# Phase 2 Report: Hair Dryer

MCEN 4026

570-076
257-319
821-429

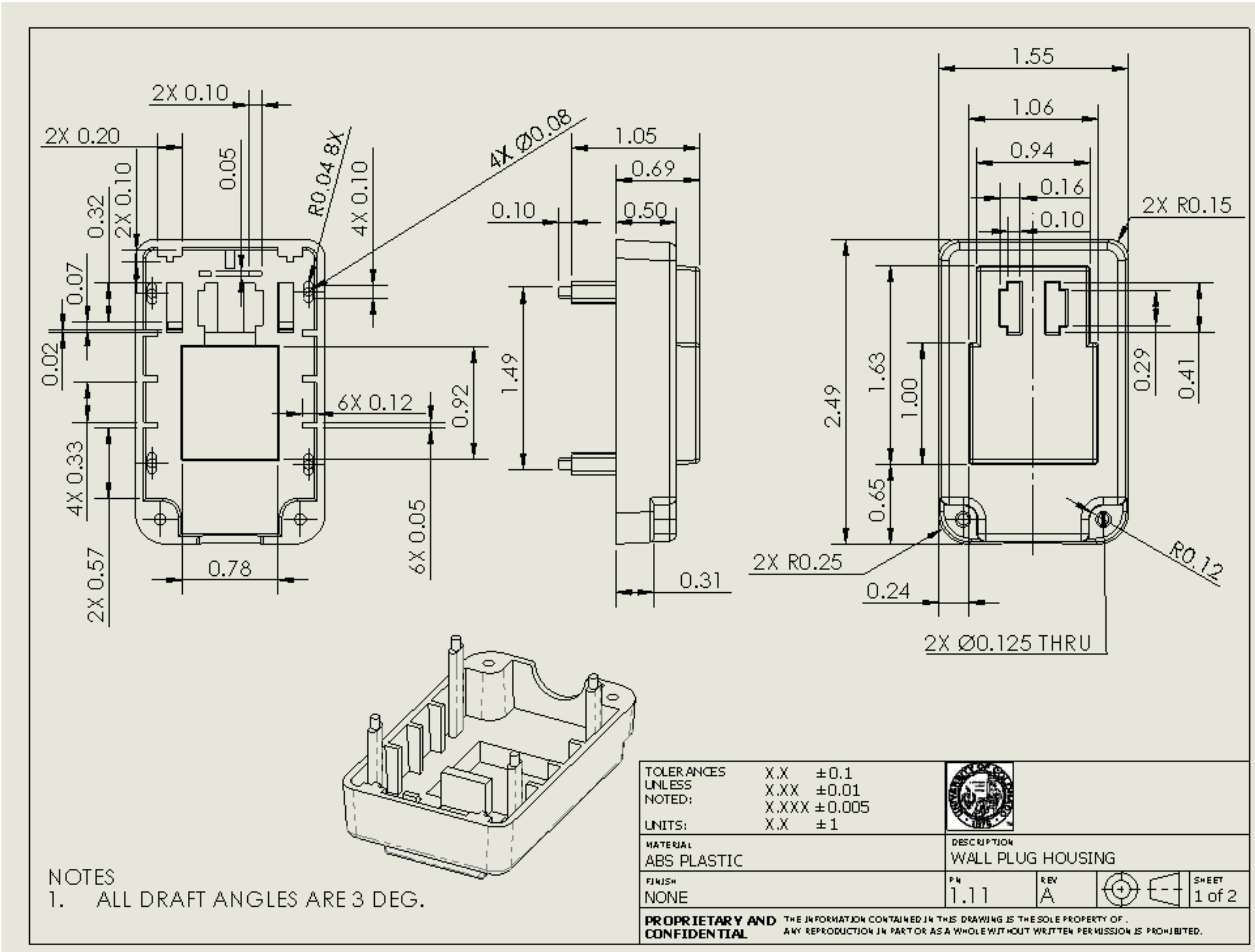
## Part A: BOM

**BILL OF MATERIALS (BOM)**

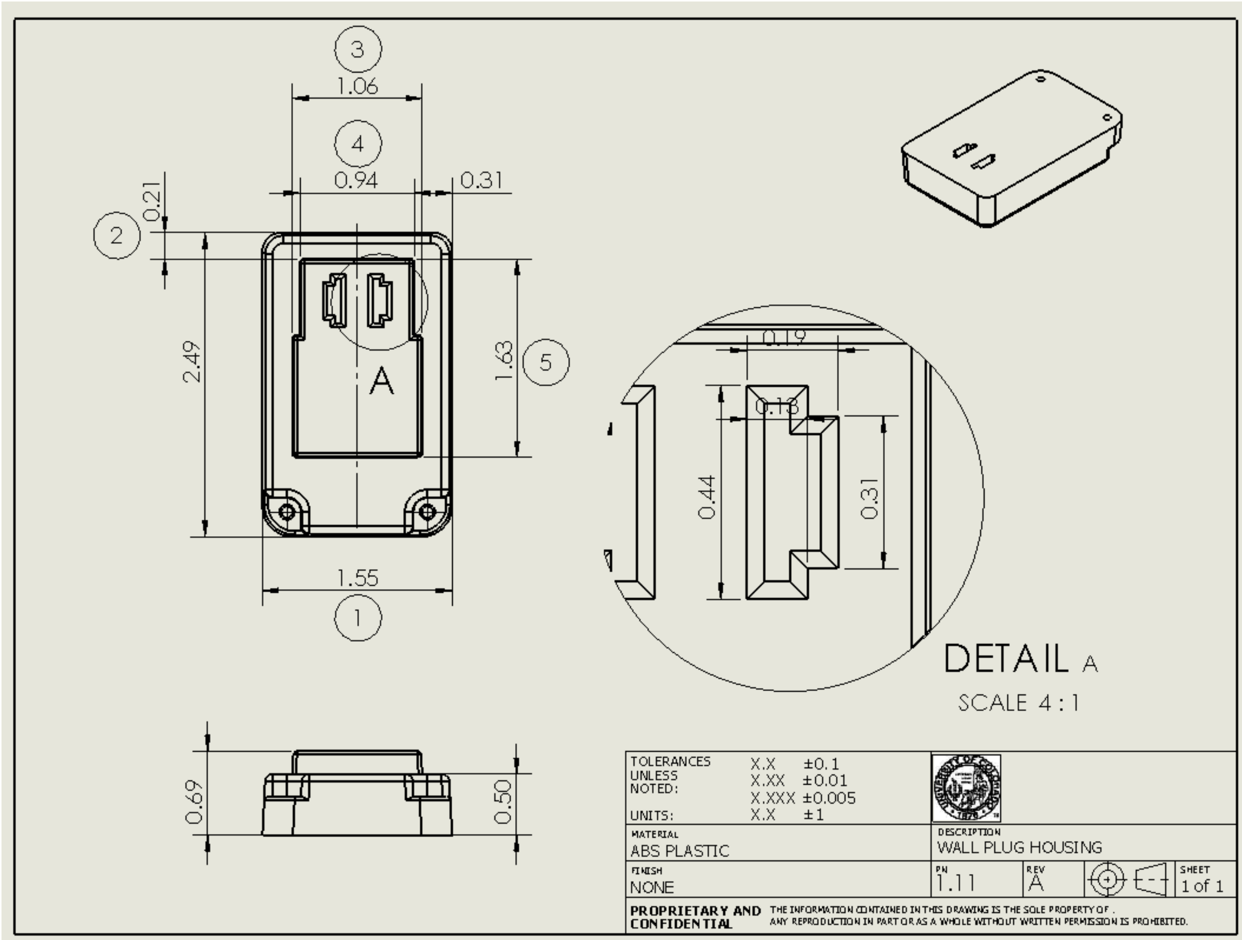
| Sr. No | Type of Assembly | Part Number | Part Description | Quantity | Cost | Type of Part | Material | Primary MFG Process | Recyclable? | Estimated Volume (in^3) | Material Density |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | User Interface | 1.1 | Left Handle Shell | 1 | $ 0.30 | Custom-Built | ABS | Injection Molding | Y | 0.915 | 1.07 g/cm^3 |
| | | 1.2 | Right Handle Shell | 1 | $ 0.30 | Custom-Built | ABS | Injection Molding | Y | 0.915 | 1.07 g/cm^4 |
| | | 1.3 | Heat Assembly Shell | 1 | $ 0.50 | Custom-Built | ABS | Injection Molding | Y | 3.89 | 1.07 g/cm^5 |
| | | 1.4 | Fan Cover/Filter | 1 | $ 0.50 | Custom-Built | ABS | Injection Molding | Y | 3.56 | 1.07 g/cm^6 |
| | | 1.5 | Slider Switch Cover | 1 | $ 0.25 | Custom-Built | ABS | Injection Molding | Y | 0.305 | 1.07 g/cm^7 |
