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New Engine Tunnel Insulation System for Commercial Trucks

Zhiming Luo
Aearo Technologies LLC - a 3M Company
7911 Zionsville Road
Indianapolis, IN 46268
zhiming.luo@mmm.com

ABSTRACT

Two new engine tunnel insulation systems were developed with 3M proprietary Thinsulate™ materials. One was a standard composite tunnel liner to replace fiberglass composite liner; another was a premium tunnel liner to replace fiberglass liner and decoupled foam barrier cover. In the process to design the new insulation systems, a full SEA sleeper truck model was used for a DOE analysis for a variety of materials and their combinations. Then the selected tunnel systems based on analytical DOE study were evaluated for sound transmission loss performance per ASTM E90. Meanwhile, system level thermal performance was assessed per ASTM C518 for material thermal conductivity and HTTR (High Temperature Test Rig) for composite touch temperature. Finally two newly designed tunnel systems were recommended.

1. INTRODUCTION

Quiet interior is critical for long haul truck drivers to stay alert and focused as the drivers typically work at maximum 60 hours in 7 days and about 41% of the drivers drive nodding off/falling asleep, or drowsiness[1]. To better insulate the cab and make it comfort, many efforts have been made such as addressing specific noise paths, optimal designing of the entire sleeper insulation, implementing new thermal acoustic materials etc.[2, 3]. Engine tunnel insulation system is an important part of the solution to reduce interior noise make drivers comfort. As the truck engine compartment design becomes more compact, it brings the challenges not only to prevent the powertrain noise but also the heat engine/turbo radiated from transferring into interior. The design of engine tunnel insulation system has to address noise and thermal requirement simultaneously.

In this new tunnel system development process, 3M proprietary Thinsulate™ materials were evaluated with other materials such as foam and LAB composite (Lightweight Acoustic Barrier) through analytical DOE study. Based on the analytical DOE results, selected composites were proposed for further acoustic and thermal performance validation. According to their performances, two versions of Thinsulate™ based tunnel liners were recommended to replace current standard package comprised of fiberglass composite only liner and premium package comprised of fiberglass composite liner and foam barrier cover.

To evaluate noise and thermal requirements for the tunnel insulation system, ASTM E90 sound transmission loss, ASTM C518 material thermal conductivity and HTTR (High Temperature Test Rig) touch temperature were used for benchmarking.

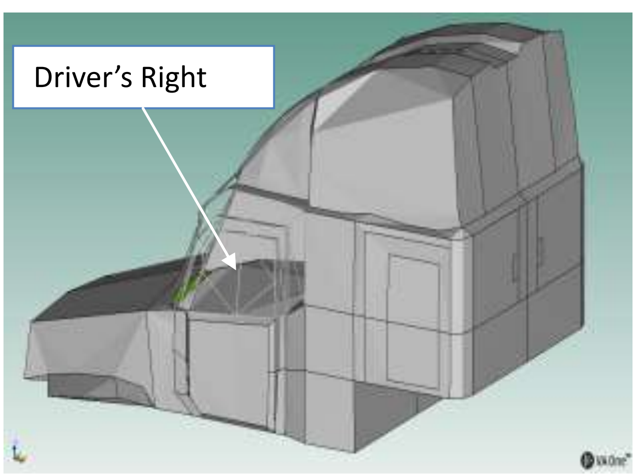
2. ANSLYTICAL STUDY

There were a number of materials and their combinations that could be used for tunnel liner and tunnel covers. To assess acoustic performance of new designed tunnel insulation systems, a full truck SEA model was used for analytical DOE study as showed in Figure 1. Predicted SPL@DRE (Sound Pressure at Driver's Right Ear) was used for acoustic performance comparison for each treatment configuration. In the model, a generic engine noise source was applied. The impact of resistive membrane was also evaluated. Several configurations were proposed for further lab test to verify their performances.

