Washer-Dryer Model For Lunar Laundry

Team Daedalus

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Background

On the ISS, there is no laundering system for clothes. Therefore, astronauts wear clothes until they are visibly dirty or unwearable then discard the clothes. This method is sufficient for short-term ISS missions but is problematic for long-duration missions on the lunar surface. This ultimately makes a compact, water conservative, and energy efficient washer-dryer a necessity for future missions on the Moon and beyond.

Objective

Design a compact, lightweight, water conservative and power-efficient washer-dryer system that minimizes excess heat and water leakage.

Front vs. Top Loader

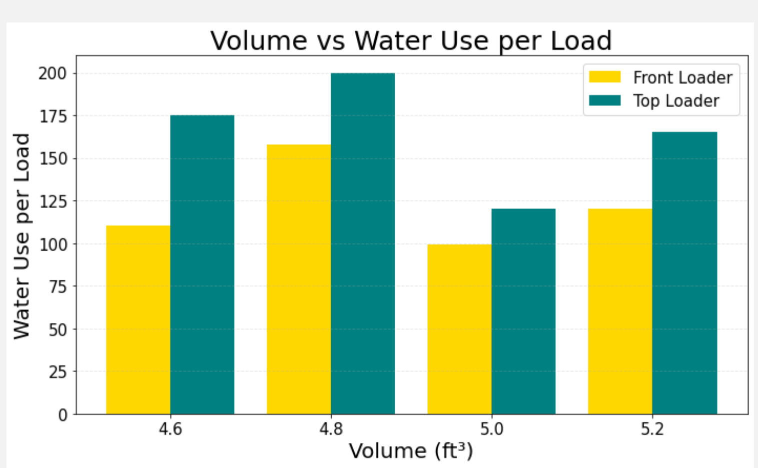
Standard Front Loader

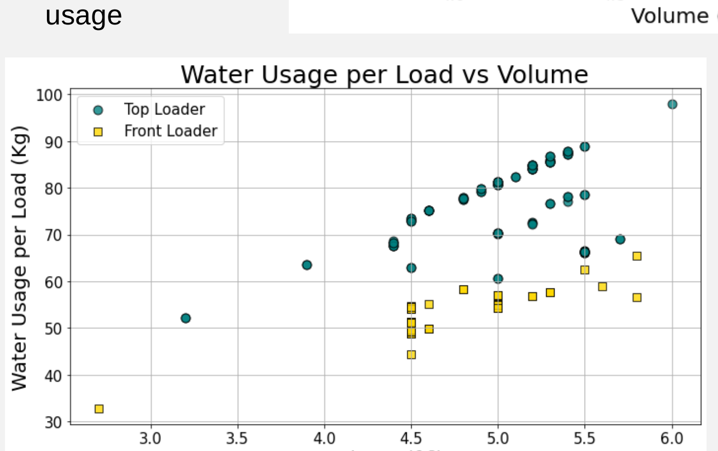
vs

Standard Top Loader

+ Front Loaders use 45% less energy than Top Loaders
+ Front Loading machines 50% less water than Top Loaders
+ Front Loaders are more compact on average

