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Development of a Mechanical Trash Compactor (Mpactor) for Exploration Missions

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NASA is developing a mechanical trash compactor (Mpactor), a pneumatically driven trash compaction system, for human space exploration missions to manage trash items such as food packaging, sanitary wipes, clothing, tape, and other types of waste. The compaction system that is under development does not involve heating, water removal, or water recovery which eliminates the need for complex ancillary hardware required to manage gaseous effluents, as well as condense the water vapor. A system called the Crew Exploration Vehicle (CEV) Compactor, intended for use in the micro-gravity environment, was developed at NASA Ames Research Center for the Constellation Program 2007. This CEV Compactor is being further developed and renamed the Mpactor (short for mechanical trash compactor). The Mpactor is being used to gather engineering data that will allow engineers and planners to scale a future design for different mission scenarios and to evaluate different bag materials and designs that help retain compaction.

Acronyms and Nomenclature

ARC = Ames Research Center
CaLV = Cargo Launch Vehicle
cm = centimeter
CEV = Crew Exploration Vehicle
CLV = Crew Launch Vehicle
CTB = Cargo Transfer Bag
CTBE = Cargo Transfer Bag Equivalent
EDS = Earth Departure Stage
ESM = Equivalent System Mass
in = inch
kg = kilogram
kN = kilonewtons
kPa = kilopascals
LSAM = Lunar Surface Access Module
ESM = Equivalent System Mass
mm = millimeter
Mpactor = Mechanical trash compactor (new name for CEV Compactor)
N = Newtons
Pa = Pascals
PSIA = pounds per square inch absolute
PSIG = pounds per square inch gauge
TCPS = Trash Compaction Processing System
VAC = voltage, alternating current
VDC = voltage, direct current

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I. Introduction

THE accumulation of trash in spacecraft, space stations, planetary surface habitats, and planetary surface rovers will present a challenge during future human space exploration missions. Trash impacts a variety of subjects such as crew operations, maintenance of sanitary conditions, spacecraft attitude control, and launch cost. Storage space must be provided for the trash. There is mass associated with the spacecraft volume due to the spacecraft structure. The reduction of spacecraft volume needed to store trash drives down launch costs.

A simplistic yet efficient method of reducing volume is via a pneumatically actuated compactor that is the subject of this paper. This compactor was developed for the NASA Constellation Program and was called the Crew Exploration Vehicle (CEV) Compactor shown in figure 1. The project came to a stop in 2007 in favor of the development of what was then called the Plastic Melt Waste Compactor (PMWC), now known as the Trash Compaction Processing System (TCPS). The investigation of non-heat aided compaction has recently been restarted at NASA Ames Research Center. The CEV Compactor has been renamed the Mechanical Compactor (Mpactor) since the Constellation Program no longer exists, and the new activities have a different focus than when the CEV Compactor was created. Originally the CEV Compactor was created for the Lunar Sortie Missions which only required two compactor bags per mission, with a single bag being able to up to a six-day accumulation of trash generated by four crew members. The trash model that was used to size the CEV Compactor was significantly smaller than the currently used trash models.

Figure 1. CEV Compactor (Now called the Mpactor)

Typically, trash occupies more volume than the form it originated from with an example being a used T-shirt or certain types of food packaging. One concept to reduce the amount of volume required to store trash is to place it back into the space where it originated from such as a food pantry or a Cargo Transfer Bag (CTB). If the original items in the pantry are stored more than one layer deep, this would be problematic. This method will require that a significant amount of time will be spent re-shuffling the supplies and trash in order remove new supplies from the storage space and find a space for the trash.

There is also the possibility of contamination of the food or other supplies due to items like wet food wastes or clothing that have been exposed to saliva, sweat, and other bacteria.

Placing trash back into the original storage space from which it originated would be acceptable if the space was completely void of supplies. The issue that arises from this is that the trash must be managed and kept in another location until the storage space is empty. This would require a temporary storage space that is used until permanent storage space is available.

Other solutions for managing trash were considered that involved placing the trash into larger bags such as a CTB and tying those bags to available attachment points within the spacecraft cabin. These attachments would be on the spacecraft frame, or a panel and the bag would intrude into the cabin space. A primary concern with this method was obstruction of crew movement and systems access within the cabin. The other concern was potential movement of bags generated by activities such as a spacecraft maneuver or reentry. Mounting within the cabin space may limit the number of attachment points, and ideal spacing and orientation to properly handle the load conditions. A single CTB has an external volume of 0.053 m^3. The single CTB is used as a metric for volumetric requirements, and the metric is termed Cargo Transfer Bag Equivalent (CTBE). The maximum mass for the CTBE is 27.2 kg. There are half, double, and triple CTBs. In the case of a triple CTB, the full mass could be as high as 81.6 kg. This is a significant mass and if it were to detach during reentry, the odds of it harming crew or equipment are very high.

