ULTRASONIC TECHNOLOGY SOLUTIONS

Ultrasonic Washer–Dryer System for Space Habitats: Design Upgrades and Parabolic Flight Readiness

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NASA FLIGHT OPPORTUNITIES PROGRAM

P&G

Launch Tennessee

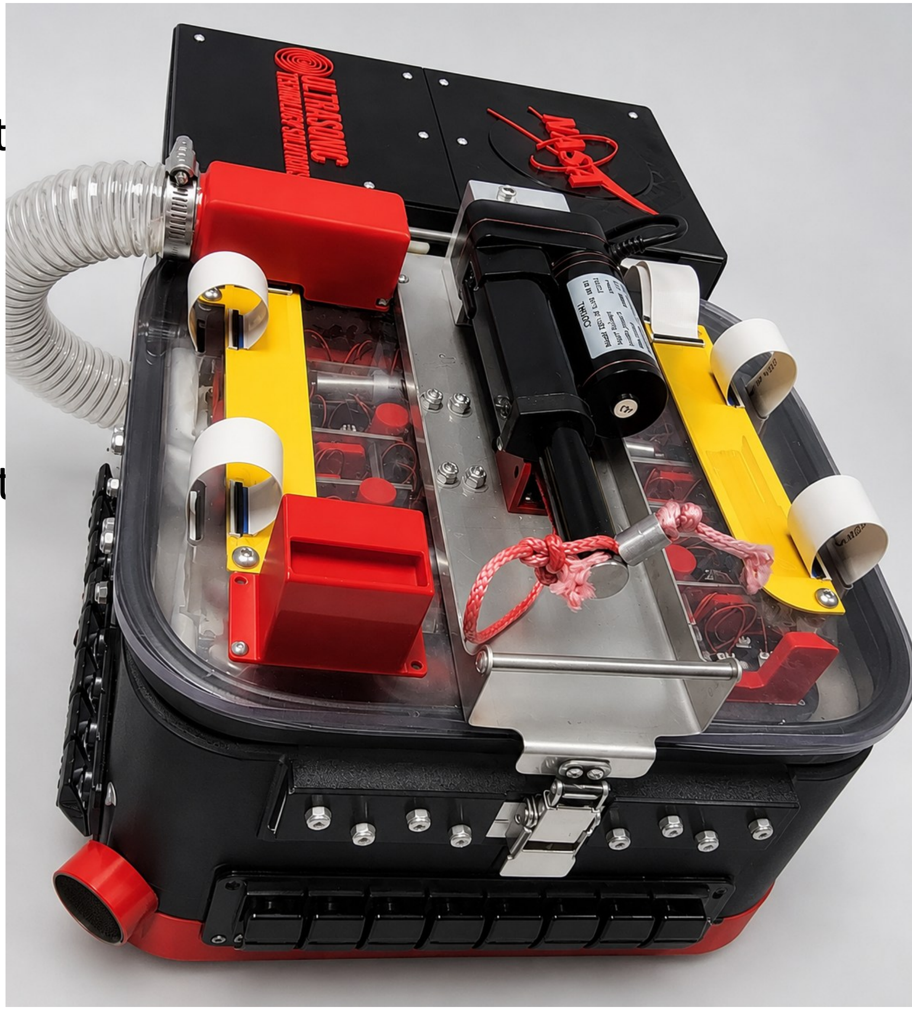
zero-G

Nelson Labs. A Sotera Health company

SBIR / STTR Small Business Innovation Research / Small Business Technology Transfer

Ultrasonic Clothes Washer/Dryer Accomplishments

- Developed a novel combined clothes washer and dryer for space applications.
- Designed to reduce waste while improving crew hygiene, comfort and safety (~90-97% reduction in clothing need).
- High energy efficiency with significantly reduced resource consumption.
- Rapid wash-and-dry cycles ranging from 83 to 135 minutes, depending on garment type.
- 15–50× lower lint generation, reducing maintenance requirement and fire risk.
- Compact and lightweight design: <15 kg mass and <0.044 m^3 volume.
- Testing demonstrated **superior cleaning performance** and odor reduction **compared with conventional residential laundry machines** under the evaluated conditions.
- Minimal water consumption per wash cycle.



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The best way to manage waste is to not generate it

Mission Need, Technology Gap, and Project Objectives

Project Goal:

- Develop a compact ultrasonic clothes washer–dryer for space habitats.
- Enable repeated garment reuse during long-duration missions.
- Reduce logistics mass, waste generation, and crew consumable requirements.
- Demonstrate a flight-ready prototype for future Lunar, ISS and Mars missions.

Issue:

- ~25% of ISS non-food logistics mass is clothing.
- No onboard laundry capability; garments are reused for multiple days and then discarded.
- Conventional thermal drying is energy-intensive and requires large hardware. Future exploration missions require sustainable clothing management solutions.

Technological Gap:

- Existing terrestrial washers and dryers are not designed for microgravity or planetary habitats.
- Thermal drying relies on water evaporation, requiring high energy input.
- Heat-pump and resistive dryers remain bulky, slow, and difficult to adapt for spaceflight.
- No current space-ready system combines efficient washing, drying, water recovery, and disinfection.

NASA Proposed Requirements:

- Clean up to 4.5kg of cotton, polyester, and wool clothing
- Less than 7 hours cleaning time
- Machine mass <50kg, external volume <0.3m^3
- Electrical power <300W
- Prototype development assumes 101.3kPa habitat pressure

Support missions:

- Orion, ISS, Artemis, and Human Landing Systems.

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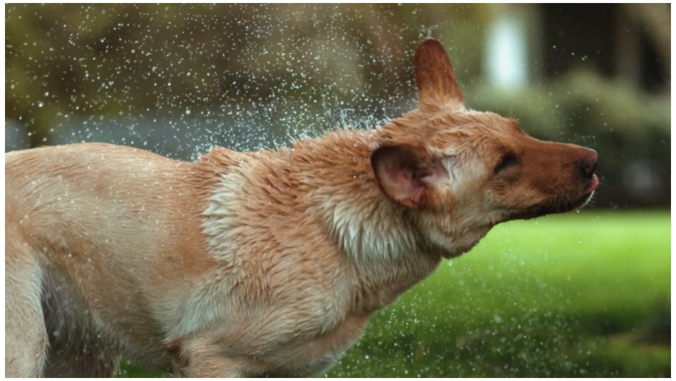
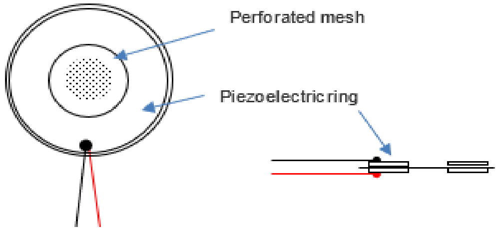
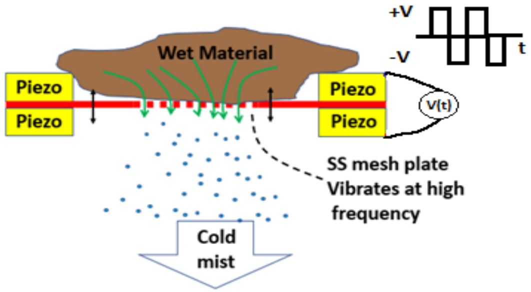
Background- Direct Contact Ultrasonic Drying