Table 1: Material Options for Tunnel Liner and Tunnel Cover

Tunnel liner	**Tunnel cover**
1″ TK0578	1/2″ compressed TK0578
1″ TK0578 + RM	1/2″ compressed TK0578 + RM
1″ compressed TK0578	1/2″ compressed TK0578 + 1 lb barrier
1″ compressed TK0578+ RM	1/2″ compressed TK0578 + A-surface/ Wear layer
1 lb barrier sandwiched with 1″ TK0578	1/2″ compressed TK0578 + 0.5 lb barrier
0.5 lb barrier sandwiched with 1″ TK0578	1/2″ compressed TK0578 + A-surface/Wear layer
	1/2" foam decoupled 1 lb barrier
	1/2" foam + A-surface/Wear layer
	1/2" LAB decoupled 1 lb barrier
	1/2" LAB + A-surface/Wear layer
	0.9 lb Fiber Mache

TK0578 – 500 gsm Thinsulate™, 1" thick; Compressed TK0578 – 1 layer or 2 layers of Tk0578 compressed to desired thickness of ½" or 1"; RM – Resistive Membrane.



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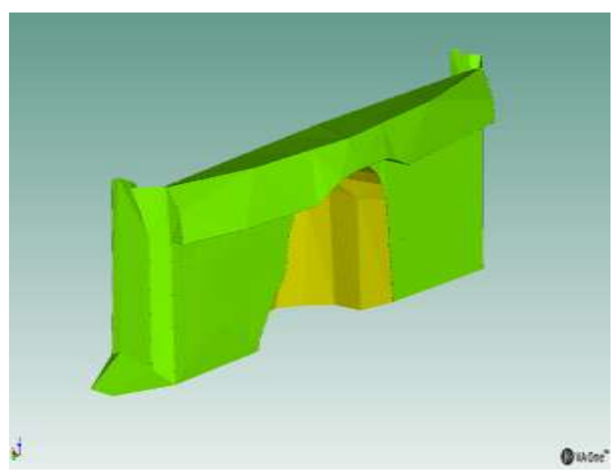

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Figure 1: SEA Models. (a) Full Truck Model and (b) Frontwall/Tunnel Model.

Two baseline insulation systems were considered. One was the standard package comprised of only fiberglass composite tunnel liner; another was the premium package with additional molded foam rubber composite. To compensate different truck platform, ABS and steel structural tunnels were both analyzed. Figure 2 and figure 3 showed the simulation results for ABS tunnel and steel tunnel respectively. It could be seen that several configurations performed better than production systems.