The issues described indicate that an additional volume should be provided for the storage of trash that separates it from food and allows it to be securely constrained in all directions. The additional space needed to store the trash increases the spacecraft volume, which increases that spacecraft mass and ultimately launch cost.

To reduce the impact of unprocessed trash on launch costs, a low energy method of providing high trash volume reduction needs to be employed.

This paper details the work performed on the Mpactor shown if figure 1, that uses a pneumatically driven ram to provide a very high compaction ratio with low energy consumption. Additionally, it compacts the trash into a form that maximizes its packing efficiency by reducing the void volume between different trash batches when placed into a storage container.

II. Background

The development of the CEV Compactor was initiated during the NASA Constellation Program to investigate the feasibility of a small compacter for the initial Lunar Sortie missions[1]. A Lunar Sortie mission would have a duration of 18 days. The initial portion of the mission included the docking of the Cargo Launch Vehicle (CaLV) carrying the Lunar Surface Access Module (LSAM) and the Earth Departure Stage (EDS) to the Crew Exploration Vehicle (CEV) which were launched separately. The docking procedure and the transit to the moon would span 6 days, the duration of the surface stay was planned to be 7 days, and the return to earth would take 5 days. The compactor was only being considered for the CEV, not the lander. The CEV Compactor was sized to accommodate the six-day trash accumulation that would occur during the outbound portion of the mission.

The CEV Compactor was designed to use a 20 psig Nitrogen source from the CEV to drive the compactor ram. The design concept would not need a vacuum pump, compressor, or any electrical or electronic components. Manually operated valves would be used to actuate and retract the compactor ram and other unpowered valves and a simple pressure gage would be used for pressure control and monitoring. The CEV Compactor produced at ARC included electrically powered components. The components included a pump for compression and vacuum , DC power supply for the compressor, and an electrical pressure switch to control the compaction piston pressure. The purpose of the those components was to produce an air source that simulated the Nitrogen gas that would be available on the CEV.

The CEV Compactor was originally designed to operate in micro-gravity conditions. One of the main areas of focus was keeping the trash and any liquids from leaving the compaction chamber and causing an inhalation hazard for the crew or possible damage to spacecraft systems. The compactor bag design was a key element of the compaction system's ability to prevent liquids in the trash from getting released into the cabin.

The early CEV Compactor design concept shown in figure 2 had perforated compaction chamber walls and used a specially designed permeable membrane bag. The perforated compaction chamber wall was surrounded by a non-vapor permeable wall. The non-vapor permeable wall used eggshell like dimples. The perforated wall would be tack-welded to the dimples on the outer wall, providing structural strength and stability to the compaction chamber while allowing the air to be drawn from the chamber, through the bag, and into the fan. The material that was going to be used for the eggshell wall concept was titanium. Figure 3 shows a closer view the eggshell concept. The perforations in the chamber wall were left out of the image due to the amount of memory required to create them in the 3-D modeling program. The bag design concept included multiple layers to constrain the water in the bag and provide odor control. The concept would have used activated carbon fiber cloth to control odors. A very low power fan was to be used to draw air into the compaction chamber when the CEV Compactor door was opened and could remain on to draw odorous vapors through the activated carbon fiber cloth when the door was closed.

Figure 2. Original Mpactor chamber design including fan

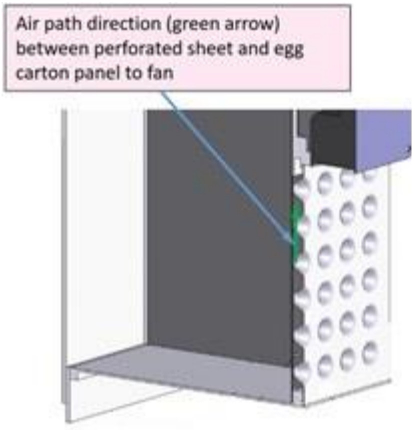

Figure 3. Perforated compaction chamber panel concept

The CEV Compactor only required two trash bags for the Lunar Sortie Missons; one for the outbound leg to the moon, and the other for the return leg to earth. The first bag was pre-installed in the compactor on the ground. When the astronauts returned to the orbiter from the lunar surface, they would remove the first bag and place it into the lunar ascent module. The second bag was then placed into the compactor. The lunar ascent module would be discarded, and the second bag would serve the crew for the return trip to the earth.

The quantity of trash that the CEV Compactor was designed for was significantly less than the current model, which is 1.1 kg per crew member, per day[2]. The original model that the CEV Compactor was designed for assumed 0.19 kg per crew member, per day for a four-person crew. The trash generation rate of 0.19 kg per crew member per day, was provided via verbal communication within NASA and was not published. The total trash accumulation over a 6-day period would be 4.6 kg.