- Invented at Oak Ridge National Laboratory
- Inspired by nature!
- Relying on vibration rather than evaporation.
- The piezoelectric elements vibrate the wet materials sitting on them.
- Introduced momentum through vibration, mechanically displacing water, ejecting it through the mesh holes, and forming a cold mist of water droplets.
- The formed mist can be captured with a filter or be carried out to the desired location using small airflow.
- By bypassing evaporation, the technology demonstrated up to 3X faster and higher efficiency compared to conventional processes







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Big Picture Idea – Technology Relies on Fully Solid-State Solutions (No Moving Parts)

Water is reclaimed and reused many times

Glands in the armpits release a **thick, oily sweat** rich in **proteins, salts and lipids**

Exercise

Salt
+
Water
+
Thick Oil
+
Dead skin cells

Ultrasonic Cleaning make particles loose from the fiber

Dilution without the need for solvents

UTS vibrational dryer

Salt/oil/dirt extracted

ICES 2023- 328 Refresher

Key Findings from Previous Demonstrations

Sunscreen Removal (Oily Soil):

- Ultrasonic cleaning produced a 12× greater change in UV reflectance (UVR%) compared to soaking alone.

Salt Removal:

- 5 minutes of ultrasonic cleaning outperformed 30 minutes of passive soaking.

Color Stain Removal:

- Stains were completely removed in under 3 minutes using ultrasonic cleaning.

Lint Generation Comparison

Method	Mass Loss	Duration
Ultrasonic	~0.2%	700 minutes (~200 cycles)
Conventional	~1.0%	20 residential wash cycles

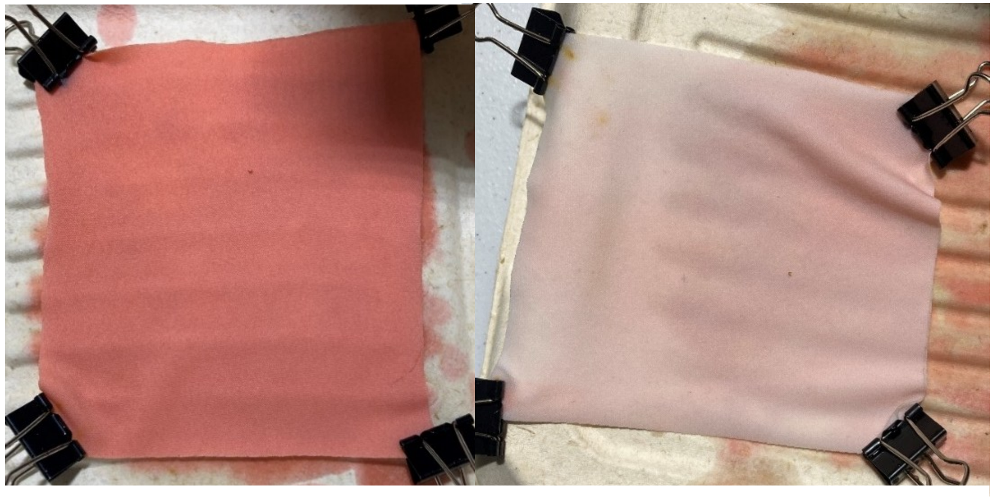
> 15-50× lower lint production, reducing fire risk

Fabric Integrity:

- No statistically significant degradation in fabric strength after 700 minutes of ultrasonic cleaning
- No visible fabric damage observed after extended ultrasonic exposure

Ultrasonic Drying Insight:

- Optimal performance was found with 4–8 layers of small-sized samples, leading to improved size reduction, speed, and energy efficiency

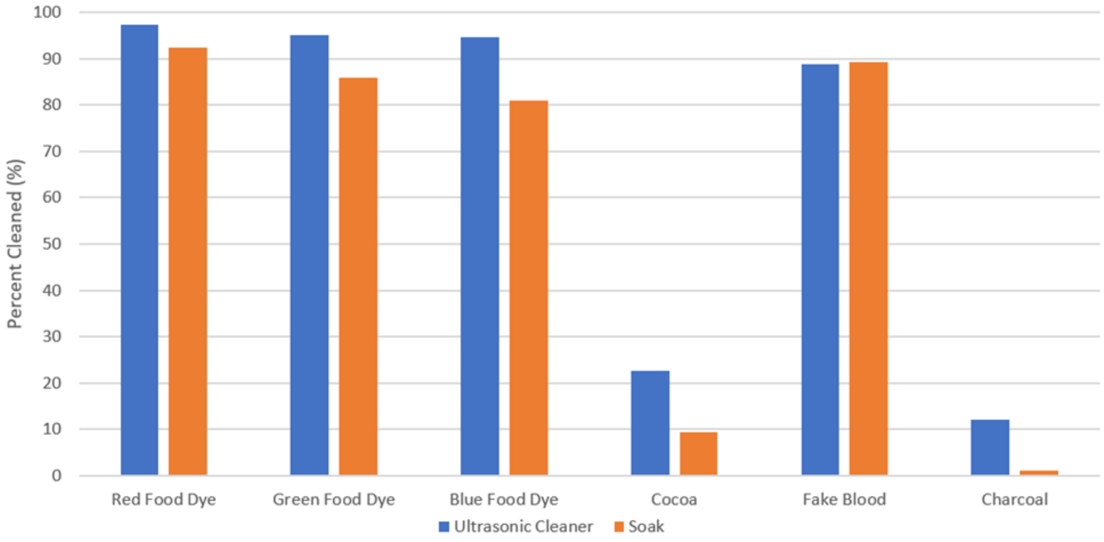


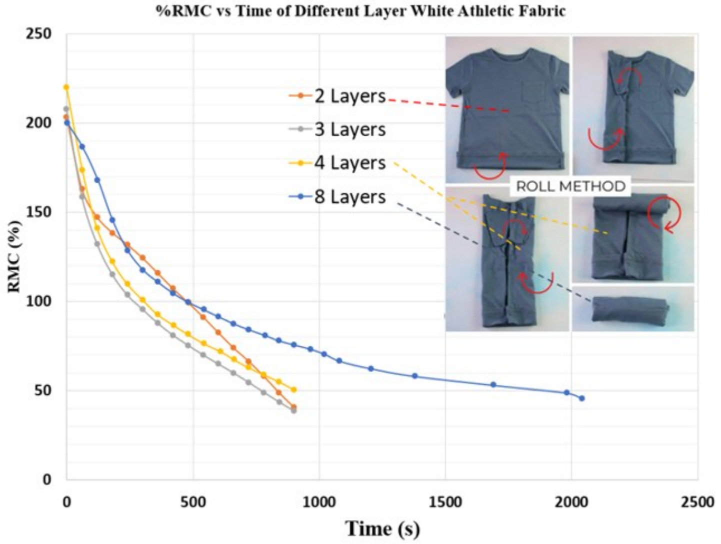
Dyed fabric after 3 min of **Soaking** before (Left) and after (Right)

