A Protogen Tutorial

Abstract

I don't know if this has been done before. Well, now it has.

Things To Know

"Throughout this book we'll share these stories with you, but before we tell these stories, we have to name our characters." -Richard Rusczyk

Coordinate System

Z is the axis sticking upward. Right hand rule applies for X and Y. (The latter two directions are arbitrary but will be specified relative to the orientation of certain objects.)

This tutorial is completely sketch based. All dimensions are examples, and are to be adjusted for your specific needs.

Terminology

Lines can either refer to line segments or extended lines. When we refer to the intersection of a line segment and another object that does not actually touch the line segment, we are usually referring to the intersection of the object and the extension of the line segment.

Notation wise, set-theoretical notation is used liberally. For instance, the intersection between lines R and S can be referred to as $R \cap S$, and for a point p inside a plane P, we say $p \in P$.

For a plane P, we say an object $p \in P$ corresponds to another object q (not necessarily in P), and vice versa, if p is identical to the result when q is projected onto P.

Useful Links

HEAD MODEL (FUSION 360)
NON-SPOILER GUIDE
64X32 LED PANEL DIAGRAM

Preface

Welcome to the first part of this hastily-written document! Whether you were approached at a Furry convention, read the lore in the Furry Friends wiki, or if this is the result of numerous futile attempts at making a Protogen yourself, we welcome you. This document will be a guide to help you get started. This is, essentially, a tutorial on making a Protogen

visor in a CAD software using only the most basic skills. But you can simply call this some documentation. This new project promises challenge, intrigue, and endless opportunities. Feel free to read this one step at a time, or skim through this if you feel like you have figured it out.

You might also need to learn some basic CAD skills. Here is a basic rundown:

- Make sketches using shapes and lines.
- Use constraints and dimensions to constrain the geometry of a sketch such that it becomes well-defined.
- You can also make sketches relative to existing material by projecting them onto the sketch plane or marking their intersections with the sketch plane.
- Sketches do not always have to be in the plane but the plane is what ishttps://www.overleaf.com/proje used in reference to things like projections.

To make sketches three dimensional there are four main operations we will use:

- Extrude the region along the line normal to the sketch.
- Revolve the region around some axis of rotation such that the revolved surface does not intersect itself.
- Sweep the region along some path that can maneuver around corners and turns (The previous 2 are special cases of this operation).
- Loft two surfaces together, either directly or using guide rails to shape the in-between solid.

You can then modify 3-dimensional solids in various ways, such as fillets, chamfers, boolean operations (splitting, intersecting, combining, etc.), shelling, mirroring, repetition, etc.

- Virtually everything on this list (in other words, everything in the SOLID TAB in Fusion 360) will be denoted as the set of "standard operations."

Notes

- I (NormalExisting) have actually printed out the parts made using this method and tested the models, however actually testing using a formed plastic visor has not been done yet, but rather with placeholder 3D prints meant to simulate a visor.

- The methods are derived based on existing models, in particular those of JF and M16.

A Protogen Tutorial

0. Getting Started

"Every journey begins with a single step." - Dao de Jing (Attributed to Lao Zi)

The first step is to download the head model and import it into the environment. Doing so might change some fundamental settings of the model, so make sure you turn on timeline history and the like so things go correctly.

In this paper we will orient ourselves such that the positive x-axis points from the head forward and the head is symmetric around the XZ-plane. The bottom of the head model (i.e. where it cuts off) is also on the XY-plane. Directions like "left" and "right" unless stated otherwise, are with respect to someone looking from the head (i.e. down the positive X-axis and with the positive Z axis up).

You might want to open a sketch on the YZ-plane and draw out a rough layout of the Protogen head. Draw like a lineart using lines, curves, and circles to show what goes where.

1. Basic Basics

"Knowing the mouse might one day leave its hole and get the cheese ... it fills you with DETERMINATION[sic]." -Toby Fox

This section is easily done using standard operations. There might exist tutorials and reference images online that tell you what needs to be done. But here is one example. Be warned that although exact numbers are given for most steps, the instructions are intentionally open-ended and encourage experimentation. The end result depends on what you believe is correct and aesthetically/functionally good.