| | | 1.6 | 0.5" Phillips and Safety Screws | 4 | $ 0.25 | Off the Shelf (OTS) Part | Steel | - | Y | | |
| | | 1.7 | Voltage Indicator Switch | 1 | $ 0.10 | Custom-Built | ABS | Injection Molding | Y | 0.03 | 1.07 g/cm^3 |
| | | 1.8 | Handle Alignment Pads | 2 | $ 0.02 | Custom-Built | ABS | Injection Molding | Y | 0.061 | 1.07 g/cm^4 |
| | | 1.9 | Cool Button | 1 | $ 0.02 | Custom-Built | ABS | Injection Molding | Y | 0.31 | 1.07 g/cm^5 |
| | | 1.10 | Reset Button | 1 | $ 0.01 | Custom-Built | ABS | Injection Molding | Y | 0.31 | 1.07 g/cm^6 |
| | | 1.11 | Wall Plug Case | 1 | $ 0.04 | Custom-Built | ABS | Injection Molding | Y | 2X 0.61 | 1.07 g/cm^7 |
| 2 | Heater | 2.1 | Heating Element Fixture | 3 | $ 0.45 | Custom-Built | Proprietary | Engraved + Added to | N | 0.77 | |
| | | 2.2 | Heating Coils | 3 | $ 0.15 | *Off the Shelf (OTS) Part* | Steel | - | Y | 0.1 | 8.05 g/cm^3 |
| | | 2.3 | Insulating Shroud | 1 | $ 0.10 | Custom-Built | Proprietary | Engraved + Added to | N | 1.63 | |