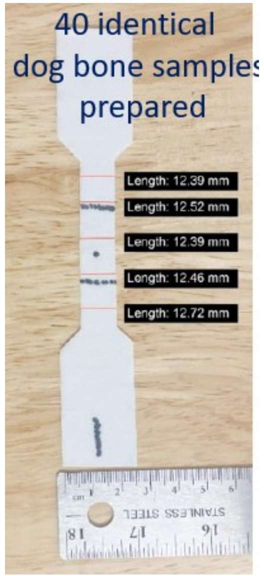
Dyed fabric after 3 min of **Ultrasonic Cleaning** before (Left) and after (Right)

ICES 2024- 292 Refresher

- **Stain Removal:**
    - Ultrasonic cleaning removed **2× more cocoa** and **11× more charcoal** than soaking
- **Salt Removal from Full-Size T-Shirts:**
    - Achieved **>86% salt removal** in just **7.5 minutes**
    - Validated using both **mass tracking** and **salinity meter** (error <2.7%)
- **Efficiency & Performance:**
    - Uses **minimal water (30 mm depth)** and **low energy**
    - Avoids thermal evaporation—removes water through **mechanical vibration**
- **Scalability & Space Readiness:**
    - Technology scaled to wash and dry **full-size, folded T-shirts**
    - Compact, energy-efficient design ideal for **ISS, Moon, and Mars missions**







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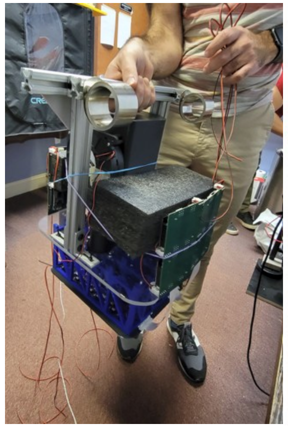
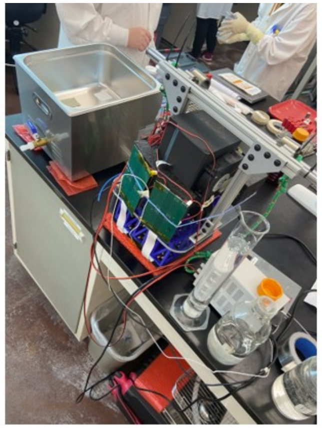
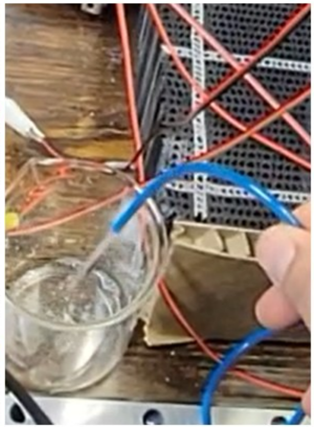
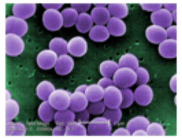




•Ultrasonic Wash–Dry System Performance

- •Demonstrated effective **washing and drying of full-sized, folded T-shirts**
- •Removed **>75% of water** in 30 minutes using ultrasonic drying
- •Full cycle (wash + dry) completes as fast as **~90 minutes**, **no human intervention**

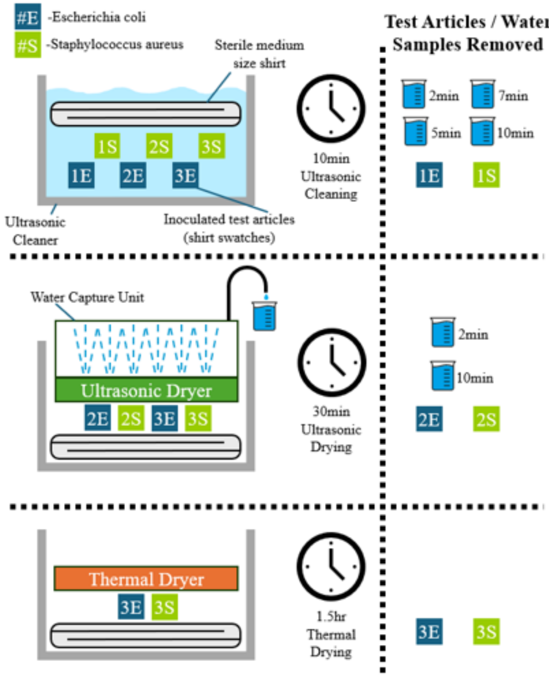
E-Coli
Commonly found in fecal contamination



Staphylococcus aureus
Very common on human skin

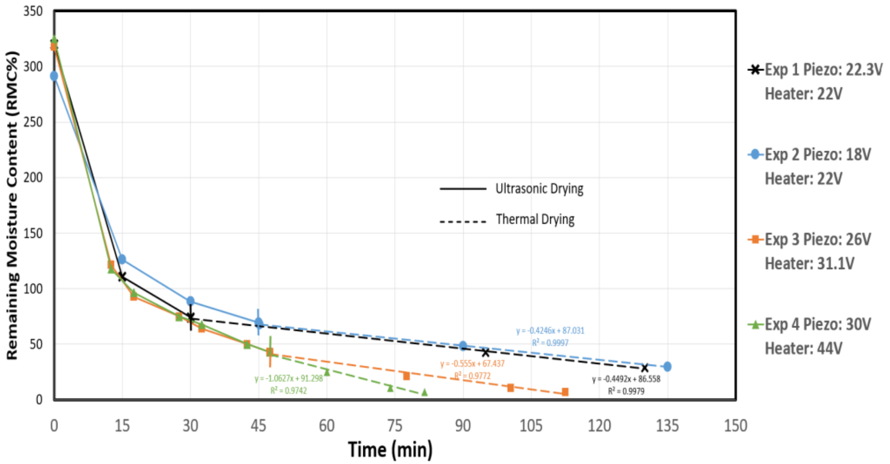
•Disinfection Efficacy

- •Achieved >**99.989% bacterial reduction** on fabric (LOG_{10} 3.91)
- •Water samples showed **98.7% CFU/mL reduction** during cleaning
- •Final mist-captured water: **<1 CFU/mL**