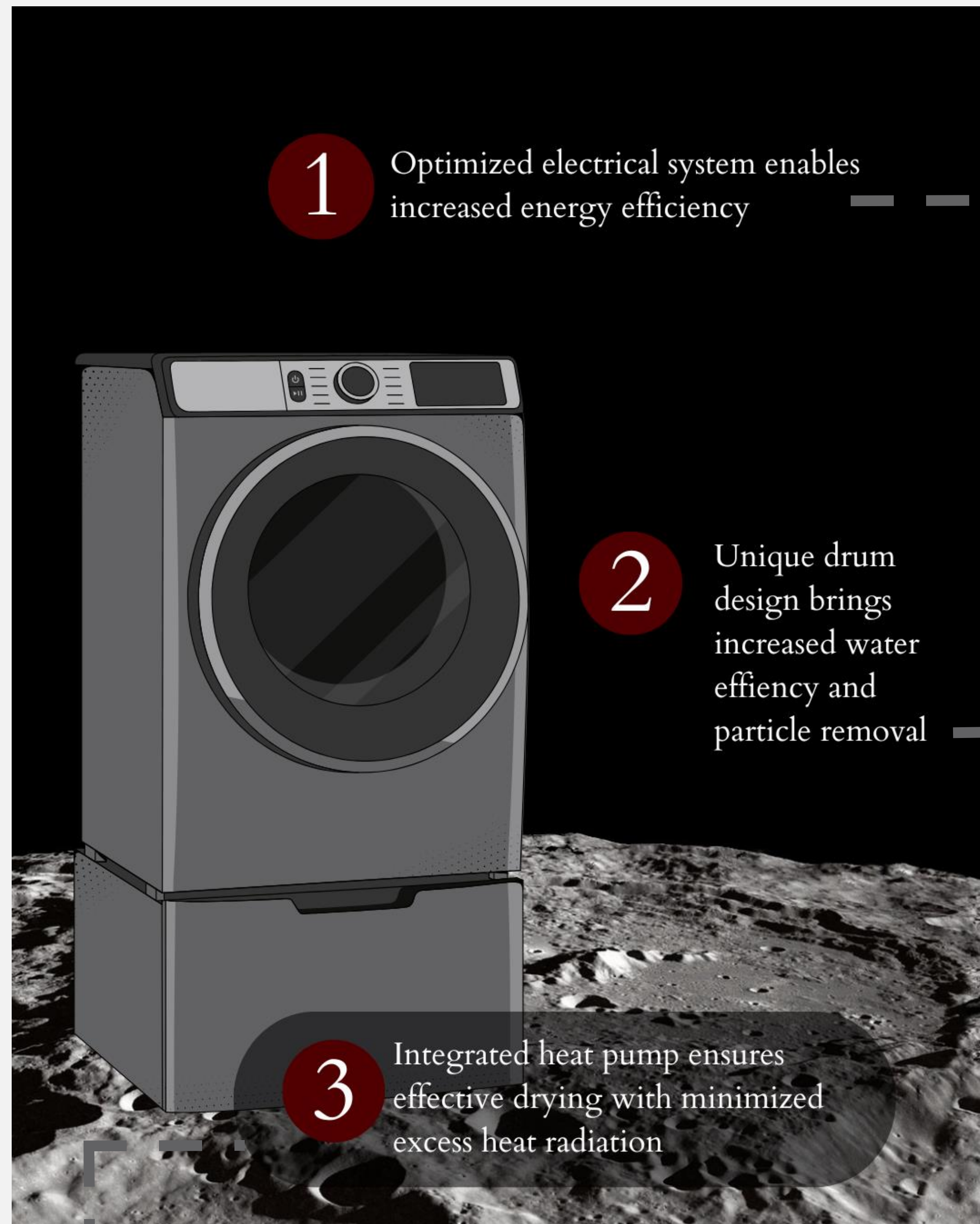
- Front Loaders with volumes between 4.6 ft³ - 5.2 ft³ have a lower energy usage overall
- Front loaders with a compact size will require a higher energy usage





- Front Loaders typically have a lower water usage than top loaders
- Lower water usage is critical in a lunar system due to lack of on-site water sources and high transport costs

Average Annual Water Recovery Cost ($)		
	Front Loader	Top Loader
2% Annual Water Loss	471,879.32	686,452.57
5% Annual Water Loss	1,179,698.29	1,716,131.42
10% Annual Water Loss	2,359,396.59	3,432,262.84



Drying System

Ventless Dryer System Comparison

Heat Pump Dryer

- Utilizes a closed-loop heat exchange for superior energy efficiency
- Operates effectively at lower drying temperatures, gentler on fabrics
- Requires a higher upfront investment due to advanced components
- Typically incurs longer cycle times compared to conventional dryers

Condensation Dryer

- Delivers quicker drying cycles by expelling moisture into a condensate tank
- Lower initial price for manufacturing
- Releases residual heat into the surrounding space
- Consumes more electricity per cycle than heat pump models

