

Feasibility of Emergency IVA Spacesuit Bladder Repair During Parabolic Microgravity Flight

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Abstract: Emergency pressure garment damage during crewed spaceflight presents a significant operational risk, particularly within confined intra-vehicular activity (IVA) environments where rapid contingency response may be required before suit exchange or vehicle safe-haven procedures (NASA, 2015). This study evaluated the feasibility of temporary emergency IVA spacesuit bladder repair techniques during parabolic microgravity flight using a low-cost analog test platform designed to approximate key aspects of flexible pressure-retention behavior. Due to the limited accessibility, operational complexity, and cost associated with flight-certified pressure garments, a full IVA spacesuit assembly was not utilized during this experimental campaign. Instead, a modified sphygmomanometer (blood pressure cuff) bladder assembly was adapted as a flexible pressure-retention analog to support a feasibility assessment of adhesive repair techniques rather than replicate the full material performance of operational IVA pressure garments. Pre-punctured test regions were repaired during repeated microgravity parabolas using modified star-shaped adhesive patches and duct-tape-style linear repair materials. To improve operability under microgravity conditions, star-shaped repair patches were modified pre-flight with integrated backing lips to facilitate rapid peeling and deployment during reduced-gravity operations. Star-shaped patches achieved complete pressure retention in two of three trials while successfully containing pressure in all three trials. In contrast, duct-tape-style repairs achieved complete pressure retention in one of three trials despite successful pressure containment in all primary trials. Adhesive interaction, material conformity, and operator handling influenced seal performance across repeated repair attempts. These findings suggest that adhesive geometry, material interaction, and microgravity-specific human factors influence emergency repair effectiveness in flexible pressure-retention systems. The results further demonstrate the utility of low-cost analog platforms for feasibility studies supporting human spaceflight contingency research. Based on the author's review of publicly available literature, this investigation represents the first known microgravity evaluation of star-shaped adhesive patch repair of an IVA spacesuit bladder analog during parabolic flight.

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1. Introduction

As commercial human spaceflight operations continue to expand, the need for practical contingency procedures capable of addressing in-flight equipment failures has become increasingly important (NASA, 2020). While modern pressure garments are engineered with extensive safety margins and redundant protective systems, puncture or damage to flexible pressure-retention components remains a potential operational hazard during crewed missions. In confined intra-vehicular activity (IVA) environments, rapid emergency response procedures may be required to preserve crew safety until suit exchange, vehicle stabilization, or mission abort protocols can be executed.

Historically, spacesuit survivability research has focused heavily on extra-vehicular activity (EVA) systems, material durability, and long-duration exposure risks associated with external spacecraft operations (Thomas & McMann, 2007). Comparatively limited publicly available research exists regarding rapid in-situ emergency repair procedures for IVA suit bladder systems under true microgravity conditions. Additionally, many prior investigations rely upon high-cost suit hardware, laboratory vacuum facilities, or ground-based simulations that may not fully replicate the operational handling challenges associated with free-floating microgravity environments.

Microgravity introduces unique human-factors and material-interaction challenges that can significantly influence emergency repair performance (Young & Shelhamer, 1990; Clément, 2011). Reduced body stabilization, altered

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reaction-force control, floating tools and materials, constrained fine motor coordination, and adhesive handling difficulties may all impact the reliability of contingency repair procedures. Repair methods that perform effectively under terrestrial gravity conditions may behave differently when applied within dynamic free-floating operational environments.

This investigation was developed to evaluate the feasibility of temporary emergency repair techniques for simulated IVA spacesuit bladder punctures during parabolic microgravity flight. Rather than utilizing a flight-certified pressure garment, a modified sphygmomanometer (blood pressure cuff) bladder assembly was adapted as a low-cost analog pressure-retention system capable of supporting repeated repair trials during active flight operations. This analog approach enabled rapid experimental iteration while maintaining operational relevance for evaluating adhesive interaction, seal formation behavior, and human-factors performance during microgravity repair tasks.

The study specifically compared the operational effectiveness of modified star-shaped adhesive repair patches against duct-tape-style linear adhesive repairs during repeated parabolic flight maneuvers. Particular attention was given to seal reliability, tolerance to imperfect operator alignment, material conformity, wrinkle formation, and overall handling performance under short-duration microgravity conditions.

Results from this experimental campaign demonstrated that adhesive geometry and microgravity-specific handling modifications substantially influenced repair reliability. Star-shaped repair patches achieved consistent temporary seal formation across all dedicated repair trials, while duct-tape-style repairs demonstrated greater sensitivity to material deformation and surface irregularities during application.

In addition to contributing operational insights into emergency IVA repair feasibility, this work demonstrates the potential value of accessible low-cost analog research platforms for applied human spaceflight investigations. The study also demonstrates how accessible experimental platforms may broaden participation in operational microgravity research.

Based on the author's review of publicly available literature, no prior published microgravity study was identified that directly evaluated star-shaped adhesive patch repair of an IVA bladder analog during parabolic flight. This investigation may therefore represent the first known microgravity evaluation of this specific emergency repair geometry.