| 3 | Wiring | 3.1 | PCBA | 1 | $ 2.75 | Custom-Built | Copper, Plastic | Hand Place & Solder | N | 0.164 | 8.96 g/cm^3 |
| | | 3.2 | AC-DC Inverter | 1 | $ 0.20 | Off the Shelf (OTS) Part | Copper, Plastic | - | N | - | 8.96 g/cm^4 |
| | | 3.3 | Power/Heat Switch | 1 | $ 0.10 | Off the Shelf (OTS) Part | Copper, Plastic | - | N | 0.164 | 8.96 g/cm^5 |
| | | 3.4 | Cool Air Switch | 1 | $ 0.10 | Off the Shelf (OTS) Part | Copper, Plastic | - | N | 0.164 | 8.96 g/cm^6 |
| | | 3.5 | Outlet Prongs | 2 | $ 0.20 | Off the Shelf (OTS) Part | Copper | - | Y | 0.02 | 8.96 g/cm^7 |
| | | 3.6 | 120V AC Wall Plug | 1 | $ 0.05 | *Off the Shelf (OTS) Part* | Copper,Insulator | - | Y | 1.26 | 8.96 g/cm^8 |
| 4 | Fan | 4.1 | Motor | 1 | $ 0.75 | Off the Shelf (OTS) Part | - | - | N | 1.57 | |
| | | 4.2 | Motor Housing | 1 | $ 0.30 | Custom-Built | ABS | Injection Molding | Y | 1.96 | 1.07 g/cm^3 |
| | | 4.3 | Fan Blades | 1 | $ 0.20 | Off the Shelf (OTS) Part | - | - | N | 0.7 | |

