Project 1: The Astronaut's Coat Rack

24-370 Engineering Design I, Spring 2011
Assigned 19 January, Parts due 7 February, Report due 9 February

Overview:

In this project, you will individually design, fabricate, and test a single component. You will design part geometry so as to minimize mass within challenging constraints on loading, material, and manufacturing. You will use conceptualization methods, sketching, simple models and analytical analysis, CAD modeling and analysis tools, and iteration as you improve your mechanical design. The designer whose component meets all requirements with minimum mass will win a prize!

Storyline:

Your supervisor at NASA asked you join the Martian Astronaut Surface Habitat team, whose exciting mission is to develop living quarters for astronauts on human missions to Mars. You answered "yes!" and made a slightly nerdy gesture. However, your first assignment is not as glamorous as you had expected; you are to design a component for the astronaut's coat rack. The astronaut team at NASA is very particular about how their attire should be hung, and has handed you a detailed set of specifications (below). You are to design a bracket that will hold the astronaut's flight helmet, which will be hung in a secure location upon arrival at the station and never thought about again. Since it is very expensive and energy-intensive to send objects to Mars, the bracket must be as light as possible. You are told that the bracket must be fabricated out of acrylic using a laser cutter, although you never get a particularly good explanation as to why. Oh well. At least your prototypes will be easy to make and test… You talk to the machinist and she gives you some expected manufacturing data for the machine you will be using (below). You also discover that several other interns have been given an identical assignment, and realize that this might be a chance to stand out as the best of the bunch.

Detailed specifications and constraints:

Loading: the bracket must be loaded with 40 ± 1 pounds force, directed downward, one time, without failing, for at least 10 seconds. The load will be applied through a 0.250 inch diameter aluminum pin centered at a horizontal distance of 2 inches from the support structure (Figure 1). The bracket will be supported by up to 4 0.250 inch diameter aluminum pegs, each connected to the support structure in one of 25 possible locations (you will choose peg locations). Failure is defined as a displacement of the loading pin of more than 0.20 ± 0.05 inches in any direction from the indicated position within a period of about 10 seconds of the full load being applied.

Material: The bracket will be made from 0.230 ± 0.005 inch thick sheets of Evonik CYRO Acrylite FF acrylic, a thermoplastic polymer. A nice, smoky, translucent charcoal color has been chosen. For this project, the part must fit on a 2.50 inch by 5.00 inch blank.

Manufacturing: The bracket will be fabricated using an Epilog Mini/Helix 8000 laser cutter. The process converts lines in a document (a PDF file) into cuts through the acrylic stock material. The laser has a finite thickness, which produces biases in cut edge locations, and also has variability, which produces random errors in cut edge locations (detailed in the appendix). This machine is very good at producing planar components, but pocketing of the material is also possible by raster cutting of the material's surface. Pocket shape and depth are encoded through shaded regions on the part drawing, with darker regions being cut more deeply. This process has poorer tolerances than the cutting process and is more difficult to design in detail with standard CAD and PDF editing software. The cutting and rastering processes can introduce other types of error as well, such as small surface ridges due to laser reflections, deposition of melted plastic near the edges of a cut, and warping of long, thin, flat features. Fortunately, your machine shop friend has measured some typical error values, detailed in the appendix below.

