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HIGH PERFORMANCE HYBRIDSIL SEAT CUSHIONS FOR NEXT-GENERATION ARMY SEAT SYSTEMS

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ABSTRACT

Through Army SBIR funding, NanoSonic has created and empirically optimized viscoelastic HybridSil polyurethane siloxane seat cushions that provide improved pressure distribution and Multi-Axial Simulation Table (MAST) vibration dampening over currently employed Commercial-Off-The-Shelf (COTS) seat cushions. The foundation of this effort was the synthesis of novel polyurethane siloxane foams and the correlation of their copolymer composition and crosslinking density with vibrational damping, pressure distribution mapping, and mechanical properties. ASTM D 3574 mechanical testing indicates HybridSil seat cushions maintain dimensional stability after extended fatigue testing. H-point testing completed in accordance with FMVSS-202A indicates NanoSonic's seat cushions afford comparable positional values to the current employed seat cushions and thus have direct integration potential.

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1. INTRODUCTION

Through Army SBIR funding, NanoSonic has created and empirically optimized viscoelastic HybridSil polyurethane siloxane seat cushions that provide improved pressure distribution over currently employed Commercial-Off-The-Shelf (COTS) seat cushions. Improved pressure distribution assists with blood circulation to the legs while in the seated position and increased mission readiness. Crucial side by side pressure distribution mapping comparing the current COTS seat cushion with HybridSil seat cushions employing the same seat pan dimensions were completed on individuals with weights ranging from 135 to 265 lbs and heights from 5'2" to 6'0."

In addition to improved pressure distribution over a broad soldier profile, NanoSonic's Phase II optimized HybridSil seat cushions demonstrated improved vibration dampening performance in the form of reduced whole-body vibration over currently employed COTS cushions during Multi-Axis Simulation Table (MAST) testing with MGA Research Corporation.

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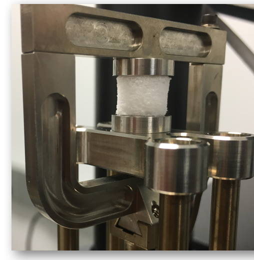
Testing was completed using a COTS seat structure and comparing the vibration dampening performance of the currently fielded cushion against HybridSil seat cushions during simulated mission profiles with a 155 lb. dummy equipped with accelerometers. It was found that NanoSonic's HybridSil seat cushions demonstrated reduced RMS acceleration, crest factors, jerk as a function of time, and acceleration power spectral density as a function of frequency over the standard army seat cushion baseline. As a result, NanoSonic's seat cushions empirically demonstrated the capacity to provide the seated soldier with reduced physical fatigue, increased general wellness, and decreased motion sickness. An image of NanoSonic's seat cushion within a COTS seat cover is included in Figure 1.

Figure 1. HybridSil COTS seat cushion

2. DYNAMIC MECHANICAL ANALYSIS

NanoSonic used dynamic mechanical analysis (DMA) to investigate the frequency dependent vibration absorption / dampening performance of its HybridSil seat cushion foams. The currently employed COTS seat cushion foam was included for direct comparative analysis. Testing was completed using a horizontal plate compression clamp fixture. Within this setup, one of the plates is fastened to a stationary stage while the other oscillates to apply a sinusoidal force at a given frequency. An image of the test fixture is shown in the right inset.



Through these efforts, the tan delta performance and elastomeric resilience of viscoelastic HybridSil foams was empirically evaluated and optimized as a function of copolymer composition, crosslink density, molecular weight, and bulk foam morphology. The tan delta value of a viscoelastic material is the ratio of its viscous to elastic response while under a sinusoidal stress, and this value directly relates to its ability to absorb and disperse vibrational energy at a given frequency and temperature. Thus, materials with greater tan delta values at a specific frequency and temperature have greater energy absorption and dispersal capabilities under those conditions.

Within the context of a seat cushion material, the tan delta provides an empirical value that NanoSonic employed to quantify the ability of HybridSil foams to absorb and deflect vibrational energy perpendicularly away from the seated soldier. In order to simulate whole body vibration (WBV), NanoSonic measured the tan delta of candidate foams over the frequency range of 0.5 to 10 Hz. Beyond 10 Hz, the DMA instrument approaches its resonance frequency and begins vibrating itself thus preventing the acquisition of accurate data.

A comparative tan delta analysis between NanoSonic's HybridSil seat cushion foam and a currently employed COTS foam is included in Figure 2. Encouragingly, the tan delta value for this system is consistently greater than the baseline COTS seat cushion foam from 1 to 10 Hz indicating it has improved vibration dampening performance. This data combined with the encouraging pressure distribution performance discussed in Section 3 indicates this foam may be used in place of the legacy seat cushion for enhanced vibrational dampening and blood flow distribution to the seated soldier.

