Robotic excavation and construction on planetary surfaces would benefit from a dust-tolerant tool coupler, to let a robot easily switch between robust end-of-arm tools such as:
- Heavy excavation bucket
- Rock ripper
- Material extruder
- Bulk commodity transport tank
- Gripper / manipulator
- Powered vibrating plate compactor
- Powered rock breaker / rotary hammer drill

We built and robotically tested several approaches for robot-to-tool couplers, and recommend a dual-pin coupler for standard use on robots and tools to allow interoperability between missions. We propose putting two parallel pins on the tool. On the robot a static top hook self-aligns the coupler and tool, and a powered locking lug clamps the other pin in the bottom slot, to securely lock the tool to the robot.

This puts all the active parts on the robot, and minimizes the mass of the tool. Four degrees of freedom are constrained by direct contact, and the top pitch is constrained by the locking lug, leaving only minimal sliding motion along the pins.

Tool-side Interface Specification:
- Pin diameter: 8mm
- Pin axis-to-axis distance: 125mm
- Minimum clearance along pins: 76mm
- Behind pin axis: 16mm

As tested: the tool holder was cut from 1.5 mm steel sheet, and steel pins welded in. Tool-side mass is 400 grams with these materials, and proved both robust and easy to couple and uncouple in extensive robotic testing with a variety of tools and operations, including using excavation tools immersed in dusty regolith simulant.

A double-size version with hollow 16mm pins would allow tools to also be lifted by human hands in EVA gloves, which could allow shared robotic or human manipulation of tools or containers.

Trade Study Summary: Robot-to-tool couplers

<table>
<thead>
<tr>
<th>Tool Coupler</th>
<th>Mass/tool</th>
<th>Dust Tolerance</th>
<th>Ease of Coupling</th>
<th>Load</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dual-Pin (this work)</td>
<td>0.4 kg</td>
<td>Excellent in simulant testing</td>
<td>Good, self-aligning</td>
<td>&gt;500 N</td>
</tr>
<tr>
<td>Beveled Box</td>
<td>1 kg</td>
<td>Wide gaps</td>
<td>Tricky to align</td>
<td>&gt;500 N</td>
</tr>
<tr>
<td>ISS-WMI</td>
<td>4 kg</td>
<td>Wedge may jam</td>
<td>Wedge self-aligns</td>
<td>500 N</td>
</tr>
<tr>
<td>FRGF</td>
<td>8 kg</td>
<td>LEO design</td>
<td>Proven automation</td>
<td>667 N</td>
</tr>
</tbody>
</table>

To attach to a tool,
1.) The robot's end effector approaches the tool tilted down, so the robot's top hook enters the tool between the pins.
2.) After making contact the robot then lifts up until the top pin is captured by the top hook.
3.) The robot then pivots the coupler until its bottom slot captures the tool's bottom pin, optionally using gravity to align the tool to the top hook.
4.) The robot can then clamp the tool's bottom pin by tilting the locking lug.

Detaching is the same steps in the reverse order.

We tested this dual-pin tool coupler system with our Break The Ice robot and a variety of excavation tools.