A “Robot Factors” Approach to Designing Modular Hardware

Nathan Melenbrink* and Justin Werfel

School of Engineering and Applied Sciences, Harvard University

Introduction

For space hardware that would be needed to support a Lunar habitat, even routine maintenance tasks typically require a coordinated sequence of complex bimanual motions. Few robots are capable of the dexterity and fine motor control needed to execute such tasks. Rather than relying on highly sophisticated robots, a “robot factors” approach [1] instead promotes autonomy by designing hardware to be easily manipulable by typical robot platforms and end effectors. Here, we outline the design principles that informed the redesign of a power module and demonstrate its operation by a 6 DoF robot arm.

AMPS

NASA’s Advanced Modular Power Systems (AMPS) project seeks to standardize future space power system architectures by using a modular approach [2]. All modules conform to a standardized form factor, but provide different functions (e.g., Bi-Directional Converter, Load Switchgear Module, etc.). Removing and replacing modules is a two-handed dexterous operation (a fingernail or small screwdriver may even be required to unlock wedge-locks). Module replacement is not suited to current NASA robots.

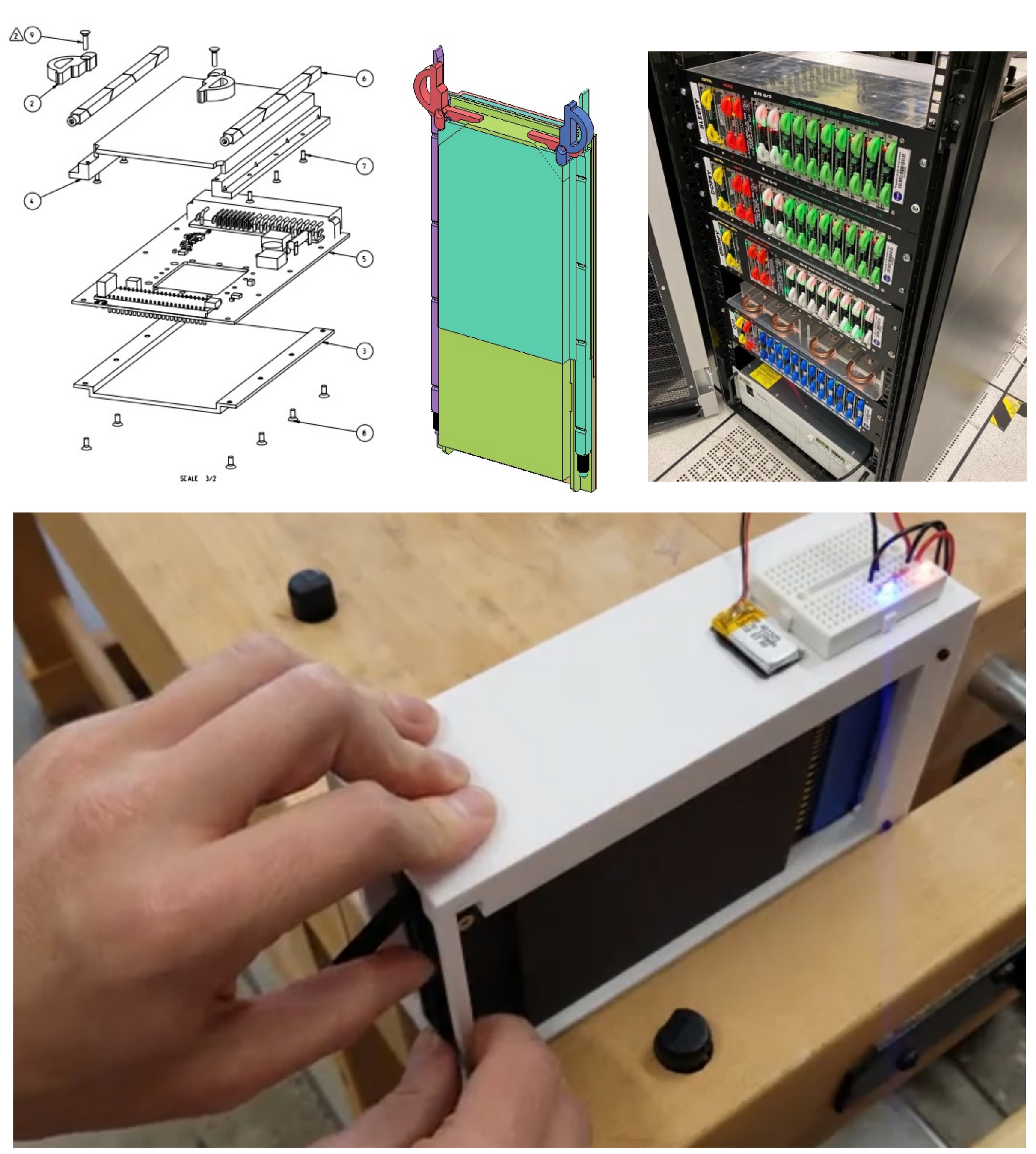

Fig. 1: (Top) The Advanced Modular Power System hardware consists of power modules that contain a PCB within a housing. It features injector/ejectors to help couple/decouple the connector, as well as wedge locks to secure the module in place after insertion. Multiple modules can be installed in a chassis, and multiple chassis are contained within a rack. (Bottom) Module replacement requires two sets of motion. The first (insertion/ejection) requires forceful two-handed operation, and the second (wedge locking/unlocking) requires dexterous manipulation.

