CHAPPiE

By: Connor Rosenberg

Section: A

Fall 2019

REQUIRED CAD FEATURES

HEAD - FRONT

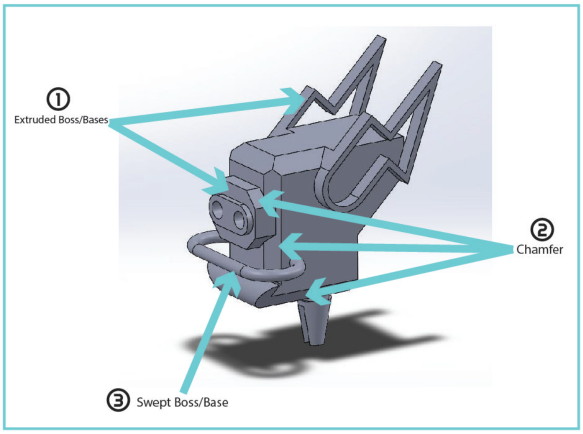


Figure 2

1. **Extrusion:** Mask and lightning bolt

2. **Chamfers:** Design detail (add's industrial look)

3. **Swept-Extrusion:** Respirator tubing

HEAD - BACK

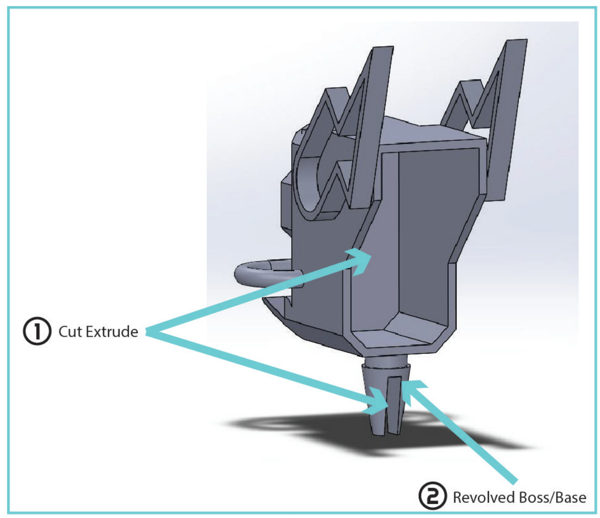
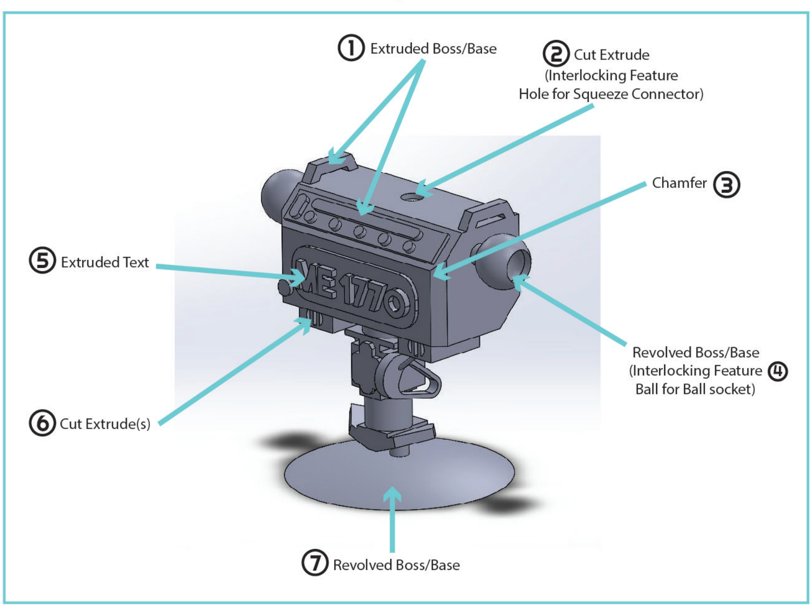


Figure 3

1. **Cut-Extrude:** Shell (reduces volume) & Squeeze connector gap

2. **Revolved-Extrusion:** Squeeze connector (interlocking part)

Figure 4



1. **Extrusions:** Design details: Handle and chest buttons

2. **Cut-Extrude:** Squeeze connector hole (interlocking part)

3. **Chamfer:** Design detail (add's idustrial look)

4. **Revolved-Extrusion:** Ball for ball-socket joint (interlocking part)

5. **Extruded-text:** Says "ME1770"