Setting Up and Bottom Layer

Open a sketch on the YZ-plane and draw a line extending upwards from the origin to somewhere in the chin (e.g. 185mm). Then draw an axis-aligned rectangle vertically centered at this line such that it goes from the top of the line to near the forehead of the head mode (so around 165mm tall). The width of the rectangle should be a bit wider than the head (e.g. 210mm). The two horizontal edges of the rectangle serve as the basis of our system. In this paper we will denote the bottom line as K_1 and the upper line as K_2.

The first reference plane is created at the bottom line and is tilted down by maybe 5 degrees or so. Denote this plane as P_1.

Draw a centerline aligned with the positive x-axis and going from the origin of the plane

outwards. (The origin of the plane is a bit behind the actual origin if you are looking at the plane from normal.)

Using this central line as the axis of symmetry, draw a perpendicular horizontal line such that its width is a bit more than the width of the head (between ears), say 170mm across. The line's midpoint should lie on the centerline and it should be placed about 110mm or so from the origin. This back edge we will refer to as B_1, whose endpoints are L_1 on the negative Y axis (right side of the head), and L_2 on the positive.

Draw the bottom of the visor: two lines $\overline{L_1L_1'}, \overline{L_2L_2'}$ extending from the ends of the back edge that are both tangent to a circular arc at L_1', L_2'. All this should be symmetrical around the x-axis.

Make the thing long enough, say 155mm from the back edge to the center of the arc, and make the arc, maybe 30 or so mm in radius. Denote the tip of this sketch (i.e. the point where the centerline and the arc intersect) as F_1, and the center of the circular arc as O_1.

Upper Layers and Guide Curves

The second reference plane is done at the top edge of our rectangle sketch, tilted farther down than the first plane. This plane we shall denote P_2 and it shall be tilted at 15 degrees.

Project the bottom sketch to this plane. Draw a similar triangle shape on here, with the arc at the tip, except this time this other back edge, denoted B_2, is placed 20mm forwards from our projected back edge (The reason why this is done is revealed later). The tangential arc should also be a bit larger, maybe like $R = 45$mm or so. Similar to the first sketch, the tip of this one (where the arc coincides with the centerline) will be denoted as F_2. The center of this new arc, denoted O_2 should correspond to O_1, the center of the arc in the P_1 sketch, when viewing normal to P_2.

This next part is a bit harder to conceptualize. Open a 3D-sketch on some plane (YZ for example) with the previous 2 sketches visible. Let (Recall) $\overline{L_1L_2} = B_1$ be the back edge of the bottom sketch, $\overline{T_1T_2}$ be the back edge of the top sketch, where L_1, T_1 are to the right from the perspective of the head. Then, let $\overline{L_1L_2} \cap YZ = A, \overline{T_1T_2} \cap YZ = B$, and let the line $L = YZ \cap P_2$. Mark point C on line L such that $\overline{AC} \perp L$. Extend ray AC upwards by some distance and mark its endpoint D. Finally, draw line $\overline{BD}$ to form the triangle $\triangle ABD$ with altitude BC. Let's define line $\overline{BD}$ to be 60mm long or something.

Draw straight lines $\overline{L_1T_1}, \overline{L_2T_2}$ connecting the back corners of the visor sections, such that you form a back face, and draw a circular arc T_1, D, T_2 from the top visor section back to the top of the line you drew earlier, such that the arc lies in the plane defined by B_2 and BD. The result is a manifold of two flat regions that is bent in the middle.

Creating the Visor

We are now ready for the magic to happen. Open a new sketch on the XZ-plane and draw some curve that stretches from the top of the circular arc, around the front of the top visor sketch, and ends at the tip of the bottom visor sketch (i.e. passing through the three points D, F_2, F_1 in sequence). The curve should be touching all three contact points. It does not necessarily have to be a smooth curve ... some people use two circular arcs instead. When I did this the curve between F_2, F_1 has radius 200, and the curve between D, F_2 is tangent at D to a line $\overline{DD'}$ that is 105 degrees clockwise (when looking from the right side of the head) from $\overline{AD}$.

