Visual Analysis of Water Dispersion Patterns During Hand Drying: A Qualitative Comparison of High-Speed Air Dryers and Paper Towels

Author: Ronald Blouch Jr
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Abstract

We present a novel qualitative analysis that visually documents the water dispersion patterns of dispersal-type high-speed commercial air dryers in functioning public restrooms and contrasts them with paper towels. The videos are the data. As of publication, Dyson, Excel Dryer, World Dryer, and their certifying companies NSF International, UL Solutions, Smart EPD) do not address what occurs to the water on washed hands after dryer air jets strike it—an inescapable element of the use cycle. You cannot specify, test, build, certify, and sell a product while never addressing the output of its input. There are zero statements across an entire industry about possibly the most important element of the sanitation cycle in terms of user and restroom hygiene. Using high-speed videography under controlled lighting, we documented visible water droplet dispersion from freshly washed hands. Dispersal-type dryers explosively throw water into the surrounding environment via high-shear forces that maximize fragmentation and aerosolization. Paper towels absorb and contain water through low-shear gentle pressure, minimizing droplet formation while visibly shedding paper fibers. Our later companion study established a mean of 7.30g of water on adult male hands after washing. In dispersal dryers, that mass redistributes onto users' clothing, walls, floors, and fixtures—visible in every video. At 150 million daily US hand dryer uses, that represents 4.6 million cups of water dispersed into public restrooms daily—1.7 billion cups annually. Manufacturers and certifiers pretend it does not exist. Paper towels disperse effectively zero. This study does not directly measure microscopic true aerosols (≤5 μm), but established aerosol science indicates high-shear processes generate 100–10,000 invisible liquid aerosols for every visible droplet. The dense clouds documented in our videos represent vast numbers of respirable particles. The particle-counting debate is secondary to the mass balance: 7.30g per use must be accounted for. Dispersal dryers spray it everywhere; paper towels capture it. These findings expose a critical omission in hand dryer engineering documentation,

quantify water redistribution at population scale, and directly challenge manufacturer and certifier silence on a foundational element of device operation.

This paper is part of an eleven-study series examining hand hygiene practices in public restrooms. The papers were written in chronological order as testing evolved. Earlier papers are left largely as they were written at the time for detail, historicity, and clarity. Studies in this series may be referenced in each document by series number (Paper 1-11) or by citation number in the reference list:

Transmission of Bacteria and Fungus via Dyson and Xlerator Hand Dryers in Starbucks, Home Depot and Whole Foods Restrooms: A Comparative Analysis; Blouch, R. A. Jr. (2025) MAIN STUDY [Preprint] Retrieved from www.handdryerstudy.com/. DOI: 10.5281/zenodo.15504115 PAPER [1]

Testing the Validity of Hand Dryer Drying Time Specifications: A Quantitative Study of Residual Water on Dyson and Xlerator Dryers in Retail Store Environments; Blouch, R. A. Jr. (2025) [Preprint] Retrieved from www.handdryerstudy.com/. DOI: 10.5281/zenodo.15503698 PAPER [2]

Visual Analysis of Water Dispersion Patterns During Hand Drying: A Qualitative Comparison of High-Speed Air Dryers and Paper Towels; Blouch, R. A. Jr. (2025) [Preprint] Retrieved from www.handdryerstudy.com/. DOI: 10.5281/zenodo.15503304 PAPER [3]

Bacterial and Fungal Contamination Assessment of Paper Towel Types: A Quantitative Analysis of White versus Brown Varieties in Retail Restrooms; Blouch, R. A. Jr. (2025) [Preprint] Retrieved from www.handdryerstudy.com/. DOI: 10.5281/zenodo.15504144 PAPER [4]

Systematic Performance Failure in Commercial Hand Dryers: A Large-Scale Quantitative Analysis of Time-To-Dry on Hands in Dyson and Xlerator Hand Dryers in Public Restrooms; Blouch, R.A Jr. (2025) [Preprint] Retrieved from www.handdryerstudy.com/. DOI: 10.5281/zenodo.17858443 PAPER [5]

Baseline Water Mass on Freshly Washed Hands: Establishing Reference Values; Blouch R. A. Jr. (2025) [Preprint] Retrieved from www.handdryerstudy.com/. DOI: 10.5281/zenodo.17858834 PAPER [6]

An Empirical Refutation of Green Energy Claims for Dyson and Xlerator Hand Dryers in Use in Public Restrooms; Blouch, R. A. Jr. (2025) [Preprint] Retrieved from www.handdryerstudy.com/. DOI: 10.5281/zenodo.17859198 PAPER [7]

Catastrophic Time-To-Dry Failures by Dyson, Excel and World Dryer Hand Dryers via the Bi-Modal Loose Water and Bound Water Mechanism: A Comprehensive Definitive Analysis; Blouch, R. A. Jr. (2025) [Preprint] Retrieved from www.handdryerstudy.com/. DOI: 10.5281/zenodo.17869567 PAPER [8]

Validation of Hand Dryer Microbial Amplification Using Broad-Spectrum Growth Media: A Replication Study with Enhanced Detection Methodology; Blouch, R. A. Jr. (2025) [Preprint] Retrieved from www.handdryerstudy.com/. DOI: 10.5281/zenodo.17859894 PAPER [9]

The Wandering Plume of Filth: A Randomized, Empirical Assessment of Visible Wall Contamination Radiating from Commercial Hand Dryers Versus Paper Towel Dispensers in Functioning Public Restrooms; Blouch, R. A. Jr. (2025) [Preprint] Retrieved from www.handdryerstudy.com/. DOI: 10.5281/zenodo.17860971 PAPER [10]

Performance Failures in Commercial Hand Dryers: An Historical Synthesis and Sequential Summary Review of an Eleven-Study Research Program; Blouch, R. A. Jr. (2025) [Preprint] Retrieved from www.handdryerstudy.com/. DOI: 10.5281/zenodo.18322481 PAPER [11]

1. Introduction

Hand drying is a critical component of hand hygiene, with substantial implications for public health. Previous research has established that wet hands transfer significantly more bacteria than dry hands. Patrick et al. [1] demonstrated that residual moisture determines the level of bacterial transfer following hand washing, making the efficacy of hand drying methods an important consideration. Comprehensive government, professional certifying companies, and manufacturers' guidelines on hand hygiene practices emphasize the importance of thorough hand drying to reduce microbial transmission risk. Boyce and Pittet [2] provided extensive recommendations for hand hygiene practices in healthcare settings. The Centers for Disease Control and Prevention [31] further emphasizes environmental infection control measures that include consideration of hand drying method impacts on facility contamination. However, significant controversy exists regarding the relative hygiene of different hand drying methods, particularly concerning the potential for these methods to disperse water droplets and microbial aerosols into the surrounding environment. A systematic review of the evidence by Huang et al. [3] noted inconsistent findings across studies and highlighted the need for more research on the comparative hygiene of different drying methods.

This study introduces a functional taxonomy for hand drying devices based on water destination. **Dispersal-type dryers** remove water from hands by high-velocity air that disperses water into the surrounding environment—onto users, walls, floors, fixtures, and into the air. **Capture-type dryers** remove water and collect it in an integrated reservoir. Paper towels function as capture-type devices, absorbing and containing water for disposal. This taxonomy (Blouch, 2025) clarifies a distinction absent from manufacturer documentation and certification standards: where does the water go?

As of publication no dryer manufacturer, certifying company, or government agency has written a single word in their product material regarding the management or destination of water after the air jets strike it at the output of a dispersal dryer. NSF International specifies rules for capture devices. Section 5.7 states that testing criteria involves water containment (NSF P335 [32]) but makes no requirement for testing or a standard for processing it.

Dispersal-type dryers, which constitute the vast majority of installed units including all Dyson Airblade and all Excel Dryer/Xlerator models, have no answer to this question in their specifications. The videos in this study provide one.

Manufacturers of high-speed air dryers have made specific claims regarding the hygienic performance of their products. Dyson LTD [10] states that their Airblade hand dryers have been "proven to aerosolize no more than paper towels" and that they are "as hygienic in drying hands as paper towels." In their marketing materials focusing specifically on hygiene, Dyson further claims their HEPA filters "capture 99.97% of particles." Similarly, Excel Dryer, Inc. [11] makes claims about the hygienic benefits of their dryers, stating they "offer a 99.99% reduction in bacteria and viruses."

The primary study supporting Dyson's aerosolization equivalence claim is Gião & Vardoulakis (2022) [16]. This study warrants scrutiny. The lead author (Gião) is a Dyson Technology Ltd. employee. The co-author (Vardoulakis) was a member of the Dyson Scientific Advisory Board and received Dyson research funding and honoraria. The study was "financially supported by Dyson Technology Ltd." and the authors acknowledge "the funder had involvement in the conceptualization of the study." This is not independent research—it is manufacturer-funded science conducted by manufacturer employees.

More significantly, the study's own data contradict its conclusions. Gião & Vardoulakis found that jet air dryers produced approximately 6.63×10^6 particles m^{-3} in the smallest measured size range (0.3–0.5 μm), while paper towels produced 3.49×10^6 particles m^{-3}—jet dryers generated nearly twice the concentration of small, respirable aerosols. For larger particles (≥5.0 μm), paper towels produced more: 2.28×10^4 versus 1.05×10^4 particles m^{-3}. The authors explain this discrepancy: "Aerosols generated by jet air dryers are likely to be liquid aerosols, while aerosols from drying hands with paper towels may contain dust from the paper."

The claim of "no significant difference" rests on conflating wet, pathogen-carrying liquid aerosols with dry paper fibers. These are categorically different hygiene outcomes. Small liquid aerosols (≤5 μm) remain suspended in air for minutes to hours and penetrate deep into the respiratory system. Large paper dust particles settle rapidly and pose minimal inhalation risk. Jet dryers produce more of the former; paper towels produce more of the latter. Calling total particle counts "equivalent" obscures this distinction.

The study's methodology further limits generalizability. All four dryer models tested were equipped with HEPA filters—a feature absent from most installed units in the field. Testing occurred in a clean chamber with purged air, ventilation disabled, and volunteers wearing coverall suits cleaned with 70% ethanol. These sterile conditions bear no resemblance to active public restrooms. Most critically, dryers were operated for manufacturer-specified times (10–14 seconds)—durations our companion study (Blouch [5]) demonstrates leave hands with 2.83g residual moisture, requiring users to continue drying for 45–90 seconds to achieve actual dryness. Aerosol generation during real-world extended drying would be proportionally greater.

Independent studies have found substantially higher levels of microbial dispersion associated with high-speed air dryers compared to paper towels, as documented in our companion microbial study (Blouch [4]).

Additionally, manufacturers make specific claims about drying efficiency that warrant scrutiny. Dyson [10] advertises complete hand drying in 10-12 seconds, while Excel Dryer, Inc. [11] claims just 8 seconds. However, our companion study by Blouch [5] has demonstrated these claims to be significantly misleading, with hands retaining approximately 39.04% of initial moisture after the manufacturer-specified drying time. This discrepancy is critical to understanding aerosol generation and water dispersion, as users typically continue drying for 45-90 seconds to achieve satisfactory dryness - dramatically increasing the duration of aerosol exposure beyond what would be expected based on manufacturer specifications.

A study by Kimmitt and Redway [8] found that viruses applied to rubber gloves were aerosolized by jet air dryers and spread further than would occur with conventional hand dryers or paper towels. Similarly, Best et al. [8] found that air bacterial counts in close proximity to a jet air dryer were 27 times higher compared to when paper towels were used. Best et al. [7] also documented significant contamination of surrounding surfaces, finding bacterial transfer to areas up to 2 meters from the drying location, suggesting extensive dispersal of water and microbes beyond the immediate drying area. Manufacturers [10][11] have contested those findings, arguing that the studies "were not conducted under conditions or scenarios that simulate real life" and that researchers contaminated gloved hands without washing them first, creating unrealistic test conditions.

The contradictory nature of these claims highlights the need for additional evidence that bridges the gap between technical microbial studies and observable real-world outcomes.

As of the date of publication of this study Neither Dyson nor Excel Dryer specify or even mention what occurs to the water from wet hands after it is struck by the forced air jet from their wall mounted dryers anywhere on their websites or in their promotional materials. There are no manufacturer documentation or marketing materials containing any discussion of where the water removed from users' hands actually goes. Excel Dryer [11] makes a single comment on its website that water from certain models "drips onto the floor, where it evaporates naturally.”

Our observations reveal a more complex and concerning pattern of dispersion.

Recent work by Hervé et al. [27] documented contamination on surfaces up to 3 meters from hand dryers, indicating significant water dispersal throughout the environment, matching the evidence of the videos in this document.

This study aims to provide that bridge through a unique qualitative visual presentation of water dispersion patterns during hand drying with paper towels and forced air hand dryers, using high-speed videography under controlled lighting conditions to make visible what is typically invisible to the naked eye. Our approach addresses two key questions: (1) the liquid aerosolization potential of different drying methods and (2) the destination of water removed from hands during the drying process.

In the context of aerosol science, it is important to distinguish between true liquid aerosols and visible droplets. Aerosols are typically defined as particles ≤5 μm in diameter, which remain suspended in air for extended periods and are invisible to the human eye. Visible droplets, generally ≥40 μm in diameter, can be observed under proper lighting conditions and settle more quickly due to gravitational forces. Baron and Willeke [12] provided comprehensive explanations of these distinctions in their work on aerosol measurement. This distinction is crucial when evaluating hand drying methods, as true aerosols pose greater risks for pathogen transmission due to their longer suspension times and ability to reach the deep lung when inhaled.