6. **Cut-Extrusion:** Ventilation box holes

7. **Revolved-Extrusion:** Base/stand for replica

BODY - FRONT

BODY - BACK

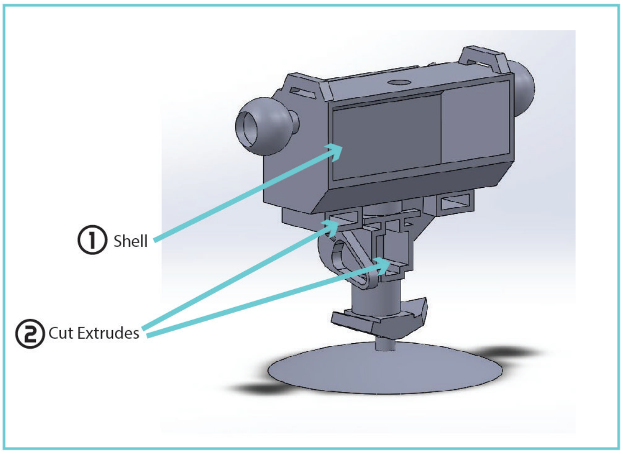


Figure 5

1. **Shell:** To reduce volume

2. **Cut-Extrude:** Vent holes and to reduce volume

ARM - FRONT

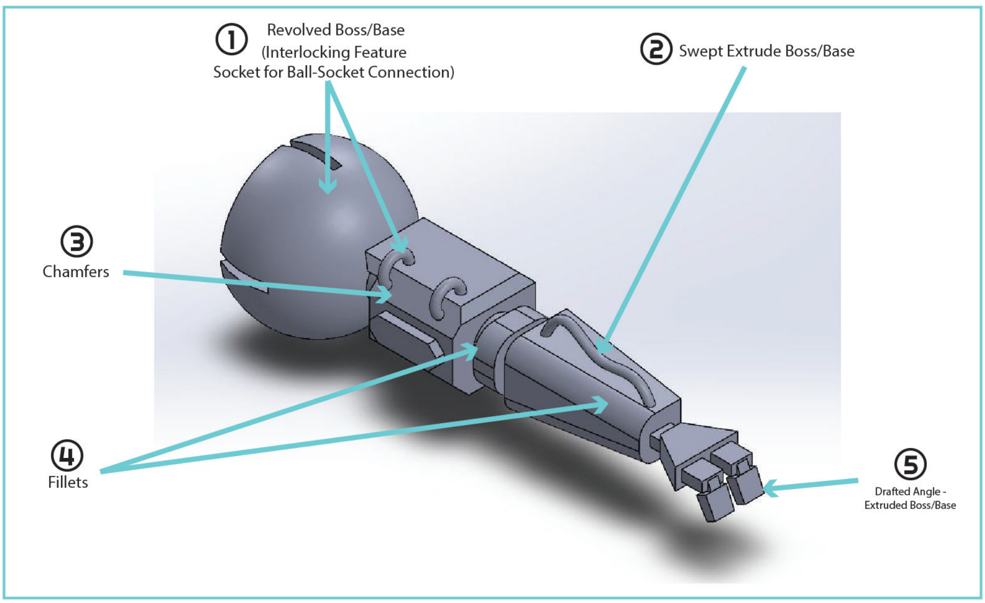


Figure 6

1. **Revolved-extrusion:** Socket for ball-socket joint (interlocking feature) & wires

2. **Swept-Extrude:** Design detail (wire)

3. **Chamfer(s):** Design detail (add's industrial look)

4. **Fillet(s):** Design detail (introduces some level of organic geometry to resemble a forearm)

5. **Drafted Angle-Extrusion:** Fingers

ARM - BACK

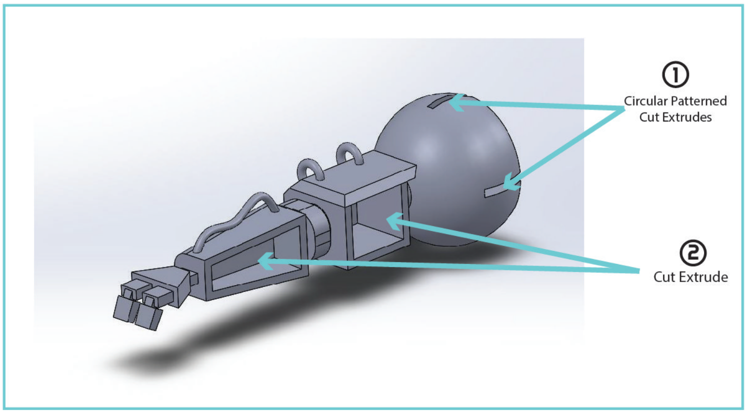


Figure 7

1. **Circular Patterned Cut-Extrudes:** Slits to allow socket to strech and snap onto ball (interlocking feature)

2. **Cut-Extrude:** To reduce volume

TOLERANCE ANALYSIS DATA

HEAD

FEATURE	APPENDIX #	DIMENSION IN CAD (in)	ACTUAL MEASURED ON 3D PART (in)	% DIFFERENCE
Diameter of Connector Base	1	0.1900	0.1925	1.31
Height of Squeeze Connector	2	0.3500	0.3488	0.343
Width of Squeeze Connector Cut-Extrude	3	0.0700	0.0465	40.3
Height of Head (Not including connectors or lightning bolts)	4	1.0000	1.0035	0.349
Width of Head	5	0.5500	0.5600	1.80
Length of Mask	6	0.5000	0.5090	1.78
Height of Mask	7	0.4100	0.4210	2.65
Diameter of Eyes	8	0.1200	L = 0.0975 R = 0.1000	L = 20.7 R = 18.2
Thickness of Lightning Bolts	9	0.1000	L = 0.1165 R = 0.1180	L = 15.2 R = 16.5

BODY

FEATURE	APPENDIX #	DIMENSION IN CAD (in)	ACTUAL MEASURED ON 3D PART (in)	% DIFFERENCE
Diameter of Base	1	2.0000	1.9860	0.702
Diameter of Waist	2	0.4200	0.4270	1.65
Length of Vent	3	0.4000	0.4145	3.56
Length of Chest	4	2.0000	2.0045	0.225
Width of Vents	5	0.6000	0.6075	1.24
Width of Chest (Without the text plating)	6	1.000	1.0005	0.050
Shell Thickness	7	0.0500	0.0595	17.4
Handle Thickness	8	0.1000	0.1020	1.98
Height of Chest (Without Handle)	9	1.0500	1.0000	4.88
Diameter of Ball (L and R)	10	0.4900	L = 0.4810 R = 0.4830	L = 1.85 R = 1.44

L & R ARMS

FEATURE	APPENDIX #	DIMENSION IN CAD (in)	ACTUAL MEASURED ON 3D PART (in) - LEFT ARM	ACTUAL MEASURED ON 3D PART (in) - RIGHT ARM	% DIFFERENCE - LEFT ARM	% DIFFERENCE - RIGHT ARM
Thickness of Socket	1	0.1000	0.1136	0.1111	12.7	10.5
Width of Patterned Cut-Extrudes	2	0.0400	0.0295	0.0315	30.2	23.8
Length of Bicep	3	0.4000	0.4110	0.3980	2.71	0.501
Length of Elbow	4	0.1000	0.1290	0.1051	25.3	4.97
Length of Forearm	5	0.6000	0.6115	0.6201	1.90	3.29
Diameter of Wire	6	0.0400	0.0520	0.0401	26.1	0.250
Length of Hand	7	0.1700	0.1875	0.1659	9.79	2.44
Thickness of Hand	8	0.1000	0.1100	0.1090	9.52	8.61
Width of Finger (base)	9	0.1000	0.1135	0.1102	12.6	9.71
Thickness of Bicep Shell	10	0.0400	0.0430	0.0411	7.23	2.71
Thickness of Forearm Shell	11	0.0400	0.0475	0.0509	17.1	24.0