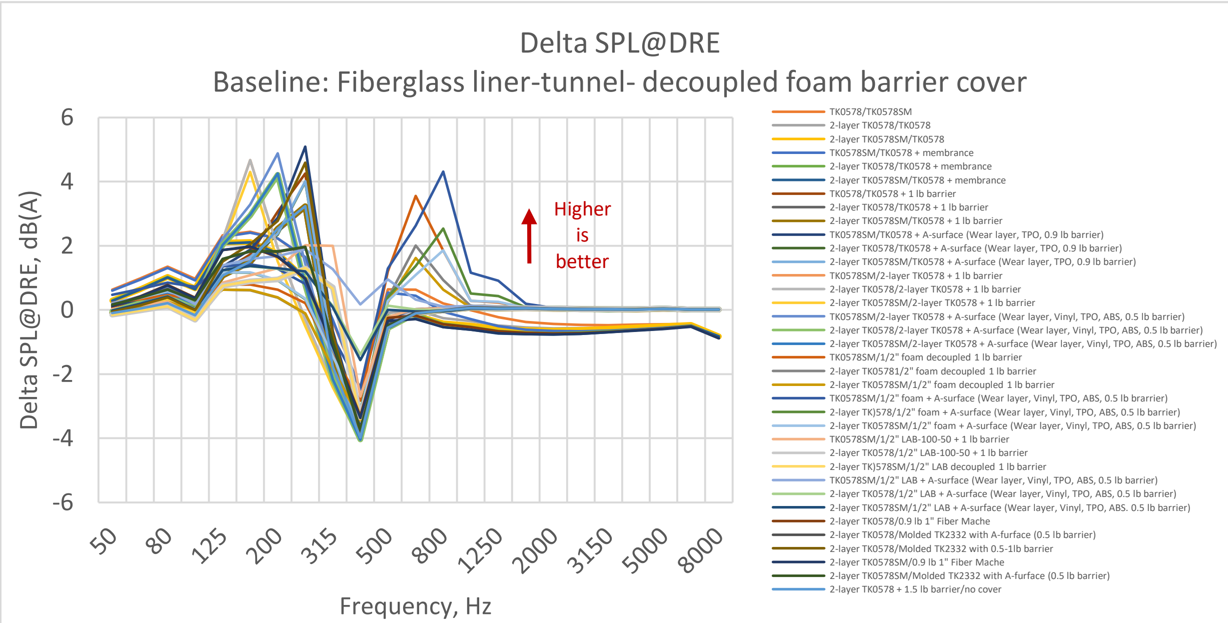


Figure 2: Analytical Results with ABS Tunnel.

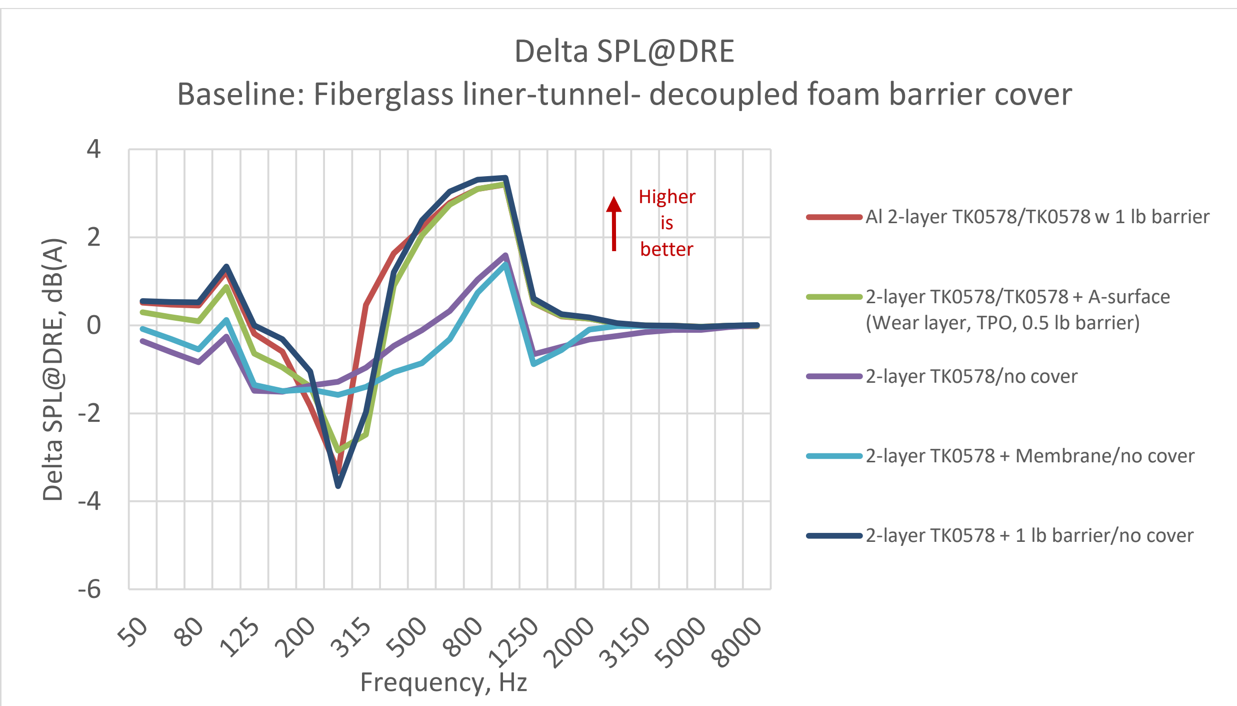


Figure 3: Analytical Results with Steel Tunnel, Al – aluminum facing

3. EXPERIMENTIAL VERIFICATION

Based on analytical results twelve configurations were recommended for further performance evaluations; sound transmission loss per ASTM E90, composite thermal conductivity per ASTM C518, and touch temperature with HTTR test.

