The Periodic Table of Forms with Fusion 360

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Learning Objectives

- Explore how modeling workflows impact design aesthetics
- Discover a methodology to deliberately craft the perception of a design
- Discover Fusion 360’s software approach to different advanced modeling techniques
- Challenge the way you approach design exploration

Description

“Why does design so often struggle to communicate its value to the world when it’s something we all recognize?” This was the question posed by Gray Holland, renowned founder of Alchemy Labs, 6 years ago when he developed the now famous Periodic Table of Forms, a table that explains how surface curves change the perception of a design. Designs have a feel. The sharp edges of a B-52 Bomber look menacing, while the curves of the VW Bug look friendly. In this hands-on workshop we will explore how Fusion 360 software unlocks these formative design types. We will explore the structure of Holland’s table and discover how to create different curvature setups. Whether you’re a new student of design and have no idea what a G0 curve is or you’re a veteran designer looking to learn new ways to adapt your portfolio, this class sets out to inspire you to push the boundaries of design and provide you with tangible Fusion 360 software tactics to do it.

Special thanks to Gray for letting us showcase his compelling and useful article!

Your AU Experts

**Mike Aubry** is always pursuing better, faster and exciting ways to design. During the ten years he’s worked in the computer aided design field, he’s been privileged to work with 100s of customers who do everything from craftsman eyewear to giant fighting robots. He has professional experience in the biomedical, wind energy, and computational fluid dynamics simulation industries. Mike is passionate about hackathons, and he loves working with anyone and everyone inspired to solve interesting problems. He proudly works as an Evangelist for Autodesk Fusion 360 – a 3D CAD/CAM tool that strives to aggregate the product development process into a single cloud based tool. He has a mechanical engineering degree from the University of Portland.

**Mike Prom** is the modeling Product Manager for the Fusion 360 team. Over the years he has worked for industrial equipment companies like Case New Holland, Bobcat and Arctic Cat. He also designed medical beds for Tri W-G and was one of the first employees of a startup making motorized ice fishing houses. Mike enjoys designing custom furniture, working on cars and mountain biking. He received his degree for mechanical engineering from North Dakota State University.

Introduction

**Great Design Matters Now More Than Ever**

Too often we settle in our designs, focusing instead on things like cost and manufacturability. It boxes us into design compromises and commits us to long design cycles that stagnate our brands.

What if we told you that all of this is rapidly changing?

Today’s manufacturing environment is in the midst of a dramatic transition. Additive manufacturing techniques (aka 3D printing) continue to improve and decrease in cost. Subtractive fabrication processes (aka CNC machining) continue to become more cost effective and readily available. We are quickly moving towards a world where products that previously required overseas fabrication runs of several units will be more cost effective and more desirable if they are manufactured locally and on-demand.

How will this affect “great design”? This manufacturing renaissance will be the catalyst to spur vocational innovation. In the zero limits, on-demand manufacturing societies of the future, designers who provide profound insight into the usage and form requirements of their customers will be profoundly rewarded. Those who do not will atrophy, much like the paper draftsmen of the 90s, and be relegated to tasks not yet automated.

It is critical to make sure we as designers provide to our customers the exact functionality and form they specify. Never before has the need to apply and move quickly between different modeling techniques been so imperative. Too often a modeling technique available to a designer is the one they are chained to. No more. The future demands a product design platform built to evolve and adapt quickly as these macro disruptive changes unfold.

This is where Fusion 360 comes in. Fusion 360 has a broad set of modeling tools that allow us to create every single one of the shapes in the periodic table of forms. In this class we will go through three step-by-step exercises that increase in modeling complexity and will allow us to utilize three different
modeling environments available within Fusion 360: Solid modeling, sculpting, and patch ("surface") modeling. Employing these techniques with an attention to the design impact they have will help us as designers prepare for this next industrial revolution and capitalize upon all of the exciting changes ahead.

Gray Holland’s “Periodic Table of Forms”

Six years ago Gray Holland, renowned founder of Alchemy Labs, published a paper that sought to communicate more explicitly how surface curves change the perception of a design. Designs have a feel. The sharp edges of the 15ft tall Megabot in Figure 1 look menacing, while the curves of the new Star Wars BB8 droid in Figure 2 look friendly:

These curves and edges are called “transitions,” and they are described by their continuity designation: “Positional,” “Tangential,” or “Curvature.” Positional continuity (Referenced as “C0,” “Curvature 0,” “G0,” or “Gaussian 0”) describes the hard edge formed when two surfaces intersect. Tangential continuity (Referenced as “C1” or “G1”) is defined by creating a circular arc transition between the two surfaces where the arc aligns with classic geometric tangency at both ends. C1 surfaces are smooth but have visible break where the transitional curve ends and the attached surfaces begin. Curvature continuity (“C2” or “G2”) is achieved when this rate of curvature transition is controlled such that it is not discernable where one surface ends and the other begins.