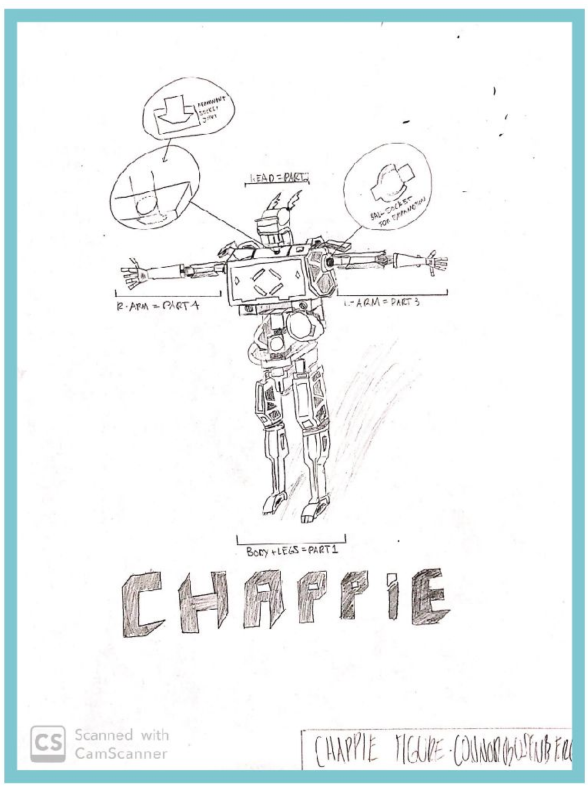
PROJECT DESCRIPTION

For this project, I decided to model my own iteration of the robot from the movie "Chappie". I have always been interested in humanoid robots, and I thought that modeling one would be perfect for this project. I chose to design Chappie, because I can both demonstrate my proficiency in Solidworks, and exhibit my creative-ingenuity by challenging myself with designing a product that has a strong level of complexity, and requires advanced modeling techniques to design it.

Originally, I wanted to design a full-body Chappie replica with arms, legs, a body, and a head but, upon meeting with my professor about the idea, we decided that modeling a Chappie replica from the waist up was a better idea (due to the size restrictions in the project guidelines - more details in "Challenges Faced in Manufacturing" section). Therefore, my Chappie replica is simply a robot with arms, a head, and torso with a large base at the bottom.

Additionally, while a static model of Chappie would have been much more simple to design, I wanted my replica to be dynamic and have its arms and head be able to move. Therefore, designed Chappie with a(n) ball-socket(s), and permanent squeeze joint so the arms and head could move freely (see the "Interlocking Features of Design" section for more detailed information).

(*Figure 1*)



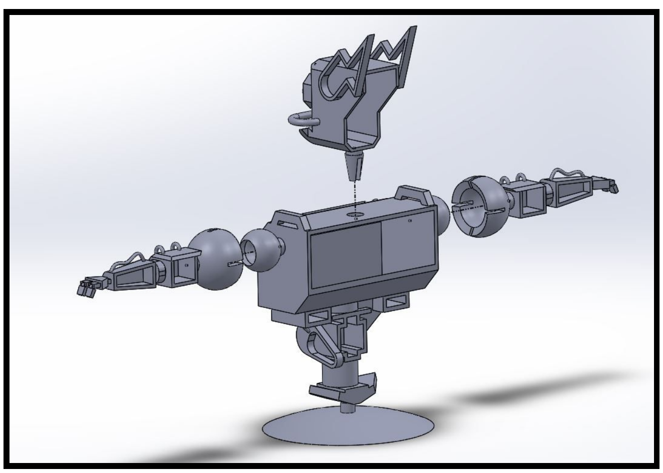
(Figure 1 displays the final submitted concept sketch)

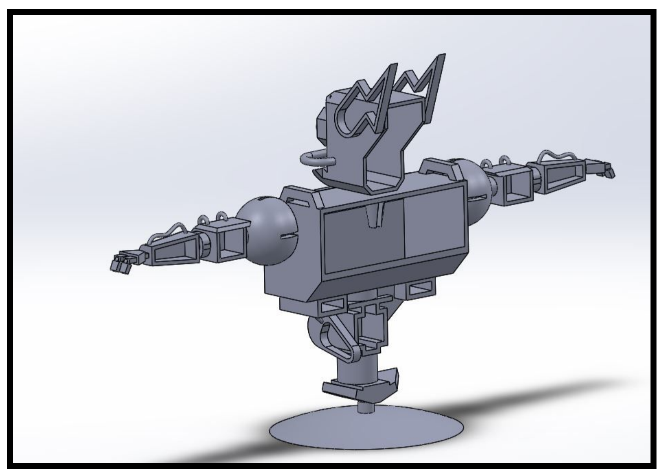
INTERLOCKING FEATURES

As previously mentioned, I intended for my Chappie model to be something that people could display on their desk, however, I also did not want it to be completely static as well. Therefore, utilizing ball-socket, and permanent squeeze joints, I was able to introduce a befitting range of motion into my design.

With the ball-socket joint, I was able to mimic the range of motion that people have with their arms. To accomplish this, I used a revolve-extrude feature to create a sphere on each side of Chappie's body, and offsetted the diameter of that sphere (in a new part file) by 0.01 inches to create the inside of the socket for Chappie's arm. This creates similar spherical geometry that would allow the ball to nest into the arm-socket. This interlocking feature is unique because, instead of functioning only one plane of motion (like with most secure connections), it can utilize a wide range of motion on multiple axis, therefore making it the perfect feature for Chappie's arms.

Likewise, with a permanent squeeze joint connection, I was able to securely connect the body and head of my replica, while also allowing a full 360 degrees of rotation. To accomplish this, I simply revolve-extruded the geometry for a squeeze connector, and added a tolerance of 0.01 inches between the base of the squeeze connector, and hole at the top of Chappie's body model. However, for the nubs that get squeezed together, I added an extra 0.01 inches to the diameter of the hole in Chappie's body, so the head could not be pulled out once it is clicked into place without excessive force. Figures 8 and 9 illustrate how each of the interlocking features connect.





Left = (figure 8), Right = (figure 9)

(figures 8 and 9 illustrate how the interlocking features connect)

DESIGN FOR MANUFACTURING CONSIDERATION

As previously mentioned, my project was inspired by the robot from the movie, Chappie, so I frequently found myself re-watching Chappie's movie scenes, and looking at Chappie's posters for inspiration throughout the design process. However, I should note that I explicitly decided early on that I did not want to simply re-model the movie version of Chappie because... that would be boring! I wanted to add my own creative spin on his original design so, while I did use his original model as inspiration, there were no features that I explicitly/exactly copied (However, I did try to mimic Chappie's base geometry so my iteration would resemble Chappie and not another robot) *(see appendix A1-A3 for inspiration examples)*.

On the other hand, because I decided not to copy any existing Chappie models, I had to completely estimate Chappie's dimensions and ratios. For instance, I observed that in the movie, Chappie's entire chest block was at least 4 times the length of his abdomen, so I kept that in mind and made my chest piece 2 inches, and the abdomen 0.5 inches. The same thought process was applied to all of the parts in my models.

