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This DURIP grant has allowed for the purchase of three 3D printers: MCor Matrix, Stratasys Objet 260 Connex and Markforged Mark One. These printers (along with existing Stratasys Fortus 400mc) are an essential and invaluable part of the newly formed Aerospace 3D Digital Fabrication Laboratory at the William E. Boeing Department of Aeronautics & Astronautics at the University of Washington (UW) - Seattle. This departmental facility is

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Number of graduating undergraduates who achieved a 3.5 GPA to 4.0 (4.0 max scale):......	0.00
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Sub Contractors (DD882)

Inventions (DD882)

Scientific Progress

Technology Transfer

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Date: 02/29/2016

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Figure 1: MCor Matrix 3D printer (*paper printer*)

Figure 2: Stratasys Objet 260 Connex 3D printer (*graded polymer printer)*

Figure 3: Markforged Mark One 3D printer (*composite material printer)*

MCor Matrix (see Figure 1) produces high quality 3D printing and rapid prototyping in a fraction of the time taken by traditional 3D printers, using eco-friendly, inexpensive office paper and water-based adhesive. The build envelope is 256 mm x 169 mm x 150 mm. MCor produces the world’s only paper based 3D printers using standard letter paper to make 3D models for concept design evaluation, form-fit function testing, display and communication models, casting patterns and models for teaching. Models built on this printer can be tailored as a core material for lightweight sandwich structures. Another research goal is to be able to manufacture *multifunctional-layered structures*, by reinforcing nanoparticles in desired layers in the paper stack. We are currently exploring various methods that would allow impregnation of nanoparticles in papers, in order to build preliminary multifunctional structural models. This instrumentation is to be used in conjunction with an ongoing ARO sponsored effort on "Progressive damage and failure modeling of layered 3D textile composites."

Objet 260 Connex (see Figure 2) allows building material models as large as 255 mm x 252 mm x 200 mm. It has high accuracy (16 micron per layer) and 14 photocopolymers to simulate a range of material properties. This printer will be useful in manufacturing thin walled shell structures (or its assemblage), which are used as energy absorbers. Specifically, we will be exploring the design of patterned cellular shell structures that have post-peak response that is more stable and that have higher energy absorbing capability compared to the usual thin cylindrical shell. In past studies (D'Mello et al. [1]), it has been shown that curved walls are better suited in their axial crumpling characteristics with respect to energy absorption compared against straight-sided axially crushed counterparts. Manufacturing of an assemblage of such shells will be guided by numerical models created in commercially available finite element software ABAQUS. The geometry will be imported to SolidWorks, which will export the geometry file as an STL file, which then can be used in printing the 3D model. Mechanical performance using compressive crushing of the 3D printed part will be studied in conjunction with the parent finite element geometry, which will be virtually compressed using the finite element method executed using the ABAQUS/Explicit solver. Moreover, the 3D printer will allow for printing non-uniform wall material in order to tailor not only wall thickness, but also wall material for the design of optimal energy absorbers. Lastly, such patterned shell structures can then be filled with softer elastomers, either manually through a secondary manufacturing process or within the 3D printer itself as a unified *"composite" cellular solid*. Introduction of such soft elastomers in the voids of such cellular solids will also allow for additional tailorability of their post-peak response. Preliminary results using uniform cellular, filled honeycombs are provided in D'Mello & Waas [2].

Markforged Mark One (see Figure 3) is a composite materials printer that can print carbon fiber, fiberglass, Kevlar and nylon. The build size is 320 mm x 132 mm x 154 mm with layer resolution of 0.1 mm. It can print solids that are 20 times stiffer and 5 times stronger than traditional ABS plastic models. Scaled models of various composite layups can be created using this printer. Such scaled models are effective in both research and in teaching. This printer will also allow students in the Aero/Astro department to manufacture lightweight composite parts for building drones and other model aircraft structures. Potential research directions that will be pursued by the PI are in the design of lightweight models for prosthetics, and also in manufacture of tailored face sheet material for sandwich structures (whose cores will be manufactured either by the MCor Matrix or by the Objet Connex).

References:

1. R. J. D’Mello, S. Guntupalli, L. R. Hansen and A. M. Waas, “Dynamic axial crush response of circular honeycombs,” Proceedings of the Royal Society A, Vol. 468, pp. 2981-3005, 2012.
2. R. J. D’Mello and A. M. Waas, “Synergistic energy absorption in the axial crush response of filled circular honeycombs,” Composite Structures, Vol. 94, Issue 5, pp. 1669-1676, 2012.