2. Methodology

Experimental Objective

The objective of this experimental campaign was to evaluate the feasibility and operational effectiveness of temporary emergency repair techniques for simulated intra-vehicular activity (IVA) spacesuit bladder punctures during short-duration microgravity exposure achieved through parabolic flight operations. The investigation focused on adhesive repair performance, operator handling characteristics, seal integrity, repair geometry, and microgravity-specific human-factors considerations associated with emergency contingency repair procedures.

Flight Environment

Testing was conducted during a series of parabolic flight maneuvers designed to generate repeated short-duration microgravity intervals approximating operational reduced-gravity conditions encountered during crewed spaceflight. Each parabola produced approximately 20 seconds of microgravity exposure during which repair procedures were performed manually by the operator while free-floating within the aircraft cabin environment.

A total of 12 parabolas were completed during the experimental flight campaign. Six parabolas were allocated specifically for emergency repair testing associated with the simulated IVA bladder puncture investigation.

Three parabolas were dedicated to evaluating modified star-shaped adhesive repair patches, while three parabolas were allocated to duct-tape-style linear adhesive repair trials. The remaining parabolas were utilized for experimental setup stabilization, operational familiarization, observational review, and contingency recovery between repair sequences.

The experimental environment introduced multiple operational human-factors constraints including altered body stabilization, reduced reaction-force control, free-floating materials, constrained fine motor coordination, and dynamic object drift characteristic of microgravity operations.



Analog Bladder Test Assembly

Due to the limited accessibility, operational complexity, and cost associated with flight-certified pressure garments, a full IVA spacesuit assembly was not utilized during this investigation. Instead, a modified sphygmomanometer (blood pressure cuff) bladder system was adapted as a low-cost flexible pressure-retention analog intended to approximate key aspects of IVA bladder-layer behavior. Although the sphygmomanometer bladder differs from flight-qualified spacesuit bladder materials such as urethane-coated nylon in construction, thickness, and mechanical properties, it provides a flexible pressurized membrane suitable for evaluating relative adhesive handling, conformity, and seal behavior during microgravity operations. The analog was intended to support a feasibility assessment rather than replicate the full material performance of operational IVA pressure garments.

The modified bladder assembly was integrated into a custom test platform designed to:

- simulate flexible membrane puncture response,
- support repeated repair trials,
- permit visual inspection of seal formation,
- and evaluate adhesive interaction with flexible pressurized materials.



Figure 1. Experimental hardware used for microgravity repair evaluation.

Pre-flight layout of the bladder analog assemblies, repair materials, pressure monitoring equipment, and control specimens utilized during the investigation. The test platform was designed to support repeatable evaluation of emergency IVA bladder repair techniques under parabolic microgravity conditions while providing a low-cost alternative to flight-certified pressure garment hardware.

Predefined puncture regions were incorporated into the bladder analog prior to flight operations to improve repeatability between repair trials (Figure 1). The analog system enabled rapid low-cost experimental iteration while maintaining operational relevance for evaluating emergency repair behavior under microgravity conditions.

Repair Materials and Patch Modifications

Two primary emergency repair approaches were evaluated during flight testing:

1. Modified star-shaped adhesive repair patches
2. Duct-tape-style linear adhesive repairs

The star-shaped repair geometry was selected to evaluate whether distributed multi-point adhesive contact regions improved seal reliability on flexible membrane surfaces during microgravity operations.

Prior to flight operations, the star-shaped repair patches were modified with an integrated backing lip designed to improve handling performance during free-floating application procedures. The raised lip facilitated rapid separation and peeling of the adhesive backing material while minimizing unintended patch folding, drifting, or loss of control during deployment.



Figure 2. Modified star-shaped repair patch with integrated backing lip.

Star-shaped adhesive repair patch modified prior to flight testing with an extended backing tab ("backing lip") to improve handling and deployment during microgravity operations. The modification was designed to facilitate adhesive backing removal while reducing unintended folding, drifting, or loss of control of the repair material during free-floating application procedures.

To improve success under microgravity conditions, the star-shaped repair patches were modified prior to flight by creating an extended backing tab along one edge of the release liner (Figure 2). This modification provided a dedicated grasping point that allowed controlled removal of the adhesive backing while minimizing unintended adhesion, folding, and drift of the repair material. The modification was developed in anticipation of reduced stabilization capability and altered fine-motor performance during parabolic flight operations.

Duct-tape-style repair materials were selected as a comparative baseline due to their widespread terrestrial familiarity, rapid accessibility, and simplified deployment characteristics during emergency repair scenarios.

Experimental Procedure

During each parabola repair, the operator performed the following sequence:

1. Stabilization within the microgravity environment
 2. Retrieval and orientation of repair material
 3. Removal of adhesive backing material
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4. Alignment of repair material over the puncture region
5. Manual application and surface compression of repair material
6. Visual inspection of wrinkle formation and material conformity
7. Observation of temporary seal integrity throughout the parabola duration

Each repair trial was conducted independently during active microgravity exposure. Repair performance, handling efficiency, adhesive interaction, and operational usability observations were recorded throughout flight operations.