The currently envisioned missions will require that multiple bags beyond the two proposed for the Constellation Lunar Sortie missions would be required to handle the trash load. The bags designed for the CEV missions used a rigid frame since the storage volume of the bags was an issue due to the low quantity needed. To accommodate the increased quantity of trash bags that will be required on future missions, a new bag design will need to be developed that focuses on minimal stowage volume. This would require that the rigid frame used in the CEV Compactor bag design be eliminated. The new bag would be made entirely from soft, foldable material. A new compacter bag interface will need to be designed to accommodate the new bag design. It will be a significant challenge to design the new compactor bag interface and keep the mass of the system down. One of the objectives of the current development effort will be to develop conceptual ideas for a new bag/compactor interface for the next generation Mpactor.

III. Hardware Description

The CEV Compactor was brought out of storage and prepared for evaluation for use on possible future mission scenarios. The CEV Compactor is addressed as the Mpactor when referring to current activities. The Mpactor had not been run since 2007. Other than visual inspection to ensure safety of operation, no effort to refurbish the Mpactor was attempted before turning the system on and extending and retracting the ram piston. The Mpactor worked surprisingly well after such a long period of dormancy (approximately 17 years) and was able to achieve high system pressures and compaction.

The ability of the Mpactor to work after a period of dormancy is critical because there are multiple scenarios in which that could happen. Two likely scenarios involve the use of a pressurized rover or on the Lunar Gateway station. Using a Mars mission as an example, the compaction system in a pressurized rover on Mars would remain dormant until landing on the surface. The period of dormancy would be approximately 180 days or more depending on the type of orbital path used to get to Mars. Lunar Gateway requirements state that the Gateway station have the ability to remain functional after a dormant period of 3 years[3].

The first task after returning the Mpactor to action was to perform shakedown testing to see if any issues might exist that would have to be remedied before formal testing could take place.

Two significant issues were discovered. The first issue was pressure system leakage which was anticipated with the 17-year-old seals. The leak required that the combination compressor/pump be cycled every couple minutes which was undesirable. The second issue was the repeated failure of the combination compressor/vacuum pump which is used to extend and retract the ram piston. The combination compressor/vacuum pump was chosen because it mass, performance, and type of power (24 VDC) represented specifications of a unit that could be selected for a flight version of the Mpactor. The combination compressor/vacuum pump had to be fixed repeatedly and was eventually replaced. A larger, 120 VAC pump was used to operate the compactor. The larger pump is not considered a permanent solution. A suitable COTS combination compressor/vacuum pump has not been found that meets the power and size requirements that are envisioned for a flight version of the Mpactor. The development of a new combination compressor/vacuum pump may be required for this system unless there is a COTS version that is suitable that hasn't been discovered yet.

A. The Compaction Piston Ram and Compaction Chamber

The Mpactor compaction chamber was sized to handle a six-day accumulation of trash for a four-person crew and is 11 liters.

The compaction chamber, shown in figure 4, is rectangular with a 17.8 cm (7.00 in) by 17.8 cm (7.00 in) base and a depth of 5.3 cm (13.63 in) from the face of the fully retracted ram to the compaction chamber floor. The ram shown in figure 5 has a dimension of 15.2 cm (6.00 in) by 15.2 cm (6.00 in) leaving 0.6 cm (0.25 in) of space between the ram and the chamber wall. Some of the space between the ram and the chamber wall is taken up by the trash bag and the amount of space remaining is dependent on the bag thickness.

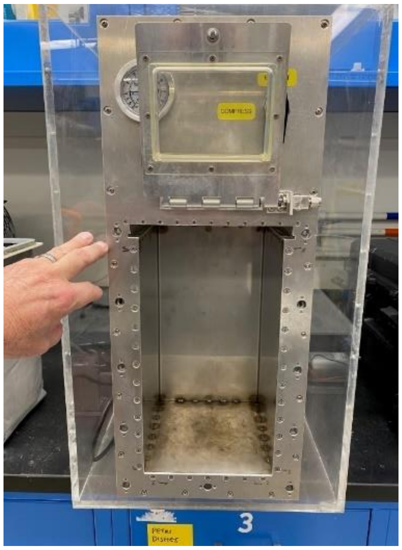

Figure 4. Front view of the Mpactor with front panel removed showing compaction chamber

Figure 5. Front view of the Mpactor with front panel removed showing compaction chamber

The Mpactor uses a double telescoping pneumatic piston, shown in figure 5, to actuate the ram. The double telescoping piston has two stages of translation to double the length of the stroke compared to a single telescoping piston. The first version of the compactor had a single telescoping piston. It was discovered that single telescoping piston did not push the trash far enough below the trash input door to prevent trash from springing back into the door space after the piston was retracted, which made it difficult to put more trash into the compaction chamber. The longer stroke of the double telescoping piston successfully pushed the trash far enough down that after trash spring-back, there was ample room to put more trash in the system. In addition to clearing the trash input area, the double telescoping piston significantly increased the level of compaction. When the ram was actuated beyond the reach of the middle piston section, the load per unit area, or compaction pressure applied to the trash was 69 percent of the gas pressure in the piston. When the compaction chamber was full enough that the middle piston would engage against the ram, the compaction pressure on the trash was roughly equal to the gas pressure in the piston.

