Advanced CAD and Additive Manufacturing Engineering

George Papageorgiou
Achilleas Sesis

“A designer is an emerging synthesis of artist, inventor, mechanic, objective economist and evolutionary strategist.”

Richard Buckminster Fuller

This book was set in Calibri and was publised in London, England, by 4Delta Ltd.

George Papageorgiou and Achilleas Sesis
Advanced CAD and Additive Manufacturing Engineering
1st Edition, May 2017

This books is part of the Advanced CAD and Additive Manufacturing Engineering (ACADAME01), and should not to be sold seperately.

CONTENT

Welcome Back	xii
A Few Words About This Book	xiii
I. Is it For You?	xiii
II. Your Onshape Design Elements	xiii
III. Your Engineering and Advanced AM Elements	xiii
IV. How To Study	xiii
Course Video Elements	xiv
Meet Onshape Again	xvii
I. GUI	xvii
II. Feature Toolbar	xvii
III. Sketch Toolbar	xxi
IV. Assembly Toolbar	xxiii
V. Drawings Toolbar	xxiv
SECTION 1 - Wind Design	2
1.1 YOUR DESIGN	2
1. Airfoil Template, Plot (WL1)	3
2. Airfoil Template, Spars (WL2)	6
Homework 1 - Rear Spar	7
3. Airfoil Template, Lightening Holes (WL3)	8
4. Airfoil Template, LE Cavity (WL4)	9
5. Airfoil Template, TE Cavity (WL5)	10
Homework 2 - Fwd. Upper Stringer	12
6. Airfoil Template, Stringers (WL6)	13
7. Root Rib (WL7)	13
Homework 3 - Mid Rib 1	14
8. Mid Rib 1 (WL8)	15
Homework 4 - Mid Rib Standard	15
9. Wing Tip Rib (WL9)	16
Homework 5 - Rib TE1	17
10. Rib TE1 (WL10)	17
11. Rib TE Standard (WL11)	18
12. Rib LE Standard (WL12)	19
Homework 6 - Truss Type Wing Rib Foundation	20
13. Truss Type Wing Rib (WL13)	20
14. Aileron, Tab (WL14)	22
15. Aileron, Aileron Structure L (WL15)	25
16. Aileron, Aileron Structure R (WL16)	26

17. Rear Spar (WL17) 27
Homework 7 - Front Spar 28
18. Cover Panel (WL18) 28
Homework 8 - Cover Panels 32
Homework 9 - Stringers 32
19. Wing Assembly (WL19) & (WL20) 32
1.2 REVISION DESIGNS 33
Homework 10 - Cobb's Totem 33
20. Cobb's Totem (RD1) 34
21. Padlock, Shackle (RD2) 35
22. Padlock, Main Body (RD3) 36
23. Padlock, Assembly (RD4) 37
24. M5 Hex Bolt (RD5) 38
25. M5 Hex Nut (RD6) 40
26. M5 Bolt & Nut Assembly (RD7) 41
Section 1 Summary 42
SECTION 2 - Rocket Design 46
2.1 Introduction 46
2.2 Falcon 9 Rocket 46
1. Profile Plot (RL1) 48
Homework 11 - Rocket segments 50
2. Engines (RL2) 50
Homework 12 - Engines Numbering 52
3. Supply Line (RL3) 53
4. Landing Legs (RL4) 54
5. Markings (RL5) 56
Homework 13 - Markings 57
Homework 14 - Creating the Grid Fin Template 58
6. Grid Fin 1/2 (RL6) 59
7. Grid Fin 2/2 (RL7) 60
8. Grid Fin, Main Body (RL8) 60
9. Grid Fin, Pad 1/2 (RL9) 61
10. Grid Fin, Pad 2/2 (RL10) 62
11. Rocket Assembly (RL11) 63
12. Version Control & Branching (RL12) 65
13. Comparing (RL13) 65
14. Drawings (RL14) 65
Section 2 Summary 69

SECTION 3 - INTRODUCTION TO ENGINEERING 72
3.1 OBJECTIVES 72
3.2 WHY ENGINEERING? 72
3.2 ENGINEERING IN A NUTSHELL 73
3.4 BASIC ENGINEERING CONCEPTS 74
3.5 SUMMARY 81
SECTION 4 - STANDARDISATION 86
4.1 OBJECTIVES 86
4.2 INTRODUCTION 86
4.3 SUMMARY 87
SECTION 5 - COMPUTER AIDED ENGINEERING AND 3D PRINTING 90
5.1 OBJECTIVES 90
5.2 COMPUTATIONAL SCIENCE AND ENGINEERING 90
5.3 SIMULATION IN ENGINEERING 90
5.4 CAE AND 3D PRINTING 91
5.5 THE MARKET OF CSE 92
5.6 SUMMARY 93
SECTION 6 - OPTIMATTER 96
6.1 OBJECTIVES 96
6.2 COMPUTATIONAL SCIENCE AND ENGINEERING 96
6.3 OPTIMATTER INTERFACE CONTROLS 96
HOMEWORK 15 - WORKING WITH STRESS 98
6.4 SUMMARY 99
SECTION 7 - ADVANCED FFF OBSERVATIONS 102
7.1 OBJECTIVES 102
7.2 INTRODUCTION 102
7.3 ENGINEERING OBSERVATIONS 102
7.4 SUMMARY 111
SECTION 8 - CLOSING REMARKS 114
REFERENCES 118
APPENDIX 122

WELCOME

Welcome Back

We hope you had a great learning experience from our Introduction to CAD and 3D Printing course, one that you have made good use of your newly discovered talents. Advanced CAD and Additive Manufacturing (AM) Engineering is the second instalment of the journey that you have embarked with us. This course is designed to capitalise on advanced tools and techniques for using Onshape CAD and to provide further insight into AM and Engineering in general. Now it's time to conquer the final element of Onshape and become a professional user of the software. On the Additive Manufacturing front, we have teamed up with 3D Matter to deliver advanced 3D printing knowledge with a focus on structural analysis, materials and processes, and design.

This course would not have been possible without the encouragement and contribution of some key partners. We would like to thank the Onshape team, who have been a source of constant support throughout every phase of this project. We also would like to acknowledge the invaluable support of the 3D Matter team for working with us in developing the advanced AM training content. Finally, we warmly thank the graphic and design work provided by Togada Studio.

4Delta Education Team

A Few Words About This Book

I. Is it For You?

Here, we have also followed a teaching approach that is created from the ground up, assuming little about your prior knowledge in some of our topics. However, we do highly recommend that you have had successfully completed the Introduction to CAD and 3D Printing course. Our aim is to turn you into a confident creator and provide you with enough engineering and scientific knowledge for you to achieve a significant level of independency.

II. Your Onshape Design Elements

Your two main design projects will be a detailed tapper aircraft wing and a model Space X's Falcon 9 rocket. Both are complimented with various other smaller design projects (Cobb's Totem, Padlock and M5 Hex Nut, and Bolt) that will be used as examples or homework material to enhance your skills further.

III. Your Engineering and Advanced AM Elements

Following your design elements, we move into the world of Engineering with a particular focus in Additive Manufacturing. We start by introducing you to some fundamental concepts that include introductory content from the professional engineering world (i.e. Standards and Computer Aided Engineering), as well as basic engineering knowledge before moving onto advanced 3D printing. In the former, we discuss forces and their effects on objects, while in the latter, working with our partners at 3D Matters, we thoroughly analyse advanced observations related to 3D printing materials, design, and processing.

IV. How To Study

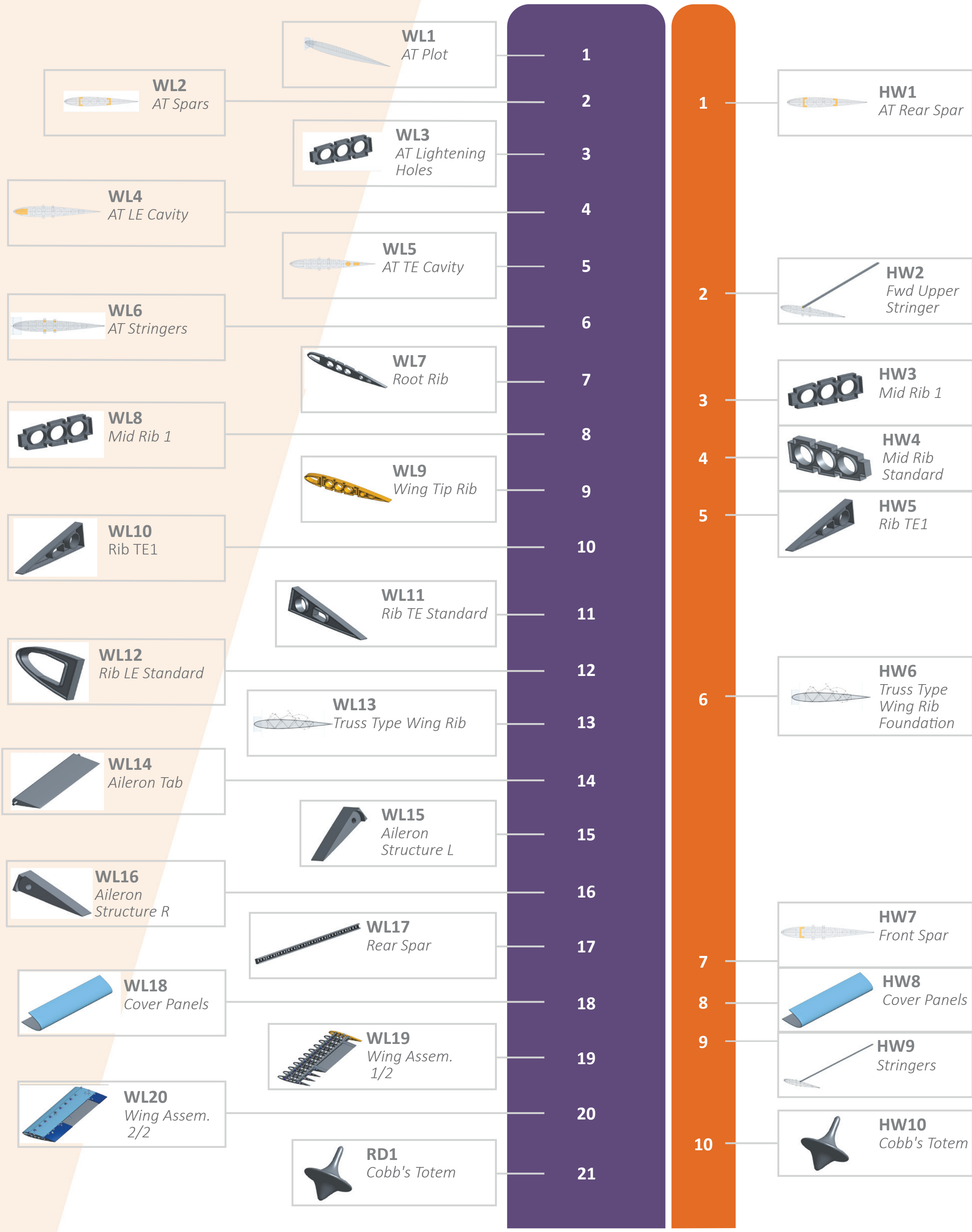
Like its predecessor, this course is presented in the form of online video material, consisting of lessons, homework, and quiz tests. The booklet companion you are holding is tailored to provide you with the theoretical foundation for the online course, making your learning experience more academically sound and complete. Below, you will find a roadmap layout of your course. Use it as a guide to track your progress.

