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Evaluation of Conditions during Weaned Pig Transport

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Evaluation of Conditions during Weaned Pig Transport

Abstract
Transport of weaned pigs poses special challenges because of their size and thermal needs as well as the extended distances and transport times. The resultant economic impact can be substantial. Compared to transport of market pigs, weaned pigs generally encounter much farther travel distances with different adapting abilities to the environmental conditions. The objectives of this study were: 1) to characterize the environmental conditions within a typical transport trailer for weaned piglets to determine if current management practices and trailer design provides an acceptable environment as evidenced by mortality rates and environmental parameters, and 2) to analyze airflow patterns of the transport trailer using a scale model in a wind tunnel. Data from 78 usable transport trips were collected for air temperature in each trailer compartment, ambient temperature, distance traveled, time traveled, stocking density, and mortality by compartment. The 78 trips had an average distance of 778 km (range of 264 to 1016 km), travel time of 8.51 h (range of 3.4 to 12.3 h), and mortality rate of 0.031% (range of 0 to 1.11%). There was no significant difference in mortality by compartment (p>0.05). The results indicate that if pigs are transported at a higher stocking density, the compartment temperatures would be similar during cold weather (e.g., 2°C). Under mild weather condition (e.g., 16°C), significant differences could exist in compartment temperature between part of the upper deck (Upper 1) and the lower deck (Lower 4) (p<0.05). In comparison, no significant differences were found at warm conditions (e.g., 29°C) (p>0.05). In addition to the weather influence, in-trailer environment is affected by the side openings which may be adjusted by the driver.

Keywords
Early-weaned piglets, Swine, Transportation, Wind tunnel

Disciplines
Agriculture | Bioresource and Agricultural Engineering | Meat Science

Comments

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ABSTRACT. Transport of weaned pigs poses special challenges because of their size and thermal needs as well as the extended distances and transport times. The resultant economic impact can be substantial. Compared to transport of market pigs, weaned pigs generally encounter much farther travel distances with different adapting abilities to the environmental conditions. The objectives of this study were: 1) to characterize the environmental conditions within a typical transport trailer for weaned piglets to determine if current management practices and trailer design provides an acceptable environment as evidenced by mortality rates and environmental parameters, and 2) to analyze airflow patterns of the transport trailer using a scale model in a wind tunnel. Data from 78 usable transport trips were collected for air temperature in each trailer compartment, ambient temperature, distance traveled, time traveled, stocking density, and mortality by compartment. The 78 trips had an average distance of 778 km (range of 264 to 1016 km), travel time of 8.51 h (range of 3.4 to 12.3 h), and mortality rate of 0.031% (range of 0 to 1.11%). There was no significant difference in mortality by compartment (p>0.05). The results indicate that if pigs are transported at a higher stocking density, the compartment temperatures would be similar during cold weather (e.g., 2°C). Under mild weather condition (e.g., 16°C), significant differences could exist in compartment temperature between part of the upper deck (Upper 1) and the lower deck (Lower 4) (p<0.05). In comparison, no significant differences were found at warm conditions (e.g., 29°C) (p>0.05). In addition to the weather influence, in-trailer environment is affected by the side openings which may be adjusted by the driver.

A 1/7th scale model of a livestock trailer was placed in a wind tunnel to examine flow characteristics within the trailer including velocity by location and direction. Trials were run with and without the front vents covered and with and without compartment partitions in place. The sides remained open for all trials. Centerline velocities in the compartments varied from 11% to 22% of the wind tunnel speed with trailer averages ranging from 14% to 16%. Pen partitions within the trailer had an impact on centerline velocity averaging 14.3% to 15.4% of wind tunnel speed (p<0.05); whereas covering the front vents or not had no effect on the centerline velocities. When the front air vents on the trailer were uncovered, air flow was from the back of the trailer toward the front. When the front air vents were covered, air flow direction was mixed with most of the upper compartments having front to back flow and most of the lower compartments having back to front flow. The lower rear compartment (Lower 4) tended to have the lowest air velocity rates with Upper 3 and Upper 4 being only slightly higher. Lower 3, Lower 2, and Upper 1 compartments tended to have the highest air velocities. Conclusions support the further investigation of changes to compartment partition and trailer rear panel design, as well as investigation of additional trailer options that may enhance or deter air flow through the trailer.

Keywords. Early-weaned piglets, Swine, Transportation, Wind tunnel.