A. ASTM E-90 sound transmission loss

Figure 4 showed sound transmission loss test setup per ASTM E90 and the fixture with tunnel system installed in test window. Tunnel fixture was built with dry walls and cavities fully filled with Thinsulate^{TM} to prevent noise flanking path. All seams were sealed with duct sealant to prevent noise leakage. Noise leakage was inspected with ultrasonic device to ensure the fixture was properly sealed.

(a) (b)

(c) (d)

Figure 4: ASTM E90 Sound Transmission Loss Suite. (a) Source Room, (b) Receiving Room, and Installed Tunnel: (c) Source Side and (d) Receiver Side.

Both source and receiving rooms are climate-controlled chambers with stationary diffusing panels installed and calibrated to ensure consistent test condition and eliminate test environmental variations. To better characterize the room spatially, rotation microphone is used for both source and receiving room. A total of 128 seconds with 8 revolutions of the rotating microphone is used to average the sound pressure level for source and receiving room. After conditioning the room, receiving room absorption A_R was measured and calculated according to ASTM E2235-04.

$$A_R = 0.921 \frac{Vd}{c} \tag{1}$$

where:
A_R= sound absorption, m^2
V = volume of reverberation room, m^3
$C = 20.047\sqrt{273.15 + t}$, speed of sound, m/s, and
t = room temperature, °C
d = decay rate, dB/s

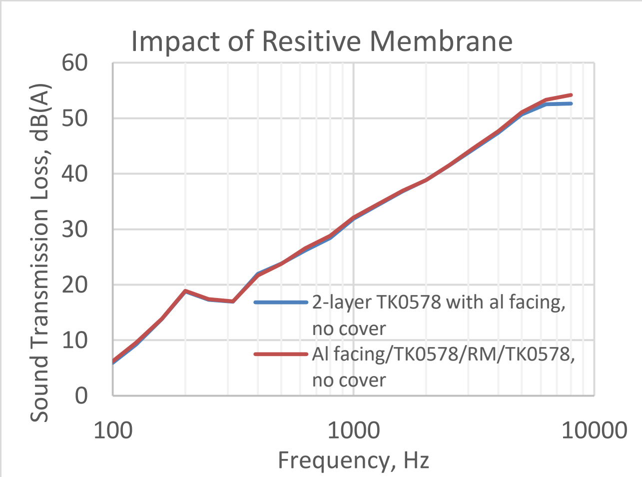
Sound transmission loss of the test specimen for each 1/3 octave frequency is calculated according to ASTM E90-09

$$TL(f) = L_s(f) - L_R(f) + 10\ log\ ^S/_{A_R} \tag{2}$$

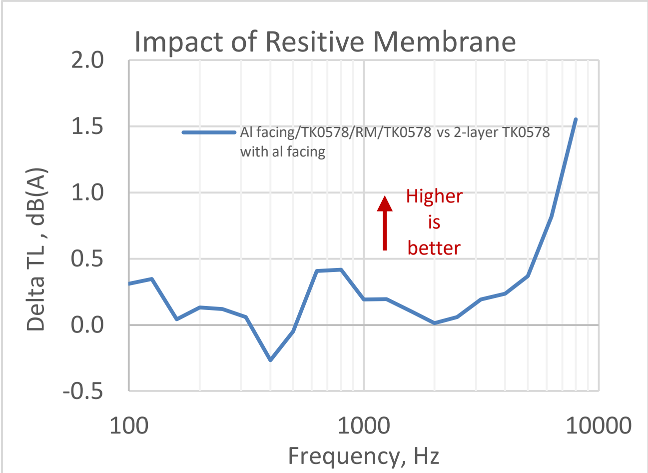
where:
$TL(f)$ = transmission loss, dB
$L_S(f)$= average sound pressure level in the source room, dB
$L_R(f)$ = average sound pressure level in the receiving room, dB
S = area of test specimen that is exposed in the receiving room, m^2, and
$A_R(f)$ = sound absorption of the receiving room with the test specimen in place, m^2