Figure 6. Front view of the Mpactor with front panel removed showing compaction chamber

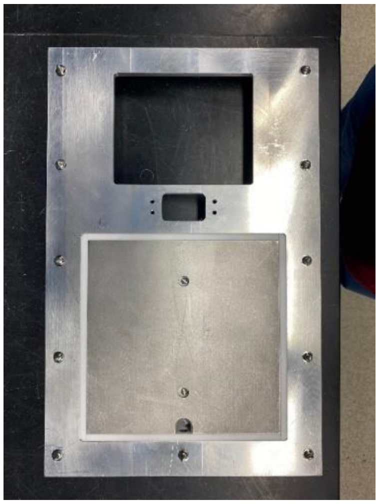

Figure 7. Front view of the Mpactor with front panel removed showing compaction chamber

The compactor was originally designed to operate at 20 psig but has since been evaluated for use at pressures as high as 99 psig. Actual testing of the hardware was performed up to a piston pressure of 45 psig. For pressures higher than 45 psig, stress conditions were determined by analysis using Finite Element Analysis (FEA) but no physical testing of the hardware was performed. Based on analysis, a maximum piston pressure of 60 psig was selected to maintain the factor of safety against failure above 3.5[4].

The maximum piston volume occurs when the piston is fully extended which is 5.9 liters (361 in^3). The Mpactor piston system falls below the criteria for it to be considered a pressure vessel. With a piston pressure of 683 kPa (99 psia), and an ambient pressure of 101 kPa (14.7 psia), the stored energy is 4,244 Joules. The criteria for being considered a pressure vessel is that the system pressure and stored energy remain less than 689 kPa (100 psig) and 19,307 Joules respectively[5]. At the maximum planned operating pressure of 414 kPa (60 psig), the stored energy is only 2,832 Joules or 14.7% of the pressure that constitutes the designation of pressure vessel. It is expected that the nominal operation pressure of the Mpactor will be at 310 kPa (45 psig). The resulting stored energy for the Mpactor piston is 2,010 Joules or 10.4% of the criteria for it to be considered a pressure vessel.

The Mpactor has a removeable front panel, shown in figure 6, which is removed to place new trash bags into the compaction chamber and remove trash-bags after they are full. The front panel houses four load cells and was designed to measure the side loads generated during compaction. The front panel contained a smaller panel called the load cell panel, shown in figure 7, that the trash would push on when compaction was occurring. The load-cell panel is a 17.8 cm (7 in) by 17.8 cm (7 in) plate with one load cell on each corner. The load cells were rated to detect loads up to 4.4 kN (1000 lbs) each. The new panel including the load cells was never tested at the time it was built. It was discovered during recent operation that load cells range proved to be far to too high. The system was tested at a chamber pressure of 310 kPa (45 psig) and the maximum load detected on one of the load cells was 107 N (24 lbs) with an average of 80 N (18 lbs) per cell for the four load cells. New load cells have been purchased that a maximum capacity of 440 N (100 lbs) each. The 4.4 kN load cells will be relocated under a plate that will register the load occurring on the bottom of the compaction chamber.

B. Ancillary Hardware

The Ram Actuator System

The combination compressor/vacuum pump that was originally used with the system was a 24 VDC piston pump with a maximum pressure of 689 kPa (100 psig) and a peak power of 62.4 Watts. The flowrate of the unit was sufficient and only affects the amount of time it takes to extend the piston, reach the targeted compaction pressure, and retract the piston.

Vacuum is used to retract the piston. The retraction process has two stages; the first is to open a valve that vents compressed air to the ambient environment, then when the piston reaches zero gage pressure (with respect to the external environment such as a lab or spacecraft cabin), the combination compressor/vacuum pump would switch on creating vacuum, and the external ambient pressure air would push the piston into its fully retracted position. Another design was considered that would use positive pressure to both extend and retract the piston. For a single telescoping piston this would have been a simple design but using positive pressure to retract the double telescoping piston would be challenging to fabricate. A conceptual design was produced that would allow the double telescoping piston to work with positive pressure for both extension and retraction, but it was never produced. The use of positive pressure to both extend and retract the piston is desirable over the vacuum retraction method because the application of dampening for piston motion control is simpler.