**Table 1.** Hair dryer Bill of Materials with material volumes and densities

**Part B: Part and Inspection Drawing**




**Drawing 1:** Detailed drawing dimensioning all critical features




**Drawing 2:** Detailed drawing with inspected dimensions numbered

**Part C: Inspection Worksheet**

| Inspection Worksheet | | | | | | |
|---|---|---|---|---|---|---|
| Bubble | Nominal Value | Positive Tol. | Neg. Tol | Measurement | Difference (Meas | Pass/Fail (Original) |
| Original Part | | | | | | Pass |
| 1 (OAW) | 1.55 | 0.01 | 0.01 | 1.55 | 0 | Pass |
| 2 (OAL) | 2.49 | 0.01 | 0.01 | 2.5 | 0.01 | Pass |
| 3 (Boss Width) | 1.06 | 0.01 | 0.01 | 1.06 | 0 | Pass |
| 4 (Boss Step Width) | 0.94 | 0.01 | 0.01 | 0.94 | 0 | Pass |
| 5 (Boss Length) | 1.63 | 0.01 | 0.01 | 1.63 | 0 | Pass |
| 3D Printed Part | | | | | | Fail |
| 1 (OAW) | 1.55 | 0.01 | 0.01 | 1.55 | 0 | Pass |
| 2 (OAL) | 2.49 | 0.01 | 0.01 | 2.48 | -0.01 | Pass |
| 3 (Boss Width) | 1.06 | 0.01 | 0.01 | 1.051 | -0.009 | Pass |
| 4 (Boss Step Width) | 0.94 | 0.01 | 0.01 | 0.93 | -0.01 | Pass |
| 5 (Boss Length) | 1.63 | 0.01 | 0.01 | 1.612 | -0.018 | Fail |
| Cast Part | | | | | | Fail |
| 1 (OAW) | 1.55 | 0.01 | 0.01 | 1.527 | -0.023 | Fail |
| 2 (OAL) | 2.49 | 0.01 | 0.01 | 2.441 | -0.049 | Fail |
| 3 (Boss Width) | 1.06 | 0.01 | 0.01 | 1.038 | -0.022 | Fail |
| 4 (Boss Step Width) | 0.94 | 0.01 | 0.01 | 0.918 | -0.022 | Fail |
| 5 (Boss Length) | 1.63 | 0.01 | 0.01 | 1.595 | -0.035 | Fail |

**Part D: Casting Calculations**

## Actual Casting System

### *Sprue*

**Geometry**

$d_{sprue}$ = 0.0254 m
$\rho_{Al}$ = 2380 kg/$m^3$
$\mu_{Al}$ = 0.004 Pas
$h_{poured}$ = 0.0889 m
g = 9.81 m/$s^2$

**Reynolds**

$v_{sprue} = \sqrt{h_{poured} * 2 * g}$ = 1.3207 m/s
$Re_{sprue} = \frac{\rho * v_{sprue} * d_{sprue}}{\text{��}}$ = 1.9960E4

### *Runners*

**Velocity**

$d_{in}$ = 0.0127 m
$d_{out}$ = 0.0063 m
$A_{in} = \frac{\pi * d_{in}2}{4}$ = 1.2668E-4 $m^2$
$A_{out} = \frac{\pi * d_{out}2}{4}$ = 3.1669E-5 $m^2$

**Reynolds**

$v_{out} = \frac{A_{in}}{A_{out}} * v_{sprue}$ = 5.2828 m/s
$Re_{runner} = \frac{\rho * v_{out} * d_{out}}{\text{��}}$ = 1.9960E4

### *Cast part*

**Velocity**

L = 0.0381 m
W = 0.0127 m
$A = L * W$ = 4.837E-4 $m^2$
$v = \frac{A_{out}}{A} * v_{out,\ runner}$ = 0.3458 m/s

**Reynolds**

$Re = \rho v \frac{\sqrt{\frac{4A}{\pi}}}{\text{��}}$ 5.1063E3

**Time to fill mold cavity**

t = 2 s

**Solidification time of part**

V = 7.53E-5 $m^3$
$A_s$ = 0.0109 $m^2$
$C_m$ = 500000 $m^2$
$T_{ts} = C_m(\frac{V}{A_s})^2$ = 23.8620 s

***Riser***

**Geometry**

$d_{riser}$ = 0.0190 m
$h_{riser}$ = 0.0762 m
$A_s = \pi d_{riser} h_{riser} + \frac{\pi d_{riser}^2}{2}$
$V_{riser} = \frac{\pi d_{riser} 2}{4 h_{riser}}$ = 2.1719E-5

**Solidification time**

$T_{ts} = C_m(\frac{V_{riser}}{A_s})^2$ = 8.9606 s

## Optimized Casting System

***Sprue***

**Geometry**

$h_{pour}$ = 0.1 m
$d_{sprue}$ = 0.005 m
$\rho_{Al}$ = 2380 kg/$m^3$
$\mu_{Al}$ = 0.004 Pas
g = 9.81 m/$s^2$

**Reynolds**

$v_{sprue} = \sqrt{h_{pour} * 2 * g}$ = 1.4007 m/s
$Re_{sprue} = \frac{\rho * v_{sprue} * d_{sprue}}{\text{��}}$ = 4.1671E3