The impact of transportation on market weight pigs has been a particular interest to researchers for some time due to economic as well as animal welfare concerns. Ritter et al. (2009) summarized mortality losses as averaging 0.69% and estimated an economic loss of $46 million in 2006. Many factors have been investigated such as weather, stocking density, transport duration, and truck type on pig mortality, behavior, physiological response, and meat quality (Abbot et al., 1995; Gade and Christensen, 1998; Gajana et al., 2013; Kim et al., 2004; Torrey et al., 2013). The Transport Quality Assurance Program (NPB, 2014) has incorporated much of this information into materials used for certification of transporters, producers, and handlers of pigs to promote best practices during transport.
Knowledge of losses affecting weaned pigs is not well documented. The economic impact, while perhaps not as obvious as that of market weight pigs, is substantial, especially if one considers the opportunity costs associated with mortality, morbidity, and potentially an increase in days to market. While the impacts may parallel those of market pigs, in general, transport distances are much farther and present different challenges because of the relative pig size and differences in environmental adaptability. The cooperating swine production company records show that the average weaned pig transport distance was 1127 km while the average market pig haul distance was 259 km over the long term, (S. Rath, personal communication, transportation and logistics manager of Smithfield Foods, Inc., 2017). A few studies have examined weaned-piglet transport. Lewis et al. (2005) examined groups of early weaned piglets transported during summer, winter and fall for 0, 6, 12, and 24 h. They concluded that all piglets initially lost an average of 6.9±2.4% of their weaning weight and returned to weaning weight 3.7±0.98 days post-weaning. Transport did not affect production parameters, but there were more “poor doers” (defined as piglets less than weaning weight at day 7 of age) in winter transport than in summer or fall, indicating that additional stressors are present during winter transport. Further studies by Lewis and Berry (2006) and Lewis (2008) indicated that longer transport may delay hierarchy development and increase risk of dehydration. Sutherland et al. (2009) examined space allowances and found that it did not influence animal well-being as measured by changes in physiological measures during an 112-min transport. They recorded airflow velocity, temperature, and relative humidity and commented that further research was needed on space and longer transport during various seasons. Wamnes, Lewis, and Berry (2008) stated that “…transport of early-weaned piglets may exacerbate the stress of weaning through additional stress related to factors associated with truck movements, such as noise and vibration, and by imposing an increased risk of dehydration following long journeys (>12h).” Hydration of early weaned pigs during transport appears to be a common concern among researchers. Zhao et al. (2016) analyzed records from a swine production company that transports weaned piglets distances up to and beyond 1500 km and found that mortality averaged 0.0333±0.01% which was a function of weather and travel distance. Mortality was significantly greater for distances over 900 km compared to those under 900 km during ambient temperatures less than 15°C and increased significantly with increasing distance for ambient temperatures above 25°C. Analysis indicated that mortality occurred more in “events” rather than on a consistent basis. Analysis of mortality the first two weeks post-transport indicated weather and travel distance could have an impact, but the causation was difficult to isolate.

Xiong et al. (2015) studied the environment within a transport trailer hauling market pigs. The trailer was instrumented to measure temperature, humidity, air velocity, and direction. Travel time ranged from 1 to 4 h during the 34 trips. They noted that extreme temperatures tended to occur more in the middle and rear zones of the trailer as compared to the front zone. Higher incidences of mortality and morbidity were noted in these same zones.

The objectives of this study were: 1) to characterize the environmental conditions within a typical transport trailer used for weaned piglets to determine if current management practices and trailer design provides an acceptable environment as evidenced by mortality rates and environmental parameters, and 2) to analyze airflow patterns of the transport trailer using a scale model in a wind tunnel.

### MATERIALS AND METHODS

#### CONDITIONS IN TRANSPORT

Trailers used for shipping weaned pigs were monitored to assess the environmental conditions during transport. Lawrence Batten Trucking primarily transports weaned piglets from a single sow farm system in Southern Illinois to wean-finish facilities in Iowa and Northern Illinois. Drivers utilized a Wilson Trailer Silverstar trailer (Wilson Trailer, Sioux City, Iowa; fig. 1) which was 2.6 m × 16.1 m (outside dimensions) with an overall height of 4.1 m. It had two main decks along with an additional lower area, typically called a “pot-belly,” created by deploying an auxiliary floor between the rear axle of the truck and axle of the trailer. Without the auxiliary floor deployed the lower deck floor follows the contour of the trailer. The separate “pot-belly” compartment was not utilized for pigs for this study; the auxiliary floor was not deployed. Figure 2 shows the approximate layout of the eight compartments referred to as “Upper” or “Lower” and numbered from front to rear. As described above, compartments Lower 2 and Lower 3 were on a lower level than Lower 1 or Lower 4 because the auxiliary floor was not deployed. The trailer was equipped with vents on the front surface, behind the cab, that could be closed with panels during cold weather and also had roof vents which could be opened or closed. The four roof vents, each approximately 0.51 m square, were spaced evenly along the length of the trailer. The distance between the cab and the front of the trailer was approximately 1.52 m. Flooring was all solid.