The combination compressor/vacuum pump kept failing after reaching the pressure setpoint and switching off preventing it from turning on again and maintaining pressure. The duration of function before failure was not always immediate but did fail immediately after some of the trials that occurred after its repair. It was found to be an inductor coil that was part of the brush assembly. The coil would break at the solder point that attached it to the brush frame. The initial remedy was to resolder it, but the problem repeated itself after being fixed.

The combination compressor/vacuum pump was not designed to be restarted under pressure which was thought to be the cause of the problem. At the time of purchase, it was not known that the unit was not designed to restart under pressure which was not provided in its specification sheet. A pressure circuit was designed that would depressurize the outlet of the pump down to ambient pressure and equalize the pressure with the inlet side of the compressor (without losing pressure in the piston). The pressure circuit served the same purpose as a Pilot Unloader Valve that is part of typical shop compressors, although the circuit differed in some aspects of the design.

The problem with the inductor coil continued to occur after employing the pressure equalization circuit, although not as frequently. The pressure equalization circuit reduced vibration loads down to what would occur during normal operation of the compressor. The failure with the inductor coil continued. Another combination compressor/vacuum pump was used in place of the 24 VDC unit. The replacement pump was originally used on the first TCPS. It was a 120 VAC unit and was oversized for the system but was sufficient for current tests. The size of the new combination compressor/vacuum pump does not impair performance of the system, but it is not representative of the size and type that would be used on a flight version of an Mpactor. The replacement combination compressor/vacuum pump was also not designed to be restarted under pressure, but the custom pressure equalization circuit design worked successfully on that unit.

It is likely that a custom combination compressor/vacuum pump may need to be developed to meet the requirements of the Mpactor and for spaceflight.

Pressure Control System

As mentioned previously, the Mpactor (when it was called the CEV Compactor) used a combination of unpowered valves to control the actuator mode, overpressure control, and human interface safety. The valve system is being changed for the current system.

For the CEV Compactor, a valve was mounted on the outer panel which the astronaut would to either extend or retract the piston. For safety, a valve was integrated with the trash input door that would depressurize the piston when opening the door, preventing it from actuating when the astronaut was putting trash into the compaction chamber. The third valve on the system was a pressure relief valve, set to relief pressure at 5 psi over the maximum targeted operating pressure. The use of the aforementioned valve setup allowed a system to be designed that was not dependent on electrical and electronic components thereby maximizing its robustness and simplicity.

For the Mpactor version of the compactor, the manually actuated valves are being replaced with electrically actuated solenoid valves allowing the experimenter to focus on data collection.

C. Compactor Trash Bags

The Original Bag Concept for Lunar Sortie Missions

Specially designed bags were made for the CEV Compactor. The original bag concept design included six layers. The innermost layer was a tough, perforated, polyethylene film that would allow vapor and liquid water to pass through to the next layer. The innermost polyethylene layer would protect the other layers from potential damage caused by trash as it is being compacted.

The second bag layer (from the innermost bag layer) was a sodium polyacrylate impregnated, permeable film, that would capture liquid water being squeezed out of the trash. Sodium polyacrylate is used in the astronaut Maximum Absorbency Garment (MAG). Sodium polyacrylate can absorb water over 100 times its mass.

The third layer was a vapor permeable, liquid impermeable membrane such as Expanded Polytetrafluoroethylene (EPTFE). The EPTFE layer would allow the air in the compaction chamber to pass while retaining the liquid water in the zone containing the sodium polyacrylate impregnated film.

The fourth layer was a woven activated carbon fiber cloth for odor adsorption. The activated carbon fiber cloth also retained structural values similar to carbon fiber cloth used for parts manufacture.

The fifth layer was EPTFE film identical to the third layer. The purpose of this layer (and one of the purposes of the third layer) was to prevent any particulates that might be generated by the activated carbon fiber from escaping to the cabin should that occur. It was not known if any particulates would be generated by the activated carbon fiber cloth, but the EPTFE was included as part of the concept to show that measures could be taken to manage this. The activated carbon fiber cloth layer in the bag would also allow odor retention to continue after the full bag was removed from the Mpactor and placed in storage. The type of storage space was not known, and this concept was included to show that a storage space would not need its own odor retention system to house the full Mpactor bags.

The sixth and final layer was identical to the first layer, the perforated polyethylene film. It provided a tough outer layer that would allow the air from inside the trash bag to be drawn out of the bag while protecting the inner layers of the bag.

The Final Bag Design for CEV Compactor

For cost reasons, the version of the CEV Compactor that was manufactured did not include the special compaction chamber design that allowed air to be drawn through the water adsorbing and odor adsorption layers of the bag. A solid walled compaction chamber was built. The bag that was developed for this setup included 3-layers; The first or inner layer was purchased from New Pig® , called Traffic Mat (TMat), the second layer was a sodium polyacrylate impregnated film, the same that was considered for the previously mentioned bag concept, and the third layer was a tough polyethylene film that was not vapor permeable like the film described in the original bag concept[6]. Figure 8 shows the CEV compactor bag design that was built and tested. The introduction of anti-microbial properties to the final bag design was considered but not included.