## *Runners*

### Velocity

$d_{in}$ = 0.0025 m
$d_{out}$ = 0.0013 m
$A_{in} = \frac{\pi * d_{in} 2}{4}$ = 4.9087E-6 m$^2$
$A_{out} = \frac{\pi * d_{out} 2}{4}$ = 1.2272E-6 m$^2$

### Reynolds

$v_{out} = \frac{A_{in}}{A_{out}} * v_{sprue}$ = 5.603 m/s
$Re_{runner} = \frac{\rho * v_{out} * d_{out}}{\text{��}}$ = 4167

## *Cast part*

### Velocity

$v = \frac{A_{out}}{A} * v_{out,\, runner}$ = 0.0412 m/s
L = 0.0381 m
W = 0.0127 m
$A = L * W$ = 4.837E-4 m$^2$

### Reynolds

$Re = \rho v \frac{\sqrt{\frac{4A}{\pi}}}{\text{��}}$ 209.86

### Time to fill mold cavity

t = 2 s

### Solidification time of part

V = 7.53E-5 m$^3$
$A_s$ = 0.0109 m$^2$
$C_m$ = 500000 m$^2$
$T_{ts} = C_m \left(\frac{V}{A_s}\right)^2$ = 23.8620 s

## *Riser*

### Geometry

$d_{riser}$ = 0.0190 m
$h_{riser}$ = 0.0762 m

$$A_s = \pi d_{riser} h_{riser} + \frac{\pi d_{riser}^{2}}{2}$$

$$V_{riser} = \frac{\pi d_{riser}{}^{2}}{4 h_{riser}} = 2.1719E\text{-}5$$

**Solidification time**

$$T_{ts} = C_m \left(\frac{V_{riser}}{A_s}\right)^2 = 0.419 \text{ s}$$

**Part E: Casting Calculations Overview and Defects**

**Overview**

The group disassembled a small, foldable hair dryer and decided to cast the wall plug housing. The wall plug housing was modeled in SOLIDWORKS to capture all dimensions, features, lofts, etc. as accurately as possible. It was then modified to optimize the part for casting in Aluminum. Optimization included draft angles, scaling the part larger, and removing some of the sophisticated details so that it was a feasible pattern for casting with. Using the 3D printed pattern, the group packed sand around it to form a two-part mold with a sprue and runner. The group then calculated the geometry of the sprue and runners, velocity of molten metal through the system, and the time taken to fill the mold cavity and solidify.

**Hot tears**

A hot tear is a defect that occurs when the solidifying molten metal is constrained from shrinking freely. Hot tears are due to non-uniform cross-sectional areas, sharp corners, and interface between different grains. The part the group cast did not have any hot tears, as the group considered these factors when modeling the part and pattern.

**Shrinkage**

Aluminum, along with most other metals, shrinks as it solidifies. The group attempted to account for shrinkage by scaling the 3D printed pattern up so that when the molten metal cooled to room temperature, the cast part solidified to a size that was within the specifications of the drawing. Risers were incorporated in the mold design to address shrinkage, as well. Risers act as reservoirs of metal and supply a constant flow to the mold cavity, so that when the metal begins to cool and shrink, more metal may be fed in to completely fill the vacated area. Unfortunately, as laid out below, the aluminum part came out too small. After comparing the 3D printed mold to the original part, we noticed that it actually had not printed at a larger scale.

**Improving Casting Results and Tolerance Analysis**

From the inspection worksheet, it is obvious that the cast part does not meet the specifications set by the drawing. In particular, everything is undersized on the cast part compared to the drawing and the original part. We suspect this is due to shrinkage, as well as the precision of the 3D printer used to print the mold. From the inspection sheet, we see that the 3D printed part is undersized or nearly undersized on most of the dimensions. This means the cavity for casting was already on the small side, and the shrinking of the aluminum as it cooled just made problems worse. To improve this, we should print our mold slightly larger. By looking at the difference between the cast part and the 3D printed part, we see that there is a 15-20% difference in size. This means that we could print the mold about 1.2 times the size of the actual part, so that the cast part is in spec once it cools. As mentioned previously, we attempted to print the mold part oversized, but an error occurred when setting up the printer that caused the part to be true to size (i.e. not scaled). Additionally, a stronger tolerance analysis could be performed on the system if more precise dimensions were available for the original part and its mating components. We suspect that the drawing we have developed is perhaps too tightly toleranced, but it is hard to tell without knowing all the dimensions and tolerances of the mating components, so we decided to keep it conservative.