1. Resistive membrane

SEA model showed the benefit of adding resistive membrane inside the TK0578 composite. The test results in Figure 5 showed that resistive membrane sandwiched with two layers of TK0578 increased sound transmission loss up to 1.5 dB.



(a)

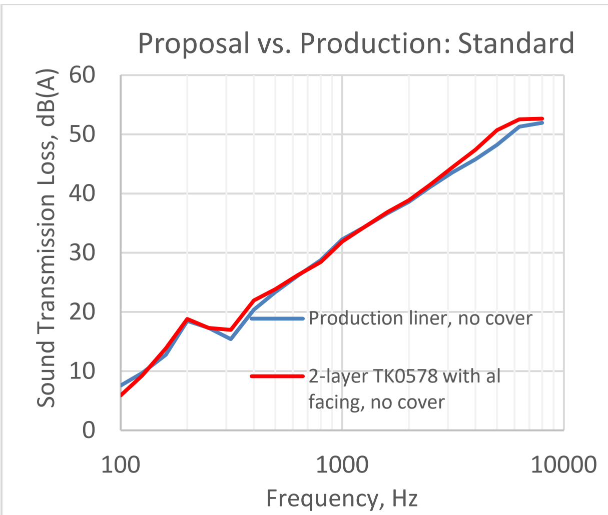


(b)

Figure 5: Resistive Membrane in the Middle of Two-layer TK0578 Composite. (a) Sound Transmission Loss and (b) Sound Transmission Loss Difference

2. Standard package

Production standard package has fiberglass composite liner only, no cover. To develop new standard package several combinations of TK0578 and resistive membrane were analyzed and tested.



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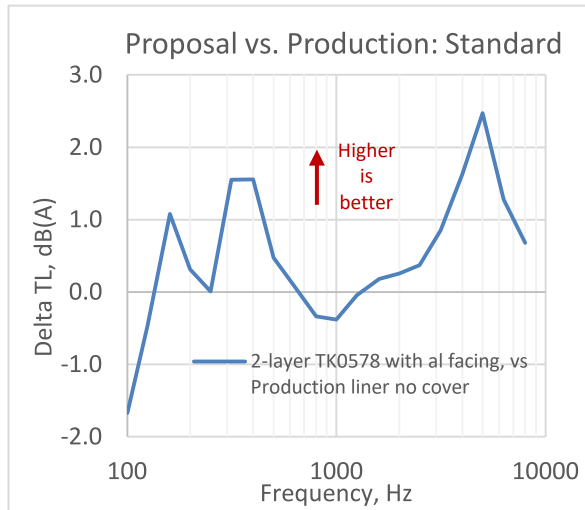


(b)

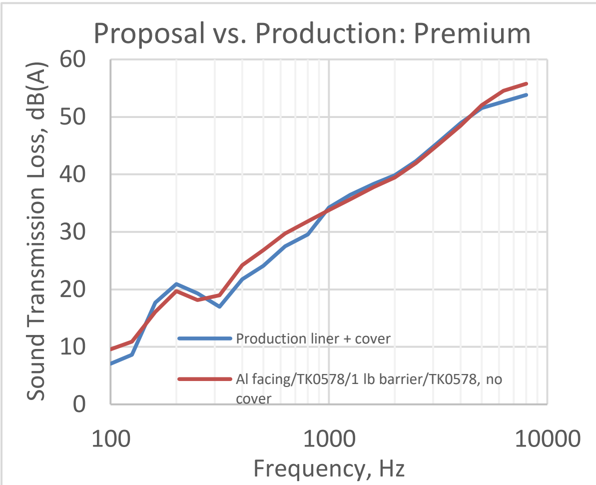
Figure 6: Standard Package Performance. (a) Sound Transmission Loss and (b) Sound Transmission Loss Difference