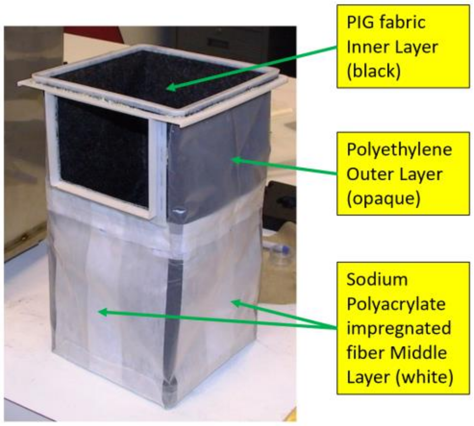

Figure 8. The bag concept manufactured for CEV Compactor

Future Bag Designs

New bag concepts are being investigated and new materials are being explored such as polyurethane films that have exceptional toughness for a thin and light material. Eventually, more complex bag systems will be explored that will combine some of the concepts considered for the CEV Compactor bag design but with the introduction of anti-microbial properties as was considered for the final CEV Compactor bag design.

Another concept that is being considered is a bag material that has low friction in one direction and high friction in the opposite direction. The purpose of the uni-directional friction property bag membrane is to reduce friction on the trash when being compacted into the bag, then increase friction on the trash when the compaction load is removed from the trash. Reduced resistance to movement in the direction of compaction will allow higher compaction when the load is being applied compared to a surface that has higher friction. When the compaction load is removed from the trash, it tends to spring back to a less compact state. Increasing the friction in the direction of the spring-back should reduce the magnitude of spring-back. The degree of reduction in spring-back for different bag materials is not known and is an area of research and development that would need to be explored to determine this.

IV. Testing

D. Tests

Recent Tests

Tests were conducted in 2024 that were originally only intended to assess issues with the Mpactor resulting from a 17 year period of dormancy. The initial round of tests blossomed into a full test set. The load on the trash was generated with a piston pressure of 172 kPa (25 psig) which resulted in a compaction pressure at the ram equaling 119 kPa (17 psig).

It was not known how compactable the current trash model would be. It was originally thought that the maximum amount of the current trash model that could be compacted into the chamber would be approximately 2.7 kg. The current trash model contains a considerable number of T-shirts and towels which tend to not maintain a compacted state after the compaction load is removed. After having compacted 2.7 kg of trash from the current trash model into the compactor, it was evident that more trash could be processed in the system. Testing continued until a full days complement of trash for a four person crew, 4.4 kg, was compacted into the system.

The first batch that was placed into the Mpactor was 1.113 kg and fit into the compaction chamber with minimal effort. The density of the trash once put into the 11-liter (10.9 liters to be more precise) compaction chamber had a value of 102 kg/m^3. The trash was compacted to a density of 283 kg/m^3, then after the load was removed, it sprang back to a final density of 202 kg/m^3 as seen in figure 9. For the first compaction, the load was removed and the ram completely retracted immediately after compressing the trash. Measurements were taken of the trash to determine spring-back, then the compaction was immediately re-initiated, and the load was allowed to remain on the trash for 30 minutes. The reduction of spring-back that resulted from extending the load application time is quite evident. Manuals for household compactors typically state that allowing the load to remain on the trash for at least 30 minutes can increase the compaction by an additional 20% to 25%.

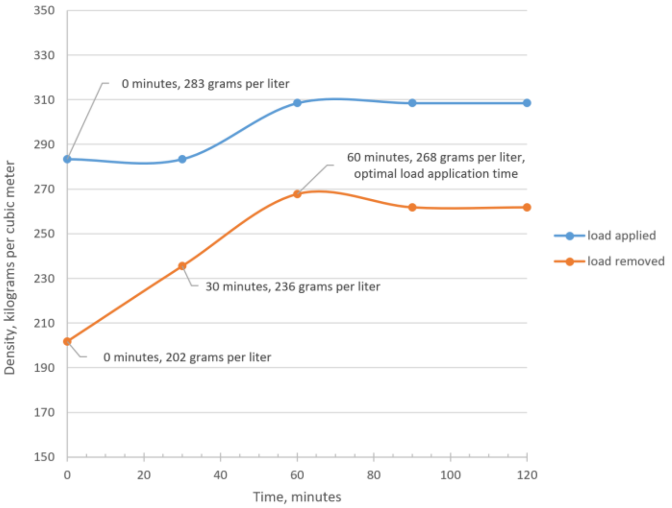

Figure 9. The effects of increased load application times and compacted trash density after spring-back

Figure 10 shows the cumulative load application times that were applied during the test set. The piston pressure for the tests was 172 kPa (25 psig) which generated a compaction pressure of 117 kPa (17 psig) at the ram. The load applications were applied in 30 minute increments with some exceptions caused by the previously mentioned combination compressor/vacuum pump failures.