Fundamental particle settling physics demonstrates the practical significance of these size distinctions. Water droplets in the intermediate size range of 10-1000 μm—invisible to the naked eye but larger than true aerosols—exhibit hang times ranging from 10 seconds to 10 minutes in still air under standard atmospheric conditions. This extended suspension time provides ample opportunity for environmental dispersion during the 45-90 second actual drying times observed in practice, far exceeding the manufacturer-specified 8-12 second drying periods. Particles smaller than 5 μm remain airborne for hours to days, while those larger than 2 mm settle within seconds, creating a sharp "physics cliff" in settling behavior that correlates directly with transmission risk.

A fundamental principle in aerosol science is that the mechanical processes generating droplets significantly influence their size distribution. High-shear processes, such as those created by high-speed air dryers operating at 400-640 km/h (192 m/s), produce dramatically different outcomes compared to gentle, low-shear processes like absorption with paper towels. Lefebvre [20] and Villermaux [16] described these differences in their respective works on atomization and fragmentation. This difference represents two extremes on the aerosol generation spectrum, with quantifiable physical consequences. Established settling velocity measurements reveal a sharp transition in particle behavior at 1-2 mm diameter, where droplets shift from immediate "stone-like" settling to extended suspension times. Above 2 mm, all water droplets reach the vacuum speed limit of 7.0 m/s (the maximum possible falling speed from room height), settling within 0.4 seconds. Below 1 mm, settling times extend to minutes and hours, creating optimal conditions for environmental dispersion and cross-contamination.

High-shear processes fragment water into polydisperse sprays where tiny aerosols (≤5 μm) typically outnumber visible droplets (≥40 μm) by factors of 100-10,000:1. Morawska et al. [16] and Johnson et al. [17] documented this phenomenon in their studies of respiratory aerosols. Conversely, gentle mechanical processes like those involved in paper towel drying predominantly produce large droplets with minimal fragmentation, resulting in proportionally fewer microscopic aerosols. Villermaux [16] and Lefebvre [20] established these principles in their respective works. This fundamental contrast in aerosol production mechanisms---not just the quantity of visible droplets---underlies the hygiene differences between these drying methods.

While our approach does not directly measure microscopic aerosols, it provides valuable insights into the dynamics of droplet dispersion during different hand drying methods and aerosol production by proxy. Principles of fluid dynamics establish that the mechanical forces visible in our study directly correlate with aerosol generation patterns. Xie et al. [14], Bourouiba [15], and Morawska et al. [15] have all demonstrated these correlations in their research. Therefore, visible dispersion serves as a reasonable baseline for evaluating relative potential for aerosol generation between these fundamentally different drying methods.

The primary research questions of this study are: (1) Does the observable pattern of water dispersion during hand drying differ substantially between high-speed air dryers and paper towels in a way that would challenge manufacturer claims of equivalent aerosolization? (2) Where does the water removed from hands during air drying actually go, and how does this compare with manufacturer documentation? (3) Do these observable patterns align with the theoretical expectations for high-shear versus low-shear processes according to established principles in aerosol science?

2. Methods

2.1 Study Design

This study employed a comparative observational design to document water dispersion patterns during hand drying using two methods: high-speed air dryers and paper towels. For each method, 10 complete drying trials were conducted and recorded. The study was designed to observe both the aerosolization characteristics and the destination of water removed from hands during the drying process.

2.2 Test Environment

2.2.1 Commercial Restroom Setting (Air Dryer Tests)

Testing of air dryers was conducted in public restrooms equipped with high-speed hand dryers in retail establishments including Starbucks, Whole Foods, and Home Depot locations. Lighting was enhanced using portable LED light panels positioned to optimize visibility of water droplets in the air. Background surfaces were selected to maximize contrast with water droplets. Camera angles were varied to capture both the general dispersion pattern and specific areas of water accumulation, including the user's clothing, surrounding walls, floors, and adjacent fixtures.

2.2.2 Controlled Studio Setting (Paper Towel Tests)

Paper towel drying tests were conducted in a photography studio with controlled lighting optimized for droplet visibility. The lighting setup was designed to match or exceed the droplet visualization capabilities of the commercial restroom setting, ensuring a fair comparison that would not disadvantage the air dryer tests. The same camera angles and positions used in the commercial setting were replicated to maintain consistency in observing both aerosol generation and water destination patterns.

2.3 Equipment

- High-speed camera in slow motion capture mode (1000 frames per second)
- LED lighting panels (4800 lumens)
- Tripod and camera mounting system
- Paper towels (standard commercial C-fold)
- Moisture measurement scale (accurate to 0.01g)
- Black backdrop where possible for contrast

2.4 Standardized Hand Washing and Drying Protocol

To ensure consistency across all trials:

1. Hands were washed using standard handwashing technique but without soap.
2. Hands were shaken twice over the sink to remove excess water
3. For air dryer trials, hands were inserted into the dryer and moved according to manufacturer recommendations until visibly dry (approximately 45-60 seconds)
4. For paper towel trials, hands were dried using two folded paper towels until visibly dry (approximately 15-20 seconds)
5. The user maintained a consistent standing position and posture across all trials to standardize the potential for water accumulation on clothing

2.5 Video Recording Protocol

All trials were recorded using the same high-speed camera settings:

- Slow motion, 1000 frames per second
- 1/250 second shutter speed
- f/5.6 aperture
- ISO 1600
- Fixed focal length of 50mm

Camera positioning was standardized to capture:

1. The hands during the drying process
2. The surrounding air space
3. The user's clothing, particularly the torso, arms, and legs
4. Adjacent wall surfaces and fixtures

2.8 Manufacturer Documentation Analysis

In addition to physical testing, we conducted a comprehensive review of manufacturer documentation, marketing materials, and technical specifications to identify any references to water destination or management during the drying process. This analysis included:

1. Product webpages for high-speed hand dryers
2. Technical specification documents
3. Installation guides
4. Marketing brochures and promotional materials
5. Statements regarding hygiene and performance claims

This documentation review provided context for comparing observed water dispersion patterns with manufacturer descriptions and claims about their products' performance and effects.

3. Results

3.1 Visual Droplet Dispersion: High-Speed Air Dryers

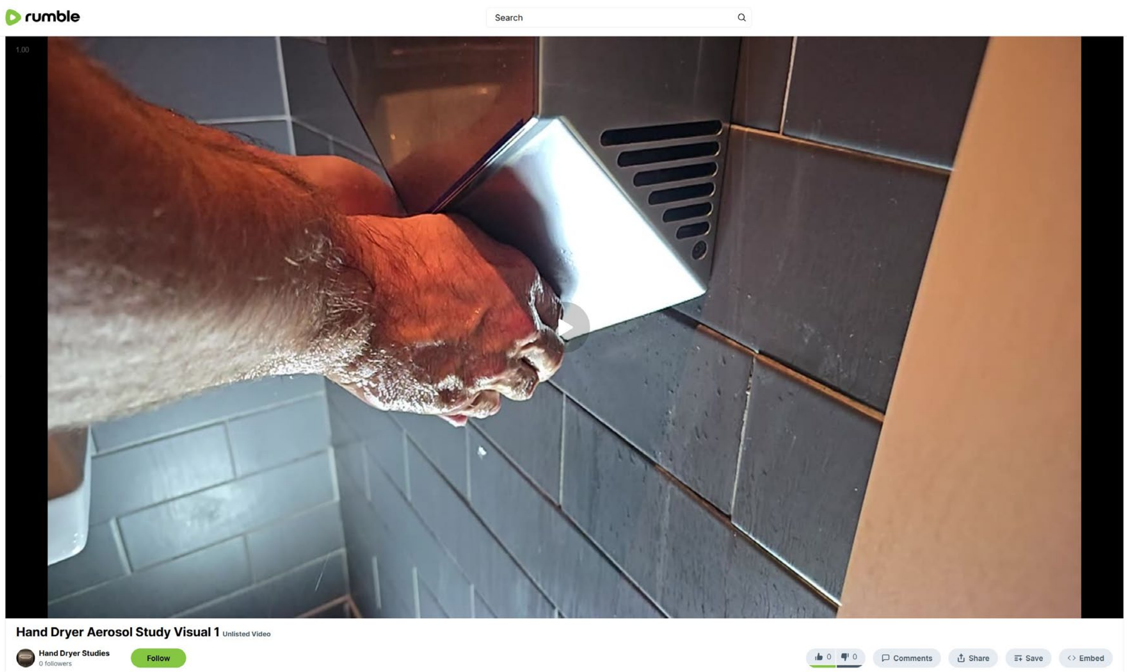
Across all 10 trials with high-speed air dryers, substantial visible water dispersion was observed. The following patterns were consistently documented:

3.1.1 Air Dryer Dispersion Patterns

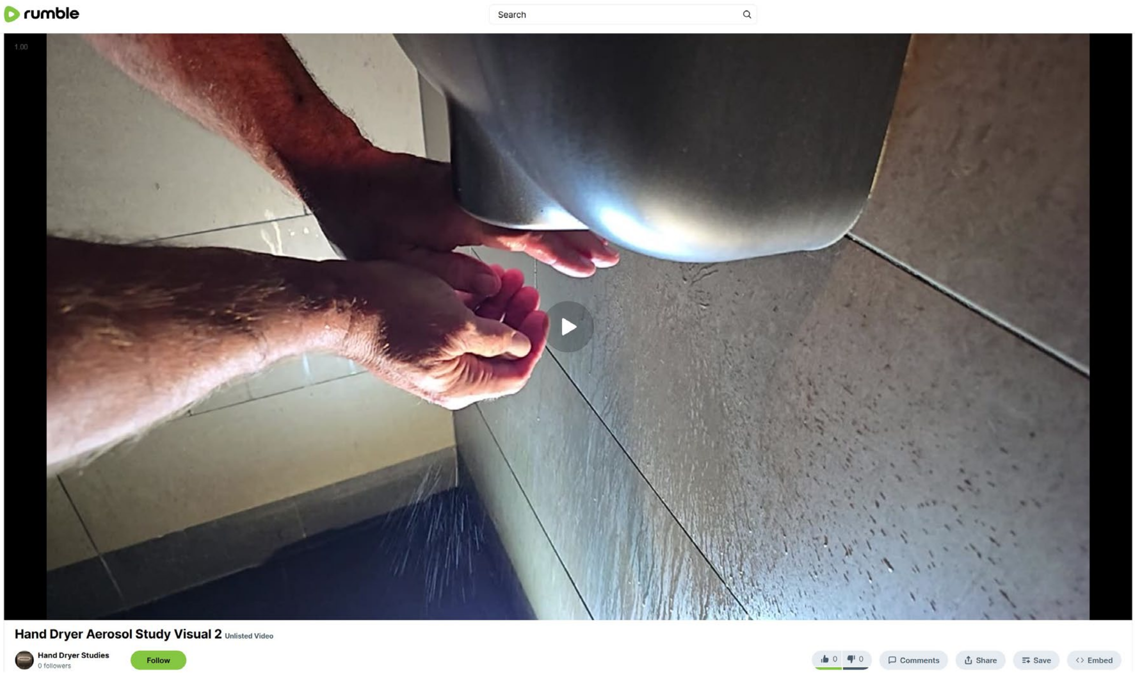
- Dense cloud of visible water droplets surrounding the hands during operation
- Significant lateral dispersion of droplets
- Visible droplets remaining airborne for 3 or more seconds
- Consistent pattern of droplets settling on surrounding walls and floor
- Multiple streams of water droplets visibly ejected from the hands toward the sides and fronts of units
- Concentrated mist formation
- Substantial backspray of water onto the user's clothing, particularly the forearms, torso, and thighs/legs
- Intense downward and outward spray patterns

- Significant accumulation of visible droplets on user's clothing and surrounding floor area