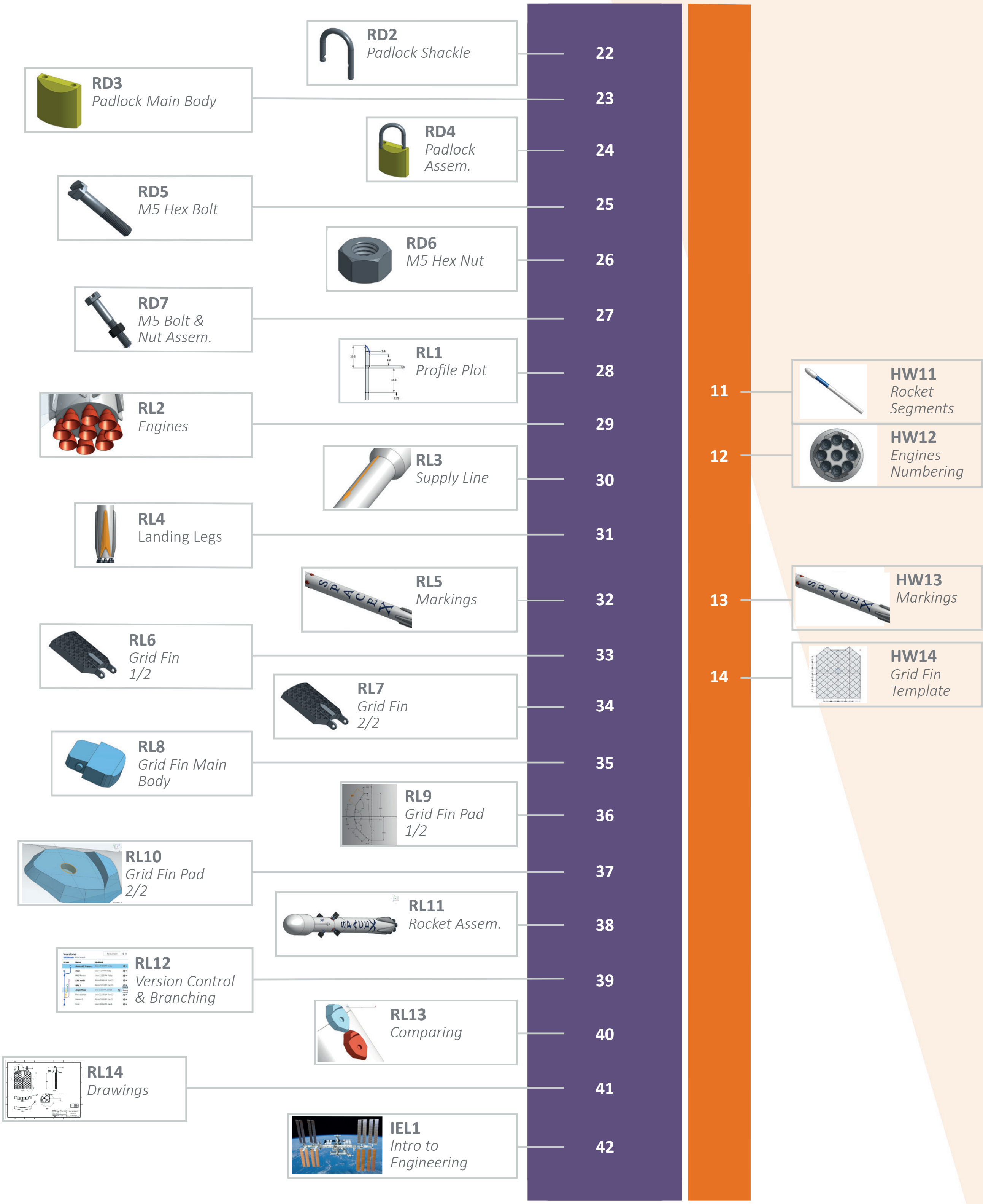
Tip Box

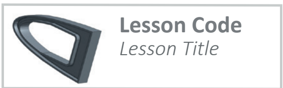
Knowledge Box

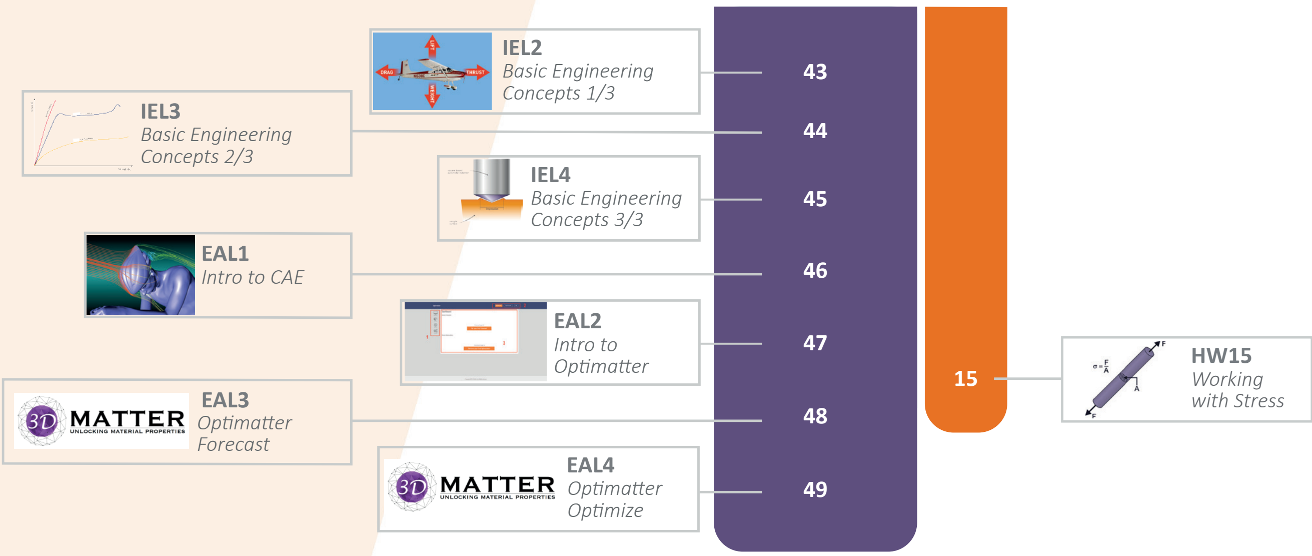
Good Practice Box

Course Video Elements




RD2
Padlock Shackle
22
RD3
Padlock Main Body
23
RD4
Padlock Assem.
24
RD5
M5 Hex Bolt
25
RD6
M5 Hex Nut
26
RD7
M5 Bolt & Nut Assem.
27
RL1
Profile Plot
28
RL2
Engines
29
RL3
Supply Line
30
RL4
Landing Legs
31
RL5
Markings
32
RL6
Grid Fin 1/2
33
RL7
Grid Fin 2/2
34
RL8
Grid Fin Main Body
35
RL9
Grid Fin Pad 1/2
36
RL10
Grid Fin Pad 2/2
37
RL11
Rocket Assem.
38
RL12
Version Control & Branching
39
RL13
Comparing
40
RL14
Drawings
41
IEL1
Intro to Engineering
42
11
HW11
Rocket Segments
12
HW12
Engines Numbering
13
HW13
Markings
14
HW14
Grid Fin Template


Lesson Code
Lesson Title



Lesson Code
Lesson Title

Meet Onshape Again

Onshape is currently the market's primary and only full cloud-based professional CAD that runs strictly on your web browser and equips you with the capability to create, manipulate, and present professional 3D CAD designs that meet all the industry's standards from the ground up. Its large partnership programmes bring in the most advanced add-on servicing for CAD, focusing on boosting your capabilities and productivity. Finally, it connects you with a large global community of designers and engineers who share the same passion and provide you with technical support that is second to none. For more information on Onshape, revisit the Introduction to CAD and 3D Printing course book.

I. GUI

The current segment will revisit the platform's toolbars with revised commands and introduce the newly formed DRAWINGS TOOLBAR. In the following section, we will provide you with a brief overview of all the commands featured in the Graphics User Interface (GUI) of Onshape. Commands that are taught in this course are presented in normal black fonts, while the ones previously taught (or not) are shown in light grey fonts.

II. Feature Toolbar

The Feature Toolbar contains the design commands used in the three-dimensional environment. If your mouse cursor is hovered over the command for few seconds you will get a description of each command with concise user instructions.

Sweep: Create, add to, subtract from, or intersect parts or surfaces by sweeping sketch regions, planar faces or lines and curves along a path.

Loft: Create, add to, subtract from, or intersect parts by putting a smooth surface between ordered profiles.

Thicken: Create new, add to, subtract from, or intersect parts by thickening faces of solids, surfaces.

Fillet: Create fillets, rounds of conic fillets with a specified radius along edges or faces.

Chamfer: Create bevelled edges on selected edges or faces.

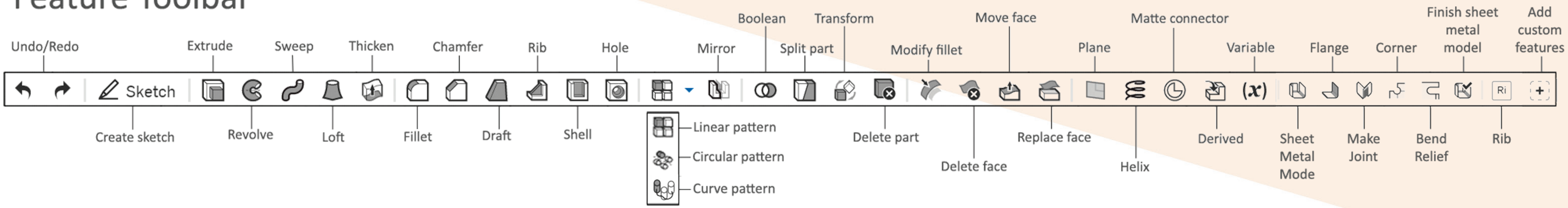
Draft: Add a draft angle to one or more selected faces.

Rib: Create ribs in parts at multiple locations based on a sketch.

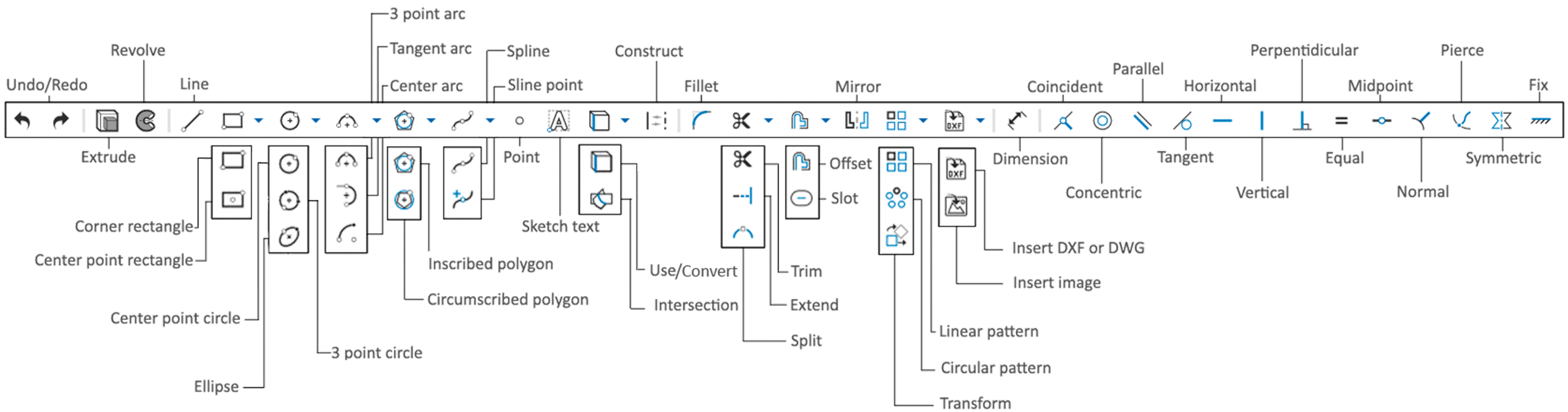
Shell: Create a hollow, thin-walled part by removing one or more faces and specifying thickness.