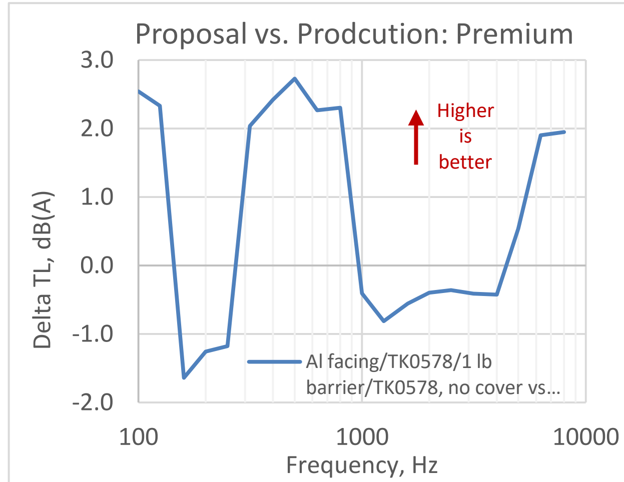
Figure 6 showed transmission loss comparison of new designed standard package of TK0578 composite to the production standard package. It could be seen in Figure 6 (b), new standard package had better overall acoustic performance and good improvements in the frequencies 160 Hz – 600 Hz and above 1,250 Hz.

3. Premium package

Current production premium tunnel insulation has an additional molded foam rubber composite tunnel cover to the standard package. It performs better thermally and acoustically than production standard package. To develop a new premium package with equivalent or better thermal acoustic performance, a series of combinations of tunnel liner only and tunnel liner with tunnel cover were studied and tested. Several new designs achieved better acoustic and thermal performance than production premium package. In reducing assembly time and overall cost, tunnel liner only premium package is favored. Figure 7 compared the acoustic performance of the new designed premium package with TK0578 composite liner only to production premium package with liner and cover.

It could be seen that compared with two parts production premium package new designed liner only premium package increased acoustic performance in sound transmission loss. New premium package had better overall performance and big improvements up to 2.5 dB at the frequencies below 125 Hz, 315 Hz – 1,000 Hz, and above 4,000 Hz.





(a) (b)

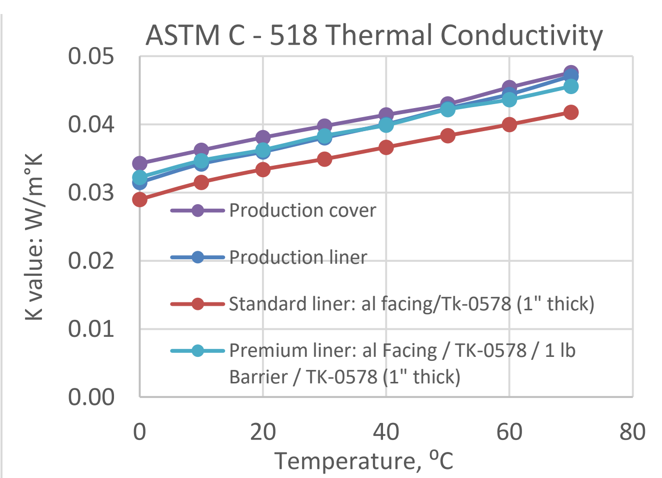
Figure 7: New Designed Premium Package. (a) Sound Transmission Loss and (b) Sound Transmission Loss Difference

B. Thermal Performance

As truck engine compartment design becomes more compacted; heat sources such as engine block, turbocharger, and pipes etc. moves closer to engine tunnel. This results in more heat could transfer into interior through the tunnel. To make driver comfort, in addition to acoustic performance, good thermal performance is also required for the tunnel insulation system to sufficiently prevent excessive heat transferring into interior. To evaluate thermal performance of the new designed insulations thermal conductivity and touch temperature of the composites were used for comparison.