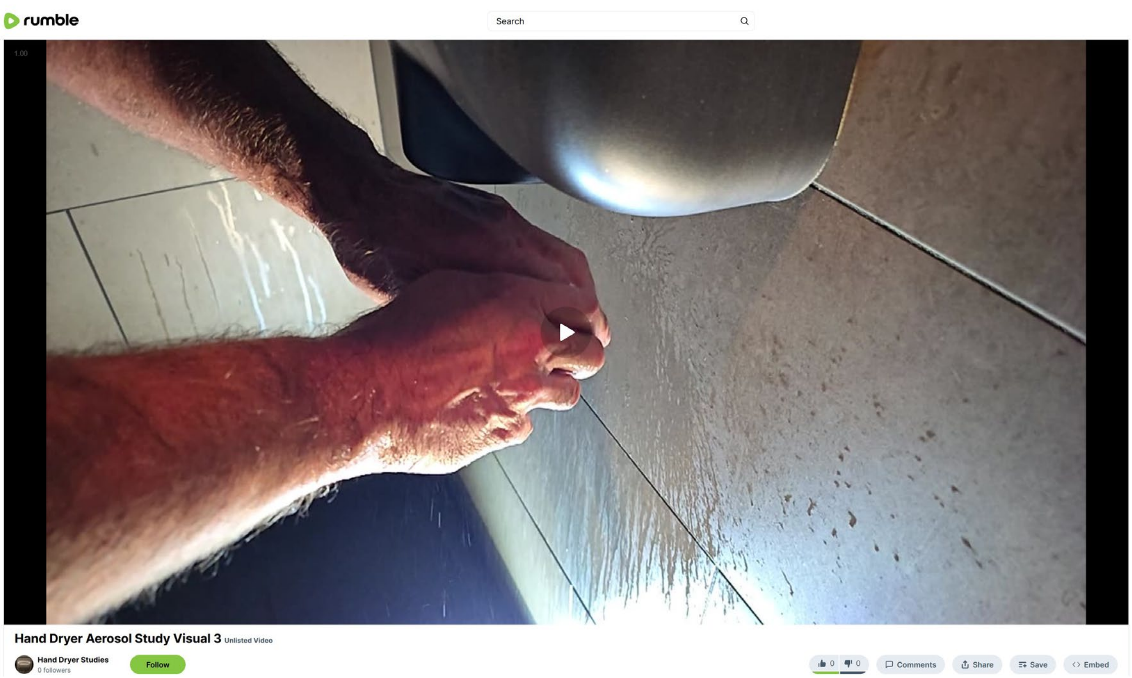
3.2 Hand Dryer Trials



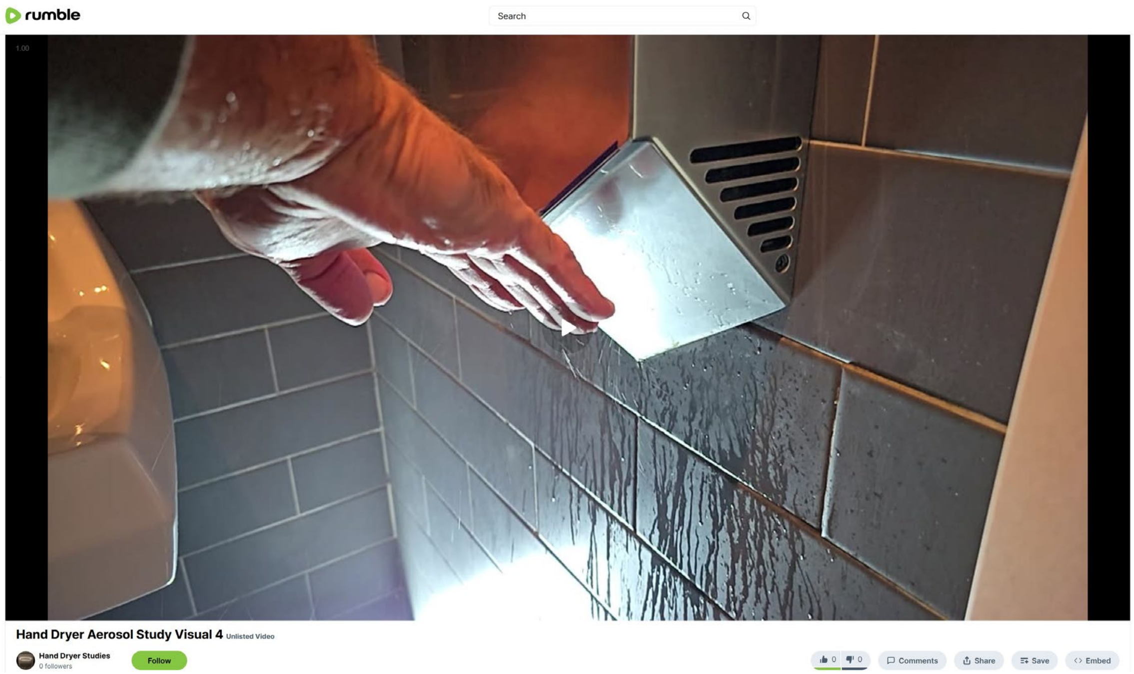
VIDEO 1: Hand Dryer Trial 1 on Rumble



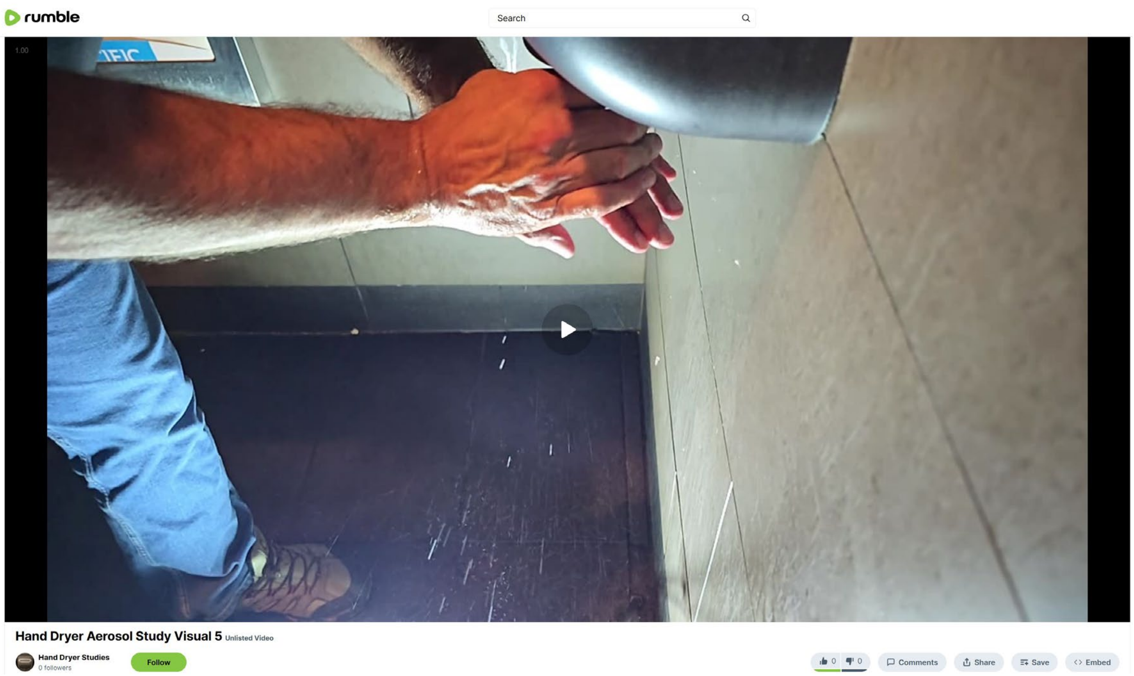
VIDEO 2: Hand Dryer Trial 2 on Rumble



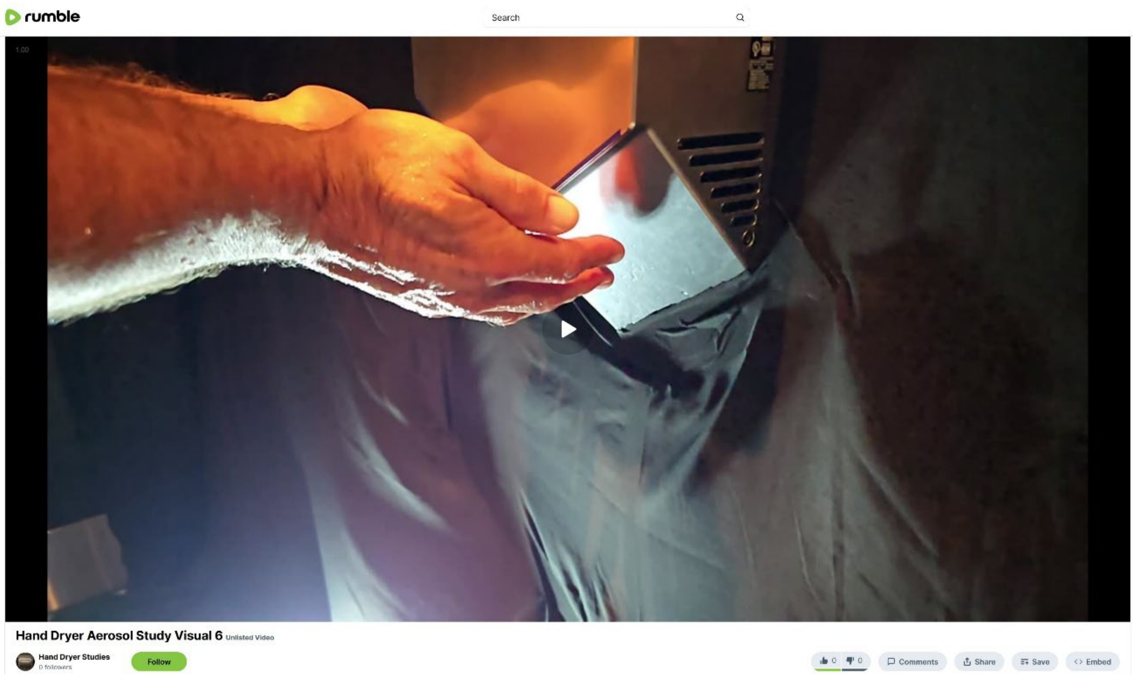
VIDEO 3: Hand Dryer Trial 3 on Rumble



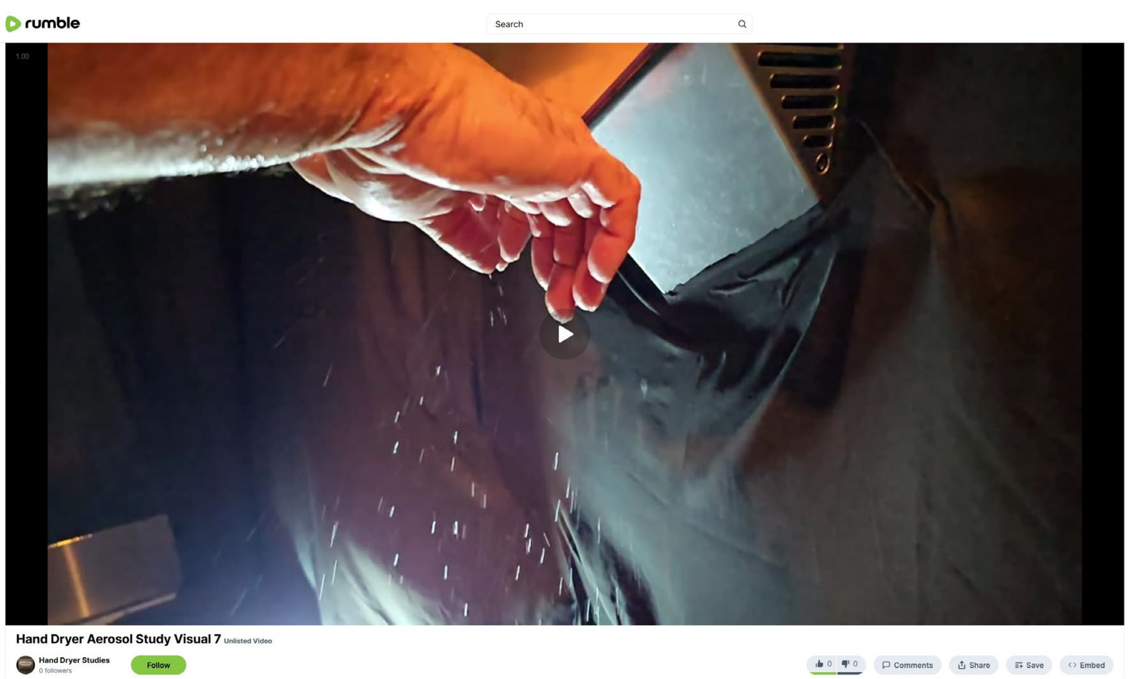
VIDEO 4: Hand Dryer Trial 4 on Rumble



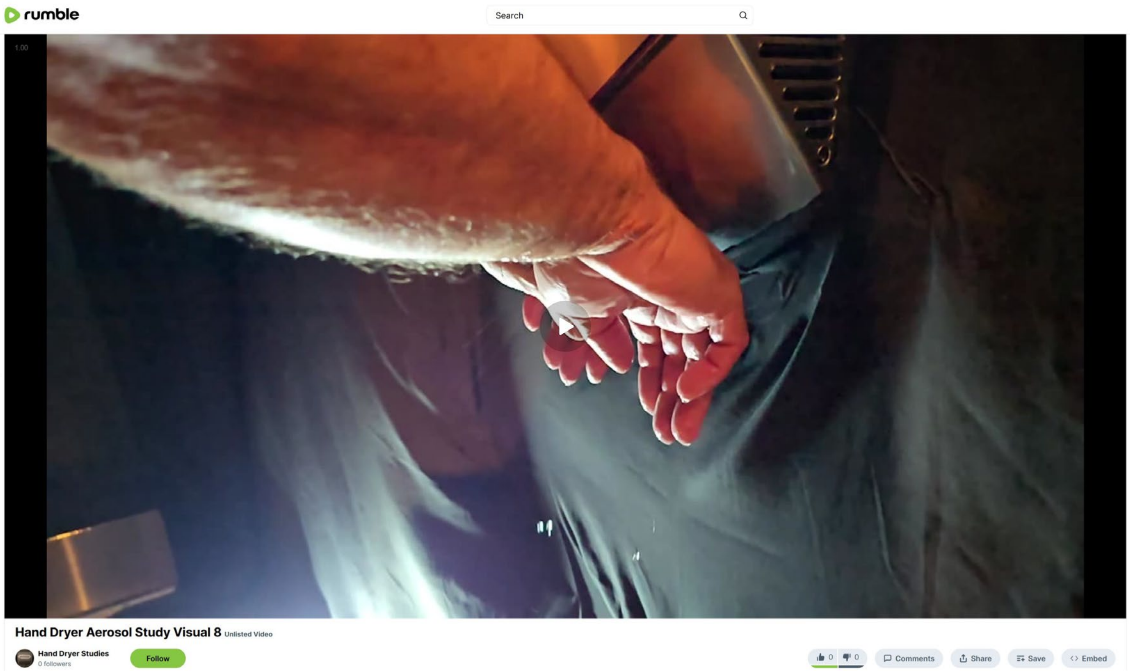
VIDEO 5: Hand Dryer Trial 5 on Rumble



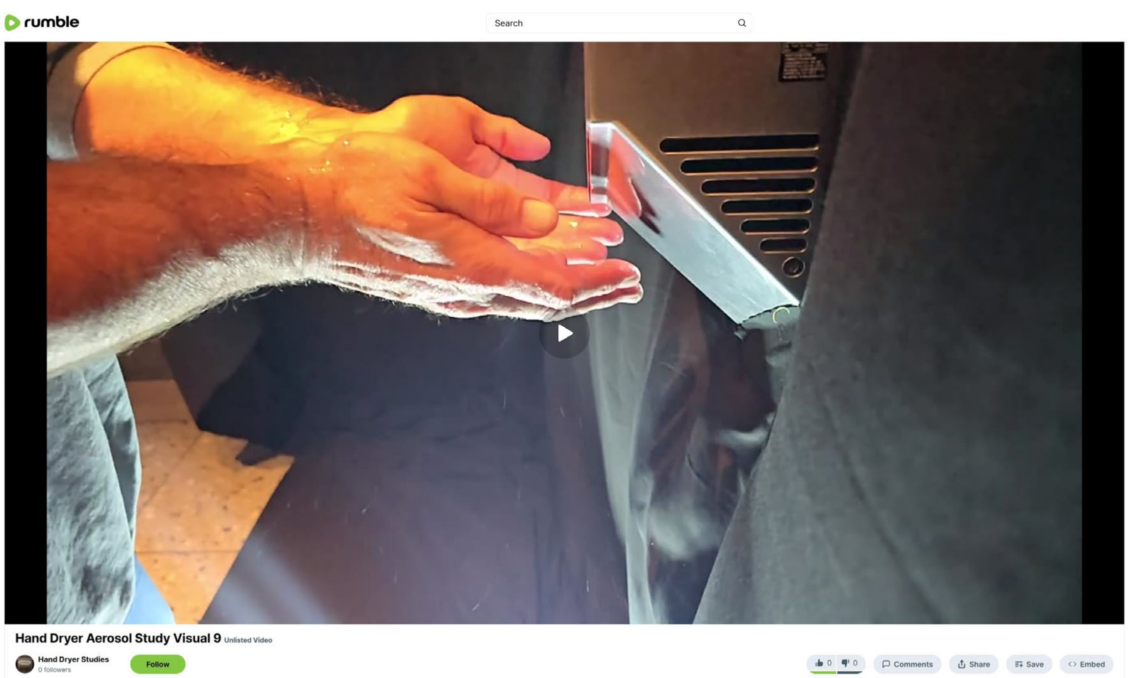
VIDEO 6: Hand Dryer Trial 6 on Rumble



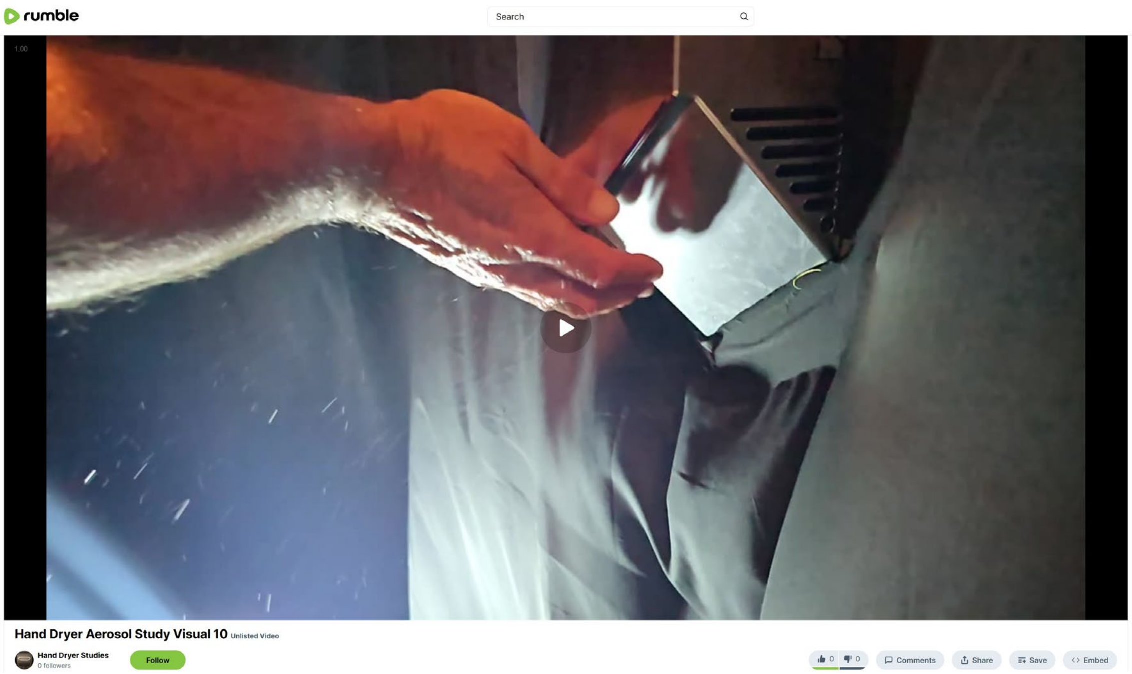
VIDEO 7: Hand Dryer Trial 7 on Rumble



VIDEO 8: Hand Dryer Trial 8 on Rumble



VIDEO 9: Hand Dryer Trial 9 on Rumble



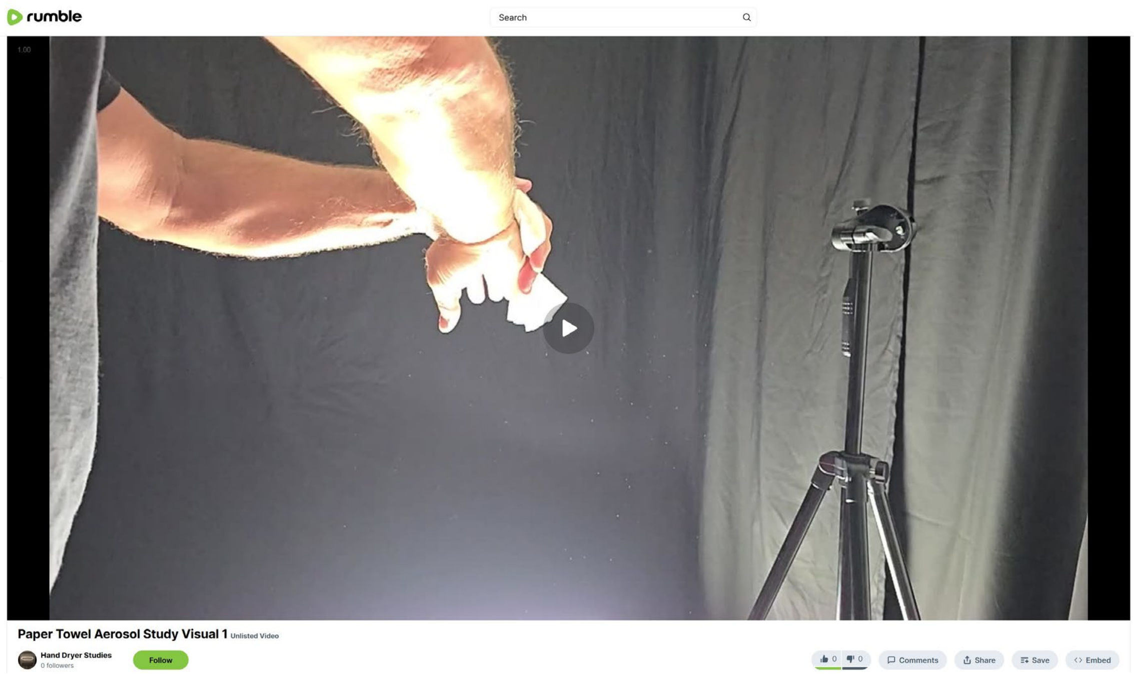