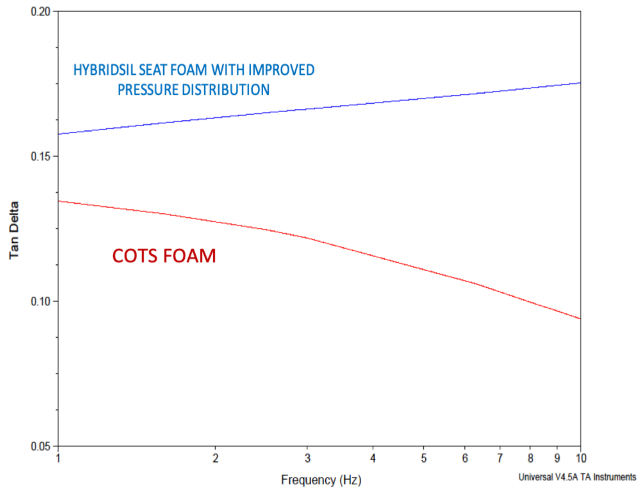


Figure 2. Plot of tan delta as a function of frequency from 1 to 10 Hz for NanoSonic's down-selected HybridSil seat cushion foam and a currently employed polyurethane foam used in a COTS seat.

3. PRESSURE MAPPING

Comparative pressure mapping analysis was completed between NanoSonic's down-selected HybridSil seat cushion and a currently employed COTS cushion. Testing was completed using a BPMS-Pressure Measurement Evolution System equipped with a Tekscan Evolution Sensor (Figure 3). To ensure optimal pressure distribution performance over the widest range of soldier body types, pressure mapping was completed on each cushion using individuals with the below heights and weights. Each HybridSil cushion was tested by the three different individuals.

- 135 lb. female with a height of 5'2"
- 195 lb. male with a height of 5'10"
- 265 lb. male with a height of 6'0"

Figure 3. Tekscan pressure mapping sensor placed over seated HybridSil seat cushion within COTS seat pan.

Side by side pressure distribution images of NanoSonic's down-selected HybridSil cushion and a currently employed COTS cushion for each individual are included in Figures 4 - 6. A summary of the average pressure reading for all individuals and NanoSonic's HybridSil cushions is included in Table 1.

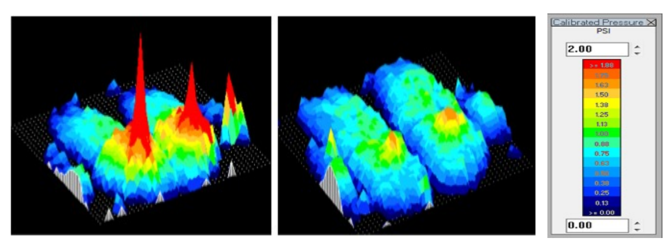


Figure 4. Pressure mapping images of COTS seat cushion (left) and down-selected HybridSil seat cushion (right) for a 135 lb. female (height of 5', 2").

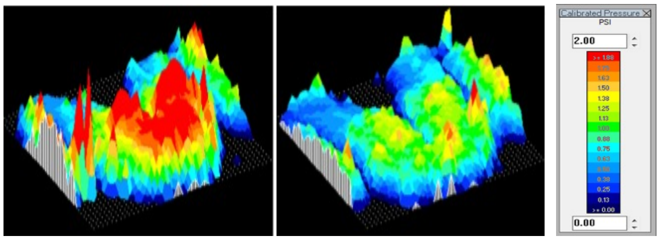


Figure 5. Pressure mapping images of COTS seat cushion (left) and down-selected HybridSil seat cushion (right) for a 195 lb. male (height of 5', 10").

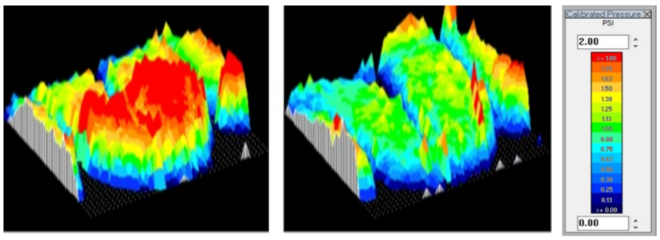


Figure 6. Pressure mapping images of COTS seat cushion (left) and down-selected HybridSil seat cushion (right) for a 265 lb. male (height of 6', 1").