While we were not technically asked to design our products in such a way that the printing process would have been quicker, engineers should always try to facilitate the manufacturing of their products. Once I planned out the basic dimensions and ratios of my CAD models, I then planned out what basic design choices and features I would use to facilitate the design and manufacturing process. In terms of expediting the design process, whenever I would add a feature to the CAD model, I would ask myself, "What tool in Solidworks would make designing this part the easiest?" For instance, when making the base of Chappie, I could lofted the base's geometry with multiple planes, or, instead, I sketched the cross section of the base on the right plane, and did a 360 degree revolve-extrude. Both give the same end result, but the revolve-extrude was more efficient (the approach I took). Overall, in terms of design, I would think about which feature could accomplish my goal swiftly, and accurately, and generally, I used revolved-extrudes for symmetrical and circular features, extrudes for basic and base geometry, and sweeps/chamfers/fillets for more organic shapes and when I wanted to add fancy details.

In terms of facilitating the actual manufacturing process, I decided to shell or cut-extrude all of my CAD models to reduce overall volume, so the SLS printer could use less material to print. By shelling my CAD parts, I not only was able to reduce the overall volume of my assembly to a mere 1.42 cubic inches, but in doing so decreased the print time for my part tenfold (*to test this I put my solid and hollow models into the CURA 3D printing software and examined the estimated print times).*

However, even with the most perfect ideas, there are bound to be potential problem areas during the manufacturing process. Before I began designing my CAD models, I tried to think through all of the potential areas where errors could arise in my print, and the main problem area that I predicted would be the intricate details of my design. With any given robot, their designs have many small details that make them unique, and while SLS 3D printers have a much smaller printing tolerance than most office/home 3D printers, they are still not perfect. Therefore, whenever I knew I would be adding a tiny detail to my design, I always made sure the feature was greater than or equal to 1 millimeter. Post print, I was extremely pleased with how my models turned out because I planned ahead for this problem.

<u>DESIGN FOR MANUFACTURING CONSIDERATION (CONT...)</u>

Likewise, another potential problem I addressed before designing was tolerancing. The CAD models are always the 'ideal' models of a part, but in reality, the printed part will always differ by sometimes the slightest bit. Therefore, it is essential to plan for parts being printed too large, or too small.

For the ball-socket joint, I needed a measurement that would ensure that the ball would securely nest in the socket, whilst allowing the socket to move freely. I decided that a ±0.02 inch gap between the ball and the inside of the socket was the perfect measurement, because it was small enough that it ensured that the ball-socket connection would be secure, but it was also large enough to guarantee that the socket has room to twist and turn freely on the ball. Therefore, I made the radius of the ball's sketch 0.22 inches, and the socket 0.24 inches. However, it is important to note that another feature that aided in the interlocking connection was the pattern extrude cut around the socket that allowed the socket to slightly expand when snapping onto the ball.

Similarly, for the squeeze connector socket, I decided on a ±0.01 inch tolerance for the gap between the socket and the base of the squeeze connector. I chose ±0.01 inches, because it gave enough room for the head to swivel, while ensuring a secure connection. So, I made the hole for the socket 0.20 inches, and the base of the squeeze connector 0.19 inches. However, it is important to note that I made the diameter of the nubs on the squeeze connector 0.22 inches to be large enough to where, once connected, it can not easily be removed.

Equally as important, throughout the design process I frequently found myself examining the assembly model to see how my parts would fit together. Using an assembly was extremely helpful because it allowed me to determine how my model would function when assembled. For instance, I used the collision detection to see how changes in the ball-socket joint's dimensions would affect the range of motion that Chappie's arms could move. Likewise, using the section view tool, I frequently cut the model of Chappie down the center to see exactly how large the gaps were between the interlocking features as well *(see appendix figure A4 for example)*. All in all, having an 'ideal' assembled CAD model of the parts was extremely helpful as it allowed me to visualize where my errors were, and what I needed to change so the printed parts would function as intended.

Thanks to my extensive planning, and many hours of practice using Solidworks, I had a clear idea of what I wanted Chappie to look like, and had a smooth modeling experience designing my idea. Therefore, there was not as much trial and error as I expected throughout the process, and when I did encounter smaller problems, I was able to resolve them by restarting a sketch or watching a how-to video on youtube. Not to mention, as I only had 1 iteration of my project, I did not have to it was a very straightforward process to reach my desired CAD model.

CHALLENGES FACED IN MANUFACTURING

Since we were able to use an SLS 3D printer, we were able to print our parts with more accuracy than other 3D printers are capable of. Therefore, the process was fairly straightforward and had little issues with the manufacturing aspect. The only issue came when I received the part in class, and had to use excessive force to get the head to connect with the body. However, upon further inspection of my CAD model, I realized that I had made a slight design error on the squeeze connector joint's geometry. I realized that I did not make the cut-extrude feature in the squeeze connector, tall enough so that the two nubs would squeeze together with less effort. While my model and its printed parts did end up interlocking in the end, in the future, to fix this design error I would increase the height of the cut extrude so the nubs would squeeze together without complication.

Additionally, while my parts fit together as intended, and I thought my overall process went fairly well, there are some areas where I could have improved. As previously mentioned, after looking at the percent difference data, I realized that the 3D printer had a higher percent difference on the smaller features. Due to this fact, I realized that I should have put more time focusing on the overall design (larger features), rather than the smaller and more intricate ones. I incorporated smaller details (such as wires and buttons) into my design to make my model as robot-like as possible. Therefore, the addition of the buttons and wires in the Chappie model added unnecessary print time, that I could have allocated somewhere else (such as designing a better working interlocking feature perhaps). On the other hand, this was my first ever 3D printed part and thanks to this project I now have this knowledge that I can apply to future prints.

In the same way, I also learned that the difference between the "ideal" dimensions of the CAD model and the actual 3D printed part were greater than I expected. For instance, I expected that the percent difference between the CAD parts and the actual parts would be very small but the average percent difference among all the features I dimensioned was 8.24%, which is much larger than I expected. I now realize how that even the top of the line printers are still not perfect, and I can now apply this knowledge to future parts and get better results.

All in all, through this project I obtained many valuable pieces of knowledge when it comes to designing and manufacturing a product, and can apply such lessons to my future designs.

TOLERANCE ANALYSIS (PARAGRAPH FORM)

As shown in the Google spreadsheet (see appendix figure A5 for example), the average percent difference among all of the measurements was 8.24% between the real dimension in CAD and the actual dimension measured with calipers once printed.