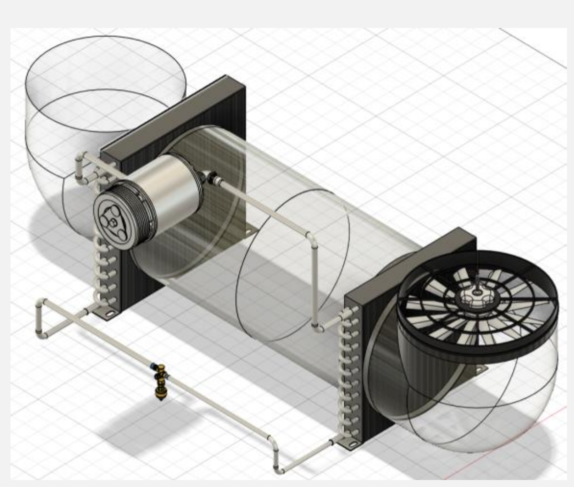
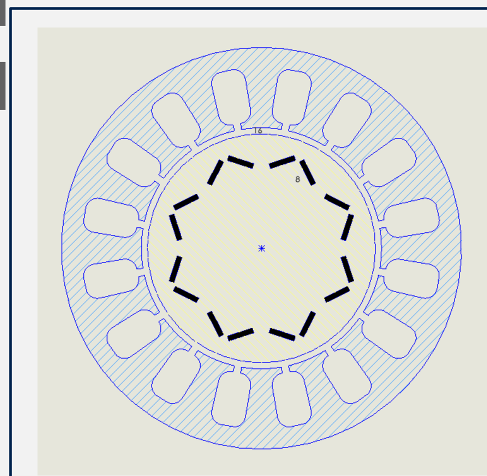


Diagram of Refrigerant Cycle

- The heat pump produces heat through the refrigerant cycle and conduction over large surface areas.
- The refrigerant cycle generates heat through the relationship described in the Ideal Gas Law ($PV = nRT$) where an increase of pressure, through the compressor, is directly related to an increase in temperature of the refrigerant.
- The hot refrigerant is then used to continuously heat the air without requiring a vent.

- Utilizing a change in pressure to control temperature allows for the heat pump to operate and dry the clothes at a lower temperature.
- This mitigates the danger of using high heat in heavily controlled environments such as a lunar base.

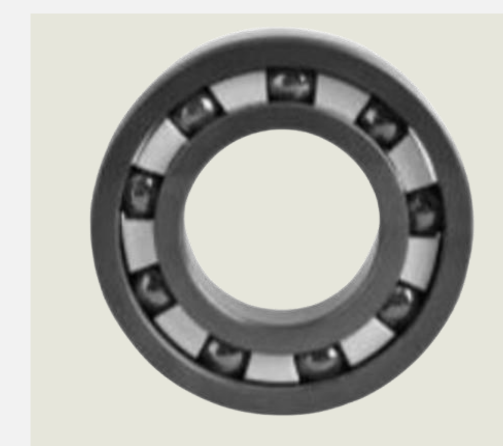
Electrical System



Cross Section of Selected Motor

- To achieve the required RPM for the system along with meeting performance specifications, a twenty-four-slot permanent magnet synchronous motor was selected.
- This motor operates at 1600 RPM and utilizes a variable frequency drive to convert the standard AC power of 60 Hz to 53 Hz.
- The provided diagram of the motor serves as a dimension reference for the development of the motor torque calculations, providing a visualization of the expansiveness of variables influencing the generated torque.

- As an additional aspect of increasing energy efficiency, a hybrid ceramic bearing was selected over the conventional stainless-steel bearings commonly found in terrestrial washing machines.
- The hybrid ceramic bearing features a stainless-steel shaft -- offering superior corrosion resistance (85-95%) -- and ceramic rollers that reduce friction by 27% whilst operating without traditional lubricant. This combination enables it to be well-suited for long-term space expeditions.



Hybrid Ceramic Bearing

- Python code performing calculations analyzing the torque produced by a concentrated winding PMSM was utilized to make the choice of selecting aluminum over copper wiring.

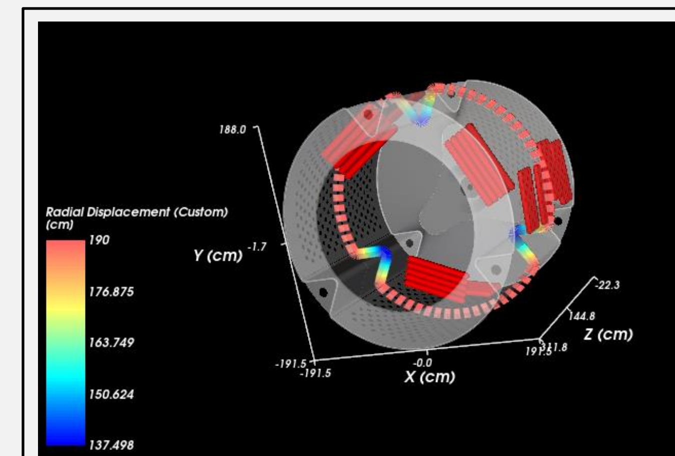
Drum

Analysis of Drum Material			
	Steel	Carbon Fiber Polymer	Titanium Alloy
Lightweight (25%)	1	7	4
Corrosion Resistance (20%)	8	5	8
Strength (20%)	8	8	9
Heat Properties (20%)	8	2	7
Affordability (5%)	7	3	2
Total:	5.1	5.1	5.9