The differences in each transition can be well shown using the curvature analysis tools within Fusion 360. In Figure 3, a Curvature Comb is used to show the rate of curvature transition on equal sized cubes where one uses a chamfer, one uses a C1 fillet, and one uses a C2 fillet. Notice how the C1 example has an abrupt curvature transition whereas the C2 transition is more gradual.
This transition affects how light refracts off the object and how the observer experiences it. In Figure 4, a set of Zebra Stripes (straight black and white lines) are projected onto the cubes:

Notice how the different curvature examples reflect the stripes. The stripes transition abruptly in the C1 and the stripes transition smoothly in the C2 example.

When we blend these curves, complex layers and tones start to emerge. Take a look at the full Table of Forms in Figure 4. Observe how simply changing edges and rounds changes how a design impacts the viewer:
Some of these models, like the C0 form in Figure 5, are fairly straightforward to create. Others such as the C1~2~0 shown in Figure 6 require more attention and technique:

Most physical designs provide clear parameters to build around. Generous rounds must be added to areas that experience structural loading. Tight edges must be maintained in areas of critical fit. Sharp edges are to be avoided where handling is involved.

Interestingly, nowhere in the Table of Forms is there any reference to what the form actually does! Without explicitly knowing what this form is used for, the value (aka its purpose) is left to the viewer to
infer. Certain forms just “look” stronger, rougher, softer, sleeker, or more elegant. As designers we can use the assumptions people make based on form shapes to take functional designs and turn them into great designs. Great design is achieved when a product not only accomplishes its engineered function but also fully communicates its purpose and sets an emotional tone befitting of its brand.

In the next three exercises you will go step by step through creating a C1 form, C2~0 form, and a C1~2~0 as shown in Figure 7.

These three forms were chosen because they showcase a variety of modeling techniques that achieve a variety of different design tones and emotions. Learning and applying these different foundational techniques to your designs will allow you to capture exactly the functionality and character you are looking for in your designs.

Let’s get started.

**Exercise 1 – Creating a C1 Form**

*Dependable. Familiar. Strong.*

The C1 form is perhaps the most common of forms applied today. It is a very functional form that employs simple to machine edges and rounds that remove sharpness. In typical cases it is easy to model in CAD. The C1’s attainability has made it a staple of traditional mechanical CAD tools like Autodesk Inventor and SolidWorks for years. As shown in Figure 8, designs that deliberately employ it evoke tones of familiarly and dependability. For example, most power tools like the Dewalt drill shown in Figure 9 opt to use the well-defined lines found in the C1:
In this exercise you will explore how Autodesk Fusion 360 employs the C1 technique using parametric modeling functionality:

**Exercise 1 – C1 Form Creation**

1. Open the file “AU Start C1.f3d”
2. In the browser, make sure the visibility for Sketch1 and Sketch2 is on:

3. Press “E” to open the Extrude dialogue box. Select the profiles contained in Sketch1 as shown. Change the Extrude Direction to be Symmetric. Enter an extrusion distance of 0.25:

4. Select the profiles as shown in Sketch 2. Choose a distance of 0.25. Make certain Operation is set to “Join” and Direction is “Symmetric.”
5. Press the F key to open the Fillet dialogue box. Select the four edges where the round cylinders connect to the square cylinder. Choose a radius of 0.25.

6. Create a fillet around the edge border that has a radius of 0.0625.


Exercise 2 – Creating a C2~0 Form

The C2~0 form represents a blending of refinement with pragmatism. A pure C2 form maintains complete smoothness throughout but can dull a design’s impact by glossing over key definitions. A purely C0 form is very exact, but its oblong edges often finish crude and unrefined.
The C2~0, as shown in Figure 10, combines these two forms so it maintains its rigidity while providing sleek refinement through areas of transition. The F22, shown in Figure 11, is a great example of the C2~0:

![Figure 10: C2~0 Form](image1.png)

![Figure 11: F22 Raptor](image2.png)