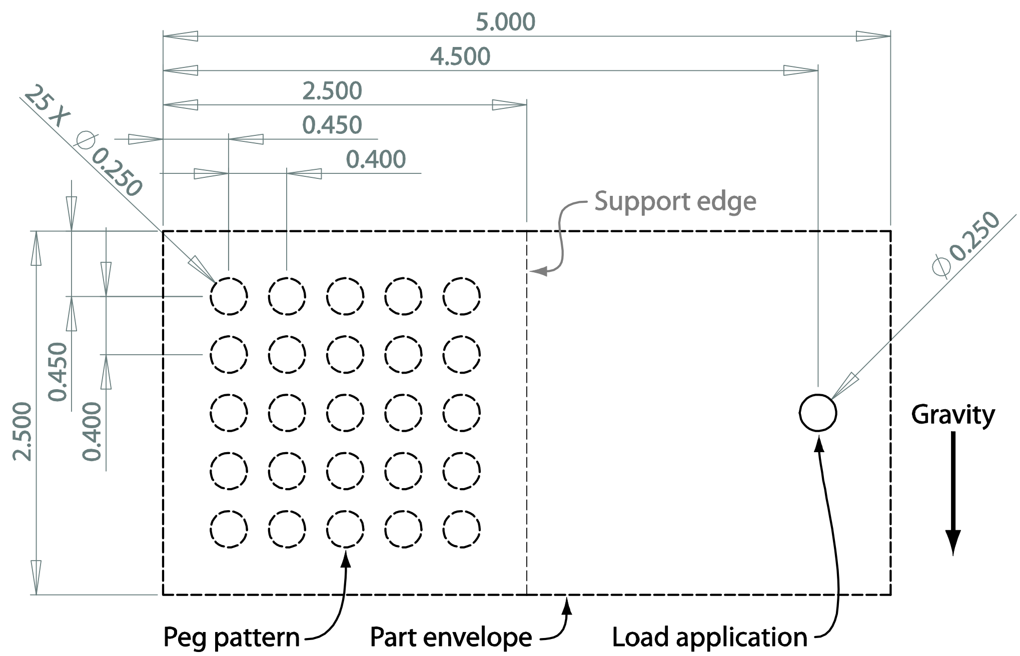

Figure 1. Loading and Support Pattern. Brackets may be supported by up to 4 pegs, which can be placed in any of the indicated positions. The loading pin must be held in the indicated position relative to the support peg pattern. The entire part must fit within the indicated envelope. The edge of the aluminum support plate is indicated for reference. Dimensions are in inches, with standard (± 0.005") tolerances.

Outcomes and evaluation:

Your parts will be manufactured by our capable team, and then tested in class. Testing will include an official weigh-in, a geometric compliance check, application of the prescribed load, and additional loading to failure (as necessary; all brackets will be broken). You will also provide a report detailing your creative efforts in sketches and notes, simple modeling and analysis of candidate designs, SolidWorks modeling and analysis of the final design, and performance projections based on your modeling.

Minimum Performance: Your bracket must be able to take the full load in order to receive full credit for this project (5% credit will be lost for premature failure). You can consider this when determining an appropriate safety factor. Your bracket must also weigh less than 10 grams to receive full credit (5% off for over-weight brackets). But don't sweat it, these should be attainable goals.

Bracket Testing: You will need to submit your manufacturing files a few days before the test date (dates are listed at top of front page). Please submit the manufacturing files in accordance with the Manufacturing Appendix guidelines, otherwise your parts might not come out as you had expected. During the test day, we will test each bracket individually in class. (Please stay for the entire testing period, as you may be called at any time and there will be an important announcement at the end of the period.) First, you will be given your laser-cut bracket and given a moment to extract the cut parts. Then, your bracket will be weighed and measured to ensure compliance with the design constraints. Next, you will be asked to place your bracket in the testing rig and help attach the weights that will provide the operational load. After everyone has taken their hands off the weights and bracket, the tester will wait for 10 seconds. If the bracket breaks, aw shucks. If the bracket holds, success! Successful brackets will then be loaded further until failure. Thus, all parts will be tested to failure.

Final Report: You will submit a final report presenting your final design, as well as the conceptualization, simple modeling, detailed modeling and analysis, and manufacturing documents that went into its creation. The report should be divided into the following sections:

1. Cover page: please place the following items on a single side of a single page
    a. Title line: Project 1, the date, and Your Name
    b. An isometric screen shot of your final design
    c. Description: 100 words or fewer describing the design's primary features
    d. Reasoning: 200 words or fewer explaining why this design is optimal for the task
    e. Your estimate of the safety factor for this part
    f. Your estimate of the failure load
    g. Your prediction of failure mode and location, in 15 words or fewer
2. Conceptual Design Sketches
    a. Please include all your notes and sketches from your idea generation sessions
    b. These will be evaluated on the basis of both apparent volume and apparent quality of design ideas. A typical set of sketches and notes might occupy 3 pages, front and back, with a medium density.
3. Simple Modeling of Candidate Designs
    a. Please evaluate at least 2 candidate designs using a simple analytical model approach
    b. Include hand-drawn sketches of the simple models that allow analytical analyses of interest. Include the analysis you performed by hand. For example, you might model one aspect of the part as a beam in bending, and then relate peak stress, beam height, and part mass in a single function. You will probably need more than one simple model to analyze different aspects of each candidate model.
4. Detailed Model and Analysis of Final Design
    a. Provide an engineering drawing of the final bracket design. Include three standard orthographic projections, e.g. front, right, and top views, as well as an isometric projection. Be sure to include hidden lines in orthographic views, but not in isometric views. Include at least 5 dimensions, with tolerances, that might be needed before sending this part to a typical machine shop.