**Chillers and Insulators**

Chillers are used to assist risers in accounting for solidification shrinkage, and may be internal or external to the molding cavity. Solidification of molten metal occurs more quickly closer to the chiller. Insulators help to provide consistency by reducing shrinkage and improving overall casting by reducing heat loss from the riser. The wall plug housing is a small enough part that chillers are not necessary. Insulators, however, would have been helpful to improve overall quality of the cast part.

**Surface finish**

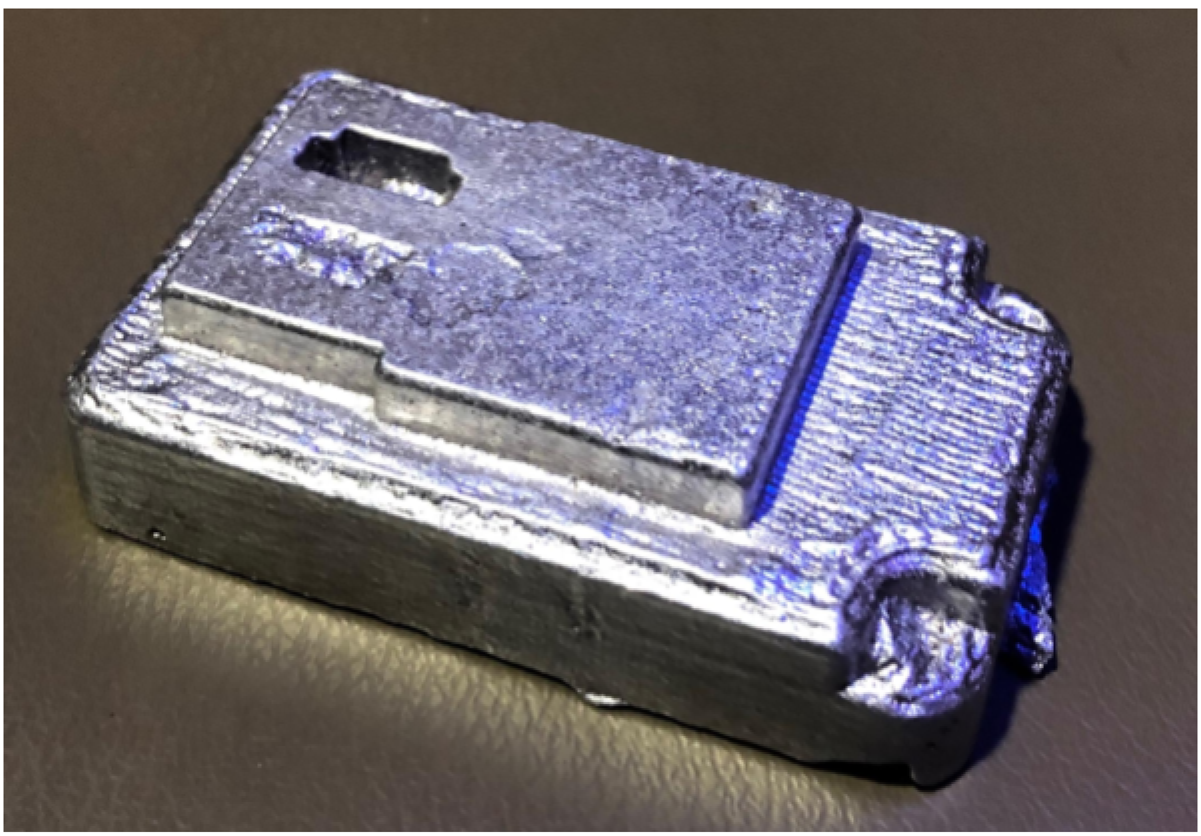
The part, overall, did not have many significant defects. We had no hot tears and no evidence of a short pour throughout the part. The riser's finish was quite smooth while the sprue has a few inclusions. There is some porosity in the cast part itself. This is due to the sand not being packed tightly enough or some crumbling of the sand as we poured the aluminum. The overall finish of our part was very smooth, with a few exceptions. These exceptions include some lumpy patches, like those seen in defects 2 and 3 in the appendix, in addition to the rough surface finish on the top of the part, which is the result of the rough finish on the mold caused by the 3D printing support material. The difference between the smooth and less smooth sections created by the 3D printing material can be seen in the image depiction casting defects 1 and 2.