Temperatures were measured at 5-min intervals in each compartment and on the front of the trailer, as shown in figure 2, using LogTag HAXO-8 Temperature Loggers (LogTag Recorders, Auckland, New Zealand) with a range of -40°C to 85°C. The stated accuracy was within ±0.5°C at 25°C. Loggers were fastened with wire-ties to gating between compartments in a consistent location just above the reach of the piglets and near the centerline of the trailer. Temperatures in two compartments (Upper 2 and Lower 2) near the floor using LogTag TRIX-8 Temperature Data Recorder with a similar range and accuracy as the HAXO-8 loggers. These were placed in containers constructed of PVC.
pipe fittings with holes to protect them from the pigs but allow air to flow through the container. They were positioned at the bottom of the gate just below the sensor in Upper 2 and Lower 2. A similar PVC container was used to shield the ambient sensor on the front of the trailer from solar radiation.

Drivers were asked to record specific data about each trip including the date, time loading began at the source farm, time transport began, time arriving at the destination farm, and time unloading was completed. Also, they were asked for the distance from the source to the destination farm, the average weight of the pigs, and the number of pigs in each compartment. During unloading, they were asked to record the number of dead-on-arrival (DOA) piglets in each compartment. The driver normally recorded any stops made and notes on which, if any, side panels were added to reduce air flow during cold weather. Decisions on side panel placement were solely based on the driver’s discretion and experience and, as such, were difficult to associate with strict guidelines.

The temperature loggers were set to record every 5 min and had memory capacity for approximately 27 days. Loggers were sanitized and mailed to the truckers along with blank data sheets. On the appropriate date, the trucker replaced the set of loggers in the trailer with the newly programmed loggers, returning the “full” data loggers to have the data retrieved and to be sanitized. Consistent locations were used. Raw data were compiled from each trip. Trips with missing data were excluded from the analysis to preserve data integrity. During one snow storm, the trailer was stranded and took over 24 h to deliver the pigs, resulting in 30 DOA pigs, which was considered an atypical event, and therefore, excluded from the data set.

Each trip produced a time-series of temperature readings for each compartment as well as the ambient measurement. The mean was calculated for each measurement location during the travel period of each trip and used for statistical analysis. These means were then examined with three different statistical analyses including an analysis of the mortality of the entire load, mortality by compartment, and temperature by compartment. Overall mortality was tested using logistic regression, a type of generalized linear model, which yielded an estimated probability of mortality. Ambient temperature, travel time, and stocking density of the entire load, along with interactions, were tested within the model. Travel time was defined as the time from when the truck left the origination farm after loading was completed until the truck arrived at the destination farm. Stocking density was the overall density of the compartments that were utilized. Empty compartments were not factored into the stocking
density of the overall load. Likewise, the compartmental mortality was analyzed using logistic regression with compartment temperature, travel time and compartment stocking density, as well as interactions, tested within the model. Compartment temperature was analyzed using a linear mixed effect model with trip being the only random effect included in the model. Ambient temperature, compartment number, and compartment stocking density were all tested for significance as model variables along with interactions. Pairwise comparisons were examined at 2°C, 16°C, and 29°C. These temperatures were within the range of seasonal temperatures and avoided extrapolation by the statistical model.

**WIND TUNNEL TEST**

A wind tunnel test was conducted to examine the relative air flow directions and velocity within the trailer. A model of an Eby Trailer livestock semi-trailer was constructed by Eby (Eby Trailer, Story City, Iowa) to be approximately a 1/7th scale of a double-deck livestock trailer (fig. 3). The model had openings in the front, rear and sides that approximated other Eby trailer designs. The floor and top were solid. The model did not exactly model the trailer used for the transport monitoring of this study because it did not include a “pot-belly” design. As such, the results may not be directly applicable. However, trailers without a pot-belly are also typically used for swine transportation. A rough model of the tractor was constructed to match the scale of the trailer. Compartment partitions were also constructed to form the eight animal compartments. These were approximately 50% solid, as is typical of partitions in full scale trailers, and were removable to allow the testing of their impact on air flow characteristics.