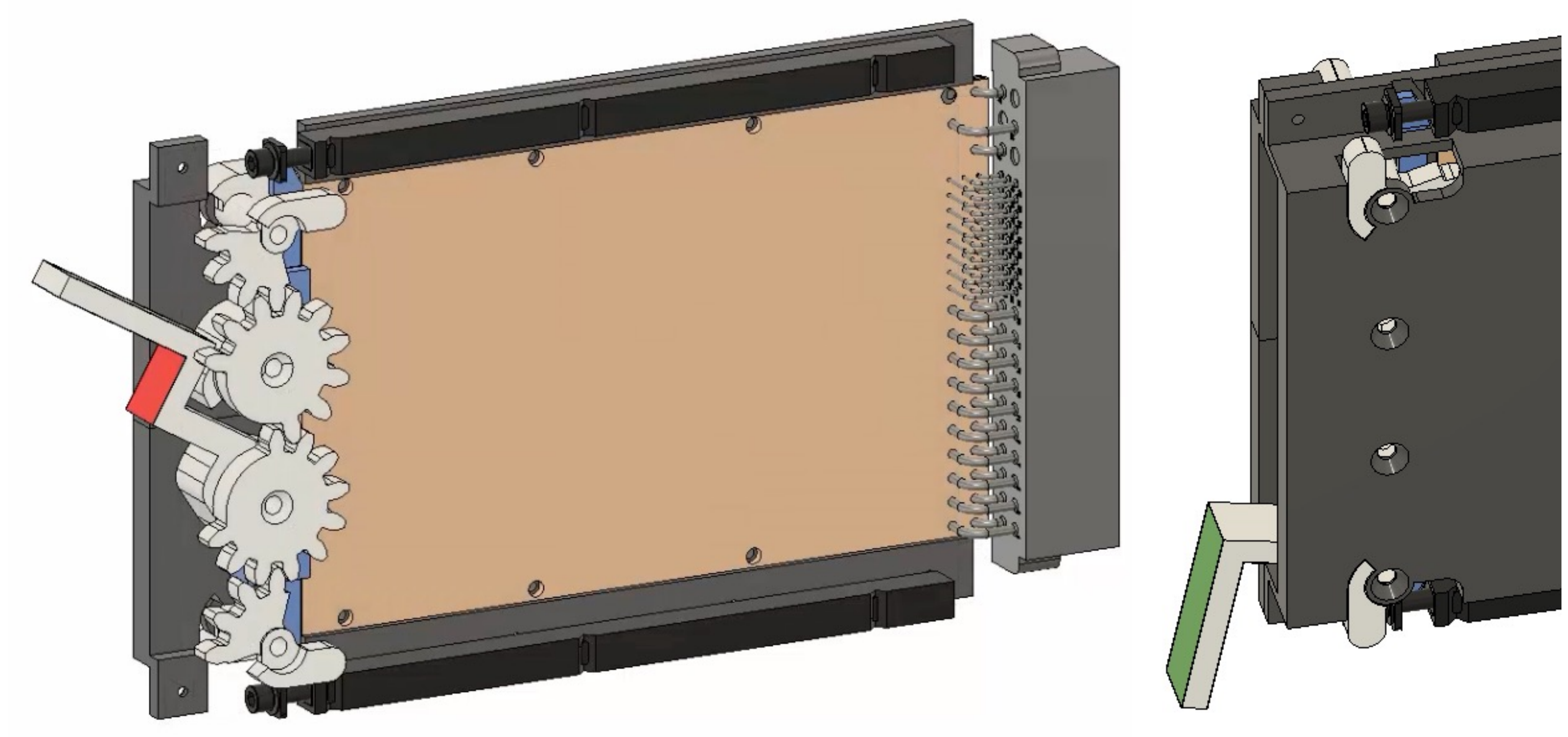

Fig. 2: The redesigned power module uses a gear assembly to coordinate different types of motion output from the single input (supplied by the robot moving a lever along a 120° stroke). For insertion, the first 90° causes the injectors to press against tabs in the chassis, mating the 47-pin connector at the rear of the module with the corresponding connector attached to the chassis. The remaining 30° engages wedge-locks that tighten against the chassis, locking the module into place. For ejection, these steps are reversed.

Design Principles

The most important redesign feature consolidates compound motions into simple mechanisms, using a gear system (Fig. 2). The design also incorporates filleted corners and edges to enforce correct alignment of the module. While planning for robot operation, a key concern was to avoid the workspace boundaries and joint limits, where accuracy and power are reduced.

Fig. 3 shows a 6-DoF robot arm demonstrating removal and insertion of a power module (making full electrical mating between the connectors). The simple mechanical advantage afforded by the longer lever reduces the torque requirement to fall within the robot’s specified range, and the gear assembly enables multiple complex operations with a single simple motion.

Robot Factors

Previous work has recognized the value of designing hardware specifically to facilitate robot manipulation, using the terms “robot factors” [1] and “robot ergonomics” [3]. These terms are styled after the field of “Human Factors” or ergonomics, which is concerned with how device design (products, processes and systems) can facilitate human operation, through reduced error, increased productivity and enhanced safety. By the same token, “robot factors” is concerned with how device design can facilitate robot performance, with the premise that more sophisticated devices reduce the need for highly sophisticated robots.

While the concept of “robot factors” has been presented in prior literature, that work has not previously demonstrated robotic operation or quantitative performance analysis.

Performance

A 6 DoF robot arm with a standard parallel-jaw gripper was programmed to autonomously insert a module, mate its connectors, and lock it into place with the simple input motion of pivoting a lever.