## Appendix

### Calculation Summary

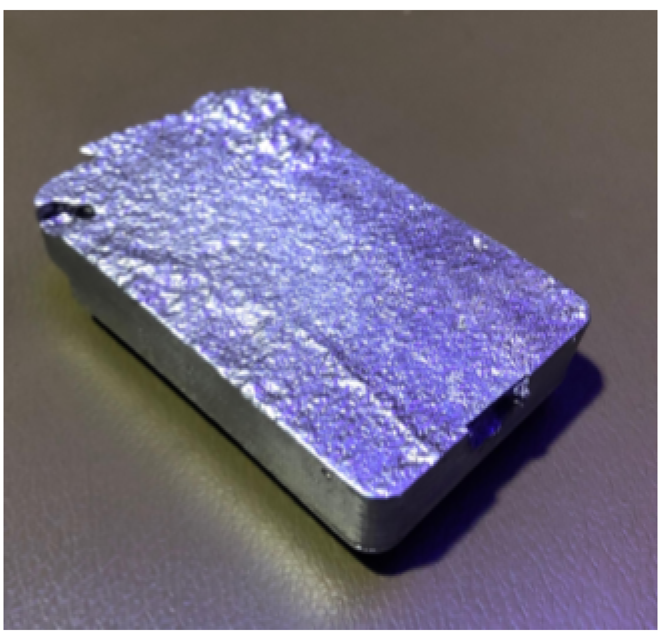
| | $h_{sprue}$ | $V_{sprue}$ | $Re_{sprue}$ | $V_{run}$ | $Re_{run}$ | $V_{part}$ | $Re_{part}$ | $t_{fill}$ | $t_{solid,part}$ | $h_{riser}$ | $d_{riser}$ | $t_{solid,riser}$ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Actual System** | .088m | 1.32m/s | 20000 | 5.28m/s | 20000 | 0.346m/s | 5100 | 2s | 23.9s | 0.0762m | 0.0190m | 8.96s |
| **Ideal System** | 0.10m | 1.40m/s | 4167 | 5.60m/s | 4167 | 0.0142m/s | 210 | 2s | 23.9s | 0.0762m | 0.0037m | 0.419s |

### Casting Defects



**Defect 1&2:** Prong hole cavity did not hold up under casting. The sand defining the pocket on the lower corner of the part collapsed either as the molten aluminum flowed in, or as the two-part mold was assembled.

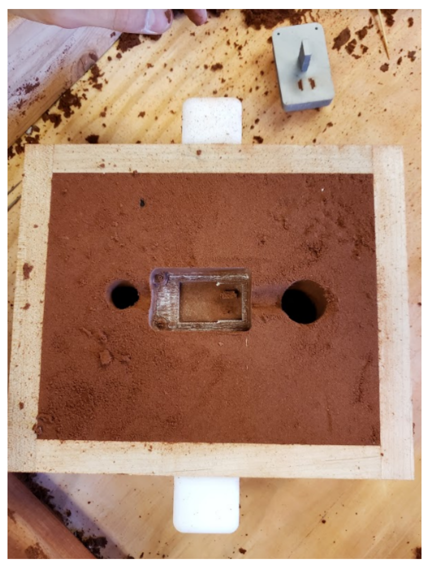
**Defects 3&4:** Lumpy finish on the closest corner and a small divot can be seen. The former is likely caused by a poor surface in the side itself, while the latter is likely the result of some sand falling off the wall of the mold cavity.



**Defect 5:** A patch of uneven finish on the left lower left edge. Another view of the divot (defect 4) is also visible in the upper left corner.

**Casting Process**

| | |
|---|---|
| 1. After modeling the part in SOLIDWORKS, the group 3D printed it which served as the pattern for creating the mold. |  |
| 2. The group coated the pattern in baby powder to ensure easy removal from the mold. |  |
| 3. The group packed sand around the pattern when making the mold. Sand was flattened and packed tightly in the two-part mold. |  |

| | |
|---|---|
| |  |
| `4. The pattern was removed from the mold, and holes for the sprue and runner were formed. The halves of the mold were then joined. |  |

| | |
|---|---|
| 5. Molten aluminum was poured into the mold and the group waited for the metal to solidify before separating the halves. |  |
| 6. The part was removed from the mold and quenched. The sprue and runner were broken off afterwards. |  |

| | |
|---|---|
| 7. The original part is shown on the left, 3D printed pattern in the center, and cast part on the right. |  |