OTHER IMPORTANT OBSERVATIONS FROM THE TOLERANCE DATA

An important observation I saw while looking at the data, was that the majority of the actual-caliper-measured parts had larger dimensions than what was dimensioned in Solidworks. I found this particularly interesting because I could potentially draw the conclusion that the SLS printers would rather print slightly larger dimensions than what was originally planned rather than have parts be slightly smaller than the ones dimensioned in CAD. This observation could be useful for printing future parts with the SLS printer if enough people's data matches my own. If the printer consistently prints larger than what was dimensioned then it might be useful to use slightly smaller dimensions in CAD.

Likewise, I noticed a trend in the percent differences between the printed parts and CAD parts. With the larger features, such as the length of Chappie's chest piece, the percent differences were smaller than the percent differences on smaller features such as the width of the squeeze connector's base. I assume that this was because it is harder for 3D printers (even the higher end ones) to accurately print intricate parts with tiny details (the squeeze connector), versus much larger features that resemble a large solid mass (such as the chest block). This is important because when designing future parts with the SLS printer, I know have the knowledge that I should try to incorporate less intricate details in my models and focus on the overall shape/build of the models.

CONCLUSION

When this project was initially assigned, I was excited because I always wanted to 3D print an item. Therefore, the most stressful part in the beginning, was choosing what to print (from my list of around 20 ideas that is…). In the end, I asked myself important questions such as, "Is this idea complex enough to have a full report written on it? Is this idea within my current skill level? Can this be something whose parts fit in a 3x3x3 cube?" And etc. At last, I decided on modeling Chappie. Because Chappie was always my favorite childhood-humanoid robot, I already had many iterations of my own potential designs floating around in my head. Once I drew out the design I chose, I planned out all my dimensions, ratios, tolerances, and the design process was smooth because of this.

In its initial state, I realized that my Chappie model looked extremely bland. I simply had the base geometry of a robot and it was more "boring" than I wanted it to be. So, with the addition of intricate details such as wires, buttons, chamfers, and text, I was able to make my robot look very interesting.

When we finally got our parts back, I was extremely happy with how my 3D printed parts turned out. As previously mentioned, my parts required more force than I expected to interlock, but once they were connected, they exhibited the full range of motion I intended them to.

CONCLUSION (CONT…)

The head could rotate a full 360 degrees, the arms could move freely at the shoulders, and the model itself had no printing hiccups, but most importantly… it looked like an actual robot!

In the end, I was pleased with how my entire design and manufacturing process went, because my designs turned out well, my parts fit together, and I felt as if I was more proficient in Solidworks than I was before modeling Chappie. However, this project's success was no accident. My process was only as stress-free as it was, thanks to the ample time I spent observing, planning, and tolerancing my product beforehand.

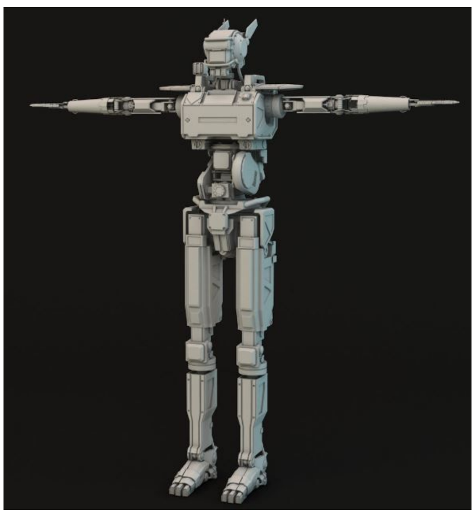
If I were to take one lesson away from this project, it would be that having a clear end goal in mind (after thorough planning) is essential for the manufacturing and design process. If I did not have a clear idea of what I wanted my Chappie model to look like, I would have been designing, and re-designing certain parts until I was pleased, which is not time or resource efficient. The overall design process would have been exponentially more difficult, but because I took the time to plan, I was able to facilitate many aspects of this project.

After completing this project, I now have more skills that I can apply to projects outside of this class. I have a much better understanding of Solidworks as a 3D AutoCAD software, I have knowledge about 3D printing that I did not have before, but most importantly... I have a perfectly functioning Chappie replica that is a symbol for how far planning, organization, and hard-work can take you when designing a product.

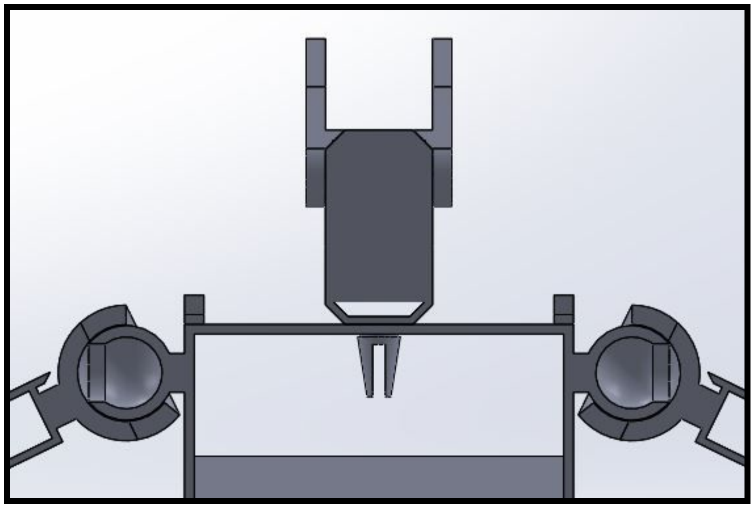
APPENDIX

(Figure A1) - Professional Chappie 3D model (Left)
(Figure A2) - Article picture of Chappie (Right)
(Figure A3) - Screenshot from actual Chappie movie (Bottom)

https://www.sonypictures.com/movies/chappie
https://www.cgtrader.com/3d-models/character/sci-fi/chappie
https://ew.com/article/2015/03/06/how-build-cooler-robot/