VIDEO 10: Hand Dryer Trial 10 on Rumble

3.3 Visual Droplet Dispersion: Paper Towels

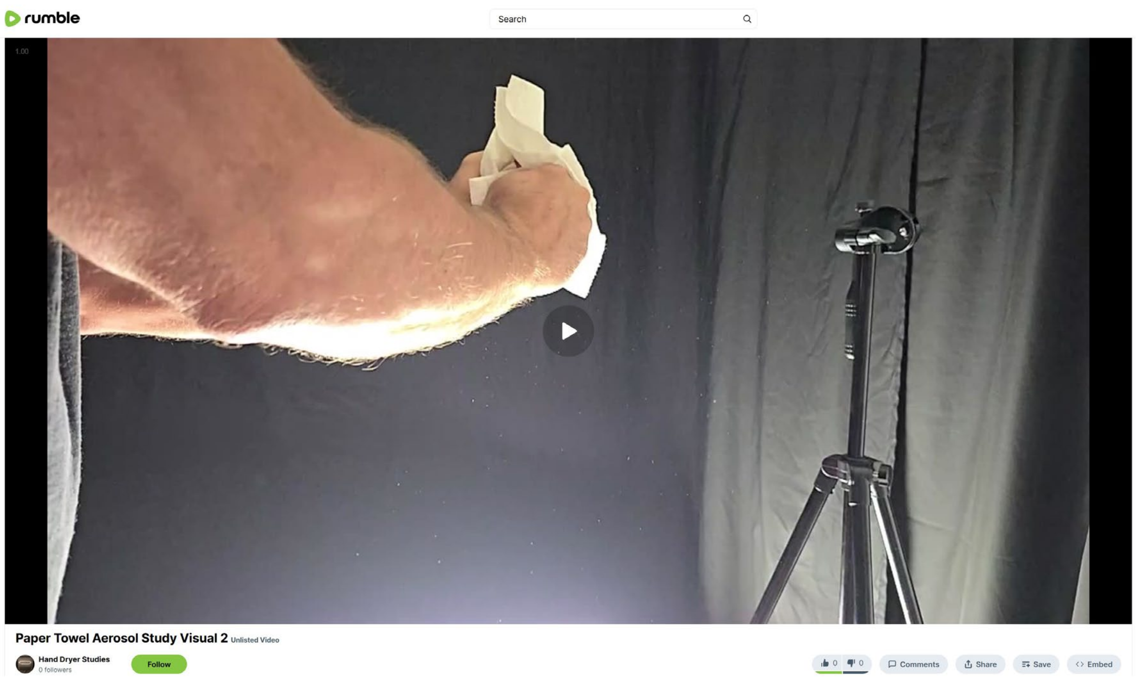
In contrast to the air dryer trials, the paper towel drying method demonstrated minimal visible droplet dispersion across all 10 trials. The following patterns were consistently observed:

- Few to no visible droplets in the air surrounding the hands
- Occasional large droplets falling directly downward
- No lateral dispersion of droplets beyond the immediate hand area
- No visible droplets remaining airborne after completion of drying
- Contained moisture absorption within the paper towel material
- No observable water accumulation on the user's clothing
- Little water dispersion to surrounding surfaces