Wind tunnel tests were conducted in Iowa State University’s Aerodynamic-Atmospheric Boundary Layer (AABL) Wind and Gust Tunnel. AABL is primarily a closed-return wind tunnel with 2.4 m (wide) by 1.8 m (high) AERO test section (177 kph max. speed, 0.2% turbulence) for aerodynamic testing. This section is followed by a 2.4 m (wide) by 2.2 m (high) ABL test section (144 kph max. average speed) for tests requiring atmospheric boundary layer (ABL) wind. It has an adjustable ceiling for maintaining a nearly-constant static pressure inside the wind tunnel along the 15.2-m fetch as desired for the generation of ABL. The test sections have glass sides on the control-room side for easy viewing of the tests. The ABL section has a 1.8 m diameter turntable in the ABL test section for mounting models that can be manually rotated from 0 to 360 degrees to change the wind angle of attack. The wind tunnel is equipped with a 2D-traverse system (automated) for mounting flow-measurement probes that can be moved anywhere inside the test section along its length supported by two side-railings mounted on its walls. The details of the wind tunnel components and wind tunnel calibration can be found in Sarkar and Haan (2008).

Vehicle models are normally placed within a wind tunnel to evaluate aerodynamic properties on the external surfaces of the vehicle. The primary concern in this study was the flow characteristics within the trailer, so the wind tunnel staff adapted a probe to measure the flow characteristics within the trailer. A Cobra probe (4-hole pressure probe, TFI Pvt. Ltd.®, Victoria, Australia) was used to measure all three velocity directional components simultaneously with high accuracy (uncertainty ±0.5 m-s⁻¹) within the trailer. The probe was mounted on the left side of the model and manually repositioned for each measurement of “left,” “center,” and “right” within each of the eight compartments within the trailer.

Several different trailer configurations were tested to examine the flow characteristics throughout the trailer. The velocity of the tunnel was set to 15.8 m-s⁻¹ (Speed 1) or...
17.9 m-s\(^{-1}\) (Speed 2) at a height of 18.4 cm, which was the centerline height of the front-end of the tractor model, at a sampling rate of 100 Hz. These wind tunnel speeds were equivalent to 96 kph and 112 kph full-scale truck speeds, common U.S. highway speeds, defined at the centerline of the tractor based on the velocity scale of 0.58. Trials were run with and without compartment partitions which were constructed to approximate the scale dimensions of typical trailer gating. Trials were also run with and without the front vent holes covered on the trailer. Side openings remained open for all trials. Each trial was 220 s after stabilization was achieved and data was averaged over the period.

### RESULTS AND DISCUSSION

#### CONDITIONS IN TRANSPORT

Data were usable from 78 trips by Lawrence Batten Trucking which included a total of 79,715 pigs. Trips which had missing temperature data or had an excessively long duration, over 24 h in one case due to a snow storm, were excluded from the analysis. Table 1 gives an overview summary of the characteristics of the 78 trips. The average stocking density of 0.069 m\(^2\)-pig\(^{-1}\) is consistent with industry recommendations of 0.060 m\(^2\)-pig\(^{-1}\) for a piglet weighing 5.45 kg. Only 28 pigs were DOA during the 78 trips used for analysis, which equals an overall mortality rate of 0.035%. Results are consistent with Zhao et al. (2016) for weaned pig transport mortality with a rate of 0.033% reported.

Each trip produced a time series of temperatures for each compartment and ambient location throughout the trip. Visual inspection of the time series temperatures for each compartment and the ambient temperature time series was used to better understand how the trailer compartments respond during travel. Figure 4 illustrates a typical trip during hot weather when all the side openings were uncovered, providing maximum air flow. Trailers were loaded in the morning after being parked outdoors and were in equilibrium with outdoor conditions. At the onset of loading, the trailer started at ambient temperature and rose quickly during the loading period, which was 45 min, for this illustration. The upper compartments reached temperatures that were nearly as high as the trailer maximum temperature during the travel period. Once the trailer started to move, the temperatures dropped substantially. During the actual travel period, the compartment temperatures tended to parallel the ambient temperature. Unloading was much quicker (reported as 20 min in this case) and exhibited a rise in temperature also. The loading and unloading periods were not included in the statistical analysis because they tended to behave differently than when the truck was in motion. It may be noted that the ambient temperature appears to rise during loading. The temperature sensor located at the front of the trailer and used to represent ambient temperature rose during loading while the truck was stationary. It is believed that heat from the loaded pigs in the trailer influenced this sensor so the ambient readings during loading and unloading were not given credence.

Figure 5 illustrates a typical trip during cold weather. Trailers were parked overnight in ambient conditions, rather than being kept in a warm facility, and thus the trailer starts off at ambient conditions. As in hot weather, the temperature climbs during the loading period and then parallels the ambient temperature during the travel period. Ambient readings during loading were influenced by heat from the trailer interior but returned to operational readings once transport began. Drivers frequently made adjustments by adding or removing side panels on the truck to alter air flow, as is customarily done based on driver experience and judgment. Because of the dynamic side panel configurations, evaluation of the winter conditions was an evaluation of the trailer along with the driver’s ability to adjust to changing conditions. This is an important consideration given that not all drivers have equal ability. For this study, 87.2% of the trips were done by one specific driver with two additional drivers contributing 11.5% and 1.3%.

