THOR-05F 3D-Printed Abdomen Preliminary Results

Dominic J. Isopi, Paul Depinet

I. INTRODUCTION

Since 3D-printing, or additive manufacturing, was popularized in the 2010s, Humanetics has been interested in the technology and continually evaluating new materials and methods. The THOR-05F Abdomen provides a great opportunity to explore 3D-printing technology. The current design is a soft urethane foam with a thin, vinyl-based skin with a complicated shape to fit around the metal parts of the lumbar and pelvis of the THOR-05F. The THOR-05F includes left and right Abdominal Pressure Twin Sensors (APTS) to measure abdomen injuries. An alternate design that improves durability and allows more performance control in the production environment is desirable. The first phase of a 3D-printed THOR-05F abdomen project was a multi-piece, glued-together assembly made from thermoplastic polyurethane (TPU). For simplicity, the APTS were not included for this phase of the project. The THOR-05F Abdomen also provides an excellent opportunity for evaluating 3D-printing in Anthropomorphic Test Devices (ATDs). See Figure 4 for a picture of the two abdomens.

II. METHODS

The 3D-printed abdomen was evaluated in two different ways: quasi-static testing and dynamic testing. The quasi-static testing was performed on a load frame by compressing the abdomen to a specific force, then releasing the load; the load frame tracked the displacement through the motion. The loading head was a half-cylinder designed to evaluate the stiffness of the foam abdomens before certification of the ATD. The foam abdomen included a set of APTS during the quasi-static testing and dynamic testing.

The dynamic testing is based off the Lower Abdomen Biofidelity Test published by Cavanaugh [1], who published Force vs. Time and Displacement vs. Time corridors. The data were scaled for a 5th percentile female in Biomechanics Response Manual by Lee [2]. BioRank based on Rhule 2018 [3] provided quantitative differentiation between the two designs. Shape and Magnitude (SM) and Phase (P) values both contribute to the Root Mean Square (RMS) value.

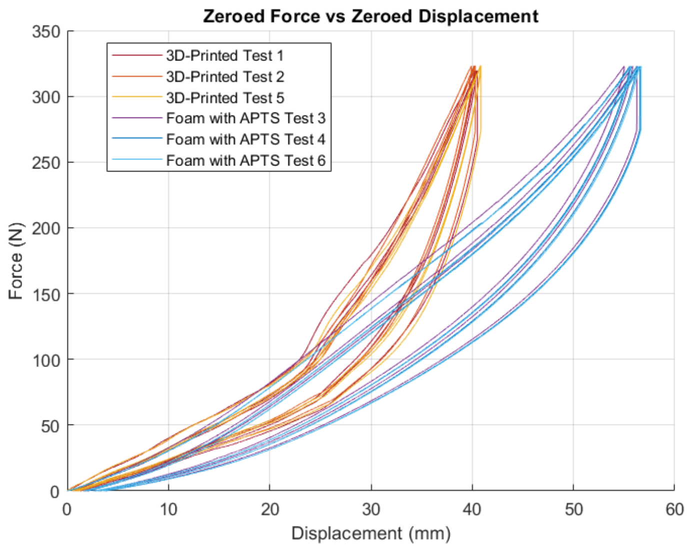

Fig. 1 - Quasi-static Force vs. Displacement data for both the 3D-printed and foam abdomens.

III. INITIAL FINDINGS

Figure 1 shows the results of the quasi-static testing. The 3D-printed abdomen is clearly stiffer over the evaluated range. However, for the first 25 mm the values and slopes are close, indicating a similar stiffness. At 25 mm, the load frame begins to engage the stiffer portion of the 3D-printed abdomen, which begins the deviation. The results are promising for the first prototype.

Figure 2 and Figure 3 show the results of the dynamic testing compared against the published data in Wang et al. [4]. Table I is a summary of the BioRank values for both designs. We can see that the performances between the two designs are similar. The 3D-printed abdomen still has a higher force than the foam abdomen, but it has less displacement. The forces for both designs are much higher than the biofidelity corridor. The BioRank values are comparable when comparing the two designs. The largest difference between the RMS values for each parameter is 0.26 and the difference between the two average BioRank values is only 0.11. This is the first prototype and further tuning with design changes should improve the biofidelity numbers of the 3D-printed abdomen.