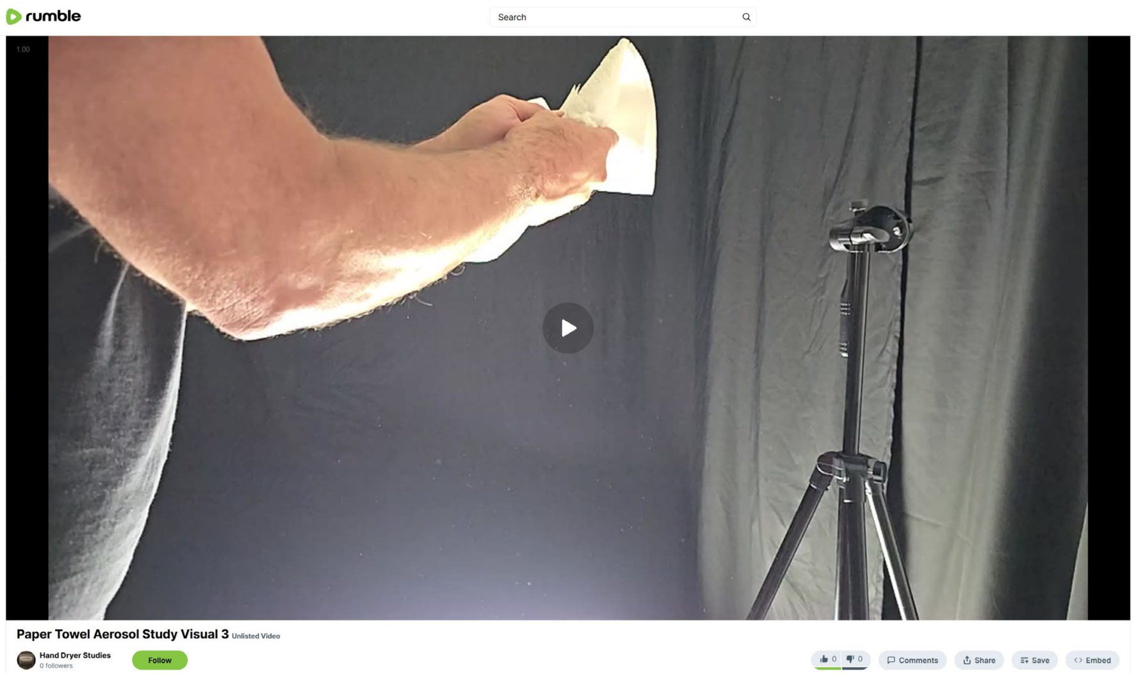
3.4 Paper Towel Trials



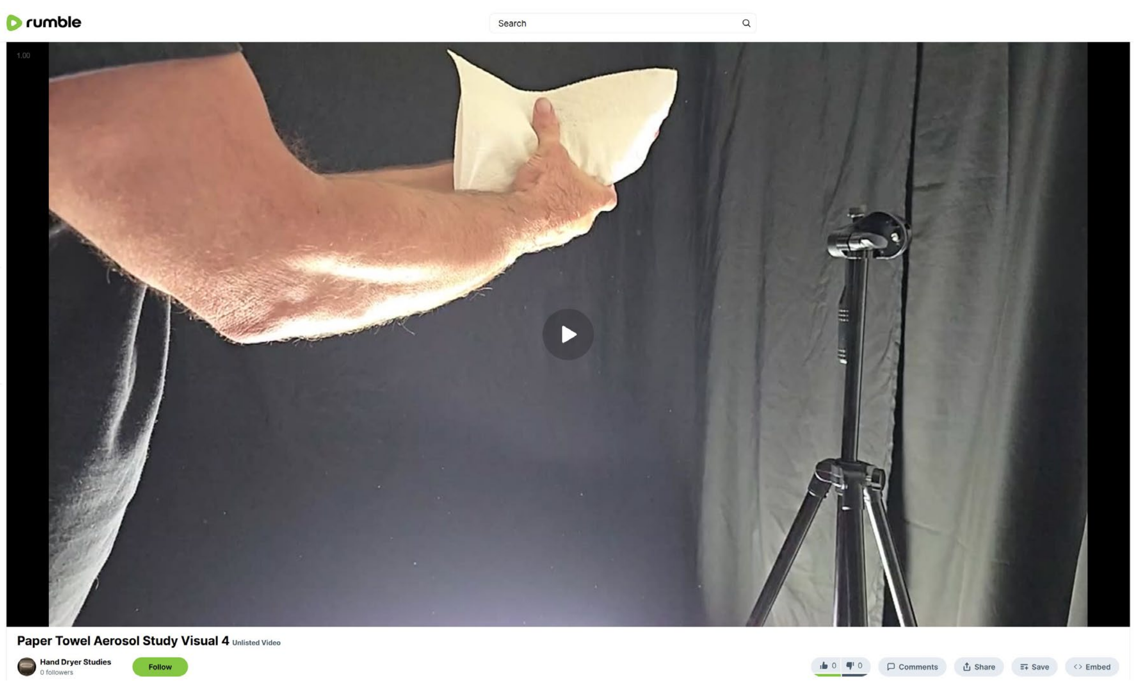
VIDEO 11: Paper Towel Trial 1 on Rumble



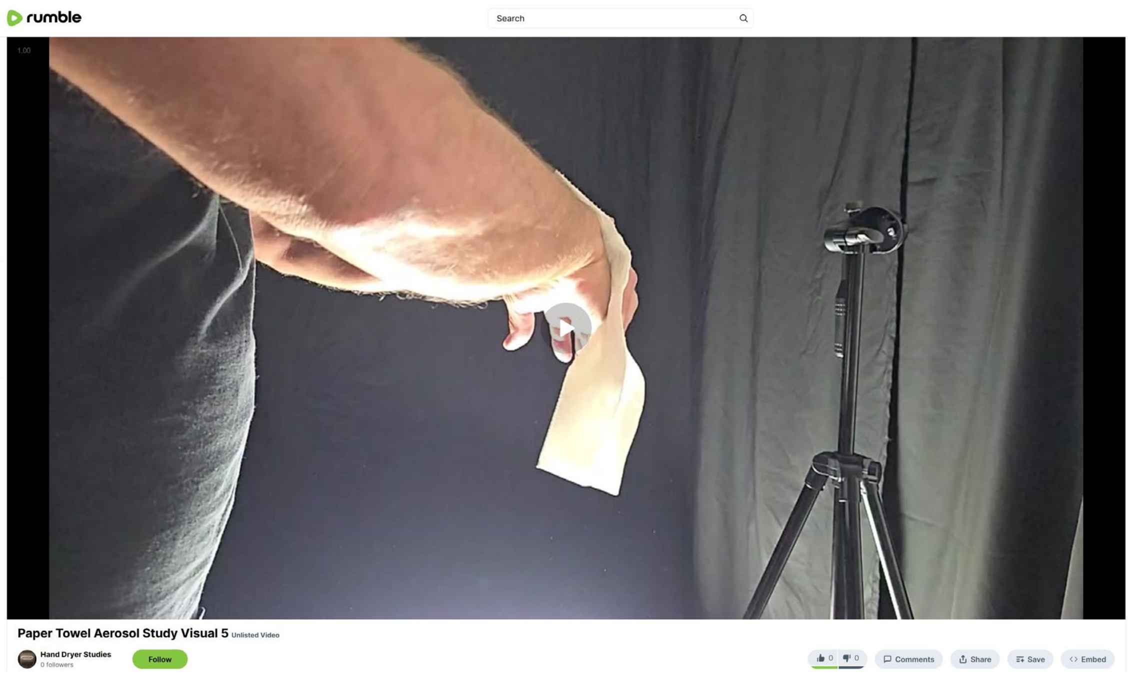
VIDEO 12: Paper Towel Trial 2 on Rumble



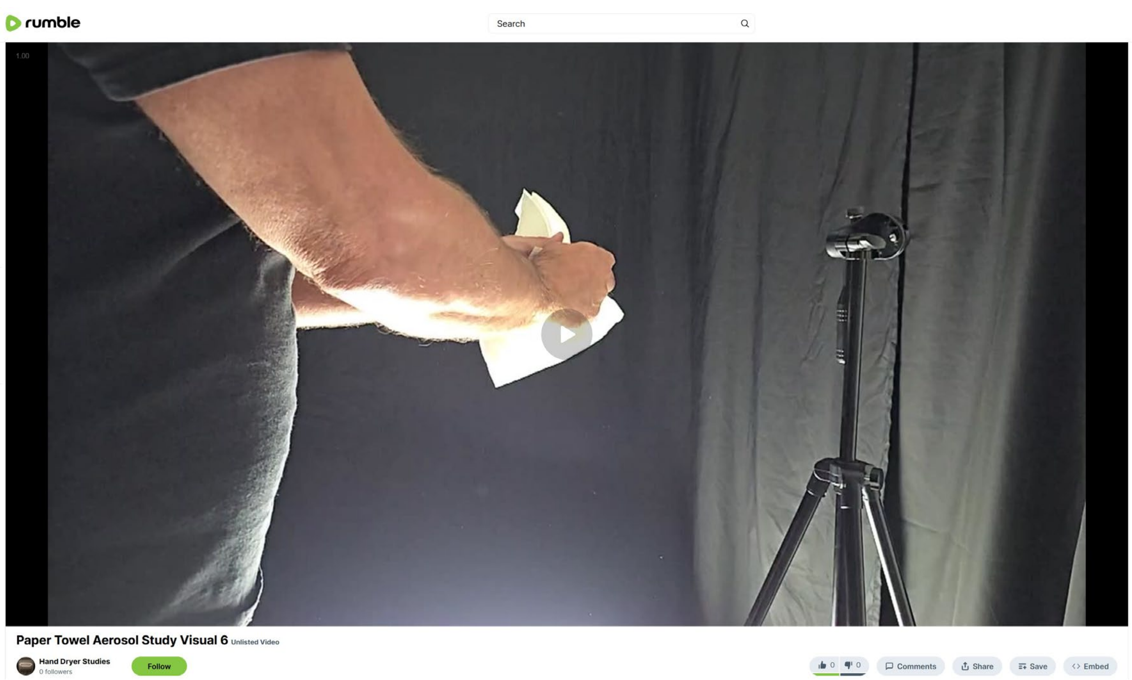
VIDEO 13: Paper Towel Trial 3 on Rumble



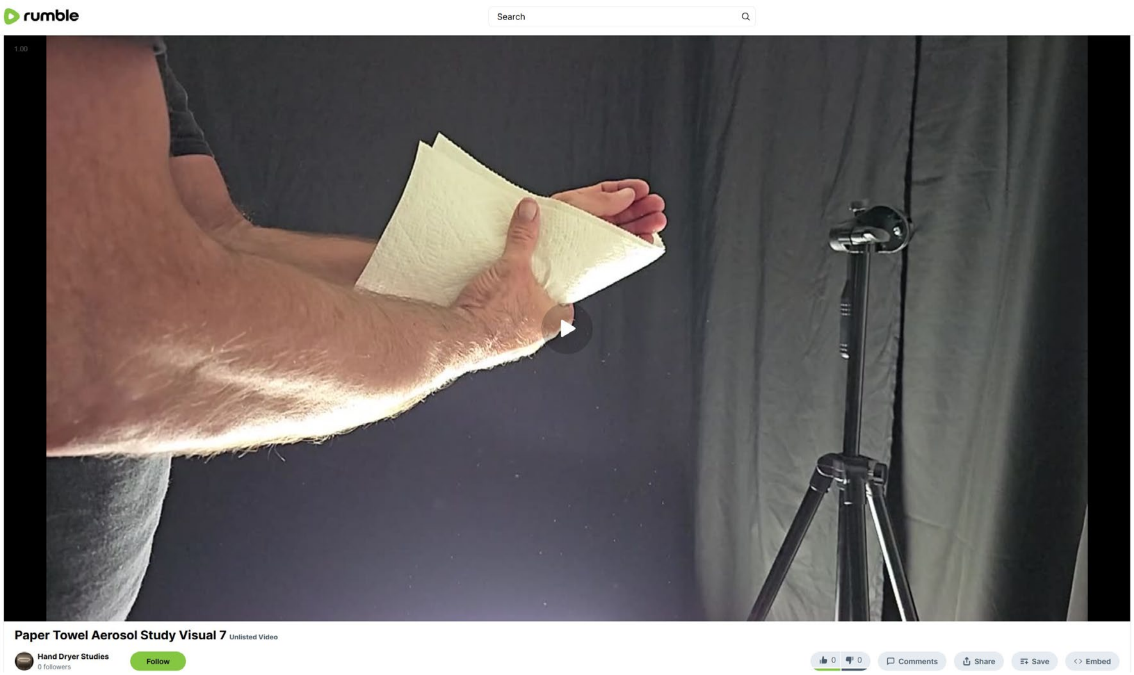
VIDEO 14: Paper Towel Trial 4 on Rumble



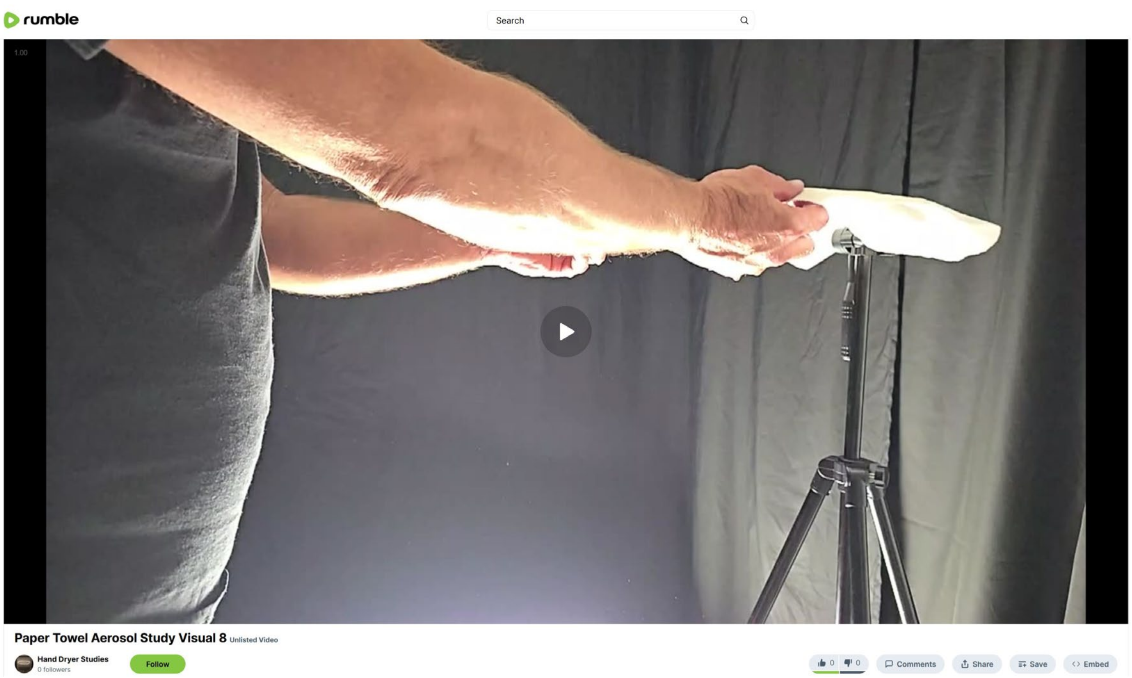
VIDEO 15: Paper Towel Trial 5 on Rumble



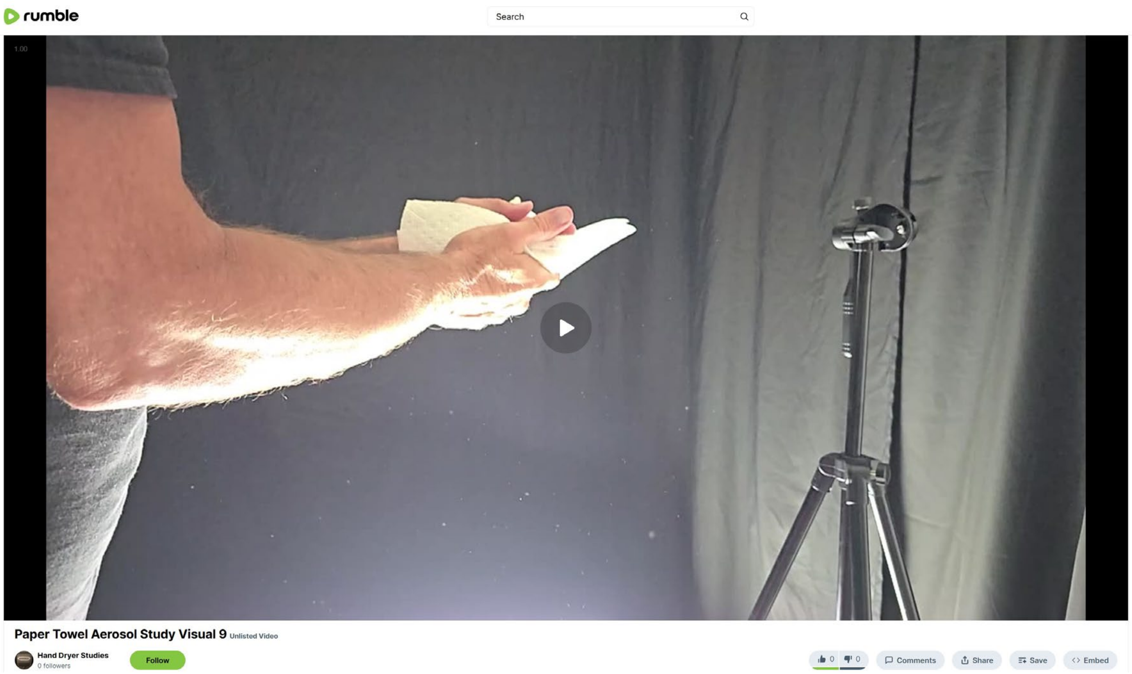
VIDEO 16: Paper Towel Trial 6 on Rumble



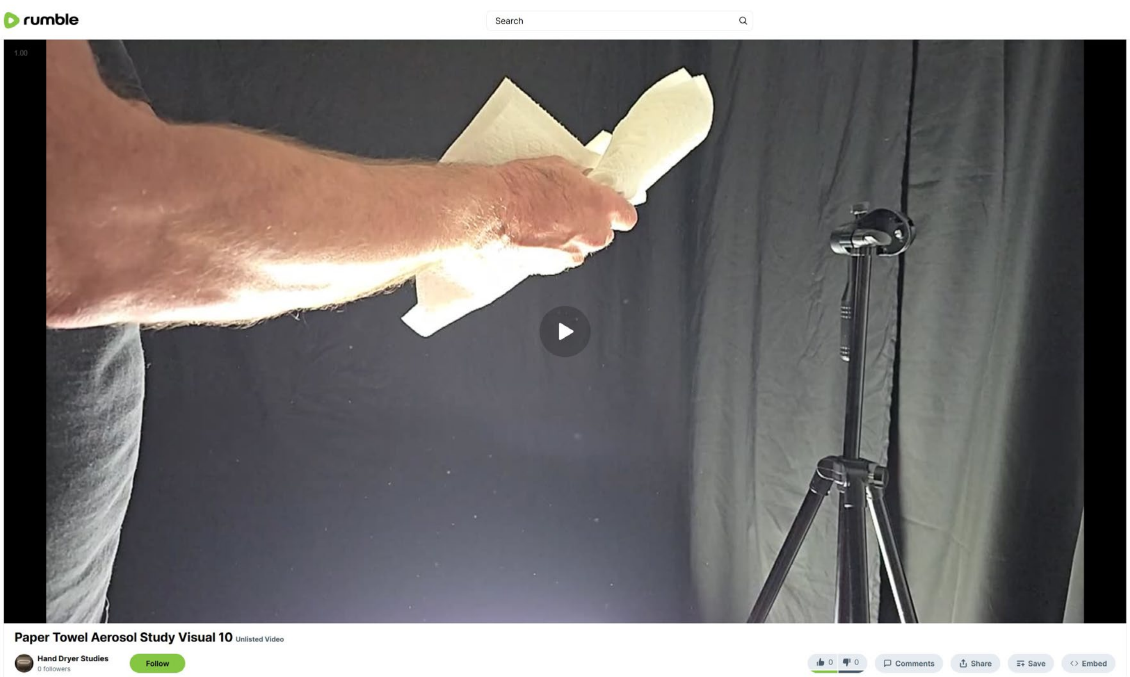
VIDEO 17: Paper Towel Trial 7 on Rumble



VIDEO 18: Paper Towel Trial 8 on Rumble



VIDEO 19: Paper Towel Trial 9 on Rumble



VIDEO 20: Paper Towel Trial 10 on Rumble

The consistent absence of water dispersion across all paper towel trials is notable, as it represents a fundamental qualitative difference in water management between the two drying methods. This observation is consistent with findings from Best et al. [7], who noted significantly lower environmental contamination with paper towel use compared to air dryers. The water is contained for disposal, rather than spread around the space.

3.4 Water Destination Analysis

A central finding of this study is the documentation of where water goes during the drying process. Our high-speed video analysis revealed consistent patterns across all air dryer trials:

Air Dryer Water Destination Patterns:

1. **User's clothing:** Substantial visible water accumulation on the user's forearms, torso, and legs, appearing as droplet patterns and damp patches
2. **Surrounding floor:** Visible droplet accumulation in a semi-circular pattern with much of the water headed toward the floor
3. **Adjacent walls:** Water droplet patterns visible on wall surfaces
4. **Airborne suspension:** Visible mist formation that persisted for after drying completion
5. **User's face and hair:** Occasional upward dispersion resulting in visible droplets reaching the user's face area
6. **User's lower body:** Concentrated water accumulation on pants and on shoes

These observations are consistent with findings from In Silico's computational fluid dynamics study [26], which demonstrated that 26.1% of particles disperse beyond the dryer unit while visibly suggesting those data are an order of magnitude low. Similarly, Hervé et al. [27] documented contamination on surfaces up to 3 meters from hand dryers, indicating significant water dispersal throughout the environment.

Paper Towel Water Destination Patterns:

In contrast, paper towel drying showed a single, consistent water destination pattern:

1. **Paper towel material:** Almost all visible moisture was absorbed into the paper towel material
2. **Disposal receptacle:** Water remained contained within the paper towel when disposed of

3. **No visible dispersion:** No observable water accumulation on clothing, surrounding surfaces, or in the air

The contrast between these patterns is striking and represents a fundamental difference in how these technologies manage the water removed from users' hands.

4. Discussion

The visual evidence presented in this study directly challenges manufacturer claims that high-speed air dryers "aerosolize no more than paper towels". The dramatic difference in observable water dispersion between the two drying methods strongly suggests corresponding differences in microdroplet aerosols too small to be seen. Additionally, our findings regarding water destination reveal a significant omission in manufacturer documentation, with Dyson and Excel Dryer failing to address where water removed from hands actually goes during the drying process.

Particle settling physics provides a quantitative explanation for this manufacturer documentation gap. Water particles in the 10-1000 μm size range—which constitute the majority of hand dryer-generated droplets by volume—have calculated hang times ranging from 10 seconds to 10 minutes under standard atmospheric conditions. During these extended suspension periods, room air currents, ventilation systems, and user movement patterns transport particles throughout the environment rather than allowing predictable settling in a single location. This physical reality makes it impossible for manufacturers to specify a single "destination" for removed water, as the actual destination depends on complex fluid dynamics that vary with each installation and use scenario.

Implications for Aerosol Generation

While this study focused on visible droplet dispersion rather than microscopic aerosol measurement, established principles of fluid dynamics support a strong correlation between the two. Mechanical forces that generate visible droplet dispersion also create smaller aerosols below the threshold of visibility as demonstrated by Bourouiba [14] and Morawska et al. [15]. The forceful air streams of high-speed dryers (moving at 400-640 km/h or 192 m/s) create ideal conditions for both droplet and aerosol generation through shear forces applied to water on the hands.

Droplet Size Distribution and Number Dominance

High-shear water aerosolization, such as that produced by high-speed air dryers, creates polydisperse droplet populations that follow log-normal distributions. In such distributions, smaller droplets (<10 μm, particularly ≤5 μm) typically dominate by number (50-90%), while larger droplets (>20-40 μm) contribute most to the visible mass due to the cubic scaling of volume with diameter as described by Baron and Willeke [12], Lefebvre [19], Lefebvre [19], and Hinds [18].

Research across multiple fields consistently demonstrates this pattern:

1. **Respiratory aerosols**: Johnson et al. [17] found that droplets <10 μm comprised 97-99% of the total number during coughing, with ratios of 50-500 ≤5 μm droplets per droplet >20 μm. Asadi et al. [20] reported that 80-90% of speech-generated droplets were <5 μm, outnumbering larger droplets by 100-1,000:1.

2. **Industrial sprays**: Studies of airblast atomizers, analogous to high-speed air dryer mechanisms, show that 50-90% of droplets are <10 μm by number, yielding 10-100 ≤5 μm droplets per ~40 μm droplet, with ratios up to 1,000:1 in high-shear conditions as documented by Lefebvre [20] and Villermaux [16].