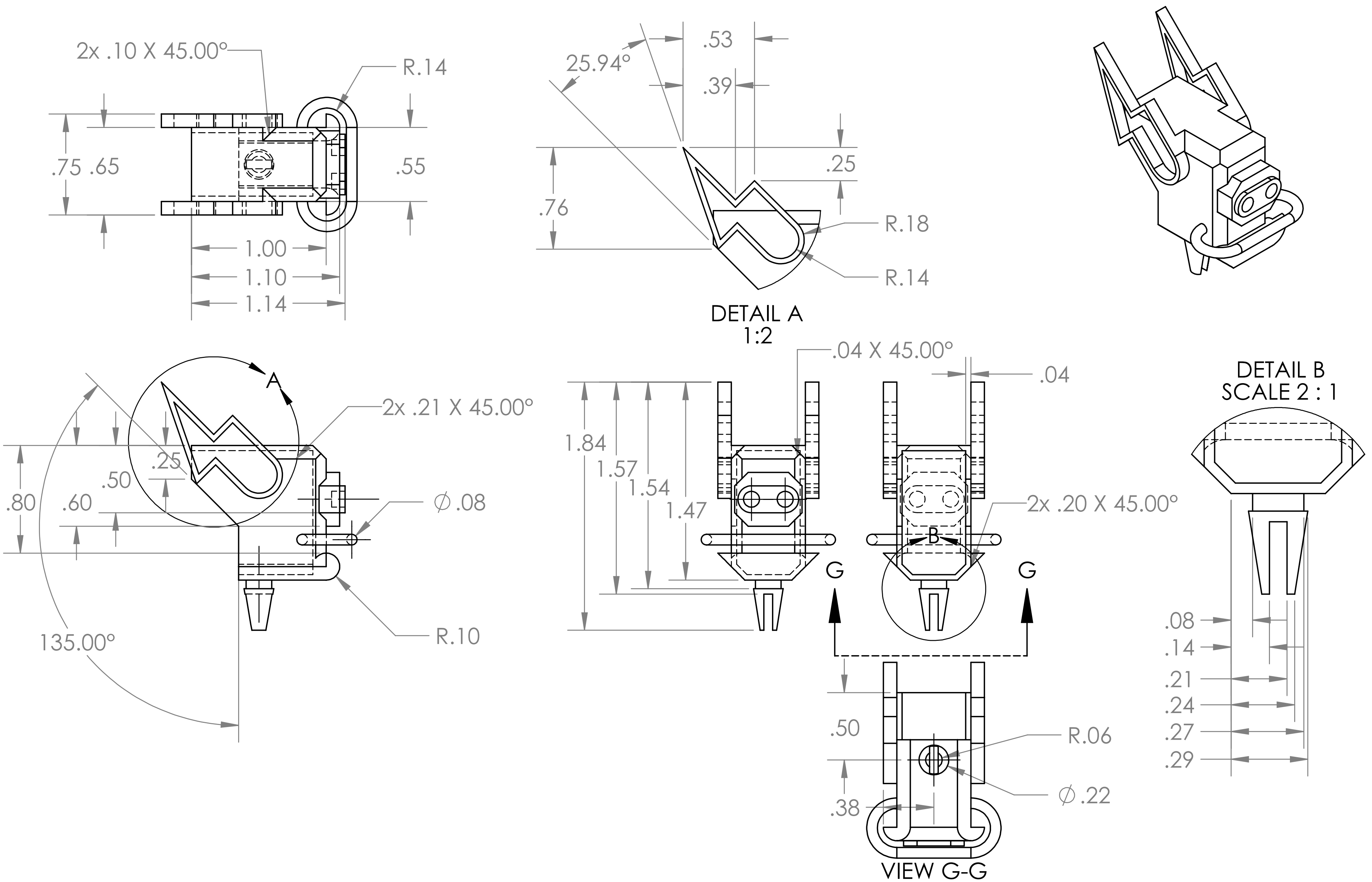


(Figure A4) - Interlocking parts cross-section view



(Figure A5) - Excel spreadsheet with % difference data

2	1.986	0.702459		0.1	0.1136	12.73408		0.702459	< AVERAGE % DIFFERENCE
0.42	0.427	1.652893		0.04	0.0295	30.21583		1.652893	
0.4	0.4145	3.560467		0.4	0.411	2.7127		3.560467	
2	2.0045	0.224747		0.1	0.129	25.32751		0.224747	
0.6	0.6075	1.242236		0.6	0.6115	1.898473		1.242236	
1	1.0005	0.049988		0.04	0.052	26.08696		0.049988	
0.05	0.0595	17.3516		0.17	0.1875	9.79021		17.3516	
0.1	0.102	1.980198		0.1	0.11	9.52381		1.980198	
1.05	1	4.878049		0.1	0.1135	12.64637		4.878049	
0.49	0.481	1.853759		0.04	0.043	7.228916		1.853759	
0.49	0.483	1.438849		0.04	0.0475	17.14286		1.438849	
	% DIFFERENCE FOR BODY							1.30719	
								0.343446	
0.19	0.1925	1.30719			% DIFFERENCE FOR L-ARM			40.34335	
0.35	0.3488	0.343446						0.349389	
0.07	0.0465	40.34335		0.1	0.1111	10.51634		1.801802	
1	1.0035	0.349389		0.04	0.0315	23.77622		1.783944	
0.55	0.56	1.801802		0.4	0.398	0.501253		2.647413	
0.5	0.509	1.783944		0.1	0.1051	4.973184		12.73408	
0.41	0.421	2.647413		0.6	0.6201	3.294812		30.21583	
				0.04	0.0401	0.249688		2.7127	
				0.17	0.1659	2.441203		25.32751	
	% DIFFERENCE FOR HEAD			0.1	0.109	8.61244		1.898473	
				0.1	0.1102	9.705043		26.08696	
				0.04	0.0411	2.7127		9.79021	
				0.04	0.0509	23.9824		9.52381	
								12.64637	
								7.228916	
					% DIFFERENCE FOR R-ARM			17.14286	
								10.51634	
								23.77622	
								0.501253	
								4.973184	
								3.294812	
								0.249688	
								2.441203	
								8.61244	
								9.705043	
								2.7127	
								23.9824	
							AVG =	***8.239619***	