Loft the bottom visor face to the top visor face using the front curve and the two back lines as rails. Then loft the top face to the circular arc section of the back profile using the curve as the guide rail.

The end result is starting to look like a Protogen visor.

2. The Rest of the [Censored] Protogen

"How to draw an owl: Draw some circles. Draw the rest of the ... owl." -Unknown

This is where it gets harder, however it should be doable using standard operations. The key insight here is to sweep along the edge of the visor to create the rim structure.

Setting Up the Headpiece

Open a sketch on P_1 and draw a line R_1 that lies inside the right straight edge of the bottom sketch. Specify a rectangle whose sides are parallel and perpendicular to R_1. The rectangle should be longer than it is wide–in my implementation it measures 35×8 mm. The longer sides should be parallel to R_1, and the back edge of the rectangle should stick out behind the visor–here it is 15mm behind, so that the point L_1 is 15 mm away from the extended line of that side.

Sweep the rectangle around the form, using the guide rails $\overline{L_1T_1}$, the circular arc at the top, and $\overline{T_2L_2}$ as the guide. Then use a plane cut to remove any material in this body below P_1. This forms the basis of the headpiece of the Protogen.

Open a sketch on P_1, draw a rectangle with $\overline{L_1L_2}$ as a side, and extending 50mm back from the visor. Using the back edge of the rectangle, construct a plane P_3 that is tilted 75 degrees counterclockwise from the horizontal, so its normal vector is in the positive X but negative Z directions.

From the back the back surface of the headpiece should appear as a strip that has two straight segments and one curved segment. Project the outline of this surface (i.e. the back face) onto

P_3. The projection should consist of an "outer edge" and an "inner edge," each consisting of a curve and two straight lines, and a "bottom" consisting of two disjoint but collinear line segments.

Then, take the curved part of the inner edge, and duplicate it but offset by a small amount, say 3mm. Make sure this offset lies inside the projection of the back surface.

Draw parallel lines starting from the endpoints of your offset curve, parallel to the straight projected lines, down to the bottom of the projection. The region bound by what you just drawn (two straight lines and one curve), the bottom, and the inner edge, forms the part of the headpiece where the fur goes. Take this region, and extrude it so that it reaches the back of the headpiece.

Setting Up the Base

Recall that the bottom of the visor, which contains objects like $\overline{B_1}, L_1, L_2, L_1', L_2', F_1, O_1$, lies in the plane P_1. The base of the headpiece (as opposed to the back of the headpiece, which we did earlier) will extend downwards from this plane.

Open a new sketch on P_1. Inside this plane are three key shapes. The first one, our original visor bottom sketch curve that passes through L_1, L_2, and F_1. The other two regions, are the quadrilateral-looking ends of the headpiece back. Project all three regions onto P_1 and into this sketch.

Let E_1, E_2 be one corner each from the quadrilaterals, so that E_1, E_2 lie on the front edges of each quadrilateral, as well as the edges closest to B_1 in each quadrilateral, and so that E_1 is on the same side of the XZ plane as B_1.

Construct a similar curve to the bottom of the visor: From E_1, E_2 draw lines $\overline{E_1E_1'}, \overline{E_2E_2'}$ parallel to the straight segments ($\overline{B_1B_1'}$ etc.) of the visor bottom, and then connect those two lines with a circular arc centered at O_1, so E_1', E_2' are the tangency points. Essentially we are offsetting the bottom of the visor outwards. Then, extend B_1 until it reaches the quadrilateral regions on each side.

To finish it off, take the original visor bottom region, the little strip that we just defined, and the two quadrilateral endpoints of the headpiece, and extrude those down from P_1 a short distance (e.g. 5mm).

To reduce the weight, open a new sketch on the bottom of the base (parallel to, but not P_1) and draw a similar triangle region: On the back straight edge (it's actually forwards from the quadrilateral regions) pick two points D_1, D_2 each 15mm away from the endpoints of the back edge. Mark the midpoint of the back edge and front curve, and draw a centerline. Construct lines $\overline{D_1D_1'}, \overline{D_2D_2'}$ parallel to the edges of the base, and connect them with a circular arc centered on O_3 of radius 45mm. (Note that O_3 does not necessarily correspond to anything). Finally, slice a hole representing this region in the bottom of the headpiece. Be careful not to slice into the visor.