3. **Environmental aerosols**: In sea spray, Fuentes et al. [21] found that <5 μm droplets constituted >90% of the number, outnumbering >40 μm droplets by 100-10,000:1. Baylor et al. [22] reported that film droplets (0.1-5 μm) from bursting bubbles outnumbered larger droplets by 100-1,000:1.

Based on this extensive body of research, we can reasonably estimate that for each visible droplet (≥40 μm) observed in our high-speed videos, approximately 100-10,000 true aerosols (≤5 μm) were generated, with 100-1,000:1 being typical for high-shear environments like those created by air dryers.

Water Destination Implications

Our findings regarding water destination raise significant concerns about both hygiene and user experience. The substantial backspray of water onto users' clothing documented in our trials represents a previously unaddressed aspect of air dryer performance. This backspray has several implications:

1. **Self-contamination**: Water removed from hands is partially redistributed onto the user's clothing, potentially transferring any remaining microorganisms from hands to clothing. This self-contamination partially undermines the hygienic benefits of handwashing.

2. **Wet clothing**: Users experience noticeable dampness on clothing after air dryer use, a practical inconvenience not addressed in manufacturer documentation. This dampness can be particularly problematic in professional or formal settings.

3. **Extended microbial viability**: Moisture transferred to clothing can provide conditions for extended microbial viability, as demonstrated by Hervé et al. [27],

who found that microorganisms can remain viable on contaminated surfaces for extended periods.

4. **Inconsistency with marketing**: The observed water backspray contradicts the "hygienic" marketing narratives of manufacturers, which emphasize cleanliness without acknowledging this significant water redistribution.

The water accumulation on surrounding surfaces raises additional concerns:

1. **Environmental contamination**: Water dispersed onto floors, walls, and adjacent fixtures creates damp environments that supports microbial growth, frequently visible as a plume of varying sizes under the dryer output airjet, as documented by Best et al. [7] in their study of environmental contamination. The U.S. Environmental Protection Agency [29] provides guidance on environmental sampling and microbiology data interpretation that supports the significance of such contamination patterns in public facilities. Huang et al. [30] established benchmark guidance values for microbiological monitoring on surfaces, providing context for evaluating the contamination potential of the water dispersal patterns we observed.

2. **Slip hazards**: The accumulation of water on floor surfaces creates potential slip hazards, particularly in high-traffic restroom environments.

3. **Maintenance implications**: The dispersal of water throughout the restroom environment increases cleaning and maintenance requirements, a practical consideration not addressed in manufacturer documentation.

   Settling velocity data explains the mechanism behind this dispersion. Particles in the 50-200 μm range—readily generated by high-speed air streams but invisible to users—have hang times of 30 seconds to 5 minutes, sufficient to travel the 2-3 meter distances documented in environmental contamination studies. Even larger visible droplets (200-1000 μm) remain airborne for 3-30 seconds, during which minimal air movement easily transports them beyond the immediate drying area. The physics demonstrates that environmental contamination is not incidental but inevitable given the extended suspension times of intermediate-sized particles.

4. **Cross-contamination potential**: Water dispersed onto environmental surfaces can facilitate cross-contamination between users, as documented by Kimmitt and Redway [8] in their study of virus dispersal.

Population-Scale Water Dispersion

The water destination patterns documented in this study occur at every dispersal-type dryer use. Combined with quantitative data from our companion residual moisture study (Blouch [2]), we can estimate the scale of water dispersal.

Hands carry approximately 7.30g of water after washing. Users following manufacturer specifications (8-12 seconds) remove approximately 4.47g before leaving with wet hands. Users drying to completion (45-90 seconds) disperse the full 7.30g. At 150 million daily US dispersal-type dryer uses, this represents:

- **Daily:** 2.8–4.6 million cups of water sprayed onto users, walls, floors, and fixtures
- **Annually:** 1–1.7 billion cups of water sprayed into public restroom environments
- **Per dryer:** Approximately 3 cups of water dispersed daily

Paper towels absorb and contain this water. Dispersal-type dryers spray it everywhere. The contrast is categorical, not marginal—and it occurs 150 million times daily.

This dispersed water is not sterile. Our companion microbial study (Blouch [1]) documented 49.6× ambient microbial amplification in dryer output air. The water droplets documented in our videos carry this amplified load onto users' clothing and environmental surfaces at population scale.

The Gião & Vardoulakis Study: A Detailed Examination

Given Dyson's prominent use of Gião & Vardoulakis (2022) [16] to support claims of aerosol equivalence with paper towels, detailed examination of this study is warranted.

Authorship and Funding: The study's conflict of interest disclosure states: "Author MSG was an employee of Dyson. Author SV was member of the Dyson Scientific Advisory Board and had received research funding and honoraria from Dyson. This study received funding from Dyson Technology Ltd. (UK). The funder had involvement in the conceptualization of the study."

This is not a limitation disclosed in passing—it is the fundamental context for interpreting the study's conclusions. The research was conceived with funder involvement, conducted by a funder employee, co-authored by an advisory board member receiving funder honoraria, and financially supported by the funder. When such a study concludes that the funder's product performs equivalently to alternatives, heightened scrutiny is appropriate.