Hole: Create simple, countersink or counterbore holes in parts at multiple points in a sketch.

Feature Toolbar

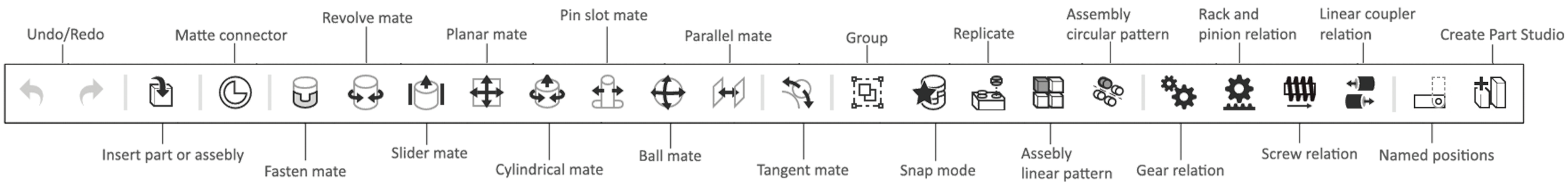


Sketch Toolbar

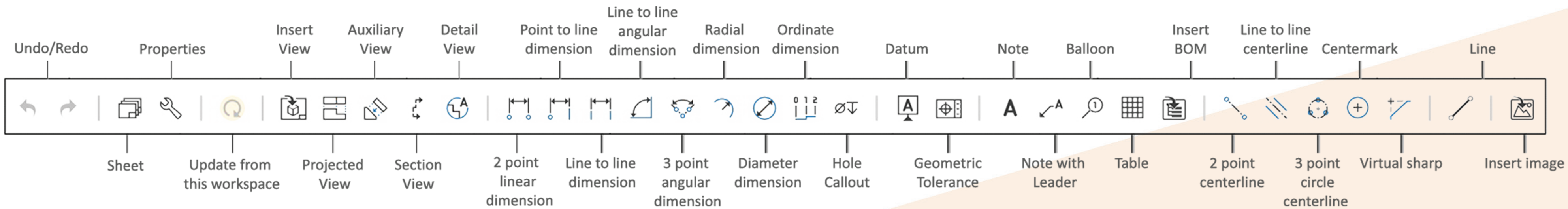


Updated 5/2017

Assembly Toolbar



Drawing Toolbar



Pattern Tool

Linear Pattern: Create multiple copies of parts or faces uniformly in one or two directions.

Circular Pattern: Create multiple copies of parts of faces uniformly around an axis.

Curve Pattern: Create multiple instances or parts, faces or features uniformly a long a curve.

Mirror (Part): Create a mirror copy of one or more selected parts, features, or faces about a plane or planar face.

Boolean: Perform a Boolean operation on two or more parts.

Split Part: Create new entities by splitting the selected entities.

Transform: Adjusts a part's location and orientation in 3D space with the option to copy the part in place.

Delete Part: Delete selected part.

Modify Fillet: Change the radius or remove existing fillets.

Delete Face: Deletes one or more faces from a part and automatically patches the space to create a solid. Fillets dependent on the deleted faces can automatically be reapplied.

Move/Create Face: Move, rotate or offset faces, modifying the part or creating new surfaces.

Replace Face: Replace one or more selected faces with another.

Plane: Create new construction planes by referencing existing planes or geometries.

Helix: Create a helix on a conical or cylindrical face.

Mate Connector: Create mate connectors on parts. Mate connectors are used to position parts in assembly mates.

Derived: Insert parts, sketches, surfaces, helices or mate connectors from one Part Studio into another in the same document with an associative link.

Variable: Assign a variable inside this Part Studio.

Sheet Metal Model: Create and activate a sheet metal model by converting existing parts, extruding sketches and thickening faces or sketches. All operations on sheet metal models are automatically represented in the flat pattern and table.

Flange: Create one or more walls, connected by a bend, on existing sheet metal parts.

Make Joint: Create a bend or rip joint where two walls come together.

Corner: Modify an individual sheet metal corner.

Bend Relief: Modify an individual sheet metal bend relief.

Finish Sheet Metal Model: Deactivate the sheet metal model in order to continue editing with non-sheet metal parts are not represented in the sheet metal table or flat pattern.

Add Custom Features: Add custom features to my toolbar from a document version. Custom features are written in FeatureScript.

III. Sketch Toolbar

The Sketch Toolbar is the environment where all your 2D designing will take place.

Line: Create a line or series of lines to create a profile.

Rectangle Tool

Corner Rectangle: Create a rectangle starting with its corner point.

Center Point Rectangle: Create a rectangle using its centre point as a starting point.

Circle Tool

Center Point Circle: Create a circle using its centre as the starting point and reference.

3-Point Circle: Create a circle by assigning 3 points along its circumference.

Ellipse: Create an ellipse using a centre point, major axis, and minor axis.

Arc Tool

3-Point Arc: Create an arc by defining three points.

Tangent Arc: Create an arc tangent connected to the end of a line.

Center point arc: Create an arc using center, start and end points.

Polygon Tool

Inscribed Polygon: Create a regular polygon defined on an inscribing circle.

Circumscribed Polygon: Create a regular polygon defined on circumscribing circle.

Spline Tool

Spline: Create a multiple point curve with points along its length.

Spline Point: Inserting points along a spline.

Point: Create points.

Text: Adds texts to a sketch.

Use Project/Convert: Project or convert edges and silhouettes of a part onto the active sketch plane.

Intersection: Select a face to intersect with the sketch plane.

Construction: Create new construction geometry or convert existing entities to construction.

Sketch Fillet: Create fillets when sketching.

Trim: Trim a curve to the first intersecting point or bounding geometry.

Extend: Extend a line to the last intersected point or bounding geometry.

Split: Split an open or closed sketch curve at one or many points.

Offset: Create copies of the selected entities at a specified distance from the original.

Slot: Creates slots around selected sketch curves including lines, splines and arcs.

Mirror (Sketch): Create the reflection of one or more selected sketch entities, about a line.

Patterns

Linear Pattern: Create multiple copies of sketch entities uniformly in one or two directions.

Circular Pattern: Create multiple copies of sketch entities uniformly around an axis. By default, pattern applies for 360° around designated axis, but this can change by altering the angle value.

Transform: Transform sketch entities using a manipulator.

Insert Tool

Insert DXF or DWG: Insert DXF or DWG files into a sketch as sketch entities.

Insert Image: Choose an image and then create a rectangle to define the image position and size.

Dimension: Create a dimension to constrain the size of sketch geometries.

Constraints

Coincident: Constrain two or more entities to share the same location in a sketch.

Concentric: Constrain circles and arcs to share a common centre point. Allow you to attach any point to the centre of a circle or arc. It can also be used to align the centre point of two circles or arcs.

Parallel: Makes two or more lines parallel.

Tangent: Constrain two curves to be tangent. Tangency can be added between arcs lines and arcs and arcs and planes.

Horizontal: Makes lines or points horizontal.

Vertical: Makes lines or points vertical.

Perpendicular: Makes two lines perpendicular.

Equal: Sets one or more sketch entities to an equal size. Lines can be set to the same length; circles can be set to the same diameter.

Midpoint: Attaches a point to the midpoint of a line or an arc.

Normal: Makes a line and a curve or a curve and a plane normal to each other.

Pierce: Allows you to constrain a sketch entity to the intersection between that entity and another sketch plane.

Symmetric: Creates symmetry between sketch entities of the same type and the centreline.

Fix: It grounds or constrains in all directions whatever sketch entities are selected.

IV. Assembly Toolbar

The assembly toolbar appears only on the assembly workspace and its something we will cover in WL19 and WL20.

Insert Parts and Assemblies: Insert parts from Part Studios or Assemblies of the document into this assembly.

Mate Connector: Create mate connectors on parts.

Fastened MatWe: Removes all degrees of freedom between two parts.

Revolute Mate: Create a revolute mate constraint between two parts.

Slide Mate: Create a slide mate constraint between two parts.

Planar Mate: Create a planar mate constraint between two parts.

Cylindrical Mate: Create a cylindrical mate constraint between two parts.

Pin Slot Mate: Crate a pin mate constraint between two parts in an assembly. The parts can translate along the centre path of the slot.

Ball Mate: Create a ball mate constraint between two parts in am assembly. The parts can rotate in all 3 axes.

Parallel Mate: Mate two parts allowing individual translational movement along any axis, and parallel rotation along any axis.

Tangent Mate: Create tangent/cam/path mate between two parts in an assembly. The tangent relationship between the parts will be maintained as the parts move.

Group: Create a group of parts or assemblies, which do not move relative to each other.

Snap Mode: Toggle snap mode on and off.

Replicate: Replicate takes a seed part or parts as input, a bolt for instance, and locates geometry identical to that which the seed is mated to (based on an additional selection).

Assembly Linear Pattern: Pattern selected parts or subassemblies and arrange them in a row or grid pattern.

Assembly Circular Pattern: Pattern selected parts or subassemblies about an axis.

Gear Relation: Constrain the angle of rotation in one revolute mate to change at a constant ratio to the angle of rotation of a second revolute mate.

Rack and Pinion Relation: Constrain the rotational degree of freedom of a revolute mate with the linear degree of freedom of a slider mate.

Screw Relation: Constrain the rotational degree of freedom in one cylindrical mate to the translational degree of freedom in the same cylindrical mate.

Linear Relation: Constrain the linear motion between two slider mates to change at a constant ratio.

Named Positions: Save and restore named positions of the assembly.

Create Part Studio: Create a new Part Studio in context of this assembly. The assembly shows up as context graphics in new Part Studio and can be referenced in Part Studio features.

V. Drawings Toolbar

Sheet: An Onshape sheet is a page of a drawing, which represents a single sheet of paper in a printed version of a drawing.

Properties: Set the specifications for your drawing dimensions in one place in order to simplify formatting.

Update From This Workspace: The update drawing icon highlights whenever the underlying design has changed and the drawing can be updated. Click the icon to update all views and properties on all sheets of the drawing. Dependent views, like section and detail views, are also updated. If needed, return the drawing to the pre-update state by restoring the previous entry in the version history.

Insert View: Place a view from a Part Studio or Assembly.

Projected View: Place a projected view of an existing view.

Auxiliary View: Create an auxiliary view; an orthographic view that is folded out 90 degrees from a selected edge in the parent view (usually from a slanted edge).

Section View: Create a section view (or jogged section view) of an existing view by placing a cutting plane line (or lines) and specifying a direction and label.

Detail View: Use Detail view to select an area of an existing view to enlarge for more detail.

2-Point Linear Dimension: Measure the distance between two points. Create horizontal, vertical, and rotated linear dimensions.

Point to Line Dimension: Measure the distance between a point and a line. Create horizontal, vertical, and rotated linear dimensions.

Line to Line Dimension: Create dimensions between parallel lines.

Line to Line Angular Dimension: Measure the interior angle between the two legs and the exterior angle formed by two lines.

3-Point Angular Dimension: Measure an angle by selecting 3 points, including a vertex and two points on the legs.

Radial Dimension: Measure the radial dimension of a circle or arc.

Diameter Dimension (Shift-D): Measure the diameter of a circle or arc.

Ordinate Dimension: Create ordinate dimensions (X, Y pairs) for a feature measured from a datum.

Hole Callout: Place a dimensional callout label on a hole.

Datum: create and place associative datum symbols to the drawing view on a surface that appears as a linear or circular edge to identify datum planes in the part.

Geometric Tolerance: Often associated with datum, use Geometric tolerance to create and place basic dimension notations in the drawing.

Note: Add multi-line text notes to any drawing, wherever you want, and use them to fill in the title blocks as well. You can define the size of the text box as well as format the text itself.