In each case, the density of the trash was calculated using the ram position immediately before it was retracted at the end of the load application time, then re-calculated after the load was removed and the ram was completely retracted. The load was applied for a total of 120 minutes on the first batch, with the load being removed every 30 minutes within the 120-minute period to assess spring-back. Figure 10 shows the change in the final trash density both before and after the load was removed all the way up to the final amount of 4.4 kg of trash that was compacted into the system.

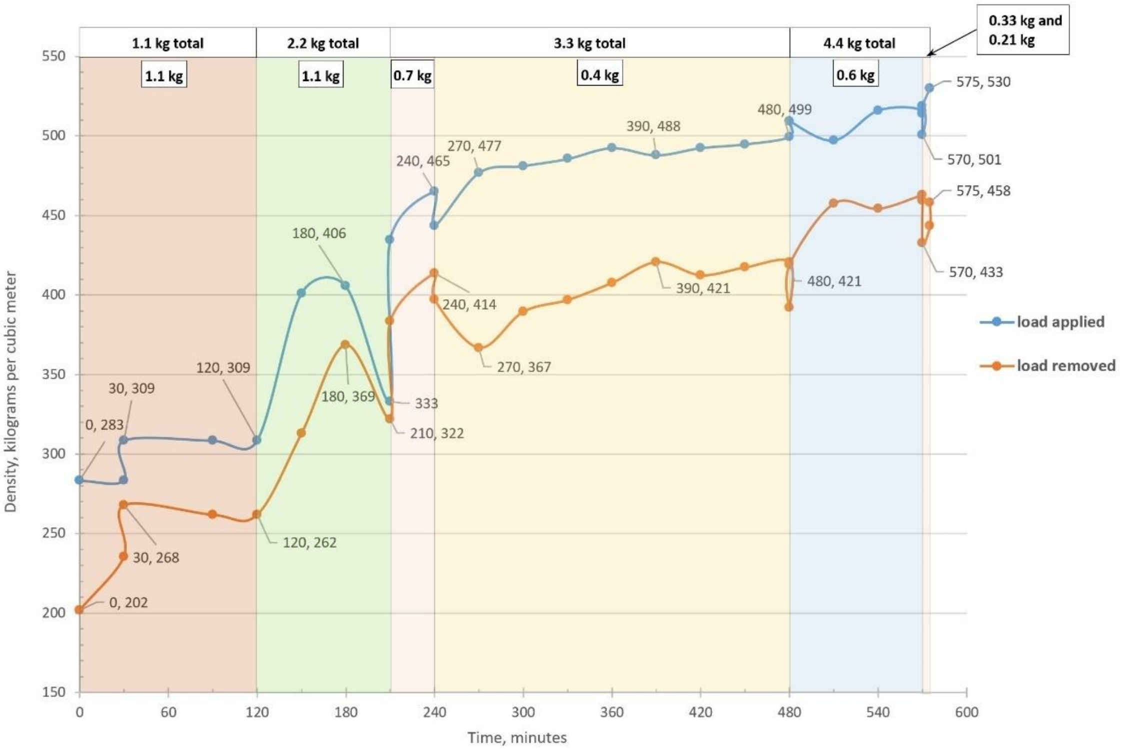

Figure 10. Cumulative load application time for trash compacted at a pressure of 117 kPa

As more trash was compacted into the chamber, the remaining headspace in the chamber got successively smaller after compaction as expected (see figure 11). The decreasing headspace limits how much trash could be put into the chamber on each successive run. There was a point at which it required more physical effort to put trash into the compaction chamber than was practical or even possible.

To overcome the physical difficulty of forcing more trash into the chamber, it was necessary to put an increasingly smaller amount of trash into the chamber after each subsequent compaction. This was done until the chamber could not accept any more trash. As expected, the solution that was used to reduce the difficulty of placing trash into the chamber increased the number of compactions required to fill the chamber. The maximum acceptable number of compactions that should occur during a 24-hour period is to be determined. The maximum number of compactions will be bound by the maximum acceptable allowance of crew time and daily compactor energy consumption.