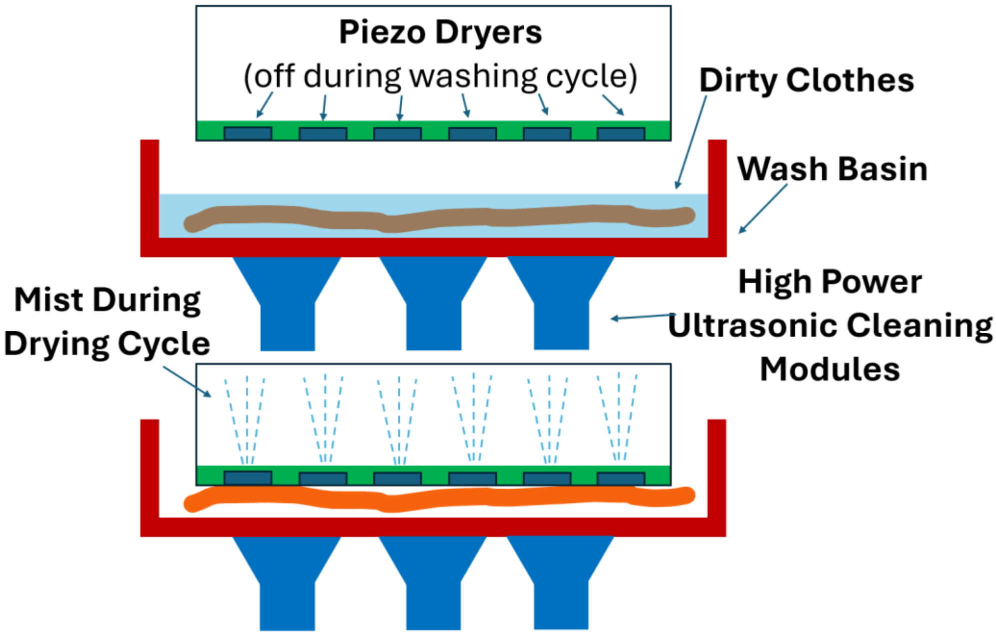
•System Design Benefits

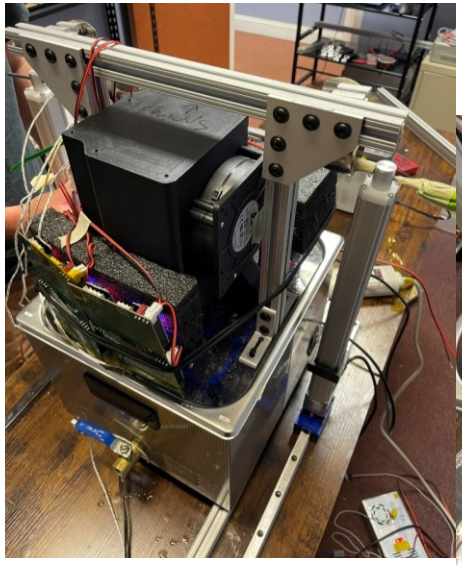
- •**Compact**, **modular**, and **portable**
- •Promising for **long-duration space missions** with minimal payload impact
- •Enhances astronaut **hygiene and comfort** in microgravity environments



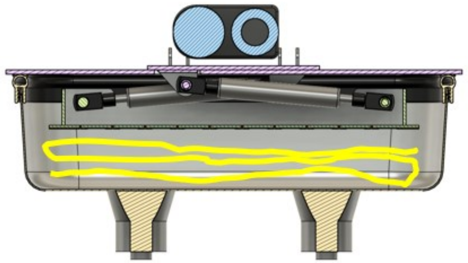
System Architecture- V1 Prototype

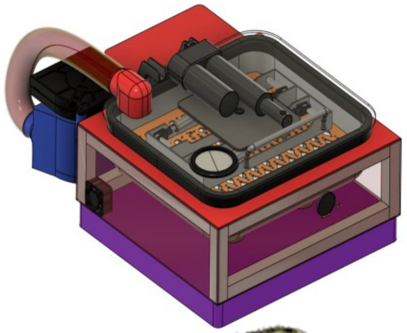
- Crew member folds and loads garment into the washer–dryer module.
- Ultrasonic washing cycle (~10 min): High-power ultrasonic transducers generate cavitation in a shallow water layer, removing oils, salts, particulates, and microorganisms from textile fibers.
- Drain cycle: Wash water is removed and routed to downstream water processing.
- Ultrasonic drying cycle: Direct-contact ultrasonic dryer modules mechanically eject bulk water from the fabric as a fine cold mist, eliminating the need for evaporation.
- Water capture unit: Centrifugal separator captures mist and liquid droplets; collected water is drained for recovery.
- Final drying cycle: Low-power thermal drying removes residual moisture to achieve desired garment dryness.
- HEPA-filtered airflow ensures clean air return to the habitat environment.
- Integrated sensors, controls, and automation enable a compact, crew-friendly laundry system for space habitats.





Upgraded Design

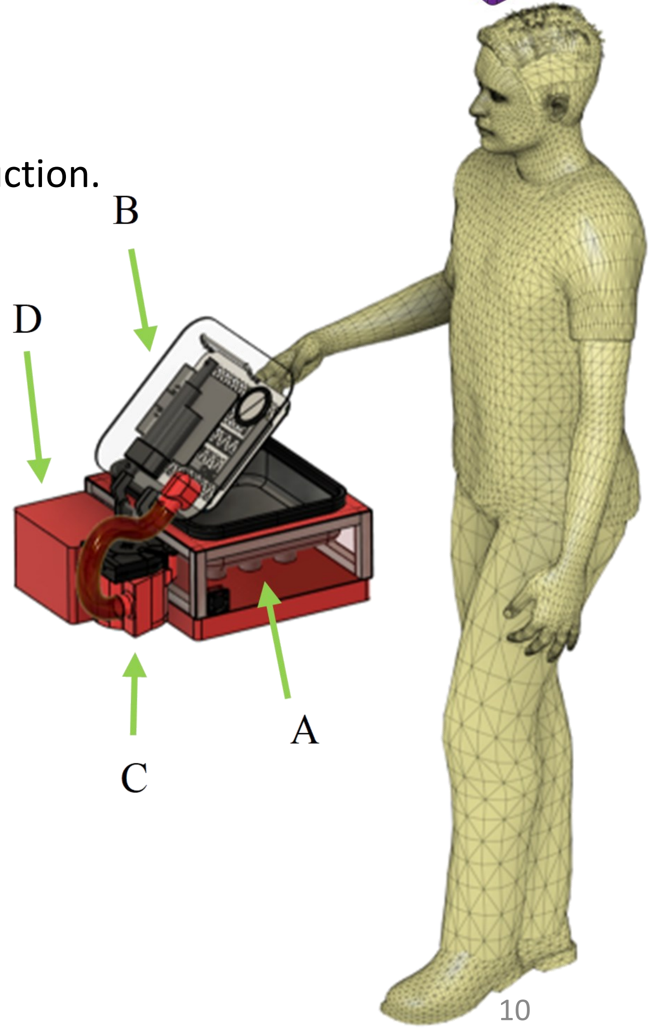




Objective: Reduce system size, improve integration, and prepare for parabolic flight testing.