During the third duct-tape repair parabola, wrinkle formation was identified following the initial adhesive application. The repair material was removed and reapplied during the same parabola, resulting in successful temporary seal formation prior to the conclusion of the microgravity interval.

Data Collection and Observational Analysis

Data collection consisted primarily of operational video review, observational analysis, and post-flight repair evaluation. Recorded observations included:

- repair success or failure,
- approximate seal retention duration,
- adhesive handling characteristics,
- patch alignment behavior,
- wrinkle formation,
- material conformity,
- repair deployment efficiency,
- and operator interaction challenges under microgravity conditions.

Macro imagery and recorded flight footage were additionally reviewed post-flight to identify failure mechanisms associated with incomplete seal formation and localized material deformation.

Evaluation Criteria

Repair performance was evaluated using the following qualitative criteria:

- successful temporary seal formation,
- seal retention throughout parabola duration,
- resistance to wrinkle-induced leakage,
- ease of handling during free-floating operations,
- tolerance to imperfect operator alignment,
- and overall operational reliability during short-duration microgravity exposure.

Comparative analysis was performed between star-shaped and duct-tape-style repair geometries to identify operational strengths, limitations, and human-factors considerations associated with each repair approach.

Experimental Limitations

This investigation was limited by the short-duration nature of parabolic microgravity exposure, the use of an analog bladder material rather than a flight-certified pressure garment, and the limited number of repair trials available during active flight operations. The experimental setup was designed primarily to evaluate feasibility, handling characteristics, and relative repair performance under operationally relevant microgravity conditions rather than full vacuum-rated pressure containment performance.

Additionally, the investigation relied primarily on qualitative observational analysis rather than quantitative pressure-retention instrumentation. A representative repair application procedure performed during active microgravity exposure is shown in Figure 3. Future studies incorporating differential pressure measurements, leak-rate monitoring, larger sample sizes, and extended-duration microgravity environments would strengthen statistical analysis and improve characterization of repair performance.



Figure 3. Representative repair application procedure during microgravity exposure, Jenee' Fox.

The principal investigator, Jenee' Fox, performs an emergency bladder repair procedure during an active microgravity parabola aboard the NRC Falcon 20 research aircraft. The image captures the manual deployment and application process used during repair trials, including stabilization of the bladder analog, manipulation of repair materials, and adhesive backing removal. The procedure was performed within the limited duration of each microgravity interval and required adaptation to reduced stabilization and altered fine-motor control conditions.

3. Results

A total of six dedicated repair parabolas were completed during the experimental campaign, consisting of three modified star-shaped adhesive patch trials and three duct-tape-style repair trials conducted during active microgravity exposure. The bladder analog was pressurized to approximately 6 psi for all repair evaluations to provide a repeatable pressure-retention test condition. This pressure was selected because it is representative of the nominal operating pressure range of many IVA pressure garments, providing an operationally relevant test condition while remaining compatible with the analog test assembly (NASA, 2015).

Human Factors Observations

During microgravity operations, several human-factor challenges were observed that influenced repair performance. Free-floating cabin objects, including a water bottle and emesis bag, were observed during some repair trials and may have contributed to operator workload. Because these operational distractions were not systematically recorded or quantified across all trials, they should be considered uncontrolled observational variables rather than confirmed causes of differences in repair performance. Reduced body stabilization and altered



reaction-force control made precise adhesive placement more challenging than under terrestrial conditions. Limitations in fine motor control were also observed during backing removal, patch orientation, and adhesive deployment. Across the three primary star-shaped repair trials, minor adhesive gathering, placement variability, and wrinkle formation were documented during deployment. Representative repair outcomes are shown in Figures 5A–5C.

Representative operational conditions observed during repair activities are shown in Figure 4. Free-floating objects, including a water bottle and repair materials, frequently drifted within the operator's workspace and occasionally competed for attention during repair deployment.



Figure 4. Representative microgravity repair environment during parabolic flight testing with Jenee' Fox.

Image captured during active repair operations showing the modified star-shaped adhesive repair patch in free flight prior to application. Free-floating cabin objects, including a water bottle, illustrate the dynamic operational environment and human factors considerations associated with emergency repair procedures in microgravity. These observations informed the evaluation of handling performance, operator workload, and repair deployment characteristics.

Star-Shaped Repair Patch Performance

Modified star-shaped adhesive repair patches achieved pressure containment in all three dedicated repair parabolas. Two of the three trials achieved complete pressure retention without continuous pressurization, while the third achieved partial seal performance due to audible leakage associated with patch misalignment and operational distractions during microgravity exposure. Successful seal formation was achieved even in cases of imperfect operator alignment during application. Across the three primary star-shaped repair trials, two maintained complete pressure retention without continuous pressurization, while one exhibited audible leakage following application. Minor adhesive gathering and placement deviations were observed during successful repairs, whereas greater misalignment was associated with partial seal performance.



Figure 5. Star-shaped adhesive repair evaluation during active microgravity exposure, Jenee' Fox.