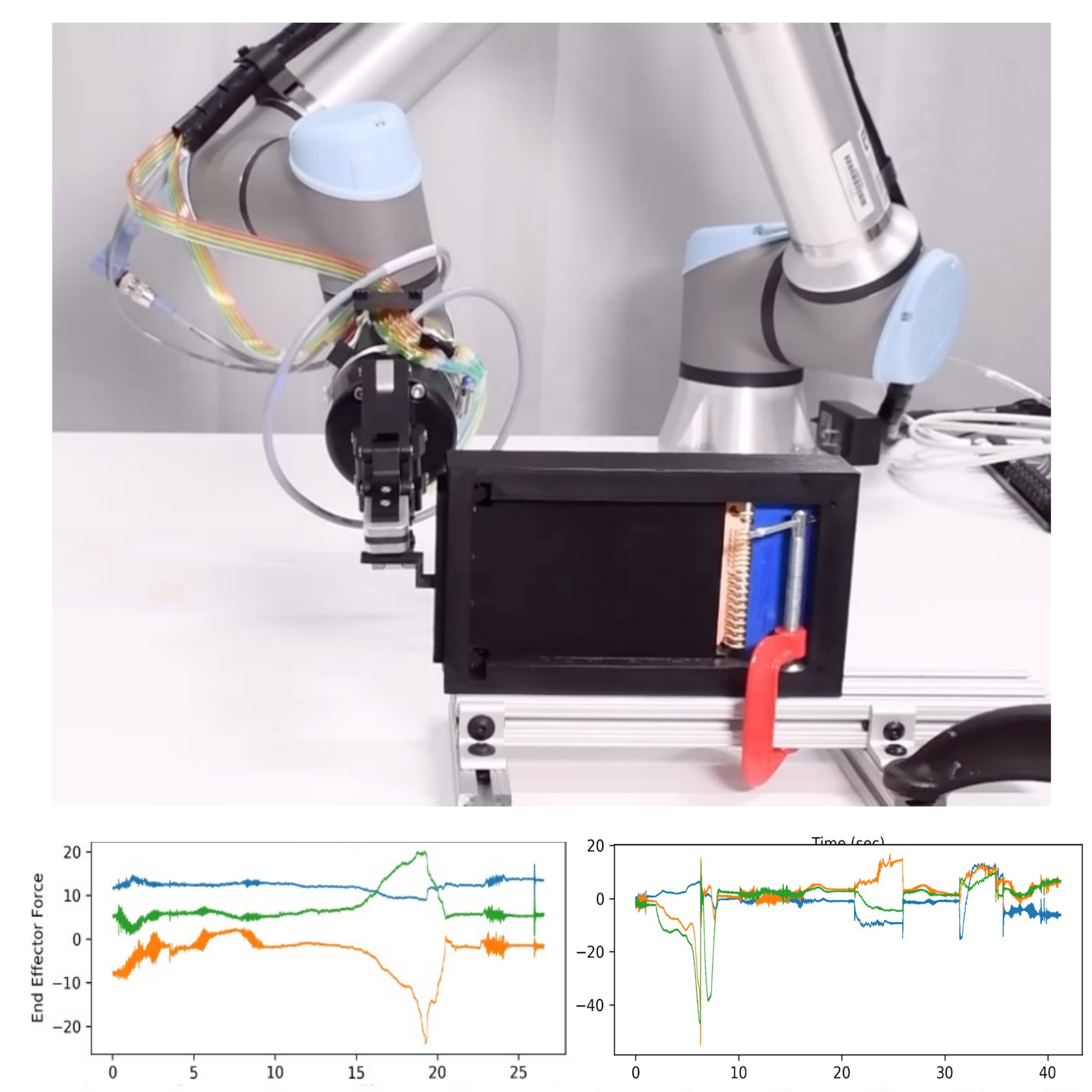

Fig. 3: (Top) The robot arm was found to be able to autonomously perform both insertion and ejection routines. A parallel-jaw gripper in the closed position is used to apply force needed to insert the module and mate the connectors. (Bottom) X, Y, and Z forces measured from the robot arm during the injection (bottom left) and ejection (bottom right) routines. For injection, a peak force of ~50N was applied to mate the connector, while a peak force of ~100N was required to uncouple the connector.

Conclusions and Next Steps

The primary contribution of this work was the development of a simple mechanism to coordinate otherwise unlinked motions. In particular, this strategy could be applied to a range of maintenance tasks that require more complex motions to be applied in series. Additionally, levers and gears were used to reduce the peak force that a robot would need to be able to impart to complete the insertion task. Furthermore, edges and corners were chamfered or filleted in order to improve alignment. The handle was designed to be easily-graspable by simple robot end effectors, and is color coded to facilitate computer vision in future work (green indicates that the module is inserted and locked, red indicates the module is ejected). Finally, we demonstrated successful autonomous operation, inserting and ejecting the module from its chassis, using a single robot arm with a limited gripper.