- Potential materials for the inner drum were determined based on their use in commercial machines and NASA systems.
- The top three candidate from a materials trade-study are shown in the table.
- Minimizing mass was the most crucial category due to the high cost of lunar transport.
- Resistance to water corrosion and textile abrasion (strength) along with heat retention capabilities were considered due to their practical importance in all washer-dryer systems.
- Titanium alloy was determined to be the most suitable material for the model as it has the properties of steel, commonly used material in terrestrial washers, with half the mass density.

- Rotations per Minute (RPM) of the drum and gravity determine how high clothes rise in the drum before falling.
- While a lower gravity $(\frac{1}{6}g)$ on the Moon would decrease the RPM required, increased capillary action makes water more attracted to itself on the Moon, increasing the RPM required to "spin" the water out of the clothes.

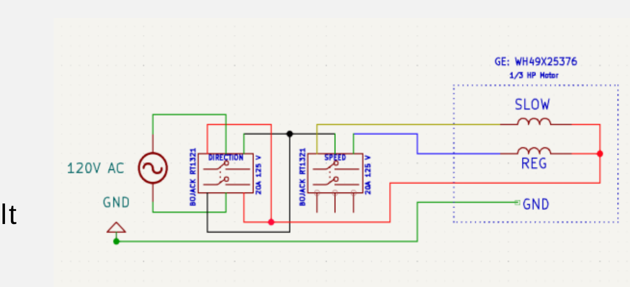
Results



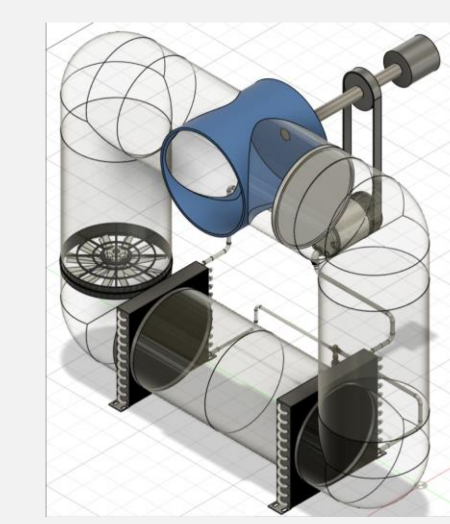
Simulations were made with PET polyester fiber particles to analyze clothing distribution, tumbling efficiency, and energy usage at different RPMs.
The radial displacement property shows the tumbling efficiency of different values of RPMs.
Higher contact with the drum is represented by the color red.

- Inner drum dimensions: 38 x 33 cm with a radius of 19 cm.
- The dimensions produce a volume of 0.037 cubic meters which can contain 4.5 kg of clothing at ¾ capacity which was clothing-to-volume ratios confirmed through analyzing terrestrial radius-to-depth ratios.
- A 1600 RPM will be used to spin the clothes during the drying cycle. A lower RPM will be used during washing and spin cycles.

- For the development of a physical prototype to demonstrate the properties highlighted throughout this research a ½ HP motor was taken from a terrestrial washer and wired to utilize the four built in speeds.
- By using dual pole dual throw switches, the motor can be alternated between a high and low RPM in either a CW or CCW rotation.



- The heat pump was designed to optimize efficiency and reduce weight.
- It features a majority aluminum build for its durability and light weight.
- Since the criteria asks for lower temperatures, we were able to scale down the compressor taking its mass from 15-20 kg to a mere 8kg for almost a 50% reduction.
- The ducts, pipes, and heat exchangers are also aluminum for the low weight and temperate durability.



Future Work

- Create a complete wiring diagram and printed circuit board (PCB) for the entire system.
- Further study into vibration reducing technology such as frequency-matching mass dampers and automated counterweights is required.
- Further research into specific sealants for use within the heat pump system.