Key Design Improvements

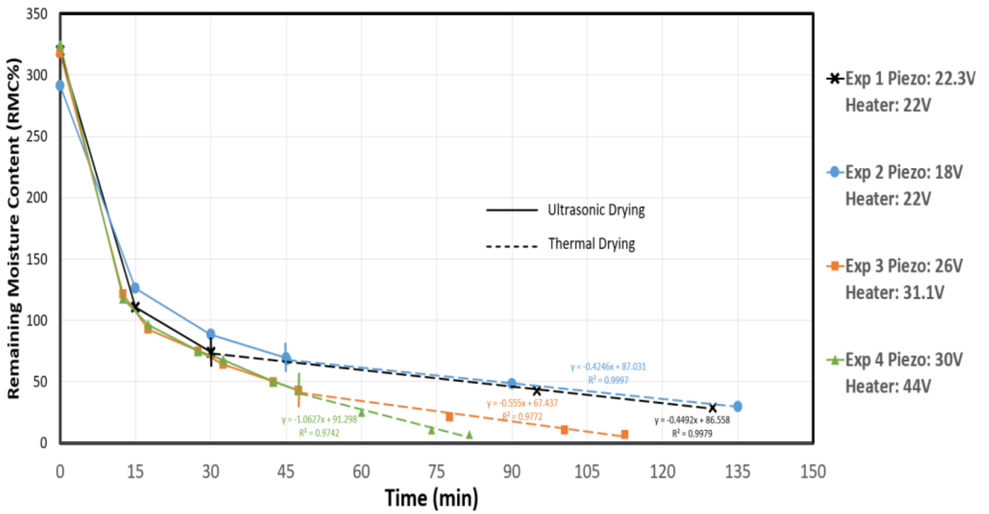
- Redesigned water-capture unit with multiple generations of optimization and size reduction.
- Miniaturized actuators, ultrasonic cleaning basin, and linear actuator system.
- Improved packaging and component integration for greater volume efficiency.
- Enhanced controls, sensors, and human-machine interface.
- Design configured for autonomous operation with minimal crew interaction.



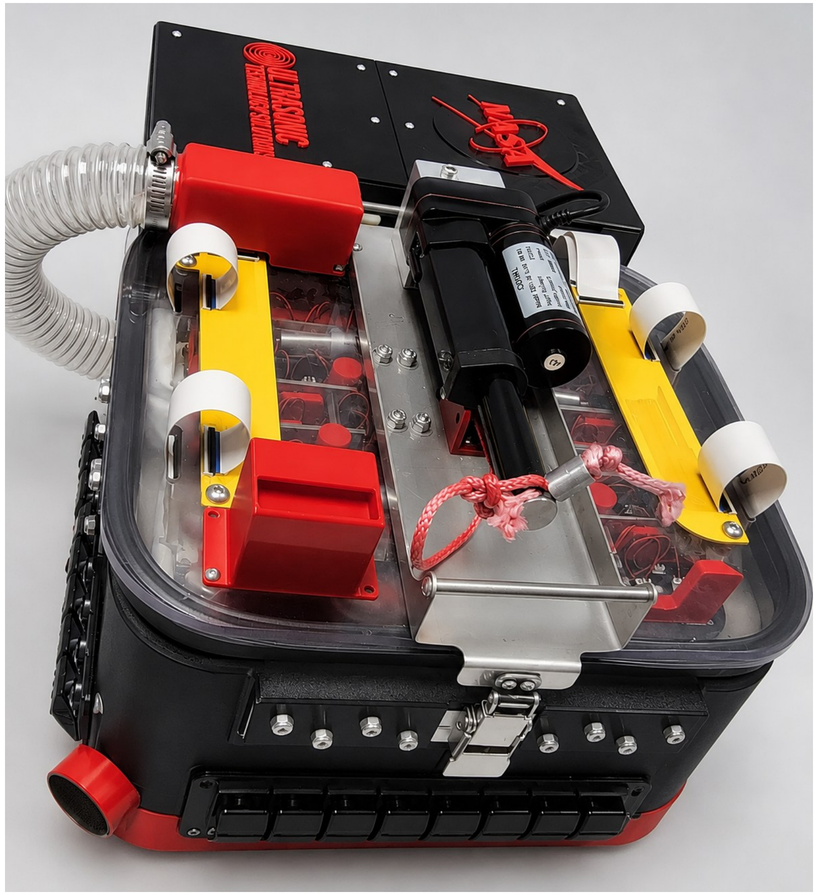
Upgraded Prototype

- Dimensions: 484 × 366 × 239 mm
- Total volume: ~44 liters
- >50% volume reduction compared with the previous 93-liter alpha prototype.
- Integrated subsystems:
- Ultrasonic cleaning basin
- Direct-contact ultrasonic dryer
- Water-capture/separation unit
- Electronics and controls package

Flight Readiness Activities



- Fabrication of upgraded prototype completed.
  - Fully Enclosed
  - Switch Panels Enable Manual Control for Short Duration Actions
- 50-cycle washing and drying reliability campaign underway.
- Water recovery characterization and downstream processing assessment.
- Preparation for parabolic flight evaluation and human interaction testing is underway.