Though not part of the focus of this research, it was noted that the duration of loading and unloading periods were different by more than a factor of two. Loading took an average of 1.37 h (range of 2.5 to 0.25 h, standard deviation of 0.52 h) while unloading averaged 0.54 h (range of 1.17 to 0.71 h, standard deviation of 0.25 h). Loading occurred at the same location throughout the study, but unloading occurred at many different sites. One might expect the variation in unloading equipment from site to site to make the unloading period duration longer than the loading period duration. The contrary result could be explained by animal behavior instead of loading/unloading facility design. No conclusion pertaining to loading/unloading can be drawn based on the limited information from this study.

#### MORTALITY

Overall mortality was analyzed using a logistic regression. Ambient temperature and travel time, along with interactions, were significant but stocking density was not (p>0.05). However, with the very small number of mortality events, with most loads having no death loss, the results are misleading. Only 10 trips out of 78 (13%) had mortality.

Compartmental mortality was analyzed with logistic regression. Modeling temperatures of 4°C and 27°C were used to represent cold and hot temperatures of transport. The estimated probability of mortality within a given compartment was a percentage probability, ranging from 0.0236% to 0.141% at a compartment temperature of 27°C and 7.48E-08% to 0.0487% at a compartment temperature of 4°C. Figure 6 provides the estimated probability and standard error of mortality in each compartment. If one looks at the ranking of the probabilities, it appears that during cold weather (when the compartment temperature is 4°C) the probability

<table>
<thead>
<tr>
<th>Condition</th>
<th>Distance</th>
<th>Travel time</th>
<th>Loading time</th>
<th>Unloading time</th>
<th>Total time</th>
<th>Pig weight average</th>
<th>Average stocking density</th>
<th>Average trip mortality</th>
</tr>
</thead>
<tbody>
<tr>
<td>Average</td>
<td>778 km</td>
<td>8.51 h</td>
<td>1.37 h</td>
<td>0.54 h</td>
<td>10.44 h</td>
<td>6.81 kg</td>
<td>0.069 m(^2)-pig(^{-1})</td>
<td>0.031%</td>
</tr>
<tr>
<td>Std Dev</td>
<td>249 km</td>
<td>2.49 h</td>
<td>0.52 h</td>
<td>0.25 h</td>
<td>2.62 h</td>
<td>0.59 kg</td>
<td>0.013 m(^2)-pig(^{-1})</td>
<td>0.136%</td>
</tr>
<tr>
<td>Range</td>
<td>264-1016 km</td>
<td>3.4-12.3 h</td>
<td>0.3-2.5 h</td>
<td>0.2-1.2 h</td>
<td>5.2-15.3 h</td>
<td>5.3-7.9 kg</td>
<td>0.045-0.10 m(^2)-pig(^{-1})</td>
<td>0.00-1.11%</td>
</tr>
</tbody>
</table>

Table 1. Summary of the 78 trips by Lawrence Batten Trucking used for analysis.
of mortality tends to be numerically higher in the lower compartments with two of the upper compartments having predicted mortality rates nearly zero. During warmer weather (27°C in the compartment) the probability tends to be higher in the upper compartments. This makes intuitive sense because mortality in winter would likely be due to “cold” conditions which could occur more readily in the lower compartments because of thermal buoyancy. Mortality in “hot” conditions could occur in the upper compartments due to heat stress conditions occurring for the same reason. However, there is no significant difference in mortality by compartment (p>0.05).

Figure 4. An example of ambient and compartment temperatures during hot weather transportation including loading and unloading periods. Lawrence Batten Trucking, 21 July 2014.

Figure 5. An example of ambient and compartment temperatures during cold weather transportation including loading and unloading periods. Lawrence Batten Trucking, 20 January 2014.
COMPARTMENT TEMPERATURES

Temperature by compartment was analyzed using a linear mixed effect model with the trip considered the blocking variable, which was random. Using random blocks will borrow information across blocks in order to obtain an overall estimate of treatment effects and will incorporate block to block variability as well as random error. Ambient temperature, compartment, and compartment stocking density were all tested for significance (table 5). Compartment, Ambient Temperature × Compartment, Density × Compartment, Ambient Temperature × Compartment × Density and Ambient Temperature × Ambient Temperature were all significant (p<0.05). Compartment means were estimated for three different ambient temperatures which represent the span of seasons, (2°C, 16°C, and 29°C) and three different compartment stocking densities (0.056, 0.070, 0.084 m²-pig⁻¹). These were based on the average and standard deviation of the observed stocking density of the loads which fall within the guidelines of the TQA recommendation (NPB, 2014).

