

Advancing Space Operations: Thermal Clamp Tile

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Purpose of the Innovation

Compared to previous space stations, the construction and long-term operation of the Lunar Gateway will require a significant increase in extravehicular (EVA) duration and frequency. One of the main challenges that comes with extended EVAs in lunar orbit is thermal regulation. Specifically, this relates to how astronauts and EVA tools are exposed to extreme fluctuations of temperature when transitioning between direct solar radiation and deep shadow. These thermal stresses can cause problems like astronaut discomfort, reduced manual dexterity, tool degradation occurring at a faster rate, increased fatigue, and many others (Belobrajdic et al., 2021).

The Thermal Clamp Tile (TCT) is a manually controlled, passive EVA support device that is designed to provide localized thermal regulation and tool stabilization during exterior Gateway operations. The purpose of this innovation is to prevent thermal stress at the immediate worksite by absorbing excess heat and releasing it gradually into the vacuum of space. By improving thermal stability near active maintenance or construction areas, the TCT improves EVA efficiency, safety, and crew endurance. This report explains the purpose of the Thermal Clamp Tile, how it supports Lunar Gateway EVA work, how it is designed and operated, and how astronauts would be trained to use it.

How It Will Help the Construction or Maintenance Process

Construction and maintenance tasks on the Lunar Gateway involve a process with precision assembly, module attachment, inspection, and required operations, all of which require

long-term exposure to harsh thermal environments (Zamora, 2023). The TCT supports these processes by acting like a temporary thermal buffer that is positioned directly adjacent to the work area. During EVA operations, astronauts may dock tools that are frequently used onto the tile's magnetic pads. This allows for excess heat to be transferred away from tool surfaces. Additionally, it eliminates the risk of components or gloves overheating, which could otherwise make them hard to grasp and affect the ability to use them properly. The stabilization function of the TCT also helps to minimize accidental tool drift while decreasing task interruption and any risk of losing equipment. Therefore, this innovation has a lot of potential in areas like smoother task execution, reduced EVA time, and improved mission efficiency overall.

Description of the Innovation

Part 1: Structural Clamp Assembly

The assembly of the clamp from a structural standpoint features two spring-loaded titanium alloy clamp arms that are designed to attach securely to standardized Gateway handrails or module edges. The high strength-to-weight ratio alongside its ability to resist corrosion and remain thermally stable in vacuum conditions make titanium a sensible, realistic aspect for incorporation (Titanium Metal Properties and Uses, n.d.). There are also oversized and insulated grip tabs, compatible with pressurized EVA gloves, that allow astronauts to both engage and disengage the clamp arms in an easy manner during exterior operations (Walters, 2025).

Part 2: Phase-Change Thermal Core

The phase-change thermal core is at the center of the tile and is composed of a paraffin-based material encapsulated within an aluminum housing. This core absorbs excess

thermal energy when exposed to elevated temperatures. It does this by transitioning from a solid to a semi-liquid state. The use of a phase-change material allows thermal energy to be stored without an immediate increase in surface temperature, protecting nearby tools and gloves from overheating (Phase Change Material, 2024).

Part 3: Radiator Fins and Tool Docking Surface

The thermal core is surrounded by shallow aluminum radiator fins with a high-emissivity coating. These fins increase surface area, which allows for stored heat to be radiated efficiently into space during periods of shadow. The exterior face of the tile includes magnetic docking pads that secure ferromagnetic EVA tools, which prevents motion that is uncontrolled and allows for passive heat transfer from the tools to the tile (What is a Magnetic Mounting Pad?, 2024).

Operation of the Innovation

Control

The Thermal Clamp Tile is manually controlled and does not rely on electrical power, motors, or software systems. The astronaut controls the device entirely through mechanical interaction. The absence of active electronics increases the reliability of the system and eliminates any demands for a power source, making the device very well-suited for EVA operations that last for longer periods of time.

Instructions

Step 1

The astronaut chooses a stable location near the work area. An example of this would be a Gateway handrail or structural bar that is easy to reach. Using the insulated grip tabs, the astronaut opens the clamp arms and places the Thermal Clamp Tile onto the handrail. After this, releasing the grip tabs allows the clamp arms to close and securely lock the tile in place. The astronaut then checks that the tile is firmly attached and does not move.

Step 2

Once the tile is secured, the astronaut places EVA tools onto the magnetic docking pads on the front of the tile. When tools are docked, heat naturally transfers from the tools into the tile's thermal core. This helps keep the tools at a safe temperature and prevents them from floating away while not in use.

Step 3

After the task is finished, the astronaut removes the tools from the docking pads and uses the grip tabs to open the clamp arms. The Thermal Clamp Tile is then detached from the handrail and is either moved to another nearby work area or stored for future EVA operations.

Training

Astronaut training for the Thermal Clamp Tile would be incorporated into existing EVA preparation programs. Training would begin with classroom instruction related to thermal dynamics, phase-changing materials, and safe operational procedures. This would be followed by hands-on training using physical mockups in neutral buoyancy laboratory environments in order to simulate the microgravity handling and attachment techniques (Maron, 2025). Virtual reality EVA simulations would be used to practice tile placement, tool docking, and thermal

management strategies in realistic Gateway exterior scenarios (Bell, 2025). Thermal response testing would also be conducted using instrumented mock tools to demonstrate heat absorption and dissipation behavior under various orbital conditions (Soga Research Group, 2022). This comprehensive training regimen would ensure that astronauts can deploy the TCT efficiently and safely during real mission operations.

Conclusion

The Thermal Clamp Tile clearly shows an innovation that is both practical and relevant to missions while also being well adapted for the unique operational challenges of the Lunar Gateway. This device essentially controls heat and keeps tools stable, which makes spacewalks safer, more efficient, and less physically demanding from a fatigue standpoint for astronauts. Its simple mechanical design, lack of power requirements, and compatibility with existing Gateway infrastructure make it a scalable and reliable solution for long-duration lunar orbit operations. As EVA demands increase during Gateway construction and maintenance, the Thermal Clamp Tile would be a strong candidate for use as a targeted approach to improve crew performance while adhering to the constraints of space-based engineering.

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