Ultrasonic Cleaning Performance – Test Matrix

Objective

- Evaluate the impact of **detergent chemistry** and **ultrasonic cavitation intensity** on cleaning performance.
- Conducted in collaboration with **Procter & Gamble (P&G)**.
- **Cleaning Conditions Evaluated**
  - Water only, 110V ultrasonic cleaning
  - Water only, 50V ultrasonic cleaning
  - Tide Ultra Oxi detergent + 50V ultrasonic cleaning
  - Tide Stain Pen detergent + 50V ultrasonic cleaning
  - Traditional consumer washing machine
- **Performance Metrics**
  - Malodor reduction
  - Visible soil removal
  - Gravimetric soil removal
  - Fabric appearance and color recovery

Samples to be Cleaned During Experiment

Key Experimental Results

- **Malodor Reduction**
  - Tide Ultra Oxi + ultrasonic cleaning showed the strong odor reduction
  - Ultrasonic cleaning significantly reduced malodor compared to traditional washing.
  - Higher ultrasonic intensity (110V) improved odor removal.
- **Soil Removal**
  - Detergent chemistry strongly influenced visible soil removal.
  - Traditional washing with Tide Infinity showed strong stain-removal performance.
  - Ultrasonic cleaning effectively removed invisible soils and odor-causing contaminants.
- **Key Observation**
- Cleaning performance depends on both:
  - Cavitation intensity
  - Detergent formulation

	Malodor Panel HIGH MO towels	Malodor Panel t-Shirts Test 1	Malodor Panel t-Shirts Test 2	Color change PE	Color change PC
Water UTS 50V	38	NA	64	0.8	-0.67
Water UTS 110V	NA	87	70	NA	NA
Water Traditional	33	99	NA	7.29	-0.72
Tide Oxi UTS 50V	51	63	NA	-0.36	-0.96
Tide Oxi Traditional	40	87	57	-12.3	-4.67
Tide Infinity Traditional	NA	NA	43	-11.3	-5.92
Tide Stain Pen UTS 50V	NA	NA	NA	0.87	-1.17
Tide Stain Pen Traditional	NA	NA	NA	6.67	-3.04
	all legs had negative comments- different intensities	Tide Oxi UTS had positive comments	Tide Infinity Traditional had positive comments		

	Malodor (Soil) Presence Measured After Cleaning on Shirts Worn During Exercise
Water UTS 50V	Medium
Water UTS 110V	None
Water Traditional	High

Color Scale	Favorable Results			Unfavorable Results

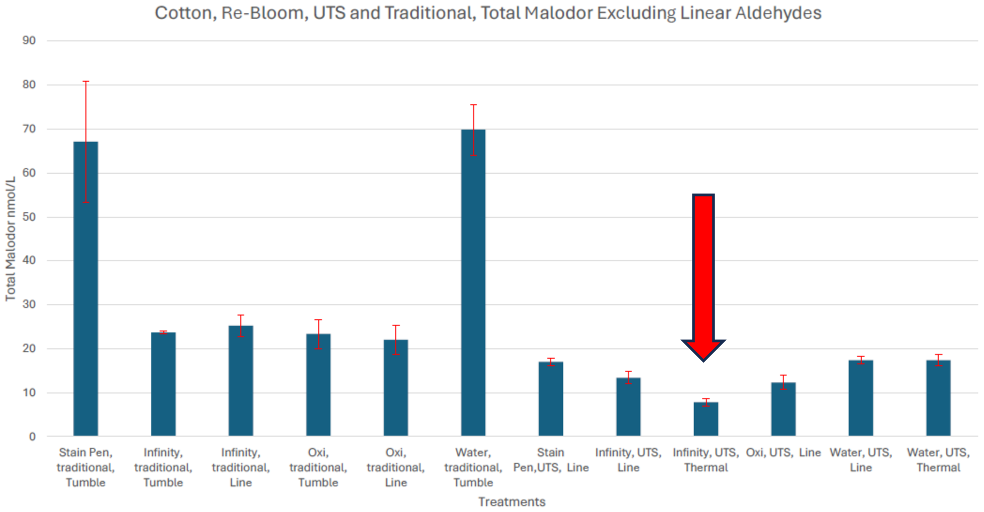
Expect to see in the next ICES conference

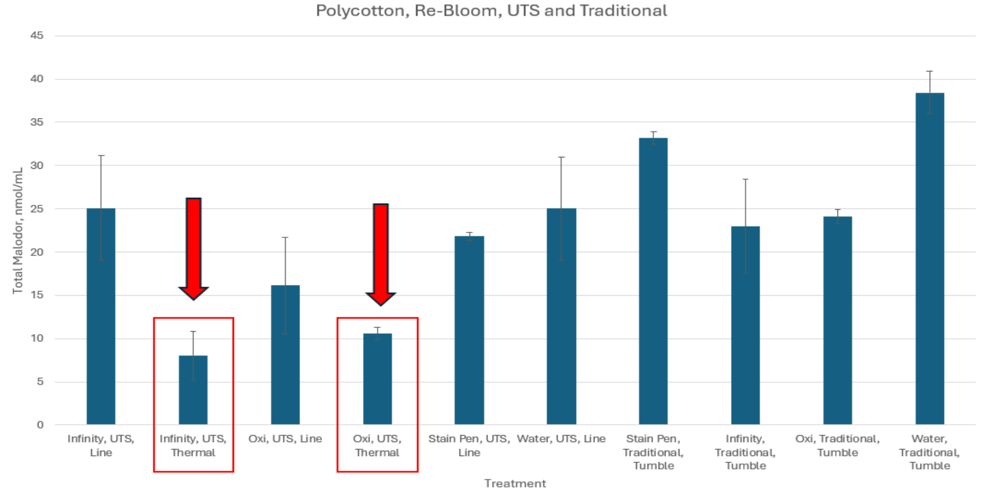
System performance and human interaction study under partial-gravity conditions.

Clothes Cleaning Testing Continuation:

- Conditions for low-water cleaning and malodor removal, utilizing ultrasonic technology and key cleaning chemistries for deep space missions
- Improve on initial learnings that identified better malodor removal (consumer panel/Gas Chromatography–Mass Spectrometry) via increased ultrasonic voltage and optimal chemistry.
- Replace initial malodor panel with a more sensitive GCMS Headspace measurement to identify specific malodor markers and the impact of voltage, drying, and chemistry on the quantitative measurements of these malodor markers.
- Continue to optimize efficient cleaning, both for malodor reduction as well as soil/lipid removal, to define the optimal conditions, including the impact of thermal drying.
- Define relevant soils to test against based on deep space planetary conditions.