What the Data Actually Show:

The study measured aerosol concentrations across particle size bins. For the smallest, most respirable aerosols (0.3–0.5 μm):

- Jet air dryers: 6.63×10^6 particles m^{-3}
- Paper towels: 3.49×10^6 particles m^{-3}
- Ratio: Dryers produce ~1.9× more small aerosols

For larger particles (≥5.0 μm):

- Jet air dryers: 1.05×10^4 particles m^{-3}
- Paper towels: 2.28×10^4 particles m^{-3}
- Ratio: Paper towels produce ~2.2× more large particles

The authors acknowledge the composition difference: jet dryer aerosols are "likely to be liquid aerosols" while paper towel particles "may contain dust from the paper." Yet they characterize total counts as showing "no significant difference."

The Hygiene-Relevant Distinction:

From an aerosol science and public health perspective, wet and dry aerosols are not equivalent:

Property	**Wet Aerosols (Dryers)**	**Dry Particles (Paper Towels)**
Composition	Water droplets	Paper fibers/dust
Pathogen carriage	Can carry bacteria, viruses, fungi	Biologically inert
Suspension time	Minutes to hours (small sizes)	Seconds to minutes (larger sizes)
Respiratory penetration	Deep lung (≤5 μm)	Upper respiratory/settling
Source contamination	Dryer airstream (49.6× ambient, Blouch [4])	Sealed paper packaging

Conflating these categories to claim "equivalent aerosolization" is scientifically misleading. A study finding that dryers produce twice the respirable liquid aerosols while paper towels produce twice the large paper dust does not support a conclusion of hygiene equivalence—it demonstrates categorical difference.

Methodological Limitations:

Beyond the compositional conflation, the study's methodology limits real-world applicability:

1. **HEPA Filtration:** All four dryer models tested had HEPA filters. The vast majority of installed dryers in US public restrooms do not have HEPA filtration. Results from HEPA-equipped units cannot be generalized to the unfiltered installed base.
2. **Sterile Conditions:** Testing occurred in a clean chamber with air purged before experiments, ventilation disabled, and volunteers in ethanol-cleaned coverall suits. These conditions eliminate the ambient contamination present in active public restrooms.
3. **Manufacturer Drying Times:** Dryers were operated for 10–14 seconds per manufacturer specifications. Our companion study (Blouch [5]) demonstrates these times leave 2.83g residual moisture—hands that are categorically wet. Real users dry for 45–90 seconds. Aerosol generation scales with duration.
4. **Dismissal of Contrary Evidence:** The authors characterize prior studies finding higher dryer contamination (Best et al. [7], Kimmitt & Redway [8]) as employing "unrealistic experimental conditions." Yet their own conditions—sterile chamber, HEPA filters, manufacturer drying times—are unrealistic in the opposite direction.

Conclusion on the Gião & Vardoulakis Study:

A Dyson-funded study, conducted by a Dyson employee, found that Dyson dryers produce nearly twice the concentration of small respirable liquid aerosols compared to paper towels, while paper towels produce more large paper dust particles. The authors characterized this as "no significant difference," supporting Dyson's marketing claim of aerosol equivalence.

This framing conflates categorically different hygiene outcomes. The visual evidence presented in this study—documenting 7.30g of water per use dispersed onto users, walls, floors, and fixtures—renders the particle-counting debate secondary. Regardless of how aerosols are counted or categorized, the water goes somewhere. Our videos show where it goes. The 670–1,095 metric tons dispersed daily into US public restrooms cannot be explained away by statistical characterizations of particle counts.

Fundamental Contrast in Aerosol Generation Mechanisms

Our visual findings highlight a fundamental contrast in the physical mechanisms of droplet and aerosol generation between high-speed air dryers and paper towels. These two hand drying methods represent opposite extremes on the spectrum of aerosol generation physics, with profound implications for hygiene and pathogen dispersion.

High-Shear vs. Low-Shear Processes, Detail

High-speed air dryers operate through high-shear forces, with air velocities of 400-640 km/h (192 m/s), creating significant disruptive forces at the air-water interface on hands. This high-shear environment resembles industrial airblast atomization, where turbulent forces fragment water into a wide spectrum of droplet sizes as described by Lefebvre [19]. The physics of droplet breakup under these conditions is well-documented across multiple scientific fields, consistently showing that higher shear forces lead to greater fragmentation and a higher proportion of microscopic aerosols as demonstrated by Villermaux [16] and Lefebvre [19].

In stark contrast, paper towel drying operates through gentle absorption and minimal mechanical disturbance of the water-air interface. This low-shear process fundamentally limits droplet fragmentation and aerosolization as explained by Baron and Willeke [12]. The physics of low-shear interactions with liquids has been extensively studied, showing that gentle processes like absorption, dripping, or slow wiping predominantly produce large droplets (when they produce droplets at all) with minimal generation of true aerosols as documented by Lefebvre [19] and Lefebvre [19].

Disproportionate Aerosol Generation

As established in section 4.2, high-shear processes like those in air dryers produce dramatically disproportionate results in terms of aerosol generation. The 100-10,000:1 ratio of microscopic to visible droplets documented across multiple scientific fields means that our observed visible droplet dispersion corresponds to vast numbers of invisible true aerosols.

Conversely, in low-shear processes like paper towel drying, the few visible droplets we observed (primarily large drops falling directly downward) correspond to proportionally fewer true aerosols. This principle is demonstrated across multiple scientific domains, from respiratory aerosols to industrial processes to environmental studies.

In our observations, paper towel drying produced minimal visible droplets, primarily consisting of occasional large drops falling directly downward. Based on established aerosol science principles, this low-shear process produces proportionally fewer true aerosols relative to these few visible droplets. Conversely, the dense clouds of visible droplets observed with air dryers likely correspond to vast numbers of invisible true aerosols, consistent with high-shear fragmentation physics.

Evaporation dynamics of suspended droplets follow established principles of atmospheric physics as described by Pruppacher and Klett [28], with smaller droplets potentially transitioning to the aerosol fraction through evaporation.

Manufacturer Documentation Analysis

Our review of manufacturer and certifier documentation revealed striking omissions regarding water destination:

- No explicit references to water management across all materials for wall mounted dryers
- Explicit mention of water management for sink-integrated models
- A single acknowledgment that water from wall-mounted units "drips onto the floor, where it evaporates naturally"
- No mention of water backspray onto users
- No discussion of water dispersal to surrounding surfaces
- Marketing emphasis on "hygienic" performance without addressing water redistribution
- Sale of "antimicrobial wall guards" by some manufacturers implicitly acknowledging water dispersal to walls without stating it directly
- No discussion of floor contamination from falling water

In their hygienic hand dryer marketing materials, Dyson [26] emphasizes HEPA filtration but provides limited discussion of water dispersal patterns. Further, few existing installed dryers have HEPA filtering and non HEPA dryers are not discussed.

This pattern of omission is significant in light of our visual evidence showing substantial water redistribution during air dryer use. The discrepancy between manufacturer documentation and observed performance represents a notable gap in product transparency and raises questions about users' ability to make fully informed decisions about hand drying technologies.

The fundamental physics of particle settling provides objective criteria for evaluating manufacturer claims. Dyson's assertion that their dryers "aerosolize no more than paper towels" can be directly tested against established aerosol generation principles: high-shear processes (400-640 km/h air streams) create particle size distributions dominated by small aerosols at ratios of 100-10,000:1 relative to visible droplets, while low-shear absorption processes generate proportionally fewer microscopic particles. The 45-90 second actual drying times documented in our companion study, combined with settling data showing minutes-long hang times for intermediate particles, demonstrate conditions optimal for extensive aerosol generation and environmental dispersion—outcomes fundamentally incompatible with equivalent aerosolization claims.

5. Conclusion

This visual analysis provides compelling evidence that challenges manufacturer claims regarding aerosol generation. It clearly displays water distribution patterns, starkly illustrating the absence of manufacturer specifications describing an integral part of the device use cycle during hand drying. It shows water containment in paper towels and a lack of visible aerosols during hand drying with them. Our findings reveal three primary elements of note: (1) high-speed air dryers create substantially more visible aerosol dispersion than paper towels through fundamentally different physical mechanisms, (2) hand dryers redistribute significant amounts of water onto users' clothing and surrounding surfaces as it is removed from hands, and (3) paper towels contain post-washing water from hands, allowing for easy sanitary disposal.

The visual evidence demonstrates extensive visible droplet dispersion during air dryer use compared to minimal to no visible droplet dispersion during paper towel use. This stark contrast correlates tightly with established, ubiquitous aerosol science on the difference between high-shear processes that maximize droplet fragmentation and low-shear processes that minimize it.

Established principles of fluid dynamics and aerosol science indicate that these contrasting mechanisms create disproportionate results in aerosol generation. In high-shear environments like those created by air dryers, true aerosols (≤5 μm) are generated at rates 100-10,000 times greater than visible droplets (≥40 μm), with 100-1,000:1 being typical. Conversely, the gentle, low-shear mechanics of paper towel drying produce proportionally fewer true aerosols relative to the few visible droplets observed. This dual contrast---both in visible droplet quantity and in the proportion of invisible aerosols generated---represents a "double advantage" for paper towels in minimizing potential pathogen dispersion.

Our documentation of water destination patterns reveals a significant omission in manufacturer specifications, claims, and promotional materials. Particle settling physics quantifies this gap [13]: water droplets in the 10-1000 μm range exhibit hang times of 10 seconds to 10 minutes, during which they disperse throughout the environment via air currents rather than settling predictably. This extended suspension time, combined with the 45-90 second actual drying periods required for user satisfaction, creates optimal conditions for the environmental contamination patterns we documented visually. As of the publishing date of this study manufacturers have completely failed to address where water goes during the drying process, with our trials showing substantial backspray onto users' clothing and dispersal to surrounding surfaces. The contrasting pattern of nearly complete water containment by paper towels and explosive water dispersal patterns by the dryers represents a clear advantage for towels in terms of both hygiene and practical user experience.

At population scale, the dispersion documented in this study represents 2.8–4.6 million cups of water daily—1–1.7 billion cups annually—sprayed from users' hands onto their clothing, walls, floors, and fixtures. Each dispersal-type dryer sprays approximately 3 cups of water into the restroom environment daily. Paper towels contain this water; dispersal-type dryers spray it everywhere. Appendix 2 quantifies these population-level implications.

The manufacturer claim of aerosol equivalence with paper towels, based on Gião & Vardoulakis (2022) [16], does not withstand scrutiny. That Dyson-funded study, conducted by a Dyson employee, found dryers produce nearly twice the respirable liquid aerosols while paper towels produce more paper dust—then characterized this as "no significant difference." Conflating wet pathogen-carrying aerosols with dry paper fibers to claim equivalence is scientifically misleading. Regardless, the visual and quantitative evidence presented here supersedes the particle-counting debate: 7.30g of water per use is dispersed into the environment, totaling 670–1,095 metric tons daily across US installations. The water goes somewhere. This study shows where.

The absence of discussion regarding what happens to the water after the dryer output air stream hits the wet hands, the physics of high-shear aerosol generation, and the undeniable redistribution of water onto users and surfaces creates a concerning public health situation. The visual evidence presented in this study bridges the gap between technical hygiene research and observable real-world outcomes, providing clear documentation of phenomena that have significant implications for public health, user experience, and informed decision-making about hand drying technologies.

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Appendix 1: Visual Summary of Hand Drying Dispersion Mechanisms

This study introduces a novel visual method for evaluating hygiene outcomes of hand drying techniques by replacing traditional qualitative descriptions with direct observation via slow-motion video. The videos are the data. The following summary distills the comparative dynamics observed across all trials into a concise, single-page format.

Comparison of Hand Drying Mechanisms

Feature	High-Speed Air Dryers	Paper Towels
Drying Mechanism	High-velocity air stream (400-640 km/h)	Absorptive mechanical contact
Shear Force Environment	High-shear	Low-shear
Droplet Fragmentation	Extensive fragmentation into fine aerosols	Minimal fragmentation
Visible Droplet Dispersion	Extensive airborne spray, backspray, mist	Occasional downward large droplets
True Aerosol Generation Potential	Very high (100-10,000:1 droplet ratio)	Minimal
Water Destination	Dispersed onto clothing, walls, floors	Contained within towel and disposed
User Self-Contamination	Frequent and substantial	Absent
Environmental Contamination	Extensive	Negligible

Appendix 2: US Population Impact Evaluation

Summary: Water Dispersion at Population Scale

This appendix applies the visual findings of this study to the installed base of commercial dispersal-type hand dryers in the United States, combined with quantitative water mass data from our companion residual moisture study (Blouch [2]).

The Quantitative Foundation

Our companion study measured water on hands before and after drying:

Metric	Value	Source
Initial water on hands after washing	7.30g (mean)	Blouch [2]
Residual moisture after manufacturer-specified drying time	2.83g	Blouch [2]
Water removed at manufacturer spec (8-12 seconds)	4.47g	Calculated
Water removed if drying to completion (45-90 seconds)	~7.30g	Calculated

Every gram of water removed from hands goes somewhere. Paper towels absorb and contain it. Dispersal-type dryers spray it onto walls, floors, fixtures, and users' clothing.

Table A2-1: Daily US Water Dispersion (150 Million Uses)

Metric	Paper Towels	Dryers (at spec)	Dryers (to completion)
Water removed per use	~7g	4.47g	~7.30g
Water contained	~7g	0g	0g
Water dispersed into environment	~0g	4.47g	~7.30g
Daily water dispersed	~0	~2.8 million cups	~4.6 million cups
Daily dispersion events	0	150 million	150 million
Daily self-contamination events	0	150 million	150 million
Daily environmental contamination events	0	150 million	150 million

Table A2-2: Annual US Water Dispersion (54.75 Billion Uses)

Metric	Paper Towels	Dryers (at spec)	Dryers (to completion)

Water removed per use	~7g	4.47g	~7.30g
Water contained	~7g	0g	0g
Water dispersed into environment	~0g	4.47g	~7.30g
Annual water dispersed	~0	~1 billion cups	~1.7 billion cups
Annual dispersion events	0	54.75 billion	54.75 billion
Annual self-contamination events	0	54.75 billion	54.75 billion
Annual environmental contamination events	0	54.75 billion	54.75 billion

Interpretation

The Scale of Dispersion

Dispersal-type dryers do not make water disappear. They relocate it—onto users, walls, floors, and fixtures.