References and Acknowledgements

Acknowledgements

We would like to thank our NASA mentors Mr. Micheal Ewert and Andrew Arends for their guidance and support during the development of this project, and Homero Castenada and Ulises Martin Diaz for their lab space.

References

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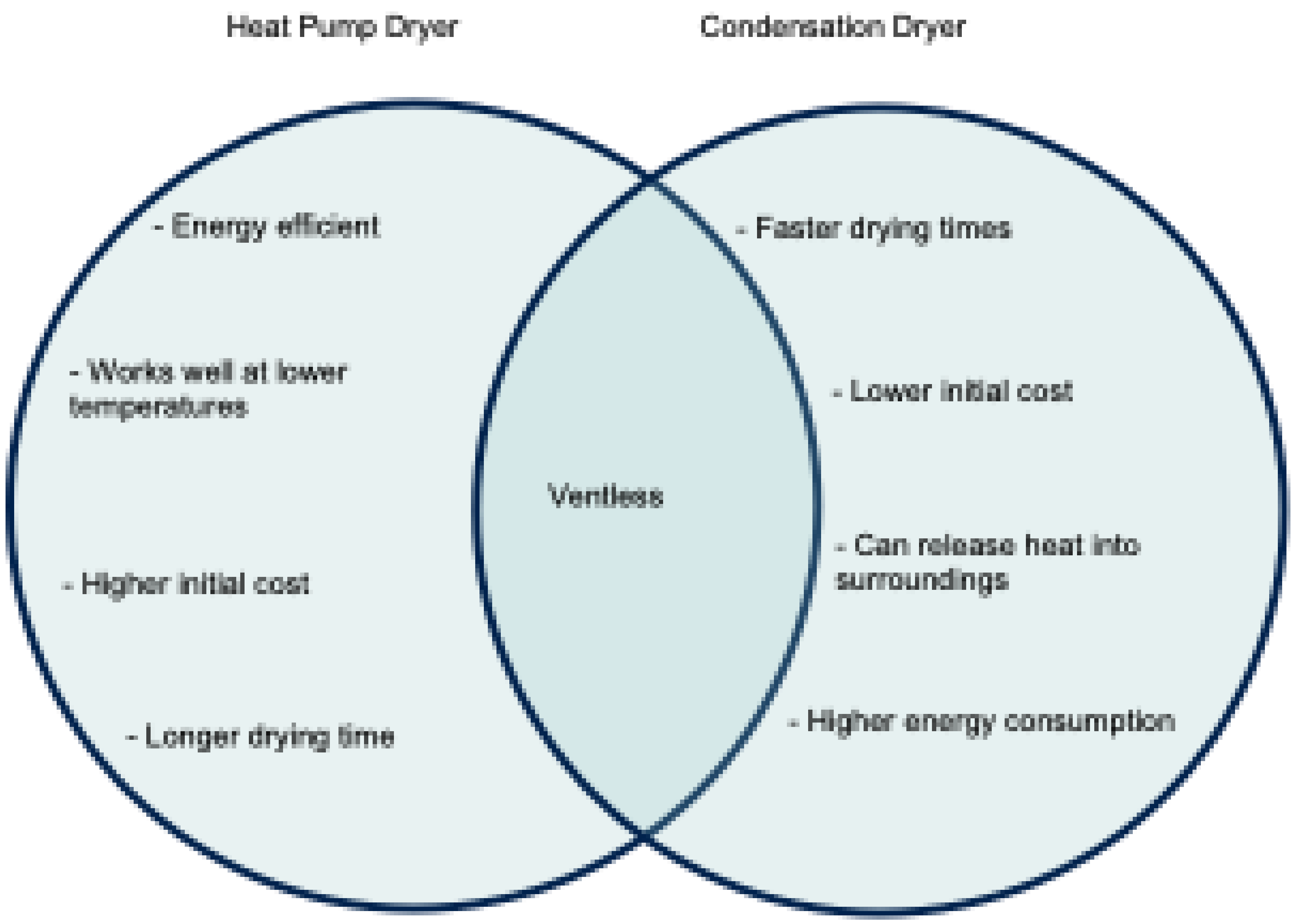
Engineering



The rotation of the inner drum causes the clothes to rise and fall, tumbling them during both the washing and drying processes. The RPM of the drum determines how high the clothes rise before falling. This changes during different cycles - for example, the clothes should rise almost to the top and then fall for the wash cycle, but they should not fall at all during the spin cycle. Gravity is what pulls the clothes down, and since gravity on the moon is ⅙ of gravity on Earth, a lower RPM is needed to raise the clothes properly. However, due to an increased capillary action, water is more attracted to itself under lunar conditions. Which makes the wetting and dewatering process much harder.