Table 1. Summary of the average pressure reading over the entire seated area on the currently employed COTS seat cushion and NanoSonic's down-selected HybridSil seat cushions.

CUSHION SAMPLE	AVERAGE PRESSURE READING		
	135 LB. FEMALE	195 LB. MALE	265 LB. MALE
COTS CUSHION	0.86 PSI	1.05 PSI	1.25 PSI
FIRST GENERATION HYBRIDSIL SEAT CUSHION	0.76 PSI	0.81 PSI	1.05 PSI
SECOND GENERATION, MULTILAYERED HYBRIDSIL SEAT CUSHION	0.68 PSI	0.80 PSI	0.92 PSI

4. MAST TESTING

The goal of Multi-Axis Simulation Table (MAST)[1-4] testing was to determine how NanoSonic's HybridSil seat cushion responded to simulated drive files, run in triplicate, provided by a defense prime contractor relative to a currently fielded COTS seat cushion. A 155 lb. dummy was used in the simulation with one of the five accelerometers underneath the dummy and on top of the cushion to measure vibrational impact on the seated soldier. This test is important because prolonged vibration at various frequencies can impact mental and physical fatigue including skeletal and muscular exhaustion. Physical fatigue due to vibrations in the "General Wellness" range is very important to mitigate so that the user can maintain alertness and ability to react quickly to changing situations. This range is between 0.5-80 Hz.[1-4]

The improved vibrational frequency dissipation of NanoSonic's seat cushion over the standard COTS cushion is demonstrated by graphing RMS acceleration vs. frequency during MAST testing. The three plots are included in Figures 7-8 show a decrease in motion in the X, Y, and Z-directions in three of the different road profiles (BB, ChB, and P3). The X-direction shows the largest difference between frequencies of 20-40 Hz during the BB road profile. The Y-direction shows a dramatic decrease between 5-15 Hz during the P3 profile. The Z-direction demonstrates the largest decrease between 20-60 Hz during the ChB profile. This data suggests NanoSonic's seat cushion affords improved vibrational dampening in the Whole-Body Vibration Range between 10-70 Hz.

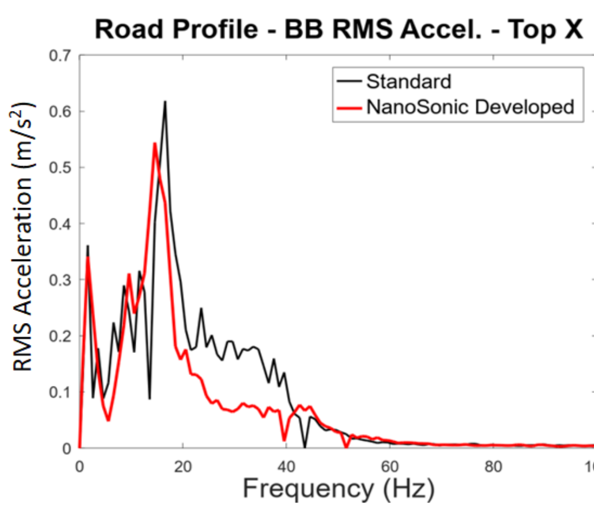
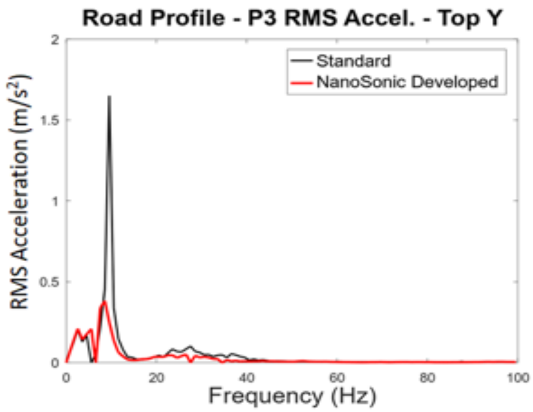


Figure 7. RMS acceleration plotted as a function of frequency in the X-direction during MAST testing of the BB road profile.



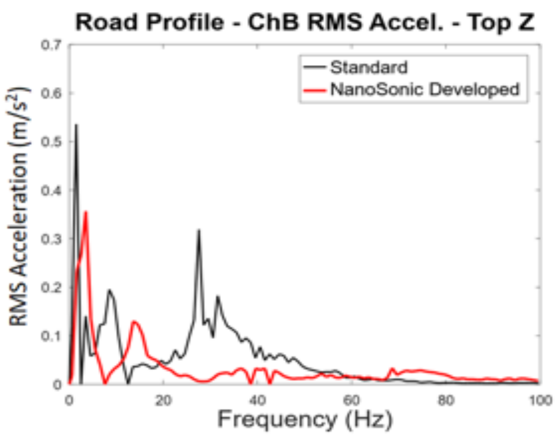


Figure 8. RMS acceleration plotted as a function of frequency in the Y and Z-directions during MAST testing of the P3 and ChB road profile.