Note With a Leader: Create notes with leader lines connecting the annotations to a drawing entity. Notes with leaders are useful when the dimension text or annotation does not fit next to the corresponding entity. You can optionally place single or multiple lines of text.

Balloon: Create a simple balloon with a leader line.

Table: Add fully customizable tables to any drawing.

Insert BOM: Place a Bill or Material table from BOM app ta (e.g. Open BoM) or from a BOM data tab (e.g. Onshape BOM to Google Sheets).

2-Point Centerline: Create centrelines using two points on your drawing.

Line to Line Centerline: Create centrelines using two lines on your drawing.

3-Point Circle Centerline: Create a circular centreline for a bolt circle diameter.

Centermark: Place a mark in the centres of circles and arcs for visibility when printing and as a reference point for dimensions.

Virtual Sharp: Create a virtual sharp associated with two linear edges.

Line: Create a line by clicking two points or a chain of points.

Insert Image: You can insert and scale JPG, PNG, and GIF images on a drawing sheet, such as a logo's and bar codes. Images can be resized by clicking and dragging on handles and can be repositioned by clicking and dragging the centre of image.

SECTION 2

Rocket Design

SECTION 2 - Rocket Design

2.1 Introduction

Welcome to your second main design project, the Falcon 9 rocket. This project serves as a refresher for many of the commands that were taught in our first introductory course and on the first main design project of this course. However, in this section we will introduce new command tools on all 3 major design environments of Onshape, Sketch, Part Modeling, and Assemblies. Furthermore, we will introduce you to Technical Drawings and Onshape's ability to run version control, branching, and design comparison.

2.2 Falcon 9 Rocket

Before we start, let's talk a little bit about your design. The Falcon 9 rocket is a two-stage, partially reusable launch system designed and manufactured by Space X for Low Earth Orbit (LEO) missions consisting of the following segments:

1. First Stage: The section of the rocket that houses liquid fuel and is used to boost the vehicle outside of the earth's strong gravitational pull.
2. Inter-stage: Connects the first and second stage of the rocket staging. In many cases, the upper stage ignites before the separation. The interstage ring is a separator, which its main purpose is to separate both stages and create safe conditions during staging.
3. Second Stage: Is used to push the payload up into space and place it in orbit. In many cases, it is also used for transfer orbiting. The Booster for the Second stage has been modified for vacuum operation as it is capable of performing at an altitude that microgravity conditions apply.
4. Payload Attach Fitting (PAF): The PAF converts the diameter of the launch vehicle to the standard interface that is used to attach the rocket's payload.
5. Engines: The Main booster stage (First Stage) of the Falcon 9 rocket comprises of nine in-house-designed and developed Merlin 1D rocket engines capable of producing 620kN (140,000lbf) of thrust each.
6. Re-entry Landing Legs: The legs, which are locked against the first stage tank during ascent, deploy during the last few minutes of the Booster's landing phase and assist the rocket to land and stand safely on the landing pad.
7. Grid Fins: Used as flight control surfaces to assist with balance and flight control during the booster stage during the descending phase of the booster (first stage) rocket.

05

It's Rocket Science

A multistage rocket is a rocket that uses two or more stages placed on top of each other, each of which contains its own engines and propellant. The architect behind the multi stage rocket concept is Dr. Robert Goddard (1882-1945); considered by many to be the father of modern rocketry. Goddard, who also happened to be the patent holder for the liquid fuel rocket device, realised after many studies, that a successful mission to other planets could only be achieved if the mass (fuel) used is jettisoned to reduce "dead" or useless weight for the remaining usable part of the vehicle, hence making the mission more efficient and feasible.

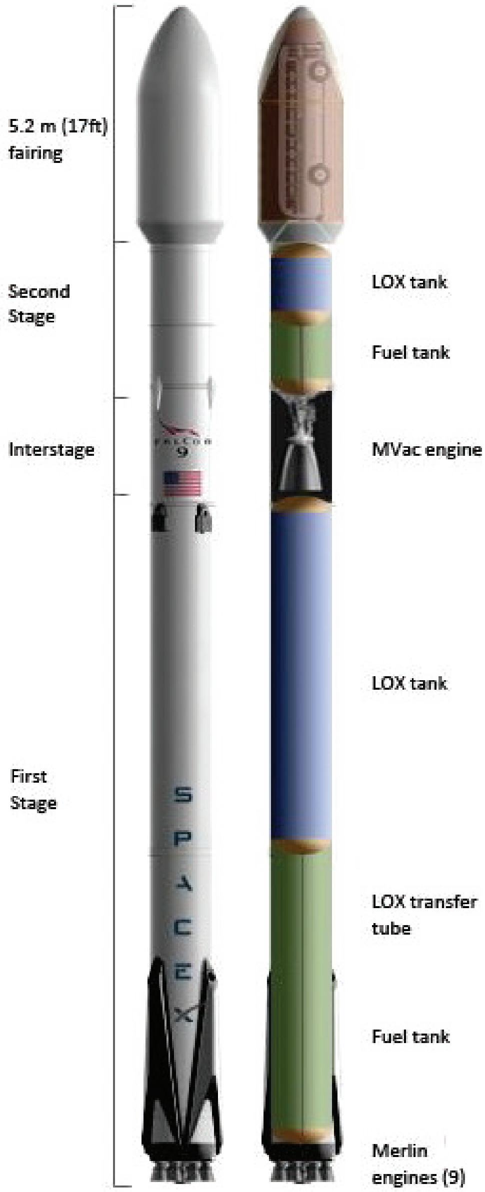


Figure 2.0: The Falcon 9 rocket and its different sections. ©Space X

Table 2.0: Falcon 9 dimensions and characteristics Source: Space X Falcon 9 User's Guide.

Characteristics	First Stage	Second Stage
Structure		
Height (m)	70 (including both stages, interstage and fairing)	
Diameter (m)	3.66	3.66
Type	Liquid oxygen tank - monocoque -	
Material	Aluminium lithium skin - domes -	
Propulsion		
Engine type	Liquid, gas generator	Liquid, gas generator
Engine designation	Merlin 1D (M1D)	Mvac
Engine designer & Manufacturer	SpaceX	SpaceX
Number of engines	9	1
Propellant	Liquid oxygen/ kerosene (RP-1)	Liquid oxygen/ kerosene (RP-1)
Thrust (Stage Total)	6,804 kN (Sea Level) (1,530,000 lbf)	934 kN (Vacuum) (210,000 lbf)
Propellant feed system	Turbopump	Turbopump
Restart capability	Yes	Yes
Tank pressurisation	Heated helium	Heated helium

For more information and reference during your design approach of the rocket see drawing **4DEdu2001**.

1. Profile Plot (RL1)

Objectives

- Create a 2D Sketch profile of the Main Rocket part.
- Revise and expand on the Spline command (Sketch).
- Explore Spline point command (Sketch).
- Spline point modification.

Part Description

In this lesson, we are going to sketch the 2-dimensional profile of the Main Rocket Body, which includes the following segments:

- First Stage
- Inter-stage
- Second Stage
- PAF (Payload Attach Fitting)
- Payload Fairing

Exploring the Commands

Spline Point (Sketch): This command tool allows you to add points along a spline. The more points you add on the spline the greater the ability to modify it. Think of spline points as control points that, by dragging them, help you modify the spline locally. The curve's smoothness is directly related to the number of spline points you have.

Understanding Spline Curves

In CAD, curves are a vital tool when it comes to the design of various complicated surfaces, such as the rocket's dome fairing, that cannot be expressed with the standard geometrical shapes (circle, straight line, square, ellipse, etc.). The representation of those irregular curves would have been far too computationally demanding and therefore a mathematical shortcut was necessary. Curve representation is achieved using two types of equations:

Parametric - where x, y, z coordinates are related by a parametric variable (θ).

$$\text{e.g. } x = R\cos\theta, \quad y = R\cos\theta, \quad z = R\cos\theta$$

Nonparametric - where x, y, z coordinates are related by a function.

$$x^2 + y^2 - R = 0$$

Parametric equations usually offer more degrees of freedom for controlling the shape of curves and surfaces than nonparametric equations do and are, therefore, preferred in CAD The following are some of the types of curves commonly used in CAD.

- **Hermite curves** - positional and derivative based curve representations.
- **Bezier curves** - a specific type of B-Spline using positional representations for the curve hull shape, which drives the overall curve shape.
- **B-Spline curves** - an improved version of Bezier curves. They provide more local control, as the curve does not shift about the parameter and the degree of the curve can be separated from the number of points.
- **Non-Uniform Rational B-Splines** (NURBS) - standard representations of curves and surfaces used heavily in most CAD programmes. They are recognised for their stability and versatility and are excellent at approximating various shapes.

For more information on the theory of curves and the mathematics behind them, see reference (5).

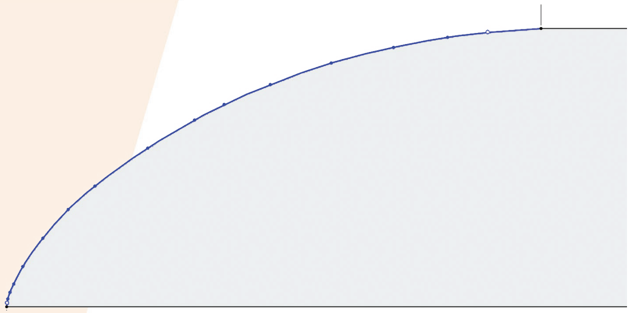


Figure 2.1: The Falcon 9's dome shaped fairing as designed using the spline points command based on NURBS curve type.

Homework 11 - Rocket segments

Upon completion of this lesson you should make sure that the main rocket design is comprised of the 5 main segments (parts) mentioned in Lesson RL1 , meaning you should revolute all 5 segments as separate parts and assign them with the names given in Figure 2.2.

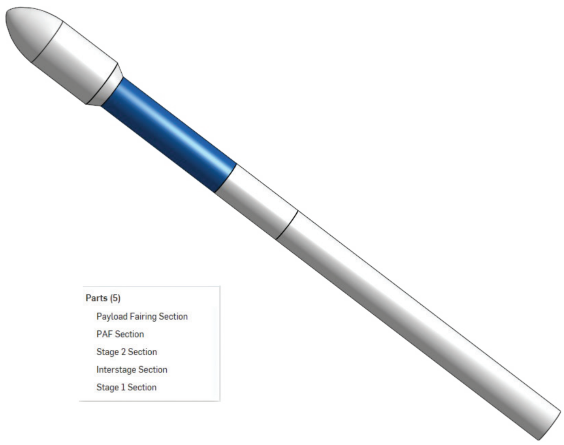


Figure 2.2: The Falcon 9's dome shaped fairing as designed using the spline points command based on NURBS curve type.

Exploring the Commands

Revolve - Solid/New (Feature): It projects a selected region or planar face about an axis. It creates a new part or modifies an existing one by adding or removing material or intersecting bodies in its path. You can also create solid bodies or surfaces.

2. Engines (RL2)

Objectives

- Naming your design steps.
- Revisit Linear Pattern command (Features).
- Explore Circular Pattern command (Features).

Part Description

The Falcon 9 first stage comprises of nine Merlin 1D liquid gas generator type engines. The Merlin 1D engine has the highest thrust to weight of any engine ever produced and it's the only new hydrocarbon engine to be successfully developed and flown in the U.S. in the past 40 years. The centre engine is used to return the booster back to earth. For design referencing on this part, see DWG: **4DEdu2002** and **4DEdu2003**. For more information on rockets and astronautics see Reference to (6) and (7).

05

How Rockets Fly

Propulsion is the action of changing the motion of a body. Propulsion mechanisms provide a force to moves bodies that are initially at rest, changes a velocity, or overcomes retarding forces when a body is propelled through a medium.

Rocket propulsion is a class of propulsion that produces thrust by ejecting stored matter (propellant).

Figure 2.3: Why a rocket launches.

