MEAT & LIVESTOCK AUSTRALIA

finalreport

LIVE EXPORTS

Project code: LIVE.234

Prepared by: Dr. R.T. Casey

The School of Mechanical and Manufacturing Engineering. The University of New South Wales.

Date published: June 2005

ISBN: 1 74036 660 3

PUBLISHED BY
Meat & Livestock Australia
Locked Bag 991
NORTH SYDNEY NSW 2059

Potential benefits of jetting to the HS model

partner logo

Table of Contents

1. ABSTRACT

The aim of the current work was to attempt to quantify the potential benefits that may be gained by including the effects of jetting into the HS model. Currently, the HS model simply uses the global parameter of Pen Air Turnover (PAT), which is assumed to be constant over a defined area. The actual air flow is more complex with regions of both high and low air velocity and may in fact give rise to induced velocity profiles which carry with them the benefit of additional cooling and as such would warrant some parameter that quantifies potential benefit. This parameter is generally termed "Jetting" for this study. For this study, a velocity ratio was used to represent the jetting. It was defined as the actual velocity divided by the nominal PAT. A set of typical data was measured experimentally aboard a modern, purpose built livestock vessel. Care was taken to ensure that the data represented typical data and to exclude extreme influences. This data was used to evaluate the jetting factor, for a typical case.

The nominal dry bulb temperature for the standard PAT case was adjusted until it gave a value of animal comfort index the same as for the cases with elevated airflow. The equivalent conditions were used as the input to the HS model with a set of voyage parameters that represented a marginal voyage under reduced stocking fractions. The change in allowable stocking fraction as calculated for the higher airflows, was then compared to the standard result. The results indicated that increases in stocking fraction can potentially be achieved under marginal conditions but no potential increase would result where stocking fractions are already at 100%.

2. EXECUTIVE SUMMARY

An experimental evaluation of the airflow aboard a candidate vessel was conducted as part of this investigation. The intention was to quantify a typical flow pattern within a typical pen with an explicit intention to avoid extreme data. This would exclude pens that were immediately adjacent to large scale air exhausts and inlets and pens that were bounded by more than one wall. Moreover, pens that were essentially in the middle of the deck were favoured where the middle is taken in the forward – aft axis. In total three pens were measured. It was found that the average velocity measured was higher than the nominal PAT by factors of 3.2, 8.5 and 10.4.

Caution needs to be exercised when interpreting these factors. It was found that the flow in the centre of the pens was highly blustery, giving an overall increase in mean velocity, above the nominal PAT. However this blustery flow results from air movement, that has already been exposed to the hot animals and is therefore expected to give less cooling potential than air issuing directly out of air distribution outlets. As such, it may be prudent to give some weighting factor based on location within a pen, when evaluating the average. Such a weighting process was not performed in this case.

Secondly, the blustery nature of the flow makes it inherently difficult to model, especially with simple analytical models. Even computational methods generally need some calibration factors to include such levels of variations, and these generally come from experiments, which are prohibitively expensive. The flow was most blustery away from the air outlets and again, it may be prudent to simply exclude such regions from the evaluation of average air velocity.

The intention of this assessment is to try and identify potential benefits that may flow from the inclusion of jetting in the HS model. As such, it is acknowledged that on some voyages, the allowable stocking fractions can be 100% and so in those cases there is no margin for potential improvements. It is only in the marginal cases where potential for improvements can be realised. These marginal cases would include voyages that are run at reduced stocking density or are prevented from sailing. Therefore, in order to equate the measured velocity ratio to potential benefits, a set of typical data was used, for a nondescript vessel that represented a marginal voyage. The conditions used for this evaluation are as follows:

Breed: 25% Bos Indicus	**Weight:** 220 kg	**Fat Score:** 3
Nominal PAT: 150 m/hr	**Departure Port:** Port Hedland	**Arrival Port:** Kuwait

These conditions were chosen as they reduced stocking fractions by 15% in August.

Equivalent temperatures were calculated that were based on equating the animal comfort index of ETI and the convective potential. These equivalent conditions were used with the above data as input to the HS model. It was found that the reduction in stocking fraction could be potentially regained in the month of August. In fact, for the conditions, it showed that 100% stocking fractions would be supported for the whole year.

It was found that the measured velocity ratio varied from 3.2 in the worst case to some 10.4 in the best case. It may be tempting to try to utilise the full potential of each pen, since there is a great difference in these values. However there is a clear complexity in varying the stocking density on a pen-by-pen basis. This would add a good deal of complexity in loading if such an approach was to be adopted. It would also add a good deal of complexity in verification of stocking levels, if such an approach was used. As such, a more simplified approach should be sought, as an alternative.