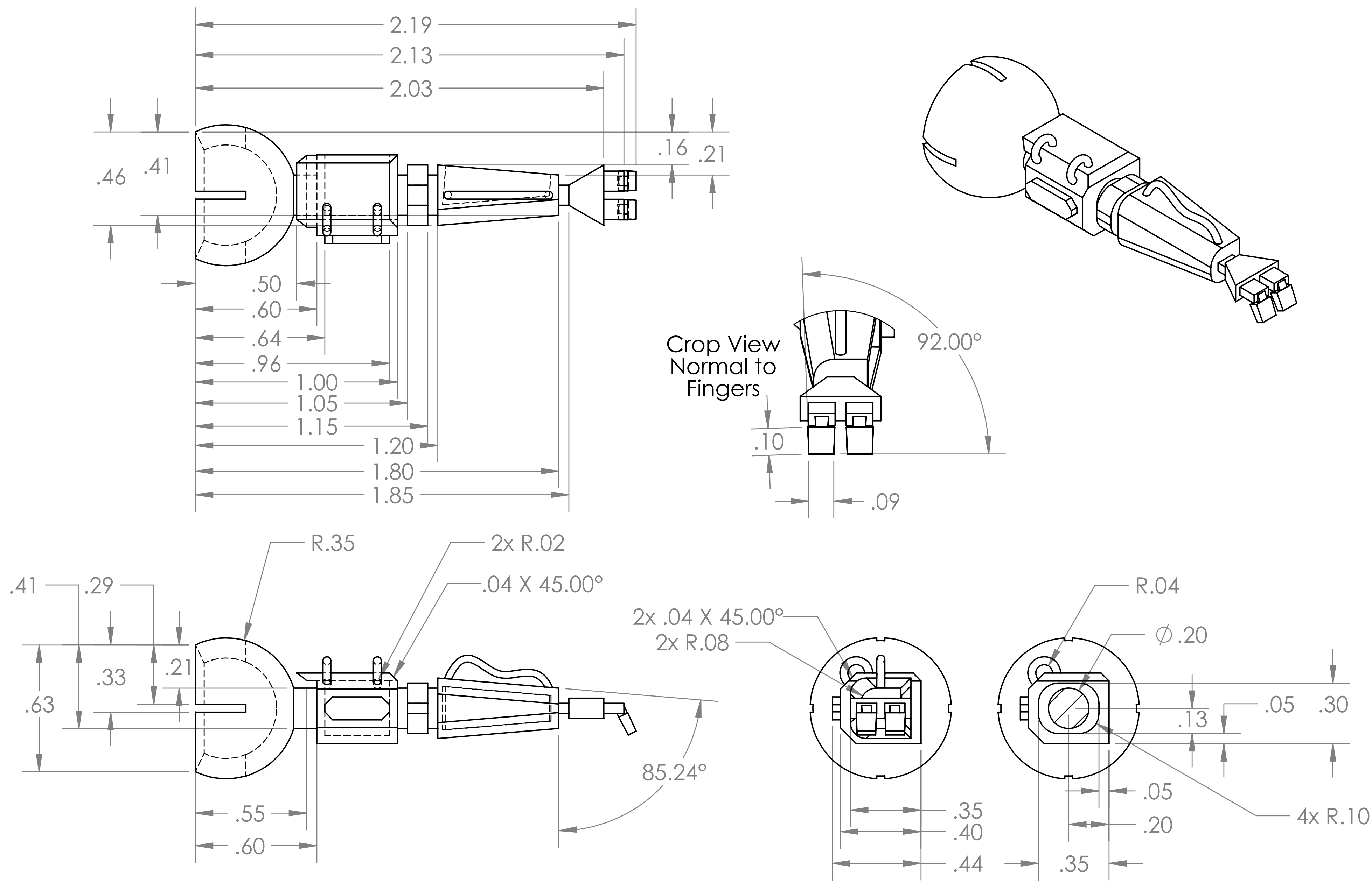


Georgia Institute of Technology

TITLE	DATE	NAME
Head of Chappie	**11/15/2019**	Connor Rosenberg

COURSE	SEMESTER	SECTION	LAB	ACTIVITY	DIMENSIONS ARE IN INCHES ANGLES ARE IN DEGREES	SIZE
ME 1770	**FALL 2019**	**A**			SCALE 1:1 SHEET 1 OF 1	**A**