The total force on the rocket is the sum of all the forces

F_{thrust} = Thrust-Drag-Weight

- Drag is due to the friction created by the air pushing against the rocket.

- Weight is due to the gravity pulling the rocket down.

- Thrust is due to the motor pushing the rocket up.

The energy source most useful to rocket propulsion is chemical combustion. Rocket propulsion systems can be classified according to the following:

- Type of energy source; Chemical, Nuclear, Solar, Electric.
- Basic function; Booster stage, Sustainer, Attitude control, Orbit station keeping.
- Type of Vehicle: Aircraft, Missile, Space Vehicle.
- Type of propellant used.
- Type of construction.
- Method of producing thrust.

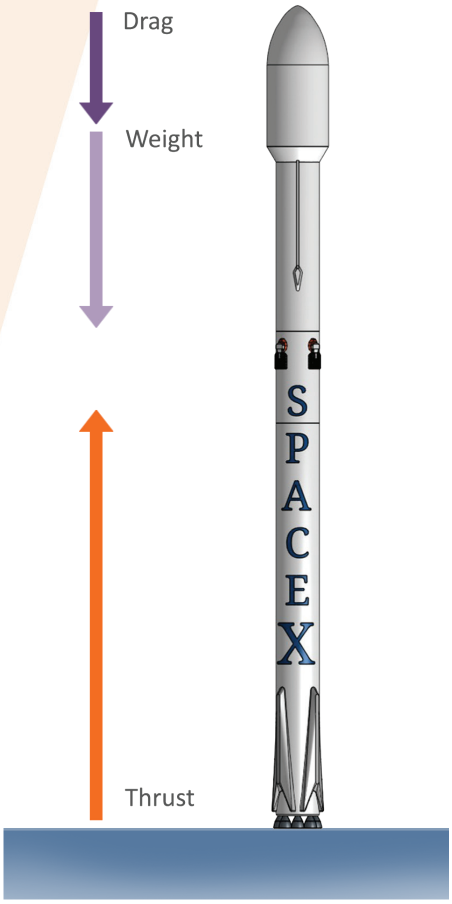


Figure 2.3: Why a rocket launches: Thrust force overcomes forces such as weight and drag, which act against it.

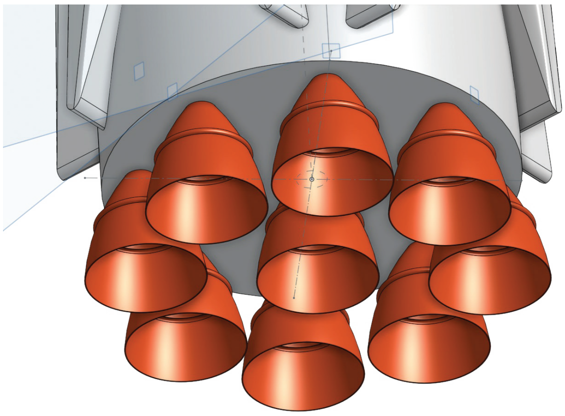


Figure 2.4: The Falcon 9's dome shaped fairing as designed using the spline points command based on NURBS curve type.

Exploring the Commands

Circular pattern - feature (Feature): It replicates selected parts, faces, or features about an axis. It allows you to create new parts or modify existing parts by adding or removing material or intersecting bodies in its path.

Homework 12 - Engines Numbering

Name the Engine Parts based on the numbering sequence displayed below.

Figure 2.5: Engine numbering diagram.

3. Supply Line (RL3)

Objectives

- Explore the Plane/Plane Point command (Feature).
- Revise Offset command (Sketch).
- Explore the Split command (Feature).
- Explore the Loft/Face command (Feature).
- Revisit the Move Face command (Feature).xplore Extrude/Up to Next command (Feature).

Part Description

In this lesson, we are going to design the propellant supply line of the Falcon 9 rocket. The propellant supply line does exactly what the terms describes, transfers fuel (propellant) from point A to point B.

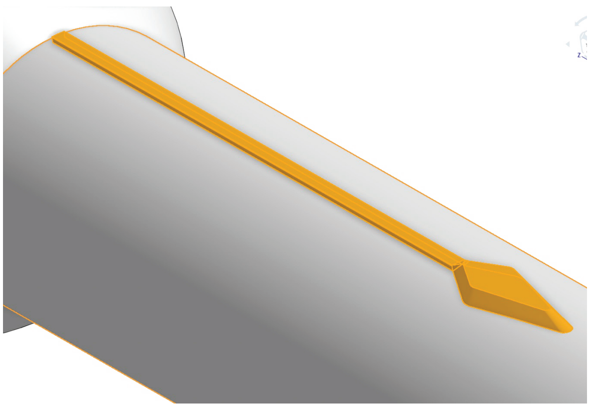


Figure 2.6: Falcon 9's supply line.

Exploring the Commands

Plane - Plane Point (Feature): The "Plane Point" option allows you to create a plane that passes through a point parallel to a plane using a plane and a point.

Split - Face (Feature): Used previously during the design of the padlock; in this case we use the surface option and we create two separate surfaces.

Loft (Feature): The loft command allows you to create a smooth transition between different profiles.

Move face (Feature): It gives you the ability to rotate or offset one or more selected faces. This direct editing is especially convenient if you don't have the parametric history of the part, as is often the case with an imported part.

06

Lofting

The term lofting originally came from the shipbuilding industry, where some aspects of ship design took place in the lofts of hangers. Loftsmen worked on "barn loft" type structures to create the keel and bulkhead forms out of wood. This was then passed on to the aircraft and automotive industries who also required streamline shapes.

4. Landing Legs (RL4)

Objectives

- Create the first landing leg.
- Explore Plane/Mid Plane command (Feature).
- Explore Plane/Offset command (Feature).
- Explore Plane/Three-point command (Feature).
- Explore Loft with Guides command (Feature).
- The how and why of using Guidelines for your Loft.
- Explore the Slot command (Sketch).
- Revise Mirror command (Sketch).

Part Description

In this lesson, we are going to design the four legs of the Falcon 9's first stage; used to land back safely on the ocean platform upon its return to earth. During flight, the legs are stowed against the rocket body, covered by the fairings that ensure no additional aerodynamic disturbance is introduced by the legs. Deployment is accomplished by a pneumatic system using high-pressure helium. When deployed, the legs have a span of about 18 meters, capable of supporting the forces of landing and the mass of the nearly empty first stage.

Figure 2.7: Falcon 9 Landing Legs displayed in retracted configuration (L) and deployed configuration (R). ©Space X

Exploring the Commands

Plane (Feature): It offers you the capability to create a new construction plane

- Mid Plane: this option allows you to create a plane at the intersection of two other planes.

- Three Point: this option allows you to create a plane that passes through three points, using three sketch points.

Loft - Guides (Feature): In the case where a loft proves hard to get smooth transition results or any results at all, it is wise to use the Guides features. The Guides features allow you to add sketches to guide the transition between shapes. When doing this, it is important that your guide sketch is properly constrained to each loft profile with either a coincident or pierce constraint.

Slot (Sketch): It lets you create a slot around selected sketch curves (including splines, lines, and arcs but no closed profiles).

05

Remember that you can hide/unhide all planes using the keyboard shortcut "p" and this could be quite helpful during the design phases, as involving too many planes can become confusing.

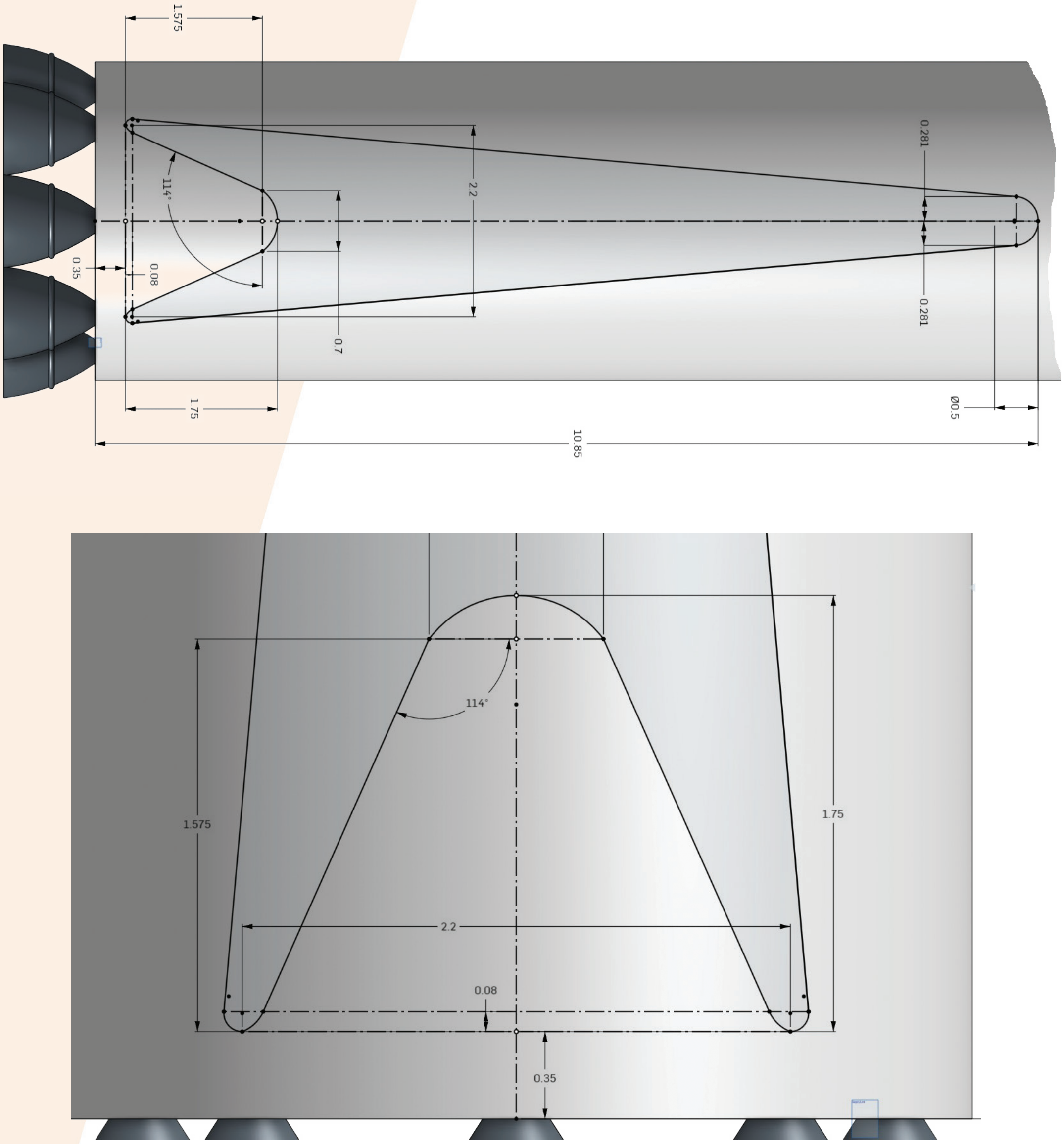


Figure 2.8: The above diagrams will help you in completing the landing leg sketch.

5. Markings (RL5)

Objectives

- Create the side markings of the rocket.
- Revise Extrude/Surface command (Feature).
- Explore Text command (Sketch).
- Explore Boolean/Subtract command (Feature).

Part Description

This is the lettering on the side of the rocket that displays the manufacturer's name. The actual font style used for our Markings is Noto Serif.

Homework 13 - Markings

Complete the Markings of the rocket based on the specs given below and by following the procedure, demonstrated in the video lesson RL5 using the letter “S” as an example.