This will require us to use a of around 1600 RPM during the dewatering process which is the maximum RPM used in commercial washer dryers. There is no point in increasing the RPM because the RMC percentage does significantly changes. RPMs will be lower during spin and wash cycles.

28% greater energy efficiency compared to standard dryers

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- A RPM of 1600 will be used which is the maximum in commercial dryer machines. Further increases show no significant improvement in the drying process.

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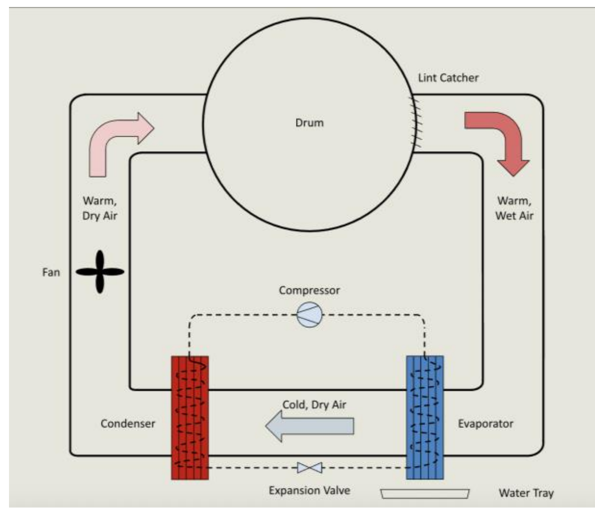
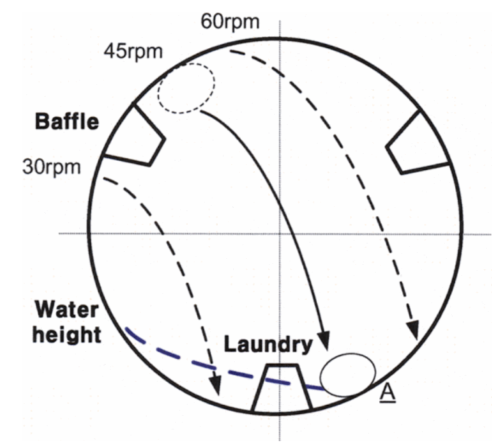
Typical terrestrial drums are made from steel, but to optimize the inner drum for our purposes, we examined a number of different materials. We looked at commercial washer/dryer drum materials, as well as unique materials that we thought would fit our purposes, and common NASA used materials. The top three materials were steel, Carbon-Fiber Reinforced Polymer, and Commercial Titanium Alloy. We stressed the importance of minimizing mass because this is directly referenced in our mission directives, and also considered resistance to water corrosion and textile abrasion, tensile strength, and properties important to the drying cycle including heat retention and heat radiation. We ranked each material from 1-10 and multiplied by the percent factor of each category, adding the score of each material. Titanium alloy is the most all-around efficient material, having the properties of steel with half the mass density. Material affordability was a small factor compared to the money saved on mass, power output, and durability of the material.

- Potential materials for the inner drum were determined based on their use in commercial machines and NASA systems.
- A trade-study was conducted to determine the material for the inner drum. The top three candidates are shown in the table.
- Minimizing mass was the highest weighted category due to high lunar transport cost.
- Resistance to water corrosion, textile abrasion and heat retention and radiation were also considered due to their practical importance in any washer-dryer system
- Titanium-Alloy was determined to be the most efficient material, having the properties of steel with half the mass density

- The drum design began with selecting a material suitable for the conditions the inner drum will function under. Steel, the conventional material of terrestrial inner drums. was compared with carbon fiber polymer and titanium alloy through their resistance to water corrosion and textile abrasion, mass, tensile strength, and heat retention and radiation. Comparison of our data led to selecting titanium alloy as our suitable material for space use. The static outer drum will consist of plastic material to counteract the vibrations and heat excess of the inner drum.
- As a design requirement was ensuring the drum holds 4.5 kg of clothing making up ¾ the drum volume, inner drum dimensions were set at a 19 cm radius and 33.03 cm depth to make up a drum volume of 0.037 cubic meters through analyzing terrestrial radius-to-depth ratios and clothing-to-volume ratios