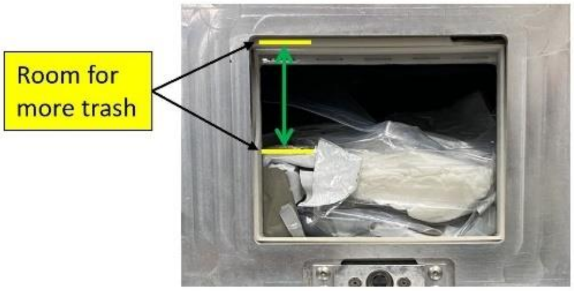

Figure 11. View of trash input door showing diminished headspace for placing more trash into the compaction chamber

It was observed that as more trash was compacted into the chamber, the ability to retain a higher level of compaction was achieved. The peak compacted trash density after spring-back was measured to be 463 kg/m^3, which is over a factor of seven times higher than the average density of trash placed in a trash bin which is 64 kg/m^3 according to the Navy report on shipboard generated wastes[7]. Also, an average density of 160 kg/m^3 was reported when manually compacting trash into a plastic bag, then wrapping it in duct tape to prevent it from springing back[8]. The trash that has been manually compacted into the plastic bags then wrapped in duct tape are referred to as trash "footballs". The Mpactor demonstrated that it was 2.9 times more effective at reducing the volume of trash compared to the "football" method.

Upcoming Tests

In upcoming tests, a variety of sustained load application times will be evaluated. The current plan is to investigate 30-minute, 60-minute, 90-minute, and 120-minute load application times. For each load application case, a total of 4.4 kg will be evaluated. The first group of tests ranging from 30 to 120 minute load times will be evaluated at one compaction pressure. Then, the subsequent groups of load application time tests will be evaluated increasingly higher pressures. The tests will be performed at piston pressures of 172 kPa (25 psig), 241 kPa (35 psig), and 310 kPa (45 psig), applied to each subsequent test group with the possibility of an additional test group being performed with a pressure as high as 379 kPa (55 psig).

The difficulty of adding more trash to the compaction chamber after each compaction will be observed. The results of the observations will qualitative unless a reasonable method of quantifying those results can be determined. One possibility is to measure the force that needs to be applied to push the trash into the compaction chamber. This would be done using a handheld compression load measuring device attached to a plunger (likely a flat plate). The NASA Spaceflight Human-System Standard, volume 2: Human Factors, Habitability, and Environmental Health Document will be used as a guideline to determine what constitutes a reasonable amount of force[9]. It is not known how representative the values using the plunger setup will be because a person using their hands and fingers has the ability to twist, or rotate, and push trash into the chamber in a method that is much more complex to measure than the simple plunger test.

V. Future Work

One of the primary purposes of the current Mpactor compaction work is to develop a data set that will allow system engineers and designers to select which compactor configuration is best suited for any particular mission of interest.

Equivalent Systems Mass analysis will be done for the different compactor configurations to aid in the selection of the optimum system for the different mission segments. The different mission segments can include use of a pressurized rover, surface habitat, or an orbiter. Missions using pressurized rovers or surface habitats can have a range of possible crew sizes and durations. This will lead to an initial down-select of configuration options suited for the selected mission scenario.

The data gained from the Mpactor tests will not include fine details about items such as compressors, pumps, tube routing, etc., which are beyond the scope of the current test plan concept. The design engineers will evaluate the configuration options that were determined in the first down-select and perform a more detailed analysis of those options which will look at system geometry, tubing configuration, ancillary hardware configuration, and effect on crew operations. A more detailed analysis performed by mechanical design engineers will lead to a final selection of the hardware system deemed most optimal for the selected mission. After the final down-select has been made, the development of a high TRL mechanical compactor can commence.

Having a data set that spans different crew size and mission duration variations will enable a rapid design selection process by providing initial hardware volume, power, required mass to suit appropriate structural margins of safety, and crew time expenditure for each different configuration.

The most critical data set will contain information on the different compaction levels resulting from the combination of both compaction pressure and compaction load application times. Each different pressure case will drive the mass of the final compactor structure, and therefore launch cost, for it to meet the required margins of safety. From the data set, the optimal compression pressure and compaction load dwell time can be ascertained. The data will reveal the points where added compaction pressure or increased load application time only provides a marginal increase in volume reduction at the cost of increased hardware mass, and energy consumption.

VI. Conclusion

The Mpactor has proven to be very effective at reducing the volume of trash that represents that properties of that produced on future human space exploration missions. The tests described in this paper demonstrated a volume reduction of 86% compared to loosely compacted trash stored in a receptable such as a typical trash can. The percent volume reduction of the Mpactor was approximately 3 times higher than that achieved using the trash “football” method.

The Mpactor development effort will provide data that will enable the selection of the optimal sized compactor for a varying range of mission types and mission durations.

The current and upcoming development efforts will determine the optimal combination of compaction pressure and compaction load application times using the Mpactor. Those results will then be used to extrapolate the mass of future compactors of different sizes. A selected number of the different compactor size options will be modeled to ensure that the extrapolated values provide an appropriate level of accuracy to make decisions about which option to develop to a higher Technology Readiness Level.

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