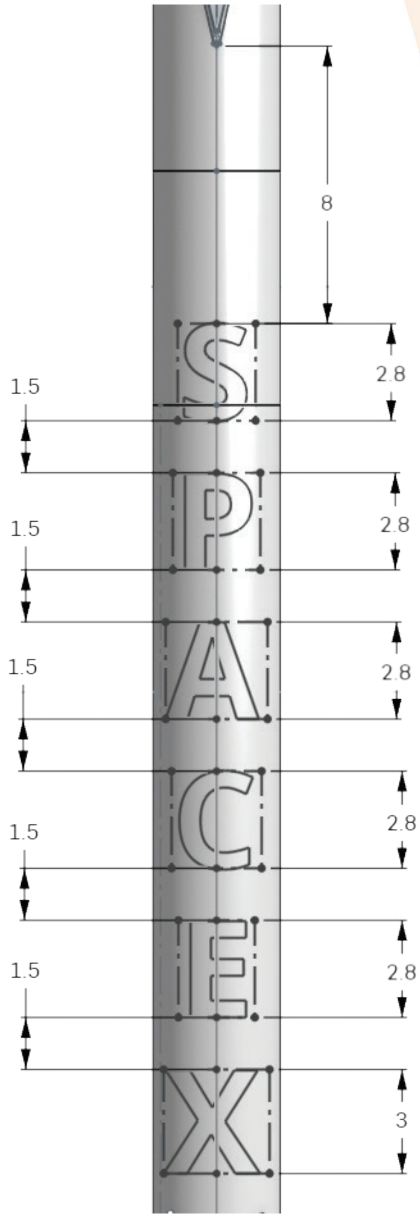


Figure 2.9: Markings dimensional specifications and location with respect to other elements of the rocket.

Exploring the Commands

Text (Sketch): The text command in Onshape allows you to insert text on your design. It offers you the freedom to change the size of the letters, the location, and the presentation (bold, italic or underlined).

Boolean/Subtract (Feature): It is the opposite of the Union option, allowing you to modify parts by removing a tool body from a target. In this case, the target is the main body of the rocket and the tool is the extruded letters within it.

Keep Tools: In this Boolean operation, one of the bodies is used as a tool to cut the other part. If you don't check the keep tools box, the body that you use as a tool will disappear after the operation. If you check the keep tools box, the same operation will happen but both bodies will be kept in the Part Studio.

SECTION 5

CAE and 3D Printing

SECTION 5 - Computer Aided Engineering and 3D Printing

5.1 Objectives

- Introduce the topic of Computational Science and Engineering.
- Discuss the progress of Computer Aided Engineering in 3D printing.

5.2 Computational Science and Engineering

With the advancement of computer technology, both in hardware and software as well as in our knowledge in applied mathematics, a new field in the technology world was emerged, and this is the Computational Science and Engineering (CSE). Historically, its origins link back to the aerospace industry shortly after Word War II, when engineers wanted to optimise the way calculations were performed to analyse their structures. Up to that point, there were really two ways of designing and building. Either by what we refer to as over-engineering, building things that will last without thinking about optimisation in any significant way or where optimisation was essential, such as for airborne and seaborne vehicles, rigorous calculations carried out by a vast number of people.

The main reason CSE exists is simulation, which is essentially computational processes used to understand, analyse, optimise and visualise complex systems. Those systems can be of any type, such as for predicting the weather, exploring the interactions between molecules, predicting financial markets, designing a bridge, plotting a space flight, investigating the strength of mechanical structures and the list goes one. In other words, there are no limitations of its application, as long as the mathematics of these systems are understood. For this reason, it is currently used within all engineering and science related sectors to a greater or a lesser extent. The reach of CSE methods is vast, with several studies indicating a multibillion-dollar market. This is not surprising, since the main advantages of CSE methods is that it saves time, money any in many cases lives.

However, it is important to highlight that physical tests are still a very important piece in the development or the understanding of systems. By no means are they obsolete, and, where possible, it is often encouraged and in some cases is needed to verify the simulation results.

5.3 Simulation in Engineering

Many concepts in fundamental engineering science view the world quite differently than one might expect. Let us take, for example, a force acting on a body with a specific mass. Using the fundamental engineering's scientific approach, both of those elements are represented as points, and not as global effects on the entire volume of the body. In other words, imagine that you take a stress ball, which you squeeze. Using basic approaches, this is literally treated as an infinitesimally small point on which you apply a force uniformly.

This is done to simplify the mathematics involved, thus requiring a significantly less amount of calculations to be computed.

Clearly, our world is three-dimensional and very dynamic with respect to time and space. For this reason, a new approach was needed to explore the effect of those forces in real scenarios, which has led to the creation of the Computer Aided Engineering (CAE) field. CAE is a critical sector of modern engineering, in fact almost all current design processes will go through a verification method, typically via involving simulation.

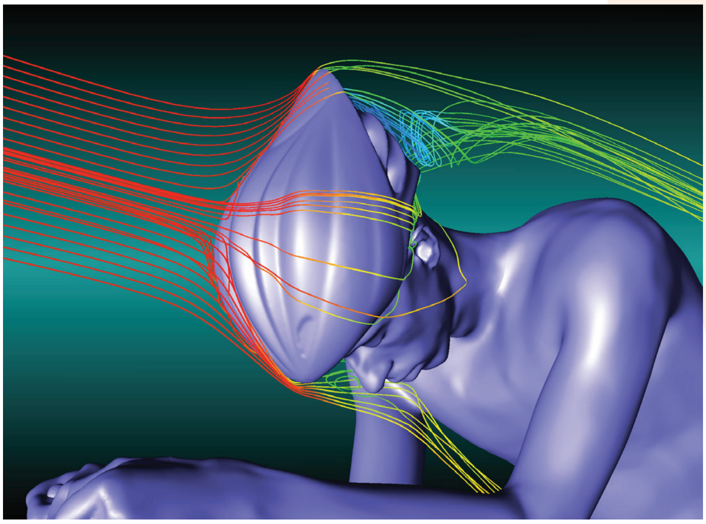


Figure 5.1: Example of CAE in action. Computation fluid dynamics (CFD) analysis of airflow travelling around the helmet of cyclist. Although simplified in this image, visualisations of this nature are common. ©Ksantosh1

5.4 CAE and 3D Printing

As we have elaborated in our first course on CAD and 3D printing, currently both of these topics are undergoing a renaissance. With that in mind, new CEA studies have started to emerge, including both material and mechanical computational analysis within a 3D printing world. For 3D printing engineers, a lot of the current CEA emphasis has been in addressing the materials consolidation process. In other words, how does the 3D printing material being powder, liquid or solid, can be modelled to simulate its formation process into a solid part. It is important to remember that the 3D printing process is a layer-by-layer deposition of material, and as a result there is a natural tendency for a gap formation between each layer or even at the microscopic level, between powder particles. In engineering these gap formations are referred to as voids, which are evidenced in Figure 5.2. In this profile image, the cross-section of a 100% infill solid part is shown, where the black gaps are the voids. These voids can be responsible for crack generation, which might result to a catastrophic failure of your part.

Figure 5.2: Electron microscopy image of a sectioned 100% infill 3D printed part using FFF technology. The darkened areas are gaps (voids). Using the scale bar on the bottom left, gaps as large as 20 um can be seen forming during the deposition process. Additionally, the layer-by-layer structure (visible in grey) informs us about the extrusion pattern and the size of the nozzle (400 um). ©Gorski et al., A.I.S.C. (2015) p403-413

Furthermore both scientists and engineers are using CEA to simulate the 3D printing processes and evaluate stresses on the parts. For example, the stress analysis results shown in Figure 5.3 of a 3D printed geometry, where red indicates regions with high stressed concentration. Now, given the numerous 3D printing technologies and materials, the overall approach becomes substantially challenging for a generic method.

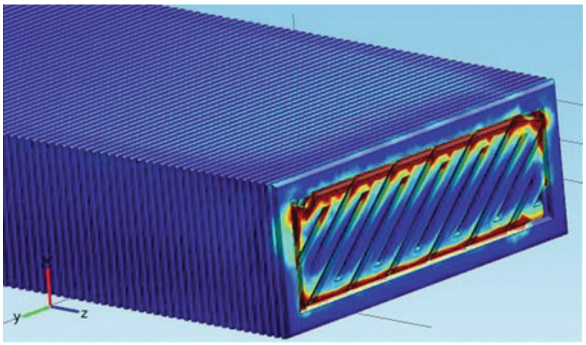


Figure 5.3: Simulation results of a 3D printed part, where the red segments indicate areas with high stress concentration, graduating to the blue areas of less stress. ©Torrado et al., J.F.A&P. (2016) p154-164

Thus far, we have presented some general information about CEA and 3D printing. Although these are established and growing technologies, both topics are undergoing an important research-led renaissance and, over the next few years, we should expect to see significant improvement in these types of analysis.

5.5 The Market of CSE

As we mentioned in the previous section, the market of CSE is vast, which resulted in its split into numerous segments. Importantly, CSE is intrinsically linked to the computer hardware sector. Essentially, CSE software are based on mathematical formulae, which are rigorously computed using some smart algorithms (and often repeatedly over specific time periods) in order to solve them and thus, give us a solution. In general, the more computer processing power available the quicker this process is. Some calculations are so complex and large that they typically require a vast network of high performance computers, operating for extensive period of times. Typical examples are predicting weather patterns, solving subatomic physics problems, understanding molecular interactions or discovering elements of our universe behaviour.

For smaller scale simulations, a high-performance desktop will often suffice, these simulations are commonly engineering related, i.e. predicting structural properties of a design or analysing the aerodynamic behaviour of a part and even the thermal and electrical properties of systems. Finally, in very simple cases, simulation can also be achieved using less expensive, lower power systems, such as mobile devices. Simply put, it all depends on how complex (mathematically) the simulation is and how efficiently the code runs.

Which bring us to our software element of the CSE market. This is essentially segmented into high performance software, allowing for a substantial amount of simulation customisation up to simpler ones, which are limited in executing specific types of simulations. However, for very specialised simulations, often the case for unique experimental projects (e.g. academia) or highly sensitive ones (e.g. defence or financial) the whole simulation code is written from scratch. Prices can also vary substantially, with open source software offered for free, or highly customisable simulation packages offered for thousands of dollars per licence. In general, the mathematics dictating the algorithm performance for a specific simulation topic is similar; however, the graphical user interface can vary significantly, where the high-end software will typically allow a smoother user interaction.

Other factors which can affect the pricing are customer support as well as access to high performance computing facilities, where simulation can be configured from your local desktop machine and executed by remote high performance servers. Choosing a software package will come down to the type of science or engineering you want to investigate, as well as the complexity of those investigations. In the following section, we will introduce a specific segment of CES market, but before we do so, we will attempt to explain why we chose engineering to use simulation.

In the following section, we focus on desktop 3D printing technology and how recent engineering observation by 3D Matter using CEA techniques supported by standardised testing might help us create better parts.

5.6 Summary

In this section, we give a broad overview of engineering and its importance in our everyday life. Not only does it secure jobs for millions of people across the world, it is also the core in any human endeavour, no matter how small it is. We also spoke about Standards and their need for them in a globalised world. We introduced some basic concepts of materials testing related terminologies and concluded with an introduction of CAE. Accumulatively, this information will serve as your foundation for understanding our following sections.

SECTION 6

OPTIMATTER by 3D Matter

SECTION 6 - OPTIMATTER

6.1 Objectives

- Introduction to OptiMatter.
- Learn how to be an advanced user of the OptiMatter platform.
- Tutorial on working with Stress.

6.2 Computational Science and Engineering

OptiMatter is a Cloud-based engineering platform, created to help you improve the quality of your printed part. OptiMatter, is developed by 3D Matter, a company based in New York City. Our friends at 3D Matter are a group of engineers focused on researching the engineering properties of the materials and structural geometries used in 3D printing.