Figures 7-9 illustrate the results of the model at various ambient temperatures to estimate compartment temperature along with 95% confidence intervals. These intervals can be used to perform pair-wise comparisons. If the 95% confidence intervals do not overlap then the pair is considered significantly different at p=0.05. Each figure shows a different pattern for high and low estimated temperatures throughout the trailer. This pattern difference may be due to the three different trailer sidewall panel configurations that would likely be used for different ranges of ambient temperatures. At an ambient temperature of 2°C (fig. 7) most of the side and front openings of the trailer would be covered during transport. For this temperature range, it appears that the warmest compartments within the trailer are predicted to be Upper 1 followed by Lower 2 and the coolest are predicted to be Lower 3 and 4. Statistically, if the 95% confidence intervals are used as the test for significance, Upper 1 is shown to be significantly warmer than only Lower 3 and Lower 4 for stocking densities of 0.07 and 0.084 m²-pig⁻¹ but not for 0.056 m²-pig⁻¹. No other compartment temperatures are significantly different (p>0.05) at 2°C.

One might expect that higher compartment temperatures would be associated with higher stocking densities during winter, but density alone was not a significant contributor to the model, though it was significant within interactions. According to figure 7, there visually appears to be a trend of a positive relationship between stocking density and temperature in compartments (L2, U1, and U2) but the opposite appears to be true for the coldest compartments (L3, L4, and U3). Therefore, visual observations support the statistical analysis that temperatures are not dependent on density alone. An underlying influence on the compartment temperature behavior in cold weather was the management of sidewall panels used to close up vent openings. Drivers decided the number and location of sidewall panels used during travel and decisions were influenced by stocking densities.

Table 5. Tests of (fixed) effects of ambient temperature, compartment and density on compartmental temperature during ground transportation.

<table>
<thead>
<tr>
<th>Effect</th>
<th>Num DF[a]</th>
<th>Den DF[b]</th>
<th>F-Value</th>
<th>P-Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ambient Temperature</td>
<td>1</td>
<td>389</td>
<td>2.04</td>
<td>0.1541</td>
</tr>
<tr>
<td>Compartment</td>
<td>7</td>
<td>389</td>
<td>2.80</td>
<td>0.0075</td>
</tr>
<tr>
<td>Amb. Temp. × Compartment</td>
<td>7</td>
<td>389</td>
<td>2.66</td>
<td>0.0106</td>
</tr>
<tr>
<td>Density</td>
<td>1</td>
<td>389</td>
<td>0.03</td>
<td>0.8696</td>
</tr>
<tr>
<td>Amb. Temp. × Density</td>
<td>1</td>
<td>389</td>
<td>0.28</td>
<td>0.5998</td>
</tr>
<tr>
<td>Density × Compartment</td>
<td>7</td>
<td>389</td>
<td>5.51</td>
<td>&lt;0.0001</td>
</tr>
<tr>
<td>Amb. Temp. × Density × Comp.</td>
<td>7</td>
<td>389</td>
<td>4.86</td>
<td>&lt;0.0001</td>
</tr>
<tr>
<td>Amb. Temp. × Amb. Temp.</td>
<td>1</td>
<td>389</td>
<td>4.68</td>
<td>0.0312</td>
</tr>
</tbody>
</table>

[a] Numerator degrees of freedom;
[b] Denominator degrees of freedom.
Figure 8 illustrates the model predictions for compartment temperatures at an ambient temperature of 16°C. At this temperature, side and front openings would be a mixture of covered and opened, depending on the driver’s discretion. In this configuration, the numerically warmest compartments in the trailer were Upper 1 followed by Upper 2 and Upper 4. Lower 4, Lower 3, and Upper 3 were the coldest. This makes intuitive sense that upper compartments would tend to be warmer than lower due to thermal buoyancy. As earlier testing indicated, stocking density appears to have little consequence regarding predicted compartment temperature. Statistically, using the 95% comparison, only Upper 1 was greater than Lower 4 for a stocking density of 0.084 m²-pig⁻¹. No other significant differences were found (p>0.05).

Figure 9 shows the estimated compartment temperatures for an ambient temperature of 29°C which would occur...
when all of the side and front trailer openings were opened. Numerically, the hottest predicted compartments were Lower 1 followed by Upper 4. Upper 3 appears to have been the coolest. However, no compartment is predicted to be statistically different from the others.