   b. Provide SolidWorks Simulation results for part stress and displacement. On a single page, paste the following 3 images: (top) screen shot of the part showing constraints and loading, (middle) screen shot of the part displaying stress results, and (bottom) screen shot of the part showing displacement results.
5. Manufacturing Report
   a. Provide hard copies of the documents you submitted for laser cutting
   b. Please also provide a short description (100 words or fewer) describing any changes you made to the design in light of the manufacturing process to be used.

Manufacturing Appendix:

Representative biases and tolerances:

- These values apply to parts created following the Laser Cutter File Format instructions.
- Outer dimensions of flat surfaces will be reduced by about -0.005 ± 0.005 inches. This means that each part edge will be located slightly inside the designed location by about 0.005 inches.
- Outer radii of round bosses (positive features) will be reduced by about -0.007 ± 0.005 inches.
- Inner diameters of round holes will be increased by about 0.002 ± 0.005 inches.
- Pocket depth for full (black) shaded regions will be approx 0.090 ± 0.008 inches.
- Pocket interior dimensions will be increased by about 0.002 ± 0.008 inches.
- Small ridges of about 0.004 ± 0.001 inches in height may occur just above laser cuts and pockets
- The bottom of pocketed regions will be textured irregularly, with amplitude of about ± 0.005".

Other sources of error:

- Warping may occur in long, thin, flat sections of material, especially if pocketing occurs on or near that material. Warping with a radius of 20 inches and a curvature of 5 degrees has been observed in fine features.
- The material sits on a honeycomb surface while being cut by the laser, and tiny reflections off of this honeycomb will cause small (0.001 inch scale) surface defects along the surface of the part.

Laser Cutter File Format:

The laser cutter uses "line art" to make cuts and shaded regions to make pockets. SolidWorks can be used to generate lines, but Adobe Illustrator will be needed to both clean up the generated drawings and to produce fills and gradients for pockets. Use the following procedure to generate files that can be used by our super TAs to produce your parts. If everything goes smoothly, this should take about 30 minutes.

1. Generate a 1:1 drawing in SolidWorks and save as a PDF file
   a. Create a new drawing in SolidWorks and create front and rear views of your bracket
      i. Select a standard A size layout (letter-size paper in landscape)
      ii. Use the method demonstrated in class to generate the drawing and front view
      iii. Create a rear view by first projecting a right view, then projecting a rear view off of the right view
      iv. Make sure that the scale of each view is 1:1 (this can be edited at the bottom of the dialog in the left panel, if necessary)