Figure 6.1: OptiMatter Logo. ©3D Matter

Essentially, OptiMatter provides data on 3D printed materials, with the aim to include all the materials and all the printing technologies available on the market. To achieve this, they constantly test and add new materials to their database. Data extracted by thousands of standardised mechanical and visual quality tests are fed into a multivariate regression model. The model then forecasts the performance, visual quality and processing capability of 3D printed parts, depending on the technology, material, and printing parameters.

6.3 OptiMatter Interface Controls

To start using the platform you can register for a FREE account at https://www.optimatter.com/ . Once you have setup your account and login you will be welcomed with the home screen, as seen in Figure 6.2.

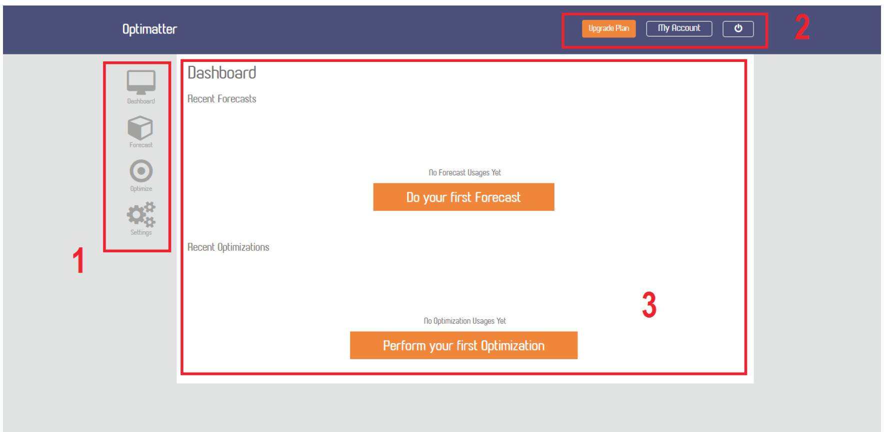


Figure 6.2: OptiMatter Home screen. ©3D Matter

On the left side (1) you have the quick access tabs, which are the Dashboard, Forecast, Optimizer, and Settings. At the top right (2), you have the controls for your account where you can essentially change your pricing plan and logout. Finally, in section (3) you can access the specific controls of each of the tab chosen.

6.3.1 Dashboard

By choosing Dashboard you will normally see the 5 most Recent Forecast or Recent Optimisations results, which are effectively historical data summaries that you can view their details. However, if you have not performed any analysis in the past, you will be given the optional button to start a new Forecast or Optimisation process.

6.3.2 Forecast

As you will see in the video lessons, the Forecast and Optimize tools have a lot of similarities with simple intuitive workings. Essentially, both are used to search the database of engineering properties created by the 3D Matter team from investigating 3D printed parts. However, the way to do it is different. The Forecast tool allows you to forecast your 3D printing materials mechanical properties based on a selection of printing processing choices, materials, and your part's approximate area.

In particular, you will be able to input various parameters, which include 3D printing technology, material type and brand, infill % and pattern, layer height and section area. Note that these parameters have been explained in the *Introduction to CAD and 3D Printing* course. It is important to highlight the concept of the Section Area, this value represent an arbitrary segment of your part's area in the x,y orientation. It is then best choosing one closer to your part's actual cross-sectional area.

6.3.3 Optimize

The Optimize tool gives you significantly more options to look through the database of materials. It allows for a comparison search outputting results as a function of lowest cost and highest speed. Importantly, you can restrict the search by filtering the results for any processing, quality or mechanical parameter. In particular, in the **first step** you have the option to choose from a selection of pre-tested 3D printing polymers. The family of polymers are divided to three 3D printing technology groups; FDM, SLA and SLS. In the FDM you have the additional option of: ASA, co-polyester, PLA, ABS, PP, Flexible, ULTEM, PC and NYLON. In the SLA you have acrylic resin and acrylic epoxy resin and in the SLS, NYLON powder. For the **second step**, you are given the option to activate and select a range of parameters including a number of materials engineering properties as well as from a collection of quality, geometrical and processing related options. In the **third step**, you click Optimize, this will then output results that best fit your choices selected in the two previous steps. The output will be displayed in two columns the Lowest Cost and the Highest Speed, detailing information about the 3D printing technology, material type and brand, infill % and pattern, as well as the estimated cost and building speed.

6.3.4 Settings

Currently in the Settings tab you can only change your password.

6.3.5 My Account

In the My Account tab, you have the option to change your registration plan package. Thus, as a FREE user you can upgrade to the FULL plan, which will give you access to the full materials database, as opposed to the two materials you have with the FREE option. There are two other options tailored to materials suppliers and developers.

Homework 15 - Working with Stress

Revisiting our introductory information in Section 3, here we attempt to give some simple guidance in using the data from the OptiMatter tool to practically address your needs, in addition a more detail analysis is presented in the following Section.

Firstly, we start by highlighting that if you are looking to create a 3D part for functional purposes remember to never exceed the load associated to stresses greater than the Yield Stress (or Strength) recommended by the Optimatter platform. Secondly as you are going to discover next, ensure that you print your part so that the net force is directly parallel to the layers deposition (xy-axis) as much as possible.

Keeping in mind Figure 6.3, to associate load (force) to yield stress you can simply use the equation of the normal stress that is:

Force = σ x A [1]

Let’s now work through an example. Let’s say that you have a part that you will be printing to carry some weight (66.14 lbs) by pulling it up (perhaps some form of a hook). We know that by using PLA as the printing material we have a yield strength of 24 MPa. The question will be how big should our design area be to support this?

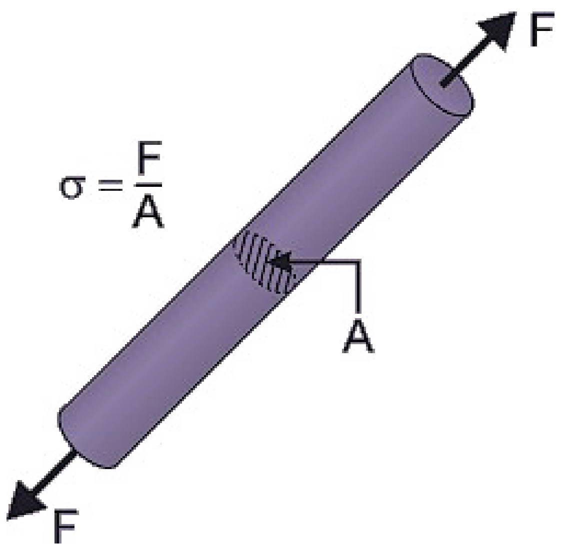


Figure 6.3: Basic stress calculation illustrated on a simple road.

First, we ensure that everything is in SI units. Thus 132.8 lbs is 60 Kg and the 24 MPa are rewritten at 24,000,000 Pa.

Next, we convert the Kg in to N using:

Force = mass x g [2]

where g is the accelaration due to gravirty, a fixed value approximated at 9.81 m/s^2.

Thus, using [2] the force associated with 60 Kg is 594.6 N. So now the minimum required area to carry a maximum load of 594.6 N using [1] is:

$$0.00002478\ m^2 \text{ or } 24.78\ mm^2.$$

If we were to literally design a circular shape of that area, that will then have a diameter of 5.62 mm.

In Figure 6.4, a relatively comparison of the values gathered thus far from the mechanical tests are presented. Using this in conjunction with the OptiMatter platform, you will have a better qualitative appreciation of the test results relative to the material properties.

	Very poor	*Poor*	*Decent*	*Good*	*Very good*	*Excellent*
Max stress [MPa]	3	6	15	25	35	50
Yield stress [MPa]	2	4	10	18	25	40
Elongation at break	1%	2%	4%	30%	100%	500%
Impact Resistance [J/m^2]	1,500	3,000	6,000	12,000	50,000	No break (="N/A")

	Very Flexible	*Flexible*	*Soft*	*Rigid*	*Very Rigid*
Young Modulus* [GPa]	N/A	N/A	0.5	1.5	3
Shore Hardness	80A	90A	N/A	N/A	N/A

Figure 6.4: Qualitative representation of the expected values accumulated from 3D printed plastic test parts. ©3D Matter

6.4 Summary

You are now fully familiar with the OptiMatter platform and its potential. Using your knowledge from our previous Sections, as well as from the first course (Introduction to CAD and 3D Printing) you can comprehend all the parameters available for you to use.