6. FATIGUE TESTING

Dynamic fatigue testing (ASTM D3574-Test I_3) was completed on NanoSonic's HybridSil seat cushion to demonstrate its extended durability during operational use. Testing involved 8,000 pounding cycles at a frequency of 70 ± 5 cycles/min, and images of this system during testing are included in Figure 9. Encouragingly, it was found NanoSonic's foam demonstrated desirable dynamic fatigue resilience with a change of thickness of only 1.5% a following 8,000 fatigue cycles.

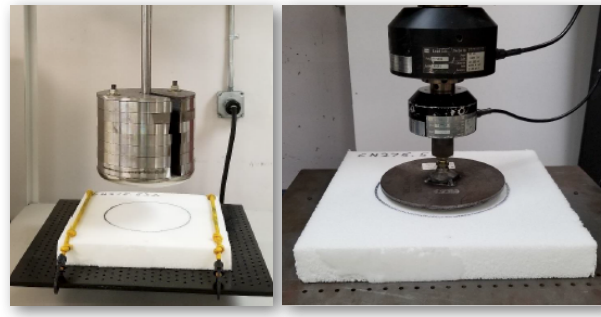


Figure 9. NanoSonic's HybridSil seat cushion foam during ASTM D3574-Test I_3 testing. The left image shows NanoSonic's HybridSil seat cushion within the 169-lb. constant force pounding machine with a 9.8" diameter while the right image displays the same foam during IFD testing within a Universal testing machine equipped with an 8" circular compression foot.

7. H-POINT TESTING

To demonstrate direct integration compatibility in place of currently fielded COTS cushions, the H-point of NanoSonic's seat cushion was measured by MGA Research Corporation using a COTS seat structure. The H-point identifies the hip pivot point of a seated soldier in a vehicle and can provide information about comfort, body placement in the seat, and spatial placement to facilitate the natural position of the human body while driving a vehicle. Since NanoSonic's seat cushions are designed with the intent to replace the currently employed COTS cushions, it is crucial for them to replicate the H-point position within a reasonable tolerance to allow for seamless implementation.

MGA Research completed the H-point Drop on the standard COTS cushion and a HybridSil seat cushion in accordance with Federal Motor Vehicle Safety Standard (FMVSS) 202A 4.2.1-4. The H-point measurements are taken by placing a weighted seat pan on top of the cushion to simulate a 170 lb. seated person and adjusting the foot plate to hold a natural position. This set-up is shown in Figure 10.

Figure 10. MGA test setup for completing comparative H-point measurements.

In the set-up, the knee, foot, and hip angle measurements are all within three degrees of one another for both seat cushions enabling direct comparison of the results. Once the mannequin was properly set-up, the H-point was measured in X and Z coordinates in reference to the rear left seat bolt. Marginal 1.3 and 3.9% differences were measured between the two seat cushions in the X and Z-coordinates respectively. Further, a 3.9% difference was determined between the three torso angles as well. This comparison indicates that NanoSonic's seat cushion affords a comparable H point to the currently employed cushion and direct integration compatibility.

8. CONCLUSIONS

NanoSonic has created and empirically optimized viscoelastic HybridSil seat cushions that may provide the seated soldier with improved comfort, situational awareness, and combat readiness. Compared to legacy, baseline military seat cushions employed on the COTS seat, crucial side by side pressure mapping analysis indicates HybridSil seat cushions provide enhanced pressure distribution for a broad range of body types.

In addition to improved pressure distribution, NanoSonic's Phase II optimized HybridSil seat cushions demonstrated improved vibration dampening performance in the form of reduced whole-body vibration over currently employed COTS cushions during Multi-Axis Simulation Table (MAST) testing with MGA Research Corporation.

H-point testing completed in accordance with FMVSS-202A indicates NanoSonic's seat cushions afford comparable positional values to the current employed seat cushion and thus have direct integration potential.

Future work will involve qualifying seating systems equipped with HybridSil seat cushions in accordance with MIL-PRF-32563, working to obtain manufacturing contracts with defense prime customers, and transitioning foam copolymer precursors to pilot scale manufacturing.

9. REFERENCES

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