1. ASTM C518 thermal conductivity

Thermal conductivity of composites was tested from 0 ^oC to 70 ^oC according to ASTM C518 standard. The comparison in Figure 8 showed that new designed systems had equivalent or lower thermal conductivity than production composites'.



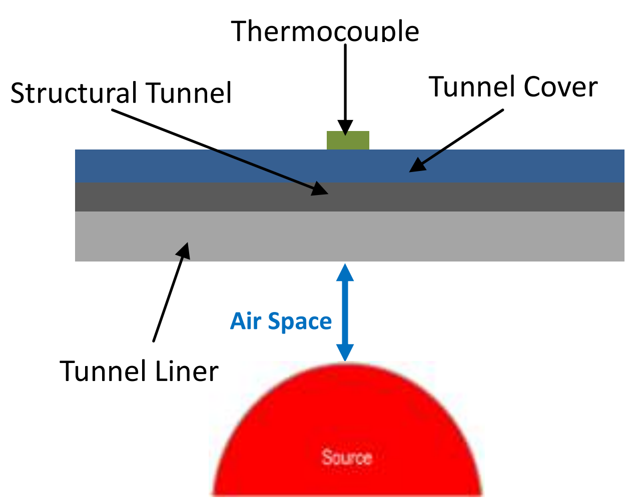


Figure 8: Thermal Conductivity of Composites **Figure 9**: HTTR Test Setup

2. HTTR touch temperature

Besides thermal conductivity, touch temperature was used for comparison in considering different system design for premium package. The new designed liner only premium package is to replace the production premium package with liner plus cover. Figure 9 depicts HTTR test setup. In measuring touch temperature, the representing tunnel insulation system is placed above a semi-circular heating rod. Four thermocouples are evenly placed along the center line of the test sample surface parallel to the heating rod. Desired heating source temperature is achieved with feedback temperature control. Once the surface temperature is stabilized with 1 °F variation within 30 minutes, touch temperature is calculated by averaging four thermocouple readings during 30 minutes period.

Comparisons of measured touch temperatures were summarized in table 2.

Table 2: HTTR Test Summary: Touch Temperature

Package	Touch Temperature, °F
Standard: production (1" thick)	101.6
Standard: proposal (1" thick)	100.1
Premium: production, liner + cover (1 ½" thick)	93.4
Premium: proposal, no cover (1" thick)	100.4
Premium: proposal, (1 ¼" thick), no cover	95.0

It showed new standard package was 1.5 °F lower than production standard package. New liner only premium package was 7 °F higher than production premium package but 1.2 °F lower than production standard package. To achieve similar touch temperature for new premium package as the current premium's one way is to make it thicker for the hot spot areas. If additional ¼" is added to the 1" composite the touch temperature difference between new design and production could be reduced to 1.6 °F.

4. CONCLUSIONS

With Thinsulate™ as core material, new standard and premium packages were developed with analytical DOE study using a full truck SEA model. Their required thermal and acoustic performances were verified with bulk test of sound transmission loss, materials thermal conductivity, and composites touch temperature. New standard package increased acoustic and thermal performance. New liner only premium package removed the cover of the production premium package. It improved acoustic performance and material thermal conductivity. Similar touch surface could be achieved with thicker local insulation for new premium package. Further acoustic and thermal performance validation work was planned with full truck test.

REFERENCES

1. Karl Sieber etc, National Survey of Long-Haul Truck Driver Health and Injury, 2014 Transportation Research Board 93rd Annual Meeting Federal Motor Carrier Safety Administration Analysis, Research, and Technology Forum January 14, 2014
2. Jason lustbader etc. Complete Cab Load Reduction, SAE 2015 Thermal Management Systems Symposium, October 1st, 2015

3. Zhiming Luo etc., NVH Package Development for a Class 8 Commercial Vehicle Using Statistical Energy Analysis, Portland, Oregon, NOISE-CON 2011, 2011 July 25-27