**Wind Tunnel Tests**

Tables 6-11 give the centerline (CL) velocity in each compartment within the scale model, the percentage of the air velocity in the compartment compared to the wind tunnel velocity at a height of 18.4 cm (based on speed 1 or speed 2), the direction of flow, and the compartment rank from highest air velocity to lowest. The direction of flow is based on the angle relative to the wind flow direction. A value of 0° indicates flow consistent with the wind tunnel direction and indicates an air flow direction from the front of the trailer toward the rear. A value of 180° indicates that air flow was opposite of the wind tunnel direction, or in other words, air velocity within the trailer model flowing from back towards the front. These are indications of the primary direction and do not indicate a straight line flow. Air velocity is assumed to be a relative indication of the air exchange rate within each compartment.

Tables 6 and 7 show results when the vent openings on the front of the trailer were uncovered and pen partitions in place, typical for summer transport. For both wind tunnel velocities all of the compartments had air flow from the rear of the trailer toward the front. The highest air velocity occurred in the Upper 2 and Lower 3 compartments for both wind tunnel speeds. The lowest air velocity occurred in Lower 2 and Lower 4. No statistical comparisons were made.

Tables 8 and 9 show results when the front vent openings were covered and compartment partitions in place, typical for warmer spring/fall transport. Air flow direction tended to move from back to front in the Upper 1 compartment but front to rear in all the other upper compartments (Upper 2, 3, 4). The lower compartments had airflow from back to front.

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**Figure 9.** Estimated compartment temperatures and 95% confidence intervals for various compartmental stocking densities (m²-pig⁻¹) and an ambient temperature of 29°C.
in the first three compartments (Lower 1, 2, 3) but front to back in Lower 4. The compartments with the highest air velocity (independent of direction) were Upper 1 and Lower 2 and the compartments with the lowest air velocity were Upper 3 and Lower 4. No statistical comparisons were performed.

Tables 10 and 11 show results when the front vent openings were uncovered and pen partitions absent. This was an unusual configuration because pen partitions are not normally removed, however it allows us to examine the impact of partitions on air velocity. Air tended to move from back to front in all of the compartments except Lower 4. The compartments with the highest air velocity (independent of direction) were Upper 2 and Lower 2 for both air speeds and the compartments with the lowest air velocity were Lower 1 and Lower 4. No statistical comparisons were performed.

Tables 12 and 13 show results when the front vent openings were covered and pen partitions absent. Air tended to move from back to front in all of the lower compartments and front to back in the upper compartments except for the front (Upper 1). The compartments with the highest air velocity (independent of direction) were Lower 2 and Lower 3 for both air speeds and the compartment with the lowest air velocity was Upper 2 for both air speeds. No statistical comparisons were performed.

The impact of having the pen partitions in place was evaluated using a paired t-test. Based on compartment within the trailer, centerline velocity was significantly different (p<0.05) when the pen partitions were in place (14.32%) versus when pen partitions were absent (15.36%). This indicates
that perhaps redesigning pen partitions to be less than 50 percent solid may result in higher velocity within the trailer, thereby aiding heat stress relief during hot weather. Side openings were open in both trials. Additionally, the impact of having the front vents uncovered versus being covered was similarly tested using a paired t test based on compartment location and absolute value of centerline velocity. No significant difference (p>0.05) was determined.

The scale model illustrated a few points that are worthy to note. These points relate to the magnitude of centerline velocities relative to wind tunnel speed, direction of air flow and areas of highest and lowest flow as impacted by the trailer configuration. However, care should be taken when extrapolating these results to a full-size trailer loaded with piglets because piglets were not modeled as part of the system and trailer configurations vary.

The magnitude of the centerline velocities within the compartments varied from 11% to 22% of the wind tunnel speed with trailer averages ranging from 14% to 16%. If this is extrapolated to an actual livestock trailer traveling at highway speeds of 113 km h⁻¹, the resulting internal air speeds would range from 3.4 to 6.9 m s⁻¹ within the compartments.

Front trailer vents appear to make a difference in the direction of air flow within the trailer compartments when the side vents are all open and pen partitions in place. When the front vents were uncovered all compartments flowed from the rear of the trailer toward the front (180°), indicating low pressure behind of the tractor cab may draw air from the trailer. When the front vents were covered the lower compartments (Lower 1, 2, 3, 4) tended to have air flow from back to front (180°) but air flow in the upper compartments tended to flow front to back (0°).

It appears that when using this scale model, the Lower 4 compartment tended to have the lowest air velocity for most cases. This may be impacted by the fact that the rear of the trailer is mostly closed due to positioning of loading ramps and the door. Upper 3 and Upper 4 also tended to have the overall lowest centerline velocities, indicating that the upper rear of the trailer has less air movement than some of the other compartments. Lower 3, Lower 2, and Upper 1 tended to have the highest air velocities.