Representative star-patch repair configuration following application to the flexible bladder analog during a microgravity parabola. The figure illustrates adhesive placement, seal formation, and wrinkle characteristics observed during the repair evaluation. A representative star-shaped repair application during microgravity testing is shown in Figure 5. Visual observations documented minor adhesive gathering, placement variability, wrinkle formation, and overall seal performance during repair deployment. Complete pressure retention was maintained in two of the three primary star-shaped repair trials. Across the three primary star-shaped repair trials, the modified repair configuration produced two complete pressure-retention outcomes and one partial seal.



Figure 5A. Star Patch Trial SP-1



Representative repair outcome for Star Patch Trial 1. Minor adhesive gathering and slight placement deviation were observed; however, the repair maintained a complete seal at 6 psi.



Figure 5B. Star Patch Trial SP-2

Representative repair outcome for Star Patch Trial 2. Minor adhesive gathering was observed on one star point. The repair maintained complete pressure retention at 6 psi.



Figure 5C. Star Patch Trial SP-3

Representative repair outcome for Star Patch Trial 3. Multiple point misalignment was observed during application. Although the bladder reached 6 psi, audible leakage was present and continuous pressure was required to maintain inflation.

Duct-Tape-Style Repair Performance

Duct-tape-style repair methods demonstrated less consistent seal performance during microgravity operations despite offering advantages in rapid accessibility and simplified deployment. One duct tape repair failed to maintain a complete seal throughout the duration of the parabola. A second repair achieved only partial seal integrity during the microgravity interval. During the third dedicated duct tape repair parabola, the initial repair application produced observable wrinkle formation within the flexible bladder analog material, negatively affecting conformity around the puncture region and preventing complete seal formation. The repair material was subsequently removed and reapplied during the same parabola. Following reapplication, a successful temporary seal was achieved prior to the conclusion of the microgravity interval.



Figure 6. Duct-tape repair assembly during parabolic microgravity flight, Jenee' Fox.

The duct-tape repair configuration is shown in free flight during active microgravity operations aboard the NRC Falcon 20 research aircraft. The repair assembly consisted of a modified bladder analog with a rectangular duct-tape repair applied over a predefined puncture region. The image illustrates the operational environment in which repair deployment, alignment, and seal performance were evaluated under reduced-gravity conditions.

Visual inspection of the repair trials identified localized rippling of the bladder analog beneath the duct-tape repairs during Trials DT-1 and DT-3. These ripples coincided with partial seal performance despite proper repair alignment. Trial DT-2 did not exhibit observable rippling and maintained complete pressure retention. A representative duct-tape repair configuration evaluated during active microgravity exposure is shown in Figure 6.

Representative outcomes from duct-tape repair trials are shown in Figures 6A–6C. One of the three primary duct-tape repairs maintained complete pressure retention without observable leakage. The remaining two primary trials required continuous pressurization because audible leakage was present.



Figure 6A. Duct-tape repair outcome for Trial DT-1.

Representative duct-tape repair applied during active microgravity operations. Although the repair was properly aligned and the bladder achieved the target pressure of 6 psi, rippling of the underlying bladder material created leakage pathways beneath the repair. Continuous pressurization was required to maintain inflation, resulting in classification as a partial seal.



Figure 6B. Duct-tape repair outcome for Trial DT-2.

Representative duct-tape repair demonstrating complete seal performance during microgravity testing. The repair was properly aligned, exhibited no observable wrinkle formation beneath the adhesive surface, and maintained pressure at 6 psi without requiring continuous pressurization. This trial represented the highest-performing primary duct-tape repair outcome observed during the investigation.



Figure 6C. Duct-tape repair outcome for Trial DT-3.

Representative duct-tape repair demonstrating wrinkle-induced leakage during microgravity operations. Although the repair was properly aligned and achieved 6 psi, deformation of the bladder material beneath the repair created leak pathways that prevented complete pressure retention. Continuous pressurization was required to maintain inflation, resulting in classification as a partial seal.

Comparative Observations

Comparative observations documented differences in seal performance, wrinkle formation, and material conformity between the two repair configurations during microgravity operations.

The modified star-shaped repair configuration demonstrated:

- improved conformity to the flexible bladder analog surface,
- increased tolerance to imperfect alignment,
- reduced wrinkle formation,
- and greater overall seal reliability during repeated parabolic testing.

In contrast, the duct-tape-style repair approach demonstrated:

- faster deployment characteristics,
- simplified material access,
- but increased sensitivity to localized surface deformation and adhesive-induced rippling.

Overall, the star-shaped repair configuration achieved two complete pressure-retention outcomes compared with one complete pressure-retention outcome for the duct-tape repair configuration. Differences in wrinkle formation, material conformity, and seal performance were documented across the repair methods and are further evaluated in the Data Analysis section.

4. Discussion

The findings of this investigation suggest that adhesive geometry, material conformity, and microgravity-specific human-factors considerations substantially influence the effectiveness of temporary emergency repair procedures involving flexible pressure-retention systems during short-duration microgravity exposure.