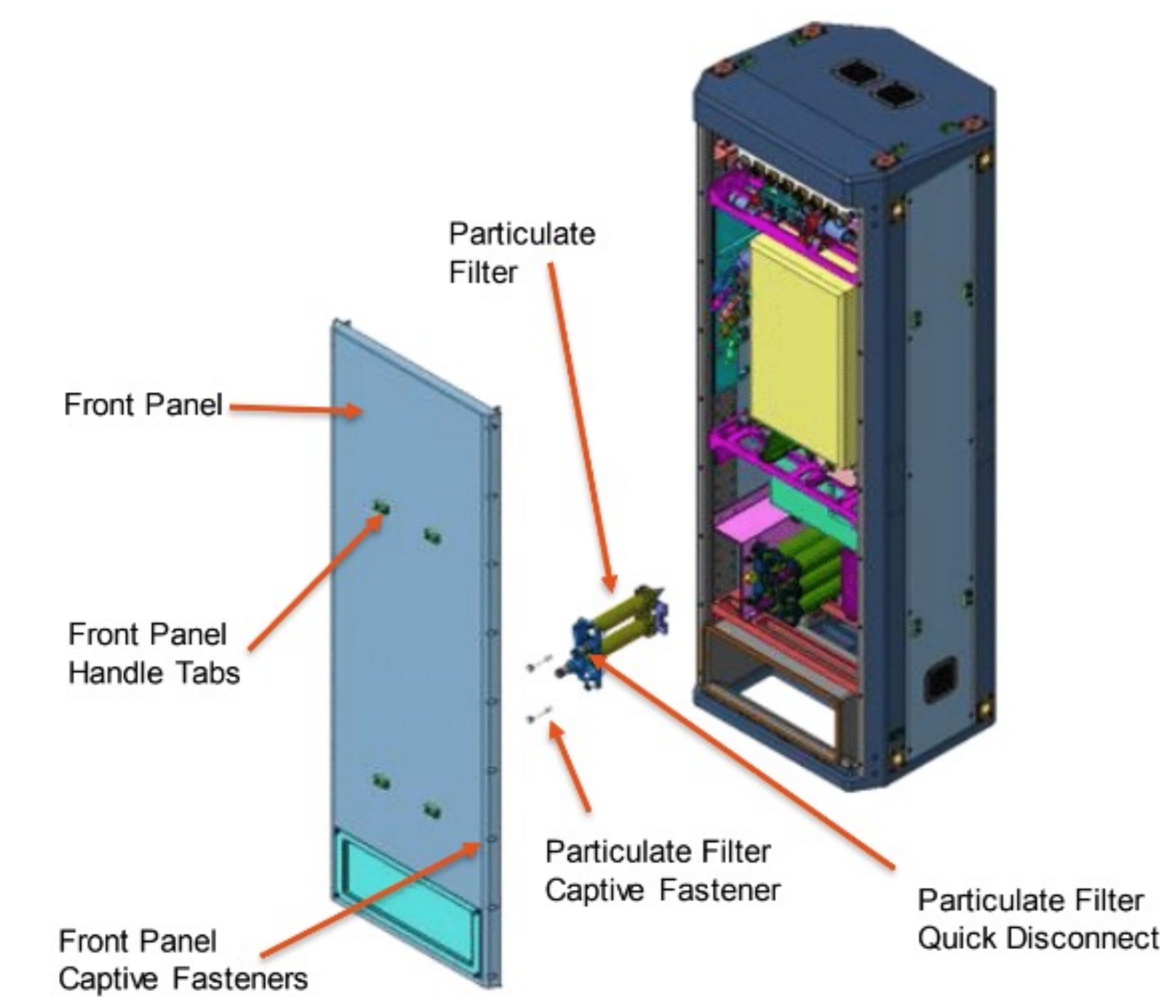

Fig. 4: In future work, we expect that the “Robot Factors” approach, and a similar design, could be applied to other hardware like filtration systems. This figure from Collins Aerospace shows the process of changing a particulate filter.

References

[1] W. C. Chiou and S. A. Starks "An Introduction to the Concept of Robot Factors And Its Application to Space Station Automation", Proc. SPIE 0580, 1985.

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[3] R. Sosa et al., “Robot Ergonomics: Towards Human-centered and Robot-inclusive Design”, Proc. 15th Intl. Design Conference, 2018.

Acknowledgments

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* Contact info: melenbrink@seas.harvard.edu