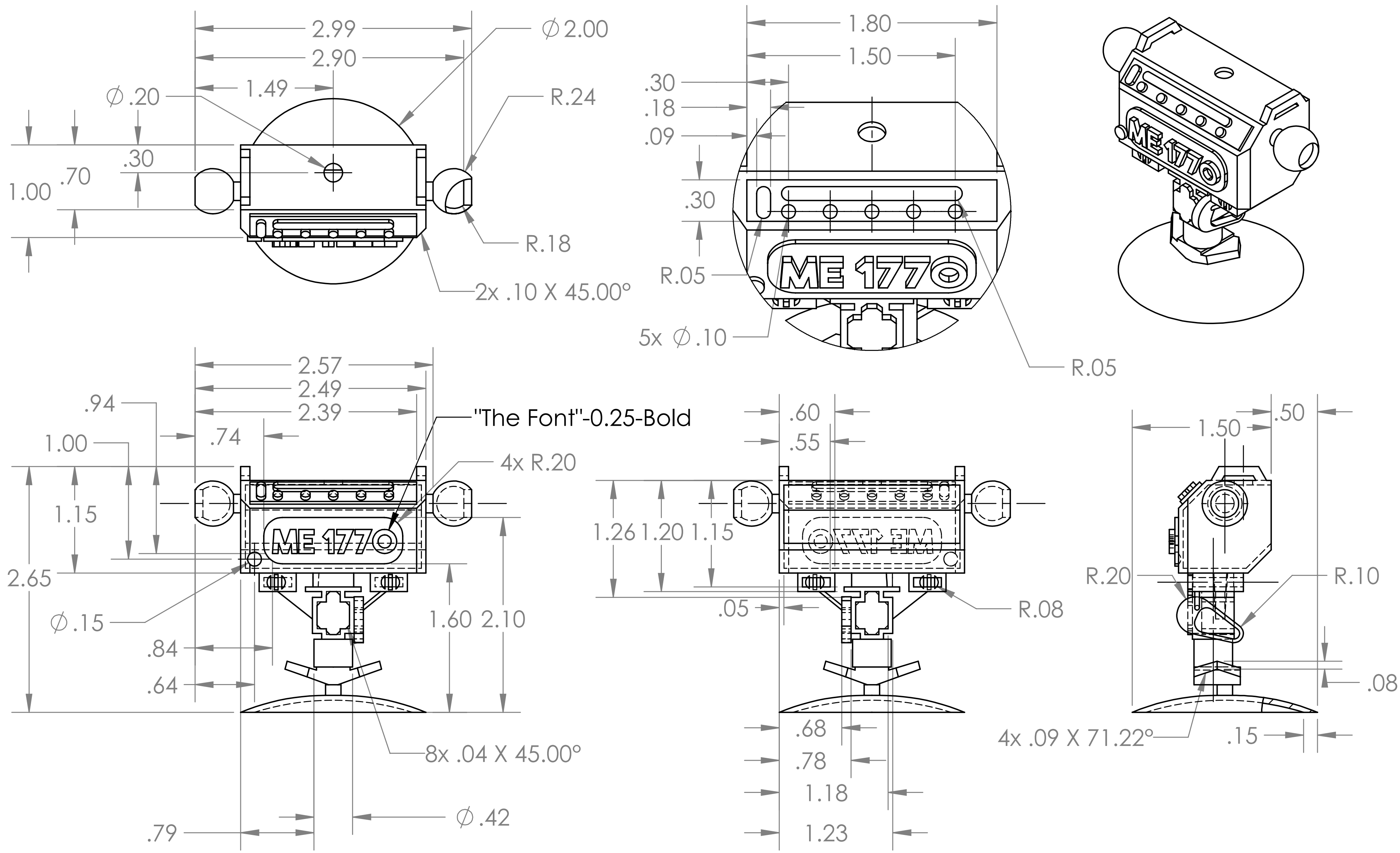
5 4 3 2 1



Georgia Institute of Technology

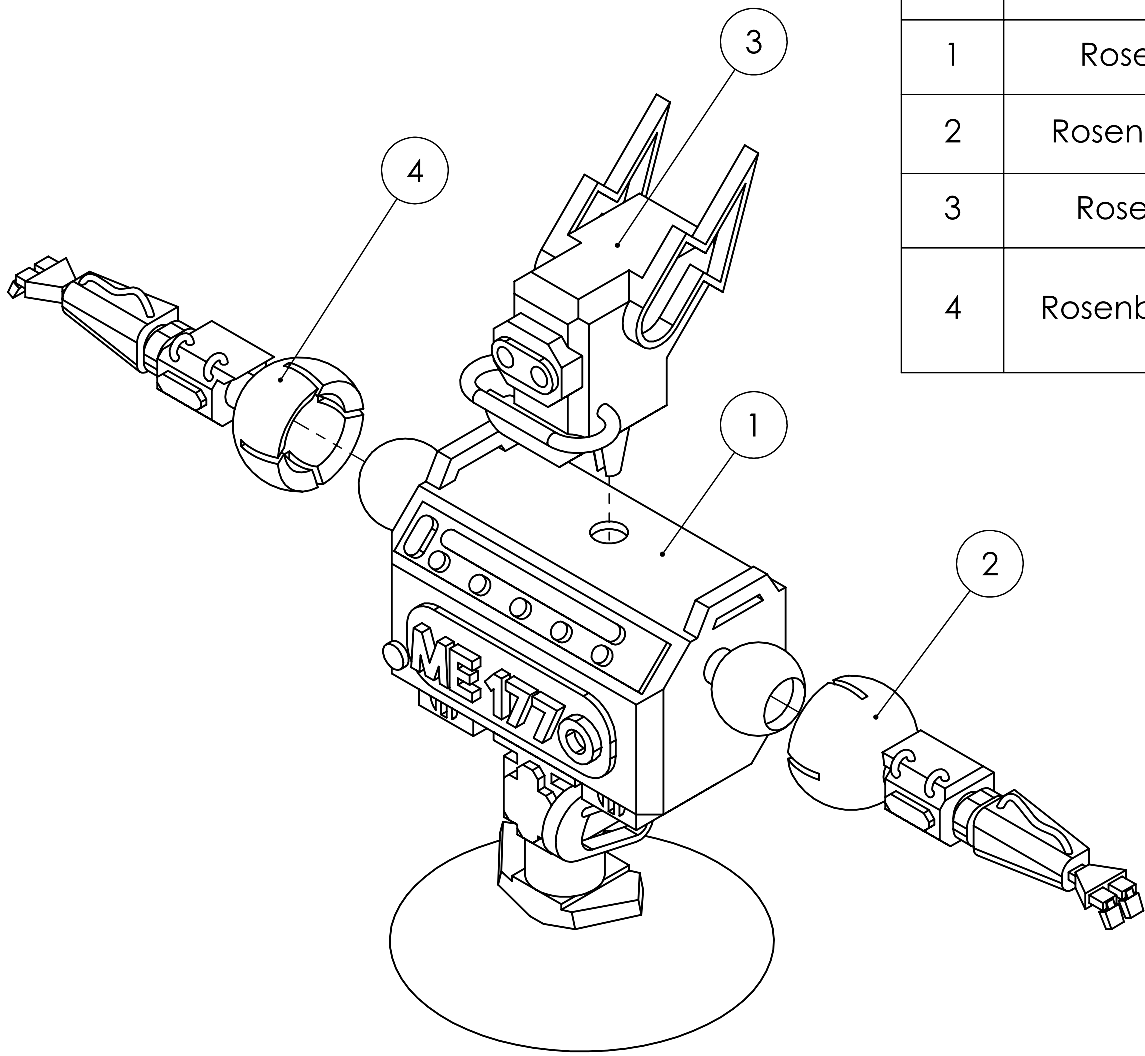
TITLE		DATE	NAME
L-Arm of Chappie		**11/05/2019**	Connor Rosenberg
COURSE	SEMESTER	SECTION	LAB	ACTIVITY	DIMENSIONS ARE IN INCHES ANGLES ARE IN DEGREES	SIZE
ME 1770	**FALL 2019**	**A**			SCALE 3:2 SHEET 1 OF 1	**A**

5 4 3 2 1



Georgia Institute of Technology	TITLE **Body of Chappie**		DATE **11/04/2019**	NAME Connor Rosenberg		
	COURSE **ME 1770**	SEMESTER **FALL 2019**	SECTION **A**	LAB	ACTIVITY	DIMENSIONS ARE IN INCHES ANGLES ARE IN DEGREES; SCALE 2:3; SHEET 1 OF 1; SIZE **A**

5 4 3 2 1



ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	Rosenberg_Connor_Body	Body of Chappie	1
2	Rosenberg_Connor_Left_Arm	L-Arm of Chappie	1
3	Rosenberg_Connor_Head	Head of Chappie	1
4	Rosenberg_Connor_Right_Arm	R-Arm of Chappie	1

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TITLE		DATE	NAME		
Chappie Exploded Assembly		11/02/2019	Connor Rosenberg		
COURSE	SEMESTER	SECTION	LAB	ACTIVITY	SIZE
ME 1770	FALL 2019	A		DIMENSIONS ARE IN INCHES ANGLES ARE IN DEGREES SCALE 1:2 SHEET 1 OF 1	A

5 4 3 2 1