Among the repair approaches evaluated, the modified star-shaped adhesive patches demonstrated the highest overall operational reliability during short-duration microgravity exposure. The comparative findings suggest that repair systems designed specifically for free-floating environments may provide greater operational robustness than repair approaches adapted directly from terrestrial practice.

The integrated backing-lip modification incorporated into the star-shaped repair patches also appeared to improve handling during microgravity operations. The raised peel feature facilitated more controlled backing removal and appeared to reduce unintended folding, drifting, or loss of adhesive control while free-floating. Although handling performance was evaluated qualitatively rather than quantitatively, these observations suggest that relatively simple ergonomic modifications may improve deployment efficiency during emergency repair procedures in microgravity.

The observed handling characteristics emphasize the importance of integrating human-factors engineering into emergency repair system design. Modifications such as distributed adhesive geometries and improved backing-removal features may reduce operator workload and improve deployment consistency under reduced-gravity conditions. These considerations are particularly relevant for commercial human spaceflight, where emergency repair procedures must be executable under time constraints and limited crew stabilization.

These observations highlight the importance of designing contingency repair systems specifically for microgravity operational environments rather than relying solely upon terrestrial repair methodologies. Small ergonomic modifications that may appear operationally insignificant under normal gravity conditions can become critical during microgravity procedures where stabilization, reaction-force control, and dexterity are substantially altered. Alignment accuracy alone was not predictive of repair success. Duct tape repairs that were properly aligned still experienced leakage due to wrinkle-induced deformation of the underlying bladder material.

The duct-tape repair results further demonstrate that repair materials performing well under terrestrial conditions may exhibit different behavior during microgravity operations. This observation reinforces the importance of evaluating emergency repair systems within operationally relevant environments rather than relying solely on ground-based performance.

These findings suggest that repair systems intended for emergency pressure-retention applications may benefit from repair geometries specifically engineered to provide more uniform adhesive contact across flexible membrane surfaces.

The use of a modified sphygmomanometer bladder assembly as an analog pressure-retention platform also demonstrated the viability of low-cost experimental methodologies for early-stage applied astronautics research. While the analog system did not replicate the full structural and environmental characteristics of a flight-certified IVA spacesuit, it provided an operationally relevant flexible membrane platform capable of supporting repeatable repair evaluation during active parabolic flight operations. This approach enabled rapid iterative testing without requiring access to high-cost aerospace hardware or laboratory vacuum facilities.

The accessibility of the analog platform may have broader implications for future educational, academic, and commercial human spaceflight research initiatives. Low-cost experimental systems capable of evaluating operational procedures under true microgravity conditions may help expand participation in applied astronautics investigations among independent researchers, universities, citizen-science programs, and emerging commercial spaceflight organizations.

Although the present investigation was limited primarily to qualitative observational analysis, the findings establish a preliminary operational framework for future studies involving quantitative pressure-retention measurements, leak-rate analysis, extended-duration microgravity environments, and advanced repair material characterization. Future investigations may additionally evaluate multilayer repair architectures, self-aligning patch geometries, vacuum-environment performance, and robotic-assisted emergency repair deployment concepts for use in commercial and governmental human spaceflight systems.

Notably, the only complete duct-tape repair occurred in the absence of observable wrinkle formation, while both partial-seal duct-tape trials exhibited wrinkle-induced leakage despite proper alignment.

Limitations

Several limitations associated with the present investigation should be considered when interpreting the experimental findings and their applicability to operational human spaceflight systems.

First, the study was conducted during short-duration parabolic microgravity exposure, with each parabola providing approximately 20 seconds of reduced-gravity conditions. While parabolic flight offers a valuable operational analog for evaluating real-time microgravity handling behavior and human-factors interactions, the limited duration of each microgravity interval restricted the ability to evaluate long-term seal integrity, long-term adhesive performance, or prolonged material interaction effects.

Second, the investigation utilized a modified sphygmomanometer (blood pressure cuff) bladder assembly as a flexible pressure-retention analog rather than a flight-certified IVA spacesuit bladder system. Although the analog platform successfully supported repeated repair trials and operational handling evaluation, the material composition, structural layering, pressure capabilities, and environmental performance characteristics do not fully replicate those of operational aerospace pressure garments.

The experimental setup was additionally limited by the absence of a vacuum environment, thermal cycling, elevated pressure differentials, and other environmental stressors associated with true orbital or extra-atmospheric operational conditions. As a result, the observed repair performance should be interpreted primarily as a feasibility assessment of microgravity handling characteristics and temporary seal behavior rather than validation of flight-certified pressure containment capability.

The study also relied predominantly on qualitative observational analysis rather than quantitative instrumentation. Direct pressure-retention measurements, calibrated leak-rate monitoring, adhesive bond-strength characterization, and statistical analysis of repair efficiency were not incorporated into the present experimental configuration. Future investigations utilizing integrated pressure sensors and quantitative performance metrics would significantly improve reproducibility and comparative analysis.