Analysis of Drum Material					
	Steel	Plastic	Aluminum	Carbon Fiber Polymer	Titanium Alloy
Lightweight (25%)	**1** (0.25) ❌	**9** (2.25)	**6** (1.5)	**7** (1.75)	**4** (1) ✅
Corrosion Resistance (20%)	**8** (1.6) ✅	**2** (0.4)	**3** (0.6)	**5** (1.0) ❌	**8** (1.6) ✅
Strength (20%)	**8** (1.6) ✅	**2** (0.4)	**4** (0.8)	**8** (1.8)	**9** (1.8) ✅
Heat Properties (20%)	**8** (1.6) ✅	**1** (0.2)	**3** (0.6)	**2** (0.4) ❌	**7** (1.4) ✅
Affordability (5%)	**7** (0.05) ✅	**9** (0.45)	**8** (0.4)	**3** (0.15)	**2** (0.1) ❌
Total:	**5.1** ❌	**3.7** ❌	**3.9** ❌	**5.1** ❌	**5.9** ✅



- Make all graphs bigger and ask Emily to adject code so the labels are bigger
- Make the venn diagram text
- Delete the rpm image
- Include 2 more columns for trade study
- Delete the code but mention its use
- Do future work and collect references

Analysis of Drum Material			
	Steel	Carbon Fiber Polymer	Titanium Alloy
Lightweight (25%)	**1**	**7**	**4**
Corrosion Resistance (20%)	**8**	**5**	**8**
Strength (20%)	**8**	**8**	**9**
Heat Properties (20%)	**8**	**2**	**7**
Affordability (5%)	**7**	**3**	**2**
Total:	**5.1**	**5.1**	**5.9**

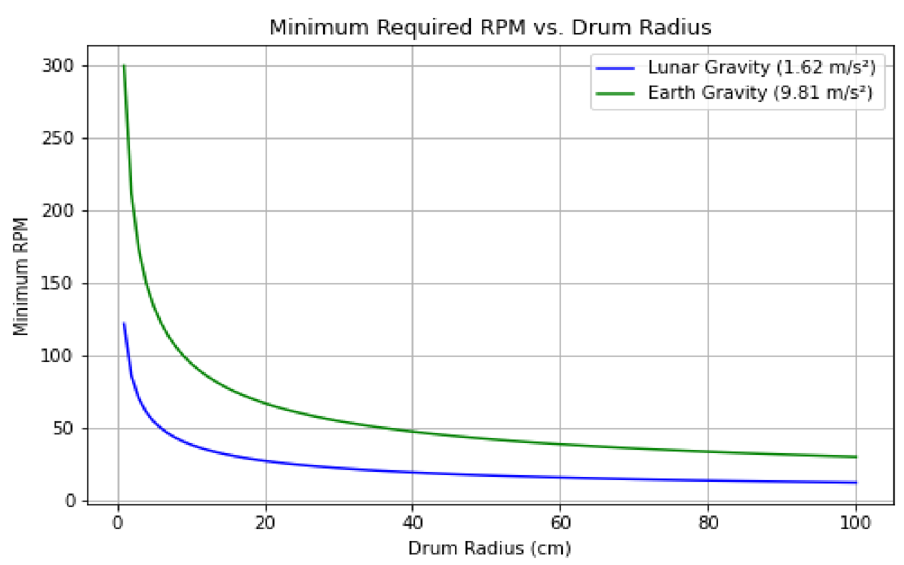


Figure #. Minimum RPM v. Drum Radius

Camden
- Yap about the electrical system
- What conclusion was drawn from each image

Emily
- Change graphs to have a larger axis and correct colors

Sara
- Yap about the drum system
- What conclusion was drawn from each image

Samih
- Confirm heat pump diagram
- Expand the text already present in that section
- Perhaps yap about heat pump

Anoushka
- Go through above checklist

Aayan
- Look over wording. All text should explain what conclusion was drawn from the images or elain a design choice. Make sure everything sounds professional
- Take what Camden/Sara/Samih yapped about each subsystem and make it into bullets for each section