The prototype demonstrated superior malodor reduction compared with conventional residential laundry machines under these test conditions





Malodor- Re-Bloom- Traditional & UTS-Cotton & Polycotton

Preliminary ESM analysis

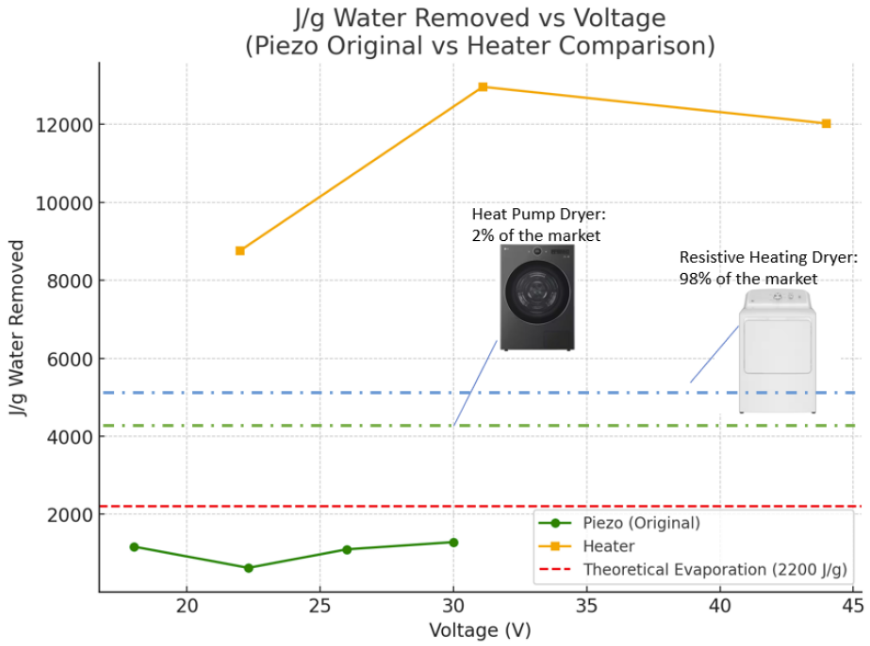
- ESM (Equivalent System Mass) includes system mass, volume, power, cooling, and crew-time impacts.
- Alpha prototype: **13.3 kg hardware mass, 93 L volume**, **ESM = 63.7–69.1 kg**.
- Upgraded design reduces system volume by **>50%** and lowers projected ESM to **~59 kg**.
- Sensitivity analysis shows **power reduction has ~5× greater impact on ESM than mass reduction**.
- Results support a compact, reusable laundry solution for future ISS, Lunar, and Mars missions.
- At such a compactness limit, now, the power consumption is the primary driver of ESM reduction.

	Performance Mode (e.g. 330W average)		Alpha Prototype	Upgraded system /Projection
	Inputs			
M	mass kg		13.29	10.00
V	pressurized volume m^3		0.09	0.04
Veq			13.40	13.40
P	total power kWe		0.33	0.25
Peq	the mass equvalent for power generation kg/kWe		87.00	87.00
C	total cooling required	kwth	0.02	0.02
Ceq	the mass equvalent for cooling infra kg/kWe	kg/kwth	146.00	146.00
CT	Total crew time required	CM-h/y	121.67	121.67
D	duration of mission y		0.20	0.20
Cteq	the mass equvalence of crew support kg/CM-h		0.96	0.96
			Combo Washer and Dryer ESM Calculated (equivalent mass)	Combo Washer and Dryer ESM Calculated (equivalent mass)
			69.03	58.57

Variable	Value ± Uncertainty	Partial Derivative	ESM reduction for -10% change in eahc vale
P	0.33 ± 0.033	∂ESM1/∂P1 = 87	-2.87
M	13.29 ± 1.329	∂ESM1/∂M1 = 1	-1.32
C	0.02 ± 0.002	∂ESM1/∂C1 = 146	-0.29
V	0.09 ± 0.009	∂ESM1/∂V1 = 13.4	-0.124
ESM	**69.49 ± 3.179**	—	—

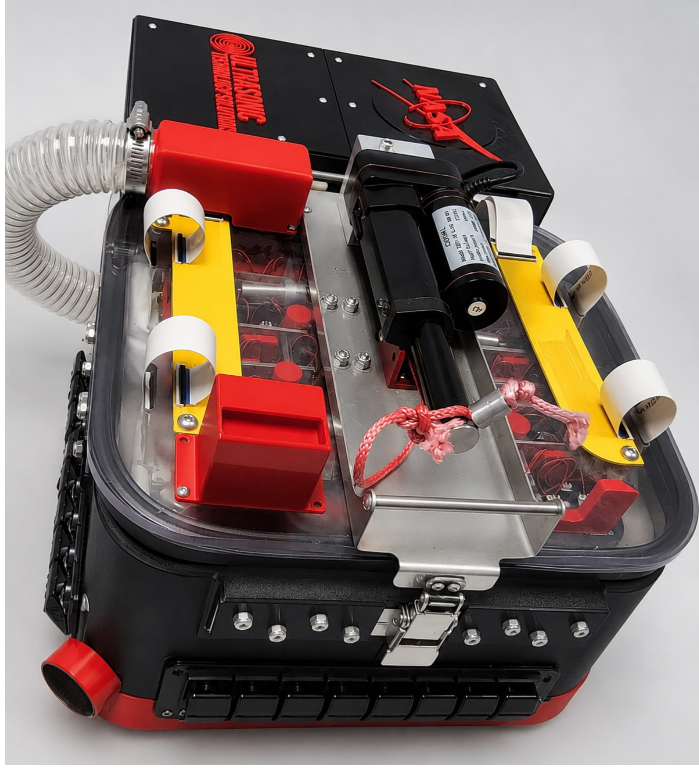
Energy Usage Comparison

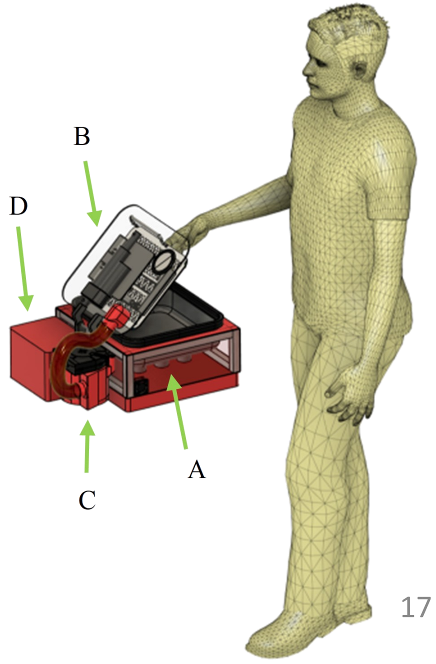
- Conventional dryers consume large amounts of energy to **evaporate water** (latent heat penalty).
- Heat-pump dryers improve efficiency but have **slow initial drying rates** and long cycle times.
- Ultrasonic drying removes water by **mechanical ejection rather than evaporation**. Measured energy consumption: **~1000 kJ/kg water removed** vs. **4000–5000 kJ/kg** for conventional residential dryers.
- Ultrasonic drying is most effective during the **high-moisture stage**, rapidly removing free water.
- The final thermal stage boosts disinfection and dryness.
- **Key Takeaway:**
  Ultrasonic drying reduced energy use by approximately 75–80% during bulk water removal compared to conventional dryers.