Overall, it is difficult to draw firm conclusions from the wind tunnel trials. There are many variables which influence air flow. These include the distance between the tractor and trailer, air spoilers, the presence of a “pot-belly” on the trailer, and the presence of vents in the top of the trailer. All these issues could change how air flows through the trailer. However, a few trends have been shown during the wind tunnel trials that are interesting and indicate that further study on actual trailers may be warranted.

**SUMMARY AND CONCLUSIONS**

**CONDITIONS IN TRANSPORT**

Loads of weaned pigs traveling from southern Illinois to Iowa and northern Illinois were monitored for temperature and mortality by compartment. After QA/QC, 78 loads were used for analysis. The following conclusions were drawn based on data analysis:

- The mortality rate of the loads was found to average 0.031% over the entire monitoring period. Ambient temperature and travel time, as well as interactions, were significant effects in the logistic regression model. However, with the very small number of mortality events, with most loads having no death loss, the results may be misleading. This does however indicate that mortality tends to come in events rather than as a steady occurrence and extra care should be taken by drivers during stressful conditions.
- When examining the estimated probability of mortality by compartment the upper deck (Upper 1, 2, 3, 4) tended to have numerically lower estimated probability in winter than the lower deck (Lower 1, 2, 3, 4). In summer the lower deck tended to have numerically lower estimated probability of mortality than did the upper deck. However, there is no significant different in mortality by compartment (p>0.05). This numerical difference may be attributed to thermal buoyancy. Additionally, this uniformity may indicate that established practices to manage the trailer environment are effective to maintain animal well-being during transport.
- A linear mixed effect model used to evaluate compartment temperature found significant interactions of ambient temperature, compartment and compartment stocking density when examining effects on compartment temperature. Stocking density and the interaction between ambient temperature and stocking density were not significant (p>0.05). This serves as an indication that the consideration of all parts of the system, ambient environment, location, and stocking density, factor into the impact on trailer environment.
- Predicted compartment temperatures were compared using 95% confidence intervals for three different ambient temperatures and three different stocking densities for each compartment.
  - At 2°C, the predicted compartment temperature of Upper 1 was significantly higher than Lower 3 and Lower 4 for stocking densities 0.070 and 0.084 m²-pig⁻¹ but all other compartments were not significantly different (p>0.05). This would tend to indicate that if pigs are more crowded, the compartment temperatures stay a similar temperature during cold weather.
  - At 16°C, the predicted compartment temperature of Upper 1 was significantly higher than Lower 3 and Lower 4 (p<0.05) at a density of 0.084 m²-pig⁻¹, but all other comparisons were not significant.
  - No significance differences was found at 29°C (p>0.05), indicating high air flow equalizes compartments.

**WIND TUNNEL TESTS**

In this study a 1/7th scale model of a livestock trailer and tractor were placed in a wind tunnel to examine the flow characteristics within the eight animal compartments. Trials were run with front vents on the trailer covered or uncovered.
and with compartment partitions in place and removed. Side-wall openings were always open. The following conclusions were drawn based on the performance of this model:

- The magnitude of the centerline velocities with the compartments varied from 11% to 22% of the wind tunnel speed with trailer averages ranging from 14% to 16%.
- Pen partitions within the trailer made an impact on centerline velocity. Compartments with a pen partition were significantly different (p<0.05) than compartments without pen partitions, 14.32% and 15.36%, respectively. This indicates that compartment partition design is an important factor to consider in trailer design.
- No significant difference (p>0.05) was found in the magnitude of centerline velocities in comparing the situation when front vents were uncovered versus when they were covered.
- When front air vents on the trailer were uncovered, air flow was from the rear of the trailer toward the front.
- When front air vents on the trailer were covered, air flow direction was mixed with most of the upper compartments having front to rear flow and most of the lower compartments having rear to front flow.
- The lower rear compartment (Lower 4) tended to have the lowest lowest air flow rates with Upper 3 and Upper 4 being only slightly higher. Lower 3, Lower 2, and Upper 1 tended to have the highest air velocities.

**Recommendations for Future Work**

Further study of animal well-being, such as animal posture, behavior and weight loss, during transport is warranted. Temperature alone, while an important consideration, does not adequately quantify animal well-being just as lack of mortality does not indicate successful animal well-being. Conclusions from this study indicate opportunities to further examine trailer design and operation. It appears that modification of the compartment partitions and the addition of openings on the rear of the trailer may enhance flow for summer transport. Additionally, other factors such as roof vents and aerodynamic features of the tractor/trailer may influence air flow, perhaps being counterproductive to air flow within the trailer. Further examination of the details of side opening management also warrants further investigation.

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**Reference**


