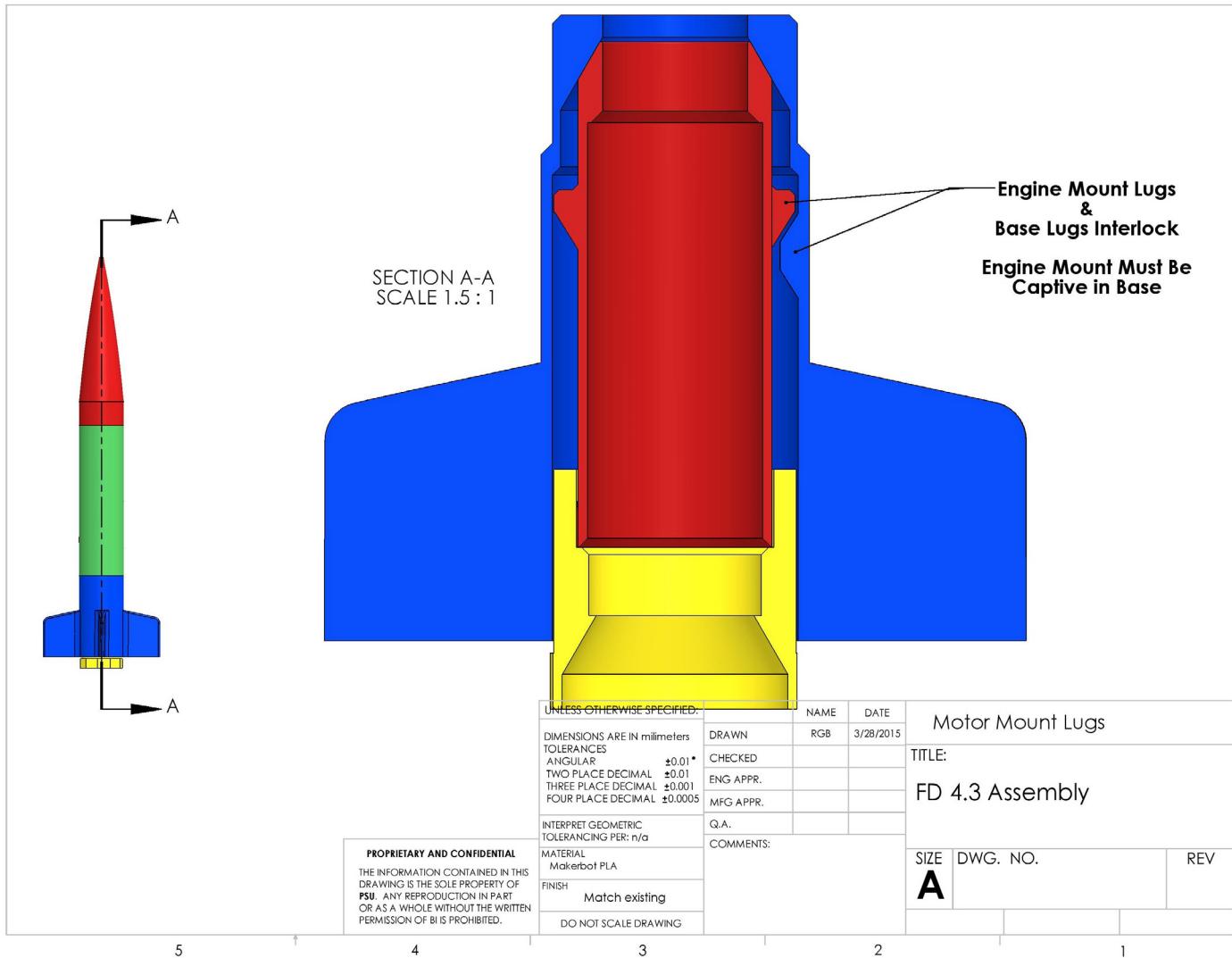
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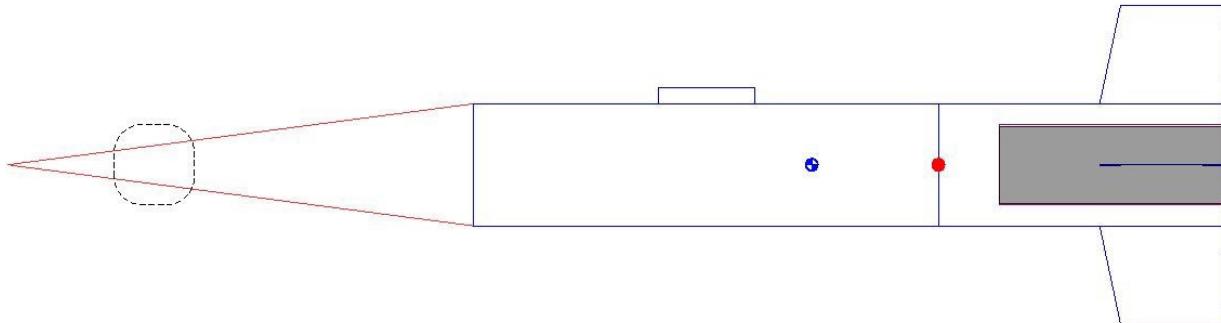


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Rocket Design



Rocket

Stages: 1

Mass (with motor): 192 g

Stability: 1.04 cal

CG: 250 mm

CP: 290 mm

D12-0

Altitude 849 ft
Flight Time 23.2 s
Time to Apogee 7.59 s
Optimum Delay 6.01 s
Velocity off Pad 32 mph
Max Velocity 160 mph
Velocity at Deployment N/A
Landing Velocity 43.5 mph

Motor	Avg Thrust	Burn Time	Max Thrust	Total Impulse	Thrust to Wt	Propellant Wt	Size
D12	10.4 N	1.61 s	29.7 N	16.8 Ns	5.54:1	21.1 g	24/70 mm

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SUGGESTED NEXT LESSONS

GOLF PUTTER

Design a golf putter and explore moment of inertia and how it affects a putter's action when striking the ball. Use the swing weight scale and the putter's length to determine the approximate head weights that will be needed for the design.



SOLAR CAR

Design, 3D print and assemble a working solar car. When developing the design consider aerodynamics, rolling resistance, torque, gear ratio, bearings and the wheel base.



WEIGHT-SUPPORT CHALLENGE

In this challenge, the goal will be to build a structure that can support a weight that is suspended above a surface.



To access additional 3D Learning Content and resources visit:

<http://www.stratasys.com/3DLC>

OPTIONAL TEXTS

SolidWorks 2011 Parts Bible by Matt Lombard

Publisher: Wiley, ISBN-10: 111800275X, ISBN-13: 978-1118002759

SolidWorks 2013 Parts Bible by Matt Lombard

Publisher: Wiley, ISBN-10: 1118508408, ISBN-13: 978-1118508404

Engineering Design with SolidWorks 2013 by David C. Planchard

Publisher: Schröff, Development Corporation, ISBN-10: 158503777X,
ISBN-13: 978-1585037773

A Comprehensive Introduction to SolidWorks 2012 by Godfrey
Onwubolu

Publisher: Schröff, Development Corporation, ISBN-10: 1585037079,
ISBN-13: 978-1585037070

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