In this exercise you will explore how Autodesk Fusion 360 employs the C2~0 technique using sculpting combined with solid modeling functionality:

**Exercise 2 – Creating a C2~0 Form**

1. Open the file “AU Start C2-0.f3d” in the Browser, make sure Sketch1 and Sketch2 are visible:

   ![browser screenshot](image3.png)

2. Select Create Form

3. Select Create/Sphere. Create two spheres of diameter 1, longitude 6, and latitude 6. Choose the starting points to be at the center points of both circles. Make one sphere oriented vertically and one sphere oriented horizontally:

   ![spheres screenshot](image4.png)
4. Double click on the sphere body to select:

5. Right Click to select Move. Rotate the body 30 degrees to align the misaligned sphere’s faces with the blue origin’s axis:

The final spheres should be aligned like this:

6. Use the shift key and left click to select the top faces of the sphere. Right click and select edit form:
7. Use the manipulator to slightly shrink the faces as shown:

8. Select Create/Flatten. Choose the Points on top of the sphere as shown and complete the flattening operation. Tip—go to a side view and drag select:

9. Make sure the sketches are still on and edit the selected faces one more time, dragging them until they are parallel with the line in the sketch:
10. Repeat the prior two steps on the remaining sphere:

11. From the side view select the bottom halves of the two spheres:

12. Right click and Delete the faces as shown:

13. Repeat steps 10 and 11 from the top view so that you are left with a quarter of each sphere. The result should look like what you see in step 13.
14. Select Create/Bridge. Choose the faces on the left as Side 1 and the faces to the right as Side 2.

15. Select Mirror Duplicate. Choose the shown plane to mirror and create symmetry on the body:

16. Repeat the prior step and use the plane as shown:
17. Use shift and the left mouse button to select the faces shown. Right click and select Delete:

18. Repeat the above deletion step on the remaining unjoined faces as well:

19. Double click the edge of the open profile. Right Click and select Fill Hole:
20. Use Fill Hole on the remaining hole:

21. Select Modify/Crease. Crease the edges as shown:

22. Repeat the crease command and crease the edges shown below as well:
23. Use Edit form to modify the geometry to resemble the shape as shown. Moving the inner circle so that it looks concentric with the outside edge:

![Image of a 3D model modification process]

24. Select Finish Form.

25. The next thing to do is create the holes. Expand the bodies folder in the browser and turn off the visibility of the body:
26. Under the create pull down select extrude, enter .175 for the distance:

![Extrude screenshot]

27. Create a sketch on the top of the new cylinder that was created, under sketch select Project Geometry and select the top circle:

![Sketch screenshot]
28. Turn on the visibility for all solid bodies.

29. Select Offset Plane.  Choose the plane as shown.  Create an offset plane of distance 0.3

30. Hold down the left mouse button over the newly created plane.  A list of selectable options will appear.  Select the workplane:

31. Right click and choose New Sketch.

32. Turn on the visibility of Sketch1:
33. Project the Sketch Circle and Geometric Point onto the sketch.

34. Add arcs to complete the profile as shown below. These are found under Sketch/Arc/3 Point Arc. Use the natural edge boarders to align the arcs:
35. Select Create/Loft. Select the shown profiles. Set the Operation to New Body:

36. Turn off the visibility of main body again, leaving just the bodies in the image below:
37. Select Pattern/Mirror. Mirror the visible body. Set pattern type to Body. Choose the Body 14 as the Object. Choose the shown face as the Mirror Plane:

38. Repeat the mirror selection. Mirror both bodies on the shown mirror plane:
39. Select the Move command. Select the two newly mirrored bodies. Set Pivot to the Origin. Check done.

40. Rotate the bodies 90 degrees as shown:

41. Turn back on the visibility of the main body.
42. Select Combine. Choose Body 13 as the Target. Choose all other remaining bodies as the Tool Bodies. Set the operation to Cut.