__Code__

**mold design**

**sprue**

```
rho = 2380; %kg/meter^3
 mu = .004; %pascal-seconds
 D_s = 1*.0254; %m (diam sprue)
 dh = 3.5*.0254; %m (height poured)
 v_s = sqrt(dh*2*9.81);
 Re_s = rho*v_s*D_s/mu;
 fprintf('Sprue of system: v = %f m/s, h=%f m, Re=%f\n', v_s, dh,Re_s);
 % runners
 D_in = .5*.0254;
 D_out = .25*.0254;
 A_in = pi*D_in^2/4; %meters^2
 A_out = pi*D_out^2/4; %meters^2
 v_out = (A_in/A_out)*v_s;
 Re_r = rho*v_out*D_out/mu;
 fprintf('Runners of system: v_out=%f m/s, Re=%f\n',v_out,Re_r);
 % cast part
 A_c = (1.5*.0254)*(.5*.0254);
 v_c = (A_out/A_c)*v_out;
 Re_c = rho*v_c*sqrt(A_c*4/pi)/mu;
 t = 2; %time from beginning of pour to end of pour
```

```
  Vol = 7.53e-5; %m^3
  SA = .0109; %m^2
  C_m = 500000; %s/m^2
  T_ts = C_m*(Vol/SA)^2;
  fprintf('Cast part: v=%f m/s, Re=%f, time to fill=%f s, solidification time=%f s\n',
v_c,Re_c,t,T_ts);
  % risers
  D = .75*.0254;
  H = 3*.0254;
  SA_r = pi*D*H + pi*D^2/2;
  Vol_r = pi*D^2/4*H;
  T_tsr = C_m*(Vol_r/SA_r)^2;
  fprintf('Risers of system: h=%f m, solidification time=%f s\n', H,T_tsr);
```

Sprue of system: v = 1.320688 m/s, h=0.088900 m, Re=19959.564648
Runners of system: v_out=5.282754 m/s, Re=19959.564648
Cast part: v=0.345755 m/s, Re=5106.288896, time to fill=2.000000 s, solidification time=23.862007 s
Risers of system: h=0.076200 m, solidification time=8.960556 s

Ideal system

```
 fprintf('\n');
  % sprue
  hsIdeal = 0.10; %0.1 m
  vsIdeal = sqrt(hsIdeal*2*9.81);
  DsIdeal = 0.005;
  ResIdeal = rho*vsIdeal*DsIdeal/mu;
  fprintf('Sprue, ideal: v=%f m/s, h=%f m, Re=%f\n',vsIdeal, hsIdeal,ResIdeal);
  % runners
  DrIdealIn = 0.5*DsIdeal;
  DrIdealOut = 0.25*DsIdeal;
  A_rIn = pi*DrIdealIn^2/4;
  A_rOut = pi*DrIdealOut^2/4;
  vrIOut = (A_rIn/A_rOut)*vsIdeal;
  RerIdeal = rho*vrIOut*DrIdealOut/mu;
  fprintf('Runners, ideal: v_out=%f m/s, Re=%f\n',vrIOut,RerIdeal);
  % cast part
  vcIdeal = (A_rOut/A_c)*vrIOut;
```

```
    RecIdeal = rho*vcIdeal*sqrt(A_c*4/pi)/mu;
    fprintf('Cast part, ideal: v=%f m/s, Re=%f, time to fill=%f s, solidification time=%f s\n', vcIdeal, RecIdeal,t,T_ts);
    % risers
    DrIdeal = 0.75*DsIdeal;
    SarIdeal = pi*DrIdeal*H + pi*DrIdeal^2/2;
    volrIdeal = pi*DrIdeal^2/4*H;
    T_tsrIdeal = C_m*(volrIdeal/SarIdeal)^2;
    fprintf('Risers, ideal: h=%f m, solidification time=%f s\n', H, T_tsrIdeal);
```

**Sprue, ideal: v=1.400714 m/s, h=0.100000 m, Re=4167.124458**
**Runners, ideal: v_out=5.602856 m/s, Re=4167.124458**
**Cast part, ideal: v=0.014210 m/s, Re=209.858748, time to fill=2.000000 s, solidification time=23.862007 s**
**Risers, ideal: h=0.076200 m, solidification time=0.418599 s**