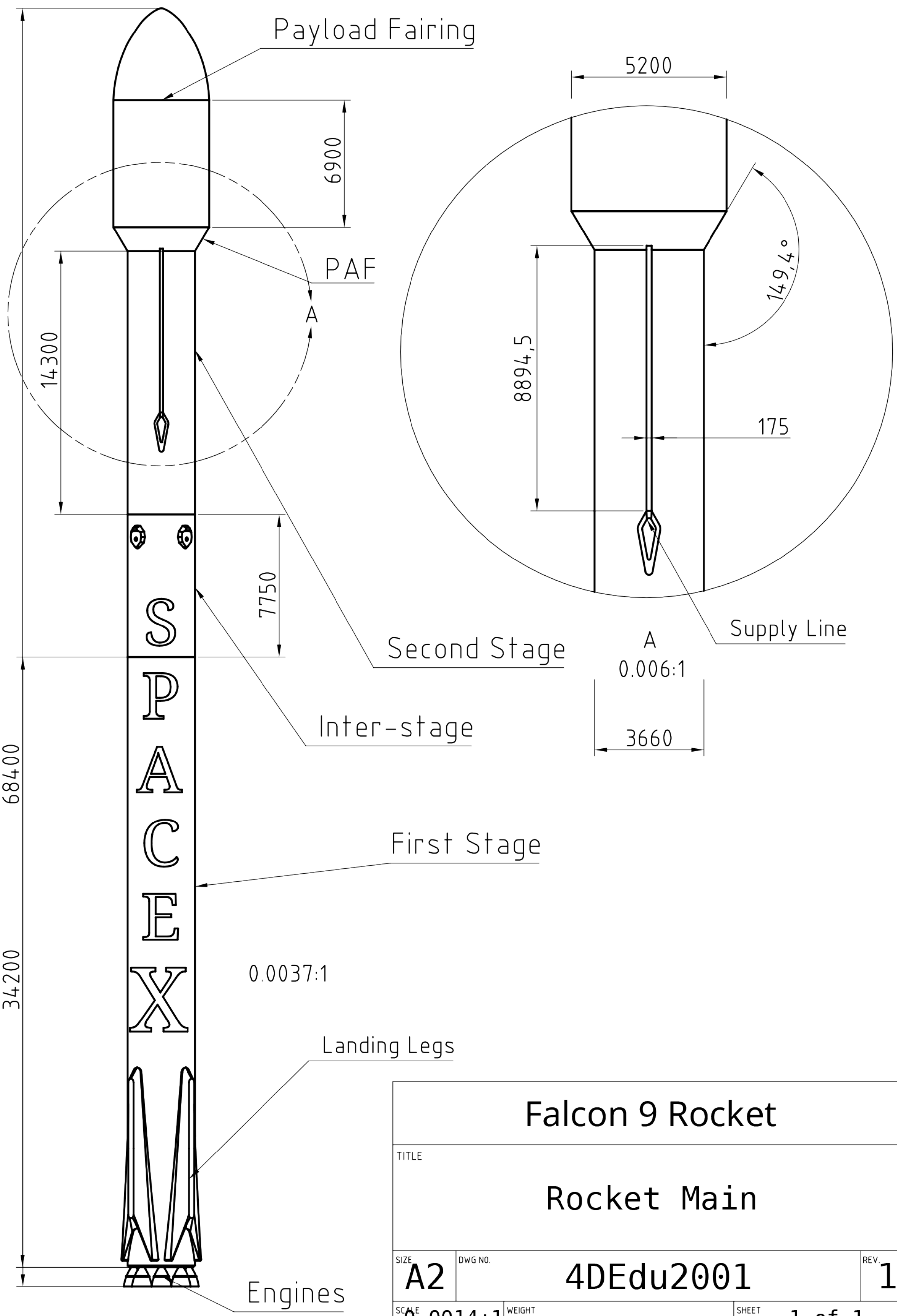
REFERENCES

REFERENCES

1. H. ABBOTT & ALBERT E.VON DOENHOFF (1959) Theory of Wing Sections, New York: Dover Publications, Inc.
2. JOHN D. ANDERSON JR. (2001) Fundamentals of Aerodynamics, 3rd Ed. McGraw Hill.
3. JAMES A. SPECK (2015) Mechanical Fastening, Joining and Assembly, 2nd Ed. London, New York: CRC Press.
4. JOHN H. BICKFORD (1998) Handbook of Bolts and Bolted Joints, New York: CRC Press.
5. PROF. OLIVER DE WECK (2005) Computer Aided Design, lectures notes, Engineering Design and Rapid Prototyping, 16.810, MIT, delivered 06/01/05.
6. JERRY JON SELLERS, WILLIAM J ASTORE, ROBERT B GIFFEN & WILEY J LARSON (2006) Understanding Space: An Introduction to Astronautics, 3rd Ed. McGraw Hill.
7. GEORGE P. SUTTON & OSCAR BIBLARZ (2010) Rocket Propulsion Elements. 8th Ed. New Jersey: John Wiley & Sons.
8. COLIN H. SIMMONS, NEIL PHELPS &DENNIS E. MAGUIRE (2012) Manual of Engineering Drawing, 4th Ed. Oxford: Butterworth-Heinemann.
9. SCOTT ROBERTSON & THOMAS BERTLING (2013) How to Draw: drawing and sketching objects and environments from your imagination, Culver City, CA: Design Studio Press.
10. ASME Y14.41-2003 (2003) Digital Product Definition Data Practices, New York: ASME.
11. MICHAEL F ASHBY & DAVID R H JONES (2005) Engineering Materials 1: An Introduction to Properties, Application and Design, 3rd Ed. Oxford: Elsevier
12. MICHAEL F ASHBY (2005) Materials Selection in Mechanical Design, 3rd Ed. Oxford: Elsevier.

APPENDIX

Drawings

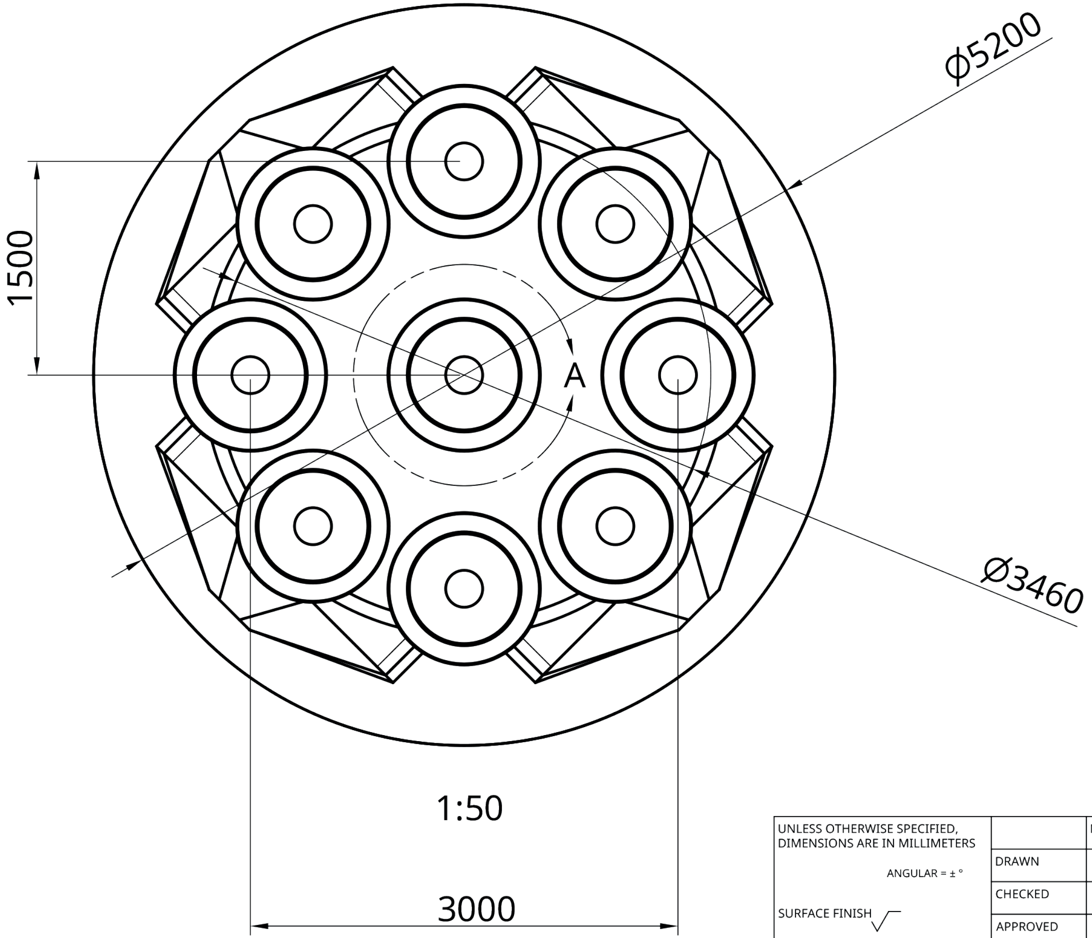


Falcon 9 Rocket

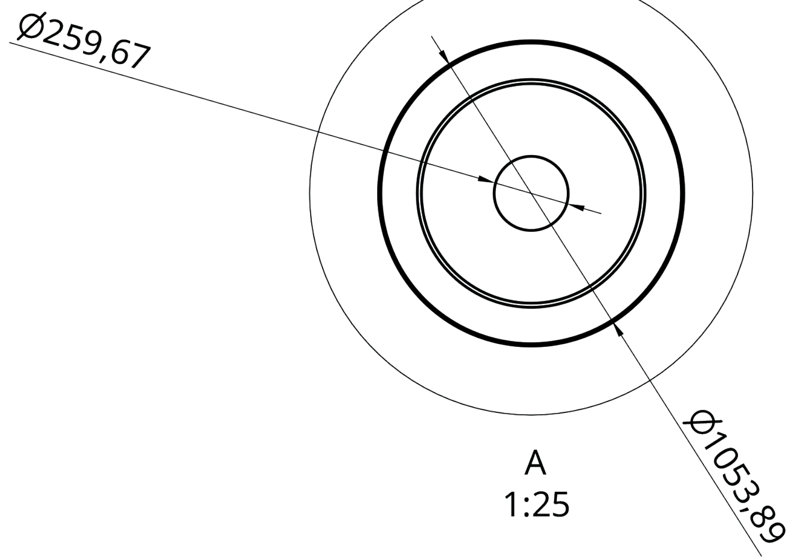
TITLE
Rocket Main

SIZE	DWG NO.	REV.
A2	4DEdu2001	1

SCALE	WEIGHT	SHEET
0.0014:1		1 of 1

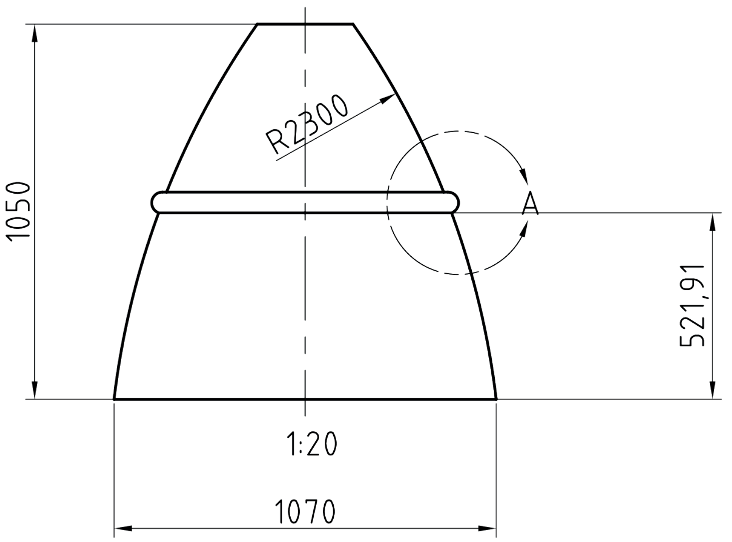


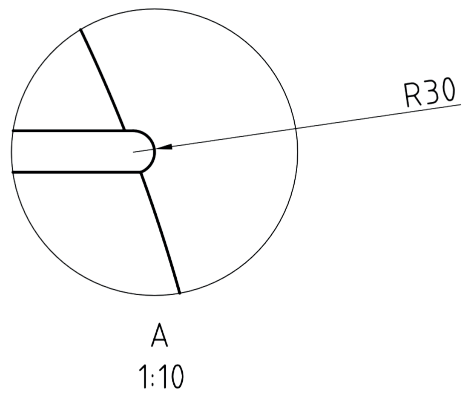
1:50

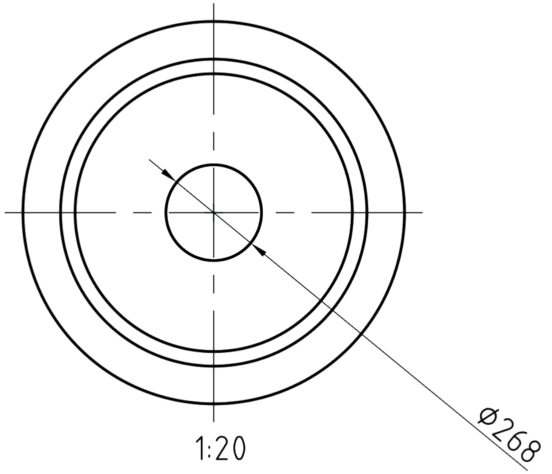


A
1:25

UNLESS OTHERWISE SPECIFIED, DIMENSIONS ARE IN MILLIMETERS		NAME	SIGNATURE	DATE	Falcon 9 Rocket
ANGULAR = ± °	DRAWN	4DeltaEDU		2017-03-10	TITLE
SURFACE FINISH	CHECKED	GIP			Engines - Bottom View
DO NOT SCALE DRAWING	APPROVED	GIP			
BREAK ALL SHARP EDGES AND REMOVE BURRS					SIZE A4 / DWG NO. 4DEdu2002 / REV. -
FIRST ANGLE PROJECTION	MATERIAL N/A		FINISH N/A		SCALE 1:100 / WEIGHT / SHEET 1 of 1







UNLESS OTHERWISE SPECIFIED, DIMENSIONS ARE IN MILLIMETERS ANGULAR∠ = ± °		NAME	SIGNATURE	DATE	Falcon 9 Rocket
	DRAWN	4DeltaEDU		2016-10-29	TITLE
SURFACE FINISH	CHECKED	GIP			Engine Nozzle
	APPROVED	GIP			
DO NOT SCALE DRAWING					
BREAK ALL SHARP EDGES AND REMOVE BURRS					SIZE A4 / DWG NO. 4DEdu2003 / REV. 3
FIRST ANGLE PROJECTION	MATERIAL Graphite		FINISH N/A		SCALE 1:25 / WEIGHT / SHEET 1 of 1

Advanced CAD and AM Engineering

Following the successful delivery of our first course "Introduction to CAD and 3D Printing", we are now presenting our second instalment. In the first part of the course we aim to complete your knowledge of the Onshape platform by working on numerous complex designs using all the available tools. In the second part we focused on introducing you to basic engineering concepts both technical and professional. This is followed by an extensive walkthrough of your new working platform Optimatter, designed to assist you in advance technical (materials and processes) analysis of your 3D printed parts.

4Delta Education