Conclusion

- Demonstrated autonomous washing and drying of full-sized, folded T-shirts in **83–135 minutes**.
- Ultrasonic drying removed **>75% of water in the first 30 minutes** and used **~75–80% less energy** than conventional dryers.
- Upgraded system reduced volume from **93 L to ~44 L** and lowered projected ESM to **~59 kg**.
- P&G testing showed that **ultrasonic cavitation improves malodor reduction**, while detergent chemistry drives soil removal performance.
- Superior clothes cleaning achieved
- Technology supports garment reuse, reduced logistics mass and waste, and improved crew habitability for **ISS, Lunar, and Mars missions**.
- **Takeaway:**
  Ultrasonic washing and drying offers a compact, energy-efficient, and scalable laundry solution for future long-duration space missions.





The best way to manage waste is to not generate it.

Clothing Payload Impact: Clothing accounts for 1/4 of the non-food supplies sent to the ISS.

Our Combo Clothes Washer-Dryer Provides:

- **> 97% reduction** in clothing payload mass
- **> 40X reduction** in clothing trash
- **> 15-50× lower lint production**, reducing fire risk

- **Process up to 16 T-shirts per day per machine**
- **Improving comfort and hygiene for crew members**

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ISS026-E-011334 (18 Dec. 2010) --- NASA astronaut Catherine (Cady) Coleman, Expedition 26 flight engineer, is pictured with a stowage container and its contents in the Harmony node of the International Space Station.

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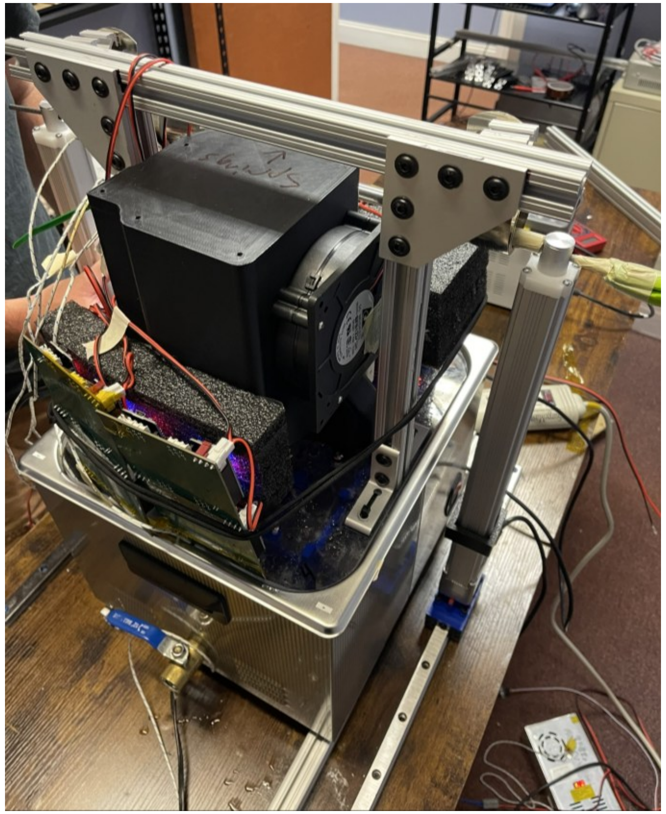
Comparing Performance Between Athletic and Cotton Shirts

Cotton Shirt Test Setup

(same conditions as athletic shirt)

- Garment folded into 8 layers
- 10 min Ultrasonic Cleaning
- 45 min Ultrasonic Drying
  - 30V input
- 44V Heater Input
  - Dried until <5% RMC



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Comparing Performance Between Athletic and Cotton Shirts

Ultrasonic Drying

- Athletic shirt ends ultrasonic drying with **less than half** the RMC of the cotton shirt (43% vs 91% RMC)

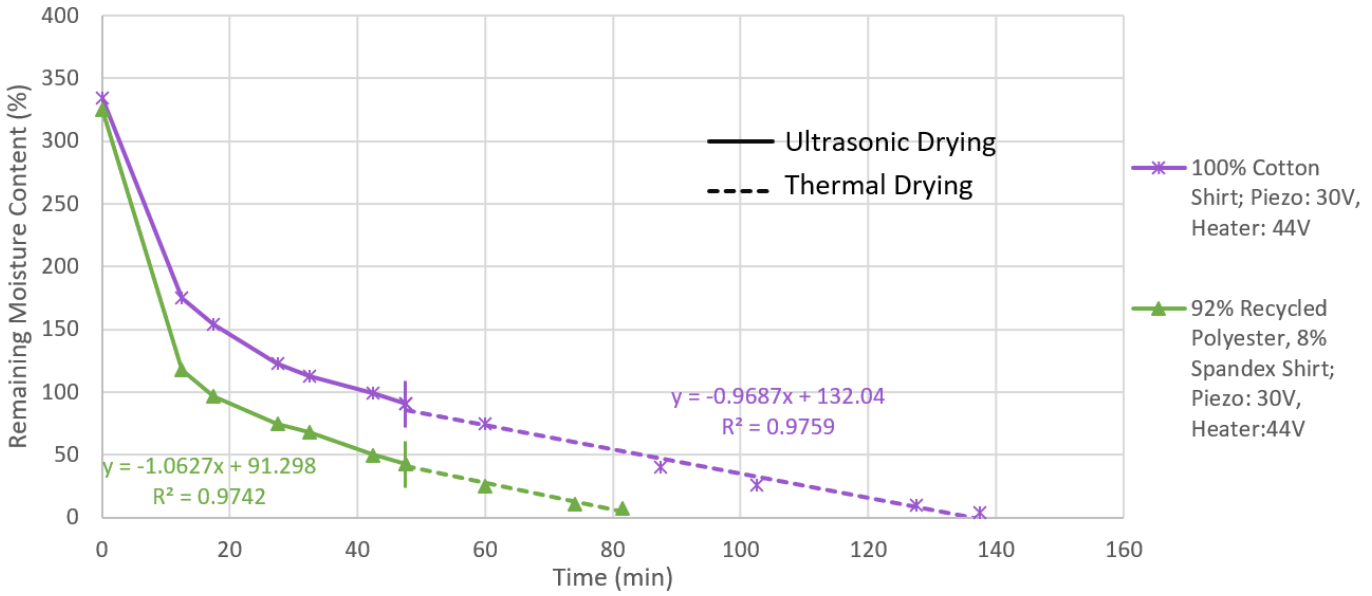
Thermal Drying

- The thermal drying rate of cotton is ~91% that of the athletic material

Ultrasonic Drying is more sensitive to the changes in material (as opposed to thermal drying)

Total Drying Time increased from

- 82 min for an athletic shirt to
- 138 min for a cotton shirt



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