1. Goals:
   a. Provide additional familiarization with machine tools by producing actual parts. Students will need to use the horizontal bandsaw and either the mill or the lathe.
   b. Use a hydraulic press to perform a forging operation.
   c. Observe the grain deformation during a forging operation.
   d. Compare the theoretical and experimental forces during a forging operation.
   e. Compare a forging operation with and without lubrication.
   f. Compare a hot and a cold forging operation.

2. TA Preparation:
   a. Ensure that there is sufficient stock material available for the lab – a good rule of thumb is 1" of material for each student in the class. The material should be a workable ductile aluminum alloy, preferably a 6061-T6 in approximately 1" diameter rod.
      i. Approximate cost -
   b. Ensure that there is sufficient Teflon sheet for the lab. This sheet should be cut into square large enough to support the testing. Some sheets will be able to be used multiple times.
      i. Approximate cost -
   c. Prepare enough cut and machined specimens for the entire class. The students will be responsible for generating one sample per lab group during the lab. The additional samples are the responsibility of the TA. This will take some time – plan for spending several hours doing this preparation.
      i. Approximate time -
   d. Ensure that the heat treat oven is turned on immediately at the beginning of lab, set to 650 deg F.
   e. Prepare the appropriate safe handling equipment, (gloves, tongs and apron) for handling the specimens when hot.
   f. As a minimum, read section 9-2 in the text to prepare to answer questions on the calculation portion of the lab.

3. Procedure:
   a. Perform this procedure in small groups of three or four.
   b. Obtain work material from the shop manager or TA. The entire class will have the same bar stock to start, so that part will need to be passed from group to group. While one group is bandsawing
their workpiece to length, the other groups can be setting up a mill
or lathe for the finish portion of their specimens.
c. Material for this lab is 1" diameter 6061-T6 or –T651 Aluminum.
d. The intention is for you to produce a piece that is 1 +/- .005". If you
do not hit the target, continue to use the same piece. That is just a
goal that will determine your entire future career success and
should be considered no more important than breathing. =)
e. Using the horizontal bandsaw, cut one 1.05 +/- .05" long specimen
from the stock material. If your piece is not within tolerance, do
NOT cut another piece.
f. Measure and record the original dimensions of each piece.
Because the bandsaw may not cut straight across, measure the
shortest length of the piece.
g. Using either the lathe or the mill, machine your specimen so that
the ends are flat and true to one another, perpendicular to the
length of the piece. Recall that you should try to obtain the 1 +/- .005”
dimension, but flat and true is the most important for this lab.
Realize that the lathe is the best tool to do this. However, it can be
done very successfully on the mill as well. At least one group
should do this on the mill so that you can all benefit from seeing the
part produced on two different machines and the difference in
approach.
h. Record the final machined dimensions of your part.
i. Place two specimens in the heat treatment oven at 650 deg F.
j. Place the first specimen on a clean, flat plate under the hydraulic
press.
k. While holding a clean, flat piece on top of the specimen, lower the
hydraulic press down to the point where it will just hold the upper
plate in place.
l. Using the hydraulic press, forge the workpiece, stopping
approximately every 1/8” of deformation. At every stop, measure
the actual deformation, and record the press force.
m. Continue to deform the workpiece to the maximum extent possible,
recording data the whole time.

n. The TA should provide you with two additional samples to work with
at this point (for a total of four). Using the next specimen, repeat
the process with one change. This time, place a piece of Teflon on
top and bottom of the workpiece. Then repeat the forging process
while recording data.
o. Ensure that your heated pieces have been in the oven for at least
½ hour.
p. **USING EXTREME CAUTION** – forge both heated workpieces
using the above procedure. One piece should be done with the
Teflon sheets, and one without.
q. Clean up the area.
r. Have one designated person e-mail me at wpederse@u.washington.edu with the data. Please put the information in Excel with the following layout:

<table>
<thead>
<tr>
<th>Specimen number</th>
<th>Bandsawed Height (in)</th>
<th>Machined Height (in)</th>
<th>Deformed Height (in)</th>
<th>Force (tons)</th>
<th>True Strain (calc)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1.075</td>
<td>1.000</td>
<td>.900</td>
<td>4.5</td>
<td>.105</td>
</tr>
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<td></td>
<td></td>
<td>.8</td>
<td>7.5</td>
<td>.223</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>.7</td>
<td>14</td>
<td>.357</td>
</tr>
</tbody>
</table>

4. Report:
   a. This is a formal lab report. Use the formal procedure provided in the casting lab.
   b. Specific items to be covered in your report:
      i. Calculate the theoretical forces required to deform the workpiece.
         1. You will need to do two calculations, one with friction, one without. Assume that the specimen with Teflon on both sides was “friction free”. Use equation 9-7, not equation 9-6.
         2. For the friction calculation, use figure 9-6, pg 312. Assume that $\mu =$ sticking.
         3. Do not worry about the elevated temperature calculation as we do not have the elevated material property data available.
      ii. Prepare the following plots:
         1. A comparison between theoretical and experimentally observed forces for the lubricated (Teflon) case.
         2. A comparison between theoretical and experimentally observed forces for the sticking friction case.
         3. A comparison of the experimentally observed forces for the dry and lubricated cases, including the elevated temperature case.
      iii. Discuss the observations and comparisons to theoretical.
      iv. Discuss the deformed “grain structure” as indicated by the deformation of the machining marks on the workpiece.
      v. Discuss the effects of heating the workpiece.
      vi. Discuss the lessons learned for trying to create a precision machined piece.