43. Select Fillet. Create 0.05 G2 fillets on the edges as shown:

44. End of Exercise 2
Exercise 3 – Creating a C1~2~0 Form

Robust. Balanced. Expensive.
The C1~2~0 form often represents the next level in high end design. The intricacy and varied nature of how its curves blend require attuned eyes and attention to structural necessity. The difference between an exceptional design and one that overreaches is subtle. The addition of a well-placed smooth element or sharp transition can make the difference between a $40k car shown in Figure 12 and a $70k car shown in Figure 13:

![Figure 12: 2012 VOLVO XC90](http://media.caranddriver.com/images/media/601419/2016-volvo-xc90-interior-photo-601421-s-986x603.jpg)

![Figure 13: 2016 VOLVO XC90](http://media.caranddriver.com/images/media/601419/2016-volvo-xc90-interior-photo-601421-s-986x603.jpg)

The C1~2~0 form is elegant and crisp. As shown in Figure 14, it uses the soft, organic shapes of C2, sharp cuts from C0 and rounded edges from C1. This form communicates that the design is expensive while showing that it is refined. When looking at this form it is inviting to touch. Notice the 2014 Apple Macbook Pro in Figure 15. There is a “feeling” that you get when you pick it up and hold it in your hands that comes from the subtle curvature and attention to finishing details which makes it stand out:

![Figure 14: C1~2~0 Form](http://www.apple.com/macbook-air/)

![Figure 15: Macbook Pro](http://www.apple.com/macbook-air/)
In this exercise you will explore how Autodesk Fusion 360 employs the C1~2~0 technique using sculpting combined with patch (surface) modeling functionality:

**Exercise 3 – Creating a C1~2~0 Form**

1. Open the file “AU Start C1-2-0.f3d.” In the Browser make sure Sketch1 and Sketch2 are visible:

2. Select create Form:

3. Select Create/Quadball. Pick the top origin plane.
4. Use the sketch point Center. Use a Diameter of 1. Span Faces of 2.

5. Repeat on the other circle.
6. Use Symmetry/Mirror-Internal to create symmetry on the two quadballs by clicking on the faces as shown:

7. Repeat for the second sphere.
8. Apply the symmetry to the top and bottom, along with the right and left side.

9. Repeat for the other sphere.

10. Select Modify/Edit Form. Use Command (Mac) / CTRL (PC) to select the top four sections of the left quad as shown. Use the manipulator to move -0.1 downward:
11. Repeat Edit Form as shown for the other sphere:

12. Select Modify/Bridge the bridge command from the modify pull down. For Side One choose the 4 faces on the left sphere as shown. For Side Two choose the four faces on the right sphere:

13. The Bridge should look like this:

14. Use Edit Form to modify the center of the body. As shown, select two edges on each side of the center. Drag the manipulator towards the center a distance of 0.08. This will
produce a pinched effect and make the form look more like the original sketch profile:

15. Use Edit Form to flatten the center of what previously was the left quadball. Select the point shown below and move the vertical arrow down towards the center -0.3:

16. Use Edit Form to move the point shown below down -0.05:
17. Select Inspect/Zebra Analysis. Choose the body to activate the zebra stripes. Change the Direction to Horizontal.

18. In the next few steps these stripes will assist in creating consistent continuity across the part. The wavy zebra stripes shown below need to be horizontal such that cuts done in later steps will be constantly applied across the surface and will not result in irregular waves:

19. Select Edit Form. Choose the edge as shown below. Alter the Planar Scale to 0.6 as shown:
20. Use Edit Form to alter the Planar Scale of the edge shown below to 1.133:

![Image of altered edge with Planar Scale set to 1.133]

21. Repeat Edit Form to alter the Planar Scale of the edge to 1.133 shown below:

![Image of edge with Planar Scale set to 1.133]

Note the change in the stripe continuity.

22. Turn off Zebra Analysis by clicking the light bulb in the browser and select Finish Form:

![Image of finished model with Zebra Analysis disabled]
23. Activate the Patch Environment. This is the environment that will be used to create the C0 edges:

24. Turn off the visibility of Bodies and turn on the visibility of all Sketches:

25. As shown, extrude the selected profiles a distance of 1 and set Direction to Symmetric:
26. To see the extruded surfaces turn on the visibility of the Bodies folder, Body4 and Body5. Turn off Visibility of Body3:

27. As shown, extrude the selected profiles a distance of 1 and set Direction to Symmetric:

28. Turn on the visibility of Body3.
29. Select the Create/Boundary Fill. For Select Tools choose the five bodies available in the Bodies Folder:

![Image of Create/Boundary Fill with bodies selected](image1)

30. For Select Cells choose the box shown and set Operation to New Component:

![Image of Select Cells with box and New Component operation](image2)

31. Turn off the visibility of the Bodies Folder. Component1 will remain shown:

![Image of Component1 remaining visible](image3)
32. Change Workspace to Model:

33. Add a 0.025 G2 fillet to the top and bottom edge of the circle that was cut in the image as shown:

34. End of Exercise.