D. J. Isopi (e-mail: disopi@humaneticsatd.com, tel: +1 248 778 2142) is a biomedical engineer at Humanetics Safety. P. Depinet is the chief engineer at Humanetics Safety.

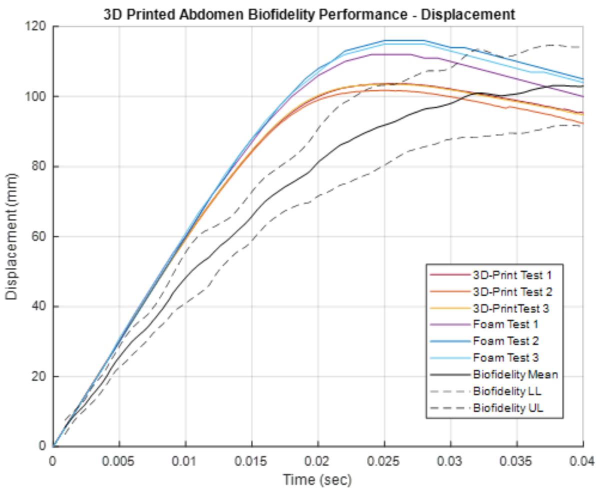

Fig. 2 - Dynamic testing displacement data for both 3D-printed and foam abdomens.

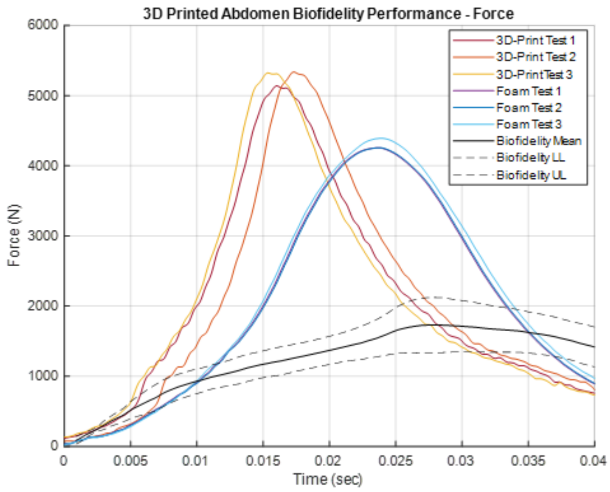

Fig. 3 - Dynamic testing force data for both 3D-printed and foam abdomens.

TABLE I
SUMMARY OF THE BIORANK 2018 VALUES FROM DYNAMIC TESTING

	Displacement			Force			
Test Number	SM	P	RMS	SM	P	RMS	Average
3D-Print Test 1	0.82	-0.31	0.88	3.84	-1.19	4.02	2.45
3D-Print Test 2	0.91	-0.35	0.98	3.83	-0.96	3.95	2.47
3D-Print Test 3	0.83	-0.33	0.89	3.89	-1.23	4.08	2.49
3D-Print Average	0.85	-0.33	0.92	3.85	-1.13	4.02	**2.47**
Foam Test 1	1.03	-0.10	1.04	3.66	-0.55	3.71	2.38
Foam Test 2	0.88	-0.08	0.88	3.66	-0.53	3.70	2.29
Foam Test 3	0.92	-0.10	0.92	3.84	-0.51	3.88	2.40
Foam Average	0.94	-0.09	0.95	3.72	-0.53	3.76	**2.36**

IV. DISCUSSION

The 3D-printed abdomen performed similarly to the foam abdomen with APTS. The quasi-static stiffnesses were very similar up to 25mm of displacement. The stiffness deviation was due to the glue lines; a glue line perpendicular to the load causes an increase in stiffness. Future work will decrease or completely remove this effect. The dynamic test results were quantitatively very close; the average BioRank had only a 0.11 difference. Further work will incorporate the APTS into the 3D-printed abdomen, while optimizing the stiffness, and will print the entire abdomen structure in one part.

V. REFERENCES

[1] Cavanaugh, J. M., *et al.*, SAE Technical Paper, 1986.

[2] Lee, E. L., *et al.*, NHTSA Publication, 2017.

[3] Rhule, H., *et al.*, IRCOBI, 2018.

[4] Wang, Z. J., *et al.*, IRCOBI, 2018.

Fig. 4 - Picture of 3D printed abdomen, left, and foam abdomen, right.