Daily: Between 2.8 and 4.6 million cups of water are sprayed into US public restroom environments every day. This is not evaporation. This is physical relocation of water mass from hands to surroundings via high-velocity air streams.

Annually: Between 1 billion and 1.7 billion cups of water are sprayed into public restroom environments.

Per dryer: Each dispersal-type dryer sprays approximately 3 cups of water onto restroom walls, floors, and users daily (based on 100 uses/day at 7.30g per use).

Where the Water Goes

The visual evidence in this study documents the destination of this water mass:

Destination	Observation
User's clothing	Substantial backspray onto forearms, torso, legs
Surrounding floor	Visible accumulation in semi-circular pattern
Adjacent walls	Droplet patterns on wall surfaces within 1-3 meters
Nearby fixtures	Contamination of sinks, mirrors, door handles
Airborne suspension	Visible mist persisting after drying completion
User's face/hair	Occasional upward dispersion reaching face area

Paper towels, by contrast, absorb this 7+ grams of water into a disposable package. Zero dispersion. Zero environmental contamination. Zero self-contamination.

The Contrast Is Categorical

Metric	Paper Towels	Dispersal-Type Dryers
Water management method	Absorption and containment	Dispersion and redistribution
Water destination	Disposable package	User, walls, floors, air
Daily water dispersed	~0	2.8–4.6 million cups
Annual water dispersed	~0	1–1.7 billion cups
Environmental contamination	None	Universal
Self-contamination	None	Universal

This is not a marginal difference in performance. One method contains water; the other disperses it. At population scale, this difference manifests as over one billion cups of water annually sprayed into public restroom environments versus zero.

Compounding Factors

The Water Is Not Sterile

The water being dispersed carries microbial load. Our companion study (Blouch [1]) documented:

Metric	Value
Median CFU in dryer output air	67 CFU
Amplification vs ambient	49.6×
Tests with dryer CFU despite zero ambient	34.48%

The millions of cups of water dispersed daily is not clean water. It is water that has passed through a microbially contaminated airstream, picking up amplified bacterial and fungal loads before being deposited on users' clothing and environmental surfaces.

Extended Drying Increases Dispersion

Users following manufacturer specifications (8-12 seconds) leave with wet hands (2.83g residual). Users who continue drying to achieve actual dryness (45-90 seconds) disperse the full 7.30g—but over an extended period that:

1. Increases total water dispersed by 63% (7.30g vs 4.47g)

2. Extends exposure to contaminated airstream by 6-10×

3. Extends duration of aerosol generation proportionally

Neither option is hygienic. Short drying leaves wet hands. Complete drying disperses more water and extends microbial exposure.

Spatial Contamination Analysis

Per-Event Water Distribution

Each dispersal-type dryer use sprays 4.47-7.30 grams of water across:

Zone	Distance	Contamination Pattern
Immediate	0-1 meter	Heavy—user clothing, dryer housing, adjacent walls
Proximate	1-2 meters	Moderate—floors, nearby fixtures, adjacent users
Extended	2-3 meters	Detectable—documented by Hervé et al.

Per-Dryer Daily Load

Facility Type	Estimated Daily Uses per Dryer	Daily Water Dispersed per Dryer
Airport restroom	200-400	6-12 cups
Mall restroom	150-300	5-9 cups
Stadium restroom	500+ (event days)	15+ cups
Office restroom	50-100	1.5-3 cups

This water accumulates on surfaces, creating persistent damp conditions that support microbial survival and growth between cleaning cycles.

Aerosol Generation at Scale

The Visible/Invisible Ratio

This study documented visible droplet dispersion. Established aerosol science indicates that high-shear processes generate dramatically more invisible aerosols:

Droplet Type	Size	Visibility	Generation Ratio
True aerosols	≤5 μm	Invisible, respirable	100-10,000 per visible droplet
Visible droplets	≥40 μm	Visible in proper lighting	1 (baseline)

The dense clouds of visible droplets documented in our videos represent a small fraction of total aerosol generation.

Daily Aerosol Events

At 150 million daily uses: - 150 million high-shear aerosol generation events - Each event producing thousands of visible droplets - Each visible droplet corresponding to 100-1,000+ invisible respirable aerosols - Total daily aerosol generation measured in trillions of particles

Manufacturer Documentation Gap

Neither Dyson nor Excel Dryer address water destination in their documentation. At population scale, this omission means:

Metric	Daily	Annual
Water dispersed without user awareness	2.8–4.6 million cups	1–1.7 billion cups
Self-contamination events without disclosure	150 million	54.75 billion
Environmental contamination events without disclosure	150 million	54.75 billion

Users cannot make informed decisions when manufacturers fail to disclose that approximately one ounce of water per use (about a shot glass) is being sprayed onto their clothing and surrounding surfaces.

Summary Comparison

Daily Impact (150 Million Uses)

Metric	Paper Towels	Dispersal-Type Dryers
Water dispersed	~0	2.8–4.6 million cups
Dispersion events	0	150 million
Self-contamination events	0	150 million
Environmental contamination	None	150 million events
Aerosol generation	Minimal	150 million high-shear events
Microbial distribution events	0	150 million (at 49.6× ambient)

Annual Impact (54.75 Billion Uses)

Metric	Paper Towels	Dispersal-Type Dryers
Water dispersed	~0	1–1.7 billion cups
Dispersion events	0	54.75 billion
Self-contamination events	0	54.75 billion
Environmental contamination	None	54.75 billion events
Aerosol generation	Minimal	54.75 billion high-shear events
Microbial distribution events	0	54.75 billion

Installed Base and Usage Methodology

Installed Base Estimate

Parameter	Value	Source
US commercial dispersal-type hand dryers	~1.5 million	Mordor Intelligence (2025); sector analysis
Operating units (80% functional)	~1.2 million	Calculated

Usage Estimates

Parameter	Value	Source
Daily uses per unit	100	Industry standard
Daily uses (US)	150 million	Calculated
Annual uses (US)	54.75 billion	Calculated
Simultaneous users (any moment)	~125,000	Calculated

Conservative Nature of Estimates

These projections are conservative:

• Water mass data (7.30g initial, 2.83g residual) represents measured means; individual variation exists

• Video documentation captured visible droplets only; true aerosol generation is orders of magnitude higher

• Dispersion radius of 1-3 meters is based on documented contamination; actual aerosol travel may extend further

• Usage estimates assume standard business hours; 24-hour facilities generate higher volumes

Conclusion

Every dispersal-type dryer use sprays 4.47-7.30 grams of water into the surrounding environment. At 150 million daily uses, this represents 2.8-4.6 million cups of water daily—1-1.7 billion cups annually—sprayed onto users' clothing, walls, floors, and fixtures.

Paper towels contain this water. Dispersal-type dryers spray it everywhere.

The visual evidence in this study documents what occurs at each of those 150 million daily events. The water mass data from our companion study quantifies it. The population impact is the multiplication:

~3 cups of water per dryer per day × 1.5 million dryers = up to 4.6 million cups of water sprayed into US public restrooms every day.

The videos are the data. The scale is the crisis.

Sources

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Appendix 3: Particle Settling Velocity and Physics

Supporting Data for Water Droplet Dispersion Analysis

Introduction

This appendix provides fundamental physics data on particle settling velocities that support the analysis of water droplet dispersion patterns observed in the main study. The settling behavior of water droplets is critical for understanding the duration and extent of airborne contamination following hand dryer use.

Conditions

Parameter	Value
Air temperature	20°C
Air pressure	1 atmosphere
Air density	1.204 kg/m^3
Air viscosity	1.81×10^{-5} Pa·s
Settling height	2.5 m (standard room height)
Vacuum speed limit	7.0 m/s (maximum possible falling speed from 2.5m height)

Comprehensive Water Droplet Settling Table

From Large Raindrops (Stone-like) to Ultrafine Aerosols (Floaty)

Size	Velocity	Hang Time	% of Vacuum	Physics Regime
10.0 mm	7.00 m/s	0.4 sec	100.0%	Drag-Limited
8.0 mm	7.00 m/s	0.4 sec	100.0%	Drag-Limited
6.0 mm	7.00 m/s	0.4 sec	100.0%	Drag-Limited
5.0 mm	7.00 m/s	0.4 sec	100.0%	Drag-Limited
4.0 mm	7.00 m/s	0.4 sec	100.0%	Drag-Limited
3.0 mm	7.00 m/s	0.4 sec	100.0%	Drag-Limited
2.5 mm	7.00 m/s	0.4 sec	100.0%	Drag-Limited
2.0 mm	7.00 m/s	0.4 sec	100.0%	Intermediate
1.5 mm	6.08 m/s	0.4 sec	86.8%	Intermediate
1.2 mm	5.44 m/s	0.5 sec	77.7%	Intermediate
1.0 mm	4.97 m/s	0.5 sec	70.9%	Intermediate
800.0 μm	4.44 m/s	0.6 sec	63.4%	Intermediate
600.0 μm	2.98 m/s	0.8 sec	42.6%	Intermediate
500.0 μm	2.52 m/s	1.0 sec	36.0%	Intermediate
400.0 μm	2.01 m/s	1.2 sec	28.7%	Intermediate

300.0 µm	1.44 m/s	1.7 sec	20.6%	Intermediate
200.0 µm	837.0 mm/s	3.0 sec	12.0%	Intermediate
150.0 µm	538.3 mm/s	4.6 sec	7.7%	Intermediate
100.0 µm	270.2 mm/s	9.3 sec	3.9%	Intermediate
70.0 µm	140.3 mm/s	17.8 sec	2.0%	Intermediate
50.0 µm	73.6 mm/s	33.9 sec	1.1%	Intermediate
30.0 µm	27.2 mm/s	1.5 min	0.4%	Stokes
20.0 µm	12.1 mm/s	3.4 min	0.2%	Stokes
15.0 µm	6.8 mm/s	6.1 min	0.1%	Stokes
10.0 µm	3.1 mm/s	13.6 min	0.0%	Stokes
7.0 µm	1.5 mm/s	27.6 min	0.0%	Stokes
5.0 µm	777.2 µm/s	53.6 min	0.0%	Stokes
3.0 µm	285.9 µm/s	2.4 hours	0.0%	Stokes
2.0 µm	130.4 µm/s	5.3 hours	0.0%	Stokes
1.5 µm	75.3 µm/s	9.2 hours	0.0%	Stokes
1.0 µm	35.1 µm/s	19.8 hours	0.0%	Stokes
0.7 µm	18.3 µm/s	38.0 hours	0.0%	Stokes
0.5 µm	10.1 µm/s	2.9 days	0.0%	Stokes
0.3 µm	4.3 µm/s	6.8 days	0.0%	Stokes
0.2 µm	2.3 µm/s	12.7 days	0.0%	Stokes
0.1 µm	0.9 µm/s	32.9 days	0.0%	Stokes

Physics Regimes Explained

Drag-Limited Regime (Large droplets >2 mm)

• Hit the vacuum speed limit of 7.0 m/s

• Fall like solid objects ("stone-like" behavior)

• Settle within seconds

• Air resistance has minimal effect

• Reynolds numbers >1000

Intermediate Regime (0.05–2 mm)

• Transition zone between stone-like and floaty behavior

• THE PHYSICS CLIFF occurs here at 1–2 mm

• Speed drops sharply from 100% to 70% of vacuum limit

• Mixed physics: both inertia and drag are significant

- Reynolds numbers 0.1–1000

Stokes Regime (Particles <50 μm)

- True "floaty" aerosol behavior
- Air resistance dominates over gravity
- Hang times measured in minutes to days
- Follow Stokes law: velocity proportional to diameter squared
- Reynolds numbers <0.1
- Includes Cunningham slip correction for very small particles

Key Findings for Hand Dryer Analysis

The Physics Cliff

Size	% of Vacuum Speed	Behavior
>2 mm	100%	Stone-like (hits vacuum limit)
1.5 mm	86.8%	Sudden drop begins
1.0 mm	70.9%	Transition zone
0.5 mm	36.0%	Extended suspension
<0.05 mm	<1%	Truly floaty

Implications for Aerosol Transmission

1. Large visible droplets (>1 mm): Settle quickly, limited airborne time
2. Medium droplets (100–1000 μm): Seconds to minutes of hang time
3. Small aerosols (1–10 μm): Hours of suspension time
4. Ultrafine aerosols (<1 μm): Days to weeks of suspension time

Relevance to Hand Dryer Study

- High-speed air creates wide size distribution of droplets
- Visible droplets (>40 μm) represent only the large end of spectrum
- True aerosols (≤5 μm) remain airborne for extended periods
- Physics supports 100–10,000:1 ratio of invisible to visible droplets
- Settling data validates long-range transmission potential

Validation

Calculations validated against experimental data:

Source	Description
Gunn & Kinzer (1949)	1500+ water droplet measurements
NASA raindrop data	Maximum ~10 m/s terminal velocity
UCSD experimental validation	Within 3% accuracy

Technical Notes

• Cunningham slip correction applied for particles <10 μm

• Vacuum speed limit enforced (no particle exceeds free-fall speed)

• Standard atmospheric conditions assumed

• Bacterial load effects negligible (<5% velocity change)

• Evaporation effects not included (static size analysis)

This physics foundation supports the observed differences in water droplet behavior between high-shear (hand dryers) and low-shear (paper towels) drying methods documented in the main study.