   b. Remove the sheet format
      i. Right click a blank part of the sheet and select “edit sheet format”
      ii. Select everything in the sheet format and delete it
      iii. Right click in the sheet and select “edit sheet” to return
   c. Remove any non-cut and non-pocket lines
      i. Select any undesired annotations, e.g. center lines, and click delete
   d. Remove the unused (right) view
      i. Select the right view by clicking the view border, then click delete
   e. Draw a the part envelope around your part
      i. Select the front view (a sketch started without selecting a view can be annoying)
      ii. Click the Sketch tab
      iii. Using the rectangle tool, sketch a rectangle around your part
      iv. Using smart dimensions, make the rectangle match the part envelope (Figure 1)
         1. Dimension the width as 5.00” and the height as 2.50”. Locate the loading hole 0.50” from the right edge and 1.25” from the bottom edge
      v. Repeat this for the rear view (flipped left-right, i.e. hole is 0.50” from left edge)
   f. Arrange the views so that the envelope is in the printable area of the page
      i. Move views by selecting the view edge (not the rectangle)
      ii. Dimensions do not need to be on the page
   g. Delete all dimensions
      i. Select each dimension, then press delete
   h. Export for Adobe Illustrator
      i. Click File --> Save As --> Save as Type: --> Adobe Illustrator files (*.AI)
2. Create separate PDFs of the front cutting lines, the front pockets, and the rear pockets
   a. Open Adobe Illustrator, which is available on cluster computers
      i. Delete any text, e.g. “SolidWorks Student Edition”
      ii. Save the Illustrator File
   b. Create a file displaying the laser cut lines, as viewed from the front
      i. Open the exported SW drawing in Adobe Illustrator
      ii. Save as a PDF document with name: LastFirst_FrontCut.pdf
         1. Click File --> Save As --> Format: Adobe PDF (*.PDF)
         2. Change the name to match the above, substituting your last & first name
         3. Click Save As, leave the default options, then click Save PDF
      iii. Delete the rear view
         1. Using the black cursor (upper left panel, top icon) select the entire view
            a. Drag a box completely around all items in the view
            b. If you cannot find the black cursor, click Window --> Tools
         2. Click delete
         3. If parts of the front view are deleted as well, undo and release mask
            a. Click Edit --> Undo
            b. Select (left click) the portion that was deleted by accident
            c. Right click on this portion, and click Release Compound Path
            d. You should now be able to delete the rear view separately

    iv. Delete any lines corresponding to pockets (otherwise these will be cut out)
        1. Select the pocket lines
            a. If the entire part becomes highlighted, right click and select Release Compound Path
        2. Press Delete (be sure all line segments are deleted)
        3. Do not delete the part envelope
    v. Change all remaining lines to 1 pt thickness and black color
        1. Select all lines
        2. In the Color dialog (upper right panel) select the outline and click on black
            a. The outline icon is a square within a square
            b. Black should be at the far right of the color gradient
            c. If the color dialog is not displayed, click Window --> Color
        3. In the Stroke dialog, select 1 pt Weight
            a. Use the drop-down box to select 1 pt
            b. If the stroke dialog is not displayed, click Window --> Stroke
    vi. You should now have the outline of your part, inside the part envelope rectangle
    vii. Save the file
c. Create a file displaying the pockets, as viewed from the front
    i. Open the exported SW drawing in Adobe Illustrator
    ii. Save as a PDF document with name: LastFirst_FrontPocket.pdf
    iii. Delete the rear view
    iv. Delete any lines corresponding to cutting lines (do not delete the envelope)
    v. Change all line weights to 1 pt and color to black
    vi. Use the Live Paint Bucket tool to fill in pocket areas
        1. Select all the lines that correspond to the first pocket
        2. Select the Live Paint Bucket (left panel, about 10 icons from bottom)
        3. Click inside the pocket geometry. The pocket is now a filled region.
        4. Select the pocket and change the fill color to denote depth
            a. Using the black pointer, click the edge of the pocket
            b. In the color dialog, select the fill color (plain square)
            c. Select the fill color
                i. Black corresponds to full depth (see spec above)
                ii. 50% grayscale is roughly half of the full depth
        5. Change the pocket edge color to “None”
            a. Select the pocket using the black pointer
            b. In the color dialog, select the edge color (square within square)
            c. Click None (white square with red hash, left side of gradient)
        6. Repeat for all pockets
    vii. You can also try using gradients to create rough fillets on your part
        1. Select the pocket (or other feature of interest)
        2. Click Effect --> Blur --> Gaussian Blur
        3. Try different Radii to see how these will affect the shape your part

4. If you use blurring, make sure that the shaded region is *entirely* within the part envelope

viii. You should now have the shaded pockets inside the part envelope rectangle

1. If you have no pockets in your design, this PDF will just have the envelope

ix. Save the file

d. Create a file displaying the pockets, as viewed from the rear

i. Open the exported SW drawing in Adobe Illustrator

ii. Save as a PDF document with name: LastFirst_RearPocket.pdf

iii. Delete the *front* view

iv. Delete any lines corresponding to cutting lines (do not delete the envelope)

v. Set line weights to 1 pt and color to black

vi. Create shaded regions representing pockets, as above

vii. You should now have the shaded pockets inside the part envelope rectangle

1. If you have no pockets in your design, this PDF will just have the envelope

viii. Save the file

e. You now have beautiful laser-cutting plans. Hurray!