Another limitation involved the relatively small sample size associated with the repair trials. A total of six dedicated repair parabolas were conducted, consisting of three star-shaped patch trials and three duct-tape-style repair trials. While operational trends and comparative observations were identifiable, the limited number of trials restricts the statistical significance of the findings and may not fully capture variability in operator performance or material interaction. Because this investigation was designed as a feasibility study with a limited number of flight opportunities, observed trends should be interpreted as preliminary operational findings rather than statistically validated performance differences.

Because repair trials were performed by a single operator, the observed handling performance reflects one level of experience and technique. Future investigations involving multiple operators and standardized performance metrics would improve generalizability and reduce potential operator-specific bias.

Despite these limitations, the investigation successfully demonstrated the feasibility of evaluating emergency IVA repair methodologies during active parabolic microgravity flight using a low-cost analog test platform. The findings establish a preliminary operational and experimental framework capable of supporting future quantitative investigations of advanced repair materials, extended-duration microgravity environments, and flight-representative pressure-retention systems.

Data Analysis

A total of six primary repair trials were evaluated during microgravity exposure: three star-shaped adhesive patch repairs and three duct tape repairs. One additional duct tape reapplication was performed during the third duct tape parabola after a wrinkle-induced leak was identified. Because this reapplication occurred as a corrective action within the same parabola, it was documented separately and not counted as an independent primary trial.

Repair performance was evaluated using three outcome categories: pressure achievement, pressure retention, and repair quality. Pressure achievement was defined as the ability of the repaired bladder analog to reach 6 psi. Pressure retention was defined as the ability to maintain pressure without continuous pressurization. Repairs that reached 6 psi but required constant pressure due to audible or observable leakage were classified as partial seals.


Table 1. Microgravity IVA Bladder Repair Trial Outcomes

Trial	Repair Method	Alignment / Application Notes	Observed Issue	Outcome	Pressure Result
SP-1	Star patch	Patch placed within 1/8 in. on one side and outside the boundary by 1/8 in. on the parallel side	Adhesive buckled and gathered on one end due to microgravity coordination restraints	Full seal	Held 6 psi
SP-2	Star patch	Properly aligned	Small 1/32 in. gathering on lower right star leg	Full seal	Held 6 psi
SP-3	Star patch	1/8 in. misalignment on four star points	Distractions included floating water bottle and emesis bag; audible hissing leak present	Partial seal	Reached 6 psi only with constant pressure
DT-1	Duct tape	Properly aligned; tape cut with teeth during parabola	Ripples in bladder material beneath tape created leak paths	Partial seal	Reached 6 psi only with constant pressure
DT-2	Duct tape	Properly aligned; tape cut with teeth during parabola	No observed leak	Full seal	Held 6 psi
DT-3	Duct tape	Properly aligned; tape cut with teeth during parabola	Ripples in bladder material beneath tape created leak paths	Partial seal	Reached 6 psi only with constant pressure
DT-3B	Duct tape reapplication	Corrective reapplication after wrinkle removal during same parabola	Initial wrinkle-induced leak corrected	Full seal after correction	Held 6 psi

Table 2

Repair Type	Trials	Full Seals	Partial Seals	Full Seal Rate
Star Patch (SP)	3	2	1	66.7%
Duct Tape (DT)	3	1	2	33.3%

Summary of Primary Trial Outcomes

Across all six primary trials, every repair method allowed the bladder analog to reach 6 psi, resulting in a 100% pressure achievement rate. However, only three of the six primary trials maintained pressure without continuous pressurization, resulting in an overall full-seal success rate of 50%.

The star-shaped patch repairs produced two full seals and one partial seal. This resulted in a full-seal success rate of 66.7% and a pressure achievement rate of 100%. The duct tape repairs produced one full seal and two partial seals, resulting in a full-seal success rate of 33.3% and a pressure achievement rate of 100%. When the duct tape failure mode in Trial DT-3 was corrected through reapplication, the repair successfully held 6 psi, indicating that wrinkle mitigation may improve duct tape repair reliability.

Comparative Findings

Star-shaped patches achieved complete pressure retention in 66.7% of primary trials, compared with 33.3% for duct-tape repairs. Although both repair methods reached the target test pressure in all primary trials, pressure achievement did not differentiate repair effectiveness. Instead, pressure retention without continuous pressurization served as the primary measure of repair quality. In SP-1 and SP-2, adhesive gathering and minor placement deviation did not prevent successful pressure retention. SP-3 demonstrated that greater misalignment across multiple star points, combined with operational distractions during microgravity, may reduce seal integrity. Although SP-3 reached 6 psi, the audible hissing leak and requirement for continuous pressure indicated a partial seal rather than a complete repair.

The comparative observations suggest that repair geometry influenced pressure-retention performance more than the ability to achieve the target test pressure. Although both repair methods successfully reached

approximately 6 psi during all primary trials, differences emerged once continuous pressurization was removed. The star-shaped repair configuration achieved complete pressure retention in a greater proportion of trials while demonstrating greater tolerance to minor adhesive gathering and placement variability. In contrast, duct-tape repairs exhibited greater sensitivity to wrinkle formation and bladder surface conformity despite acceptable alignment. These observations indicate that repair geometry and material interaction may substantially influence temporary repair reliability during microgravity operations.