Setting Up the Side Panels

The construction of the side panels is based on the M16 Protogen heads. Open a 3D sketch on P_1, project the bottom (base) of the headpiece. From the front edge of the quadrilateral region (end of the headpiece back originally), draw a parallelogram (possibly a rectangle) with long edges 80mm long and collinear with the sides of the headpiece bottom.

Then, either in 3D sketch mode or a new sketch, draw, on the FRONT of the headpiece back (not the outer surface, but the front, flat surface), a parallelogram starting at P_1 and extending 70mm up the surface. The end result should be two parallelogram (rectangular?) regions that lie on the headpiece back and base, and share an edge, that being where the back and bottom meet.

The figure has three vertices that lie on already existing bodies. Let X_0 be the corner on the shared edge, X_1 the corner on the back of the headpiece, and X_2 on the base. Construct a plane P_4 through those three points. Open a new sketch, and construct a circular arc through X_1, X_2 such that the center of the arc lies above X_1 and the arc has radius 200mm.

Extrude the rectangle that lies in P_1 downwards to match the bottom of the headpiece, and then loft the two rectangles together using the arc on P_4 as a guide. All of this should be joined to the base of the headpiece.

Take what you have just constructed, and mirror them over the XZ plane to the other side of the base.

Side Panels

To make circular side panels, begin by opening a sketch on the side plane of the headpiece back. The plane and the headpiece marks a parallelogram region with two small edges on the top and bottom, and long edges on the sides. Mark the midpoint of the top and bottom and connect them with a centerline. Then, mark a point Ω on this centerline such that it is 45mm from the bottom midpoint.

Draw a circle C_1 centered at Ω of diameter 70mm, and another circle C_2 also centered at Ω with 7mm more radius than C_1.

Extrude the circles inwards to the inner side plane of the headpiece, and then outwards by 5mm. Then, from the triangular region you constructed on the base sticking up, slice a hole using the circles. This ensures the two bodies (back and base) are not overlapping. Finally, mirror this hole to the other side.

Slice a hole of diameter 70mm (the inner circle) through the side panel. Then, construct the side fins (The implementation is left as an exercise for the reader, but you might want to consider starting with a sketch on the inside plane of the headpiece back).

Then, when all is said and done, mirror to the other side, the side panel circle, holes, fins and whatever you constructed along the way. Make sure to join the side fins to the headpiece back.

Making Connections

Slice two holes in the bottom of the side circles, so that they pass through the circles (headpiece back) and the headpiece base. The size depends on what screws you are using. For M3 screws, 5mm diameter should suffice. And of course, mirror everything to the other side as well.

An Ending?

"Every time I push these limits, it's for a future that ... maybe I won't see." -Prism the Protogen

Congratulations! You have just constructed a Protogen head in Fusion 360 using only what is covered on CSWA! That wasn't that hard, was it? Have fun with your creation, feel free to customize it, and let me (NormalExisting) know if you ever do anything with it.

The guide for now only goes to this part (more detail will be added soon^{TM}). From here, things should become a bit easier. Here are some tips for common augmentations:

General Tips

To obtain the visor mold from the visor, create a duplicate shell of the visor body 1mm inwards (or however thick your plastic is), and subtract the shell from a copy of the original visor (so it's a bit smaller than originally). Extrude the back of the shrunk visor to a plane to create a surface to rest on the vacuum former or whatever, and export as mesh. Once you form the plastic sheet you may need to cut it to fit the visor–doing so along the edges of the original visor (without the extrude) should fit snugly inside the head.

To obtain a placeholder visor you can actually 3D print, simply make the shell thicker and export as mesh. You might want to split the shell into multiple parts to save material.

To add support for electronics, first construct the shell of the visor (for testing), and then construct mounts, either joined to or separate from the base (depending on what electronics you are putting in). You can also extrude simple cuboids to mock the electronics placements.

And, of course, if you wish to modify these more "artistically" you can always export them to Blender or some other modelling program.