The duct-tape repair outcomes further suggest that bladder surface conformity played an important role in repair performance. In DT-1 and DT-3, the tape was properly aligned, but ripples in the bladder material created leak pathways. This suggests that alignment alone was not sufficient to ensure a complete seal. DT-2 demonstrated that duct tape could successfully seal the bladder when applied smoothly without underlying ripples. The successful DT-3B reapplication further supports the conclusion that duct tape can perform effectively when wrinkle-induced leak paths are corrected.

Human-factor observations also provide context for the repair outcomes. Reduced body stabilization, altered reaction-force control, and free-floating operational distractions increased the complexity of repair deployment. Because these variables were not systematically measured, they should not be interpreted as direct causes of repair success or failure; however, they provide operational context for understanding the handling challenges encountered during parabolic flight.

Interpretation

The primary distinction between the repair methods was not whether they could achieve pressure, since both repair types reached approximately 6 psi in all primary trials. Instead, the key difference was whether the repair could retain pressure without continuous input. Star-shaped patches demonstrated a higher rate of complete pressure retention during initial application, while duct-tape repairs demonstrated greater sensitivity to wrinkle formation and bladder surface conformity.

These findings suggest that pre-shaped adhesive patches incorporating distributed adhesive contact regions and microgravity-specific handling modifications may offer operational advantages for emergency IVA bladder repair. In contrast, duct-tape-style repairs remained a viable emergency repair material but demonstrated greater sensitivity to wrinkle formation and bladder conformity. While successful repairs were achieved using both approaches, the star-shaped repair configuration produced more consistent pressure-retention performance during initial application.

Because this investigation was conducted as a feasibility study using a low-cost analog platform and a limited number of repair trials, the observed differences between repair methods should be interpreted as preliminary operational trends rather than statistically validated performance differences. Nevertheless, the consistency of the observed repair behaviors provides a foundation for future quantitative investigations using flight-representative materials, integrated pressure instrumentation, and expanded sample sizes.

Overall, the comparative findings support the feasibility of performing temporary emergency IVA bladder repairs during active microgravity exposure using a low-cost analog platform. While both repair methods were capable of achieving the target test pressure, differences in pressure retention, material conformity, and operational handling suggest that repair geometry and deployment characteristics may substantially influence repair reliability. These preliminary findings establish an experimental basis for future quantitative investigations involving flight-representative pressure garments and advanced repair systems.

Key Findings

1. Both star-shaped adhesive patches and duct-tape repairs reached approximately 6 psi during all primary trials.
 2. Star-shaped patches achieved complete pressure retention in two of three primary trials.
 3. Duct-tape repairs achieved complete pressure retention in one of three primary trials.
 4. Pressure retention, rather than pressure achievement, provided the primary measure of repair effectiveness.
 5. Wrinkle formation beneath duct-tape repairs was consistently associated with partial seal performance despite acceptable repair alignment.
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6. Star-shaped adhesive geometry demonstrated greater tolerance to minor placement deviations and adhesive gathering during microgravity operations.

Human-factor considerations, including stabilization challenges and free-floating operational conditions, affected repair deployment and should be considered during the design of future emergency IVA repair systems.

5. Future Work

The findings from this investigation establish a preliminary operational framework for continued research involving emergency IVA spacesuit repair methodologies under microgravity conditions. Future studies should focus on expanding both the technical fidelity of the analog repair platform and the quantitative characterization of repair performance during active flight operations.

One of the most significant future developments would involve incorporation of a continuously pressurized bladder analog system capable of providing real-time pressure-retention measurements before, during, and after repair application. Integrating pressure sensors and leak-rate monitoring instrumentation would allow for quantitative evaluation of seal effectiveness, pressure decay, repair survivability, and comparative adhesive performance under dynamic microgravity conditions.

Future investigations should additionally evaluate the feasibility of performing multiple sequential repairs on a single pressurized bladder assembly during active flight operations. This approach would better simulate realistic contingency scenarios involving cascading damage events, repeated puncture exposure, or cumulative material degradation during extended missions. Multiple-repair testing may also provide insight into adhesive interaction between adjacent repair zones, structural fatigue effects, and the operational limitations associated with repeated emergency repair procedures on flexible pressure-retention systems.

Expanded testing involving additional repair geometries, multilayer repair architectures, self-aligning adhesive systems, and flexible composite patch materials would further improve understanding of optimal repair configurations for microgravity operations. The observed success of the modified star-shaped repair geometry suggests that distributed contact regions and microgravity-specific ergonomic modifications may represent promising design pathways for future contingency repair systems.

Future studies should also incorporate:

- quantitative deployment timing measurements,
- larger repair sample sizes,
- glove-assisted repair procedures,
- varying puncture geometries and damage severities,
- and comparative testing under both terrestrial and microgravity conditions.

Additional operational realism may be achieved through integration of vacuum-compatible materials, thermal stress testing, suit-layer analog stacking, and extended-duration microgravity platforms such as suborbital or orbital research environments.

Human-factors analysis should remain a central component of future investigations. Microgravity repair operations are heavily influenced by stabilization challenges, reaction-force behavior, object drift, dexterity limitations, and cognitive workload during contingency response scenarios. Further evaluation involving multiple operators with varying levels of training and experience may help identify standardized repair procedures and ergonomic design improvements for future commercial and governmental human spaceflight systems (Straube & Huber, 2019).

The low-cost analog methodology utilized during this investigation also demonstrates potential for broader educational and commercial research applications. Future work may explore scalable citizen-science and academic microgravity research platforms capable of supporting applied astronautics investigations without requiring access to flight-certified spacesuit hardware or large institutional aerospace facilities.

Ultimately, continued development of emergency IVA repair methodologies may contribute to improved crew survivability, operational flexibility, and contingency preparedness as commercial human spaceflight operations continue to expand into increasingly complex mission environments.

Novel Contributions of This Study

- Based on the author's review of publicly available literature, this investigation represents the first known microgravity evaluation of star-shaped adhesive patch geometry for IVA bladder repair.
- One of the first known female-led experimental investigations focused specifically on emergency IVA spacesuit repair techniques conducted during parabolic microgravity flight.
- Demonstration of a low-cost analog platform for contingency spacesuit repair research.
- Identification of wrinkle formation as a primary duct-tape failure mode in microgravity.
- Demonstration that pressure achievement and pressure retention represent distinct measures of repair performance.

6. Conclusion

This investigation demonstrated the feasibility of performing temporary emergency repair procedures for simulated intra-vehicular activity (IVA) spacesuit bladder punctures during active parabolic microgravity flight operations using a low-cost analog pressure-retention platform.

Experimental findings indicated that adhesive geometry, material conformity, and microgravity-specific human-factors considerations substantially influenced repair reliability under free-floating operational conditions. Modified star-shaped adhesive repair patches achieved pressure containment in all three dedicated repair trials and complete pressure retention in two of the three trials, representing the highest overall repair performance observed during testing.

In contrast, duct-tape-style linear adhesive repairs demonstrated greater sensitivity to localized material deformation and adhesive-induced rippling during application. Although duct tape repairs generally allowed for faster deployment, inconsistent seal integrity observed during multiple repair trials suggested that terrestrial repair approaches may not directly translate to reliable microgravity contingency performance without modification.

The incorporation of microgravity-specific handling modifications, including the addition of integrated backing lips to the star-shaped repair patches, further demonstrated the importance of ergonomic and operational design considerations for free-floating emergency repair systems. These observations reinforce the need to design contingency repair methodologies specifically for microgravity operational environments rather than adapting terrestrial repair systems without accounting for altered stabilization, dexterity, and reaction-force behavior.

The investigation additionally demonstrated the viability of low-cost analog research methodologies for applied astronautics experimentation. The modified sphygmomanometer bladder assembly provided an accessible and operationally relevant flexible membrane platform capable of supporting repeated repair evaluations during active microgravity exposure without requiring access to flight-certified aerospace hardware.

Although limited by short-duration microgravity exposure, qualitative observational analysis, and a limited number of repair trials, the study establishes a preliminary experimental foundation for future quantitative investigations involving pressurized bladder systems, leak-rate characterization, advanced adhesive geometries, and extended-duration microgravity environments.

As commercial human spaceflight operations continue to expand, the development of practical emergency repair methodologies for flexible pressure-retention systems may contribute to improved contingency preparedness, operational resilience, and crew survivability during future mission operations (NASA, 2020).

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8. References

- [1] National Aeronautics and Space Administration. (2015). NASA space flight human-system standard volume 2: Human factors, habitability, and environmental health (NASA-STD-3001, Vol. 2). NASA. <https://standards.nasa.gov>
- [2] Thomas, K. S., & McMann, H. J. (2007). U.S. spacesuits. Springer Praxis Books.
- [3] National Academies of Sciences, Engineering, and Medicine. (2011). Recapturing a future for space exploration: Life and physical sciences research for a new era. The National Academies Press. <https://doi.org/10.17226/13048>
- [4] Young, L. R., & Shelhamer, M. (1990). Microgravity effects on human sensorimotor systems. In Proceedings of the Human Factors Society Annual Meeting, 34(19), 1406–1410.
- [5] Clément, G. (2011). Fundamentals of space medicine (2nd ed.). Springer.
- [6] National Aeronautics and Space Administration Human Research Program. (2024). Human research roadmap. NASA. <https://humanresearchroadmap.nasa.gov>
- [7] Straube, U., & Huber, P. (2019). Spacesuit technologies and operational considerations for future exploration missions. *Acta Astronautica*, 162, 438–449.
- [8] National Aeronautics and Space Administration. (2020). Commercial crew program overview. NASA. <https://www.nasa.gov/commercialcrew>
- [9] International Organization for Standardization. (2019). Space systems—Crew interfaces in transport vehicles (ISO 11064). ISO.

9. Conflict of Interest

The author declares no known competing financial interests or personal relationships that could have influenced the work reported in this paper.

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