3. INTRODUCTION

The evaluation of the potential benefits of jetting was conducted as follows:

1. Experimentally evaluate a typical velocity ratio of average pen velocity divided by the nominal PAT
2. Evaluate the impact of velocity ratio on animal cooling with both ETI and Convective Potential
3. Equate the results from 2 for both the PAT and increased PAT, to give an equivalent temperature for the two
4. Run the HS model for both cases and compare the stocking fractions and available times for sailing

This approach is explained in detail below.

4 AIRFLOW MEASUREMENT

The airflow was measured within three pens aboard a candidate vessel. The outside wind speed at that time was less than 2 knots and the sea was very calm which means that the airflow within the ship can be taken to have been essentially generated by the ventilation system and not by external wind gusts. Details of the vessel are not given in this report, to protect the commercially confidential nature of the results. However, these details are kept on record for future reference if necessary.

Three typical cattle pens on fully enclosed decks were targeted as candidates as it was intended to generate a set of typical results. Therefore pens that may give rise to extremes of data were avoided, such as pens next to a large scale air inlet / exhaust or a pen bounded by more than one wall. Pens in the middle of the ship were also targeted where the middle is taken to be in the forward – aft sense. Two of the pens were bounded by one wall and the third was not bounded by a solid wall.

The air distribution system aboard the vessel was found to be of a fine scale nature. This means that many outlets were positioned above all pens. There were slight variations in the geometry of these outlets but generally all pens were well covered. To allow for variations in the outlet configuration, three candidate pens were chosen that each had slightly different outlet configurations. The exact details of the air distribution system are not presented here, but are kept on file.

Three instruments were used to make an evaluation of the general airflow. Initially, a vane anemometer was used that essentially has a small propeller that rotates according to airspeed. This instrument proved to be reasonable near the outlets of the air distribution system but was sporadic elsewhere. In fact, away from the outlets, the propeller would come to rest, and then sporadically start to turn, and then stop. A pitot tube with a micro-manometer was also used that is essentially a tube that is faced into the flow however the directional sensitivity of this instrument meant that it effectively removed many of the wind gusts arising from the blustery flow. The third instrument was a TSI dual-axis hot wire anemometer that proved to be quite adequate in measuring all facets of the flow.

The measurements revealed that the flow was highly variable in both direction and magnitude, which is generally referred to as “Blustery” flow. This level of variation made it very difficult to determine the average value of velocity (mean velocity) as the instruments would not stabilise and showed large variations even when averaged over long time constants. To overcome this issue, rapid spikes in velocity were ignored and only the slowly varying component of the signal was recorded. This process is generally termed “Low Pass Filtering”. The fastest components of velocity that were removed by this process corresponded to the highest spikes in velocity and so the low pass filtered signal represents a worst case scenario in terms of velocity as it only averaged the slowest components of velocity. In this case, the worst case scenario approach is considered reasonable because if the data shows some net benefit under such a rigid constraint, it can be stated with a good deal of certainty that the actual flow must be producing such a net benefit.

The flow was most blustery in the parts of the pens furthest from the air outlets. Measurements made close to the air outlets showed much less variation and generally just monotonically increased as they got closer to the outlet.

One point of caution arises due to the blustery nature of the flow. Different airflow sensors respond differently to such variable flow and therefore would provide a different value for the mean air speed. When experimentally assessing such a flow, two groups using different instruments may legitimately arrive at different values for the mean velocity and therefore make different assessments of the impact on heat stress. In this way, it opens up the possibility for potential argument as it may provide one group a basis to argue against an unfavourable prediction of mean airflow. It is firmly considered, that the most appropriate instrument would be a hot wire type anemometer. These instruments have a response time that is sufficiently fast to record the significant wind gusts and their directional insensitivity means that they can capture the variations from any direction. Industrial variants of the hot wire anemometer include devices with bulbs instead of wires, but it is likely that these too would prove adequate as they too have fast response and show no directional sensitivity.

Each candidate pen was divided into an equi-spaced grid of 1 metre by 1 metre and measurements were taken in the middle of each grid element, at a height of 1.5 metres above the deck. The mean velocities measured in each of the grids were then simply arithmetically averaged to give an average velocity for the pen. These average velocities were then divided by the nominal PAT of 150 m/hr or 0.047 m/sec to give an average pen velocity ratio. The results of this process are presented in Table 1.

Table-1 Average pen jet velocity

Pen No.	**Average Pen Velocity (m/s)**	**Nominal PAT (m/s)**	**Average Pen Velocity Ratio**	**Pen Area for V greater than nominal PAT**	**Pen Area for V less than nominal PAT**
1	0.40	0.047	8.5	90%	10%
2	0.49	0.047	10.4	53%	47%
3	0.15	0.047	3.2	42%	58%

It is initially obvious that the pen velocity ratio is surprisingly high in pens 1 and 2. Both of these pens were bounded on one side by a solid wall that ran parallel to the air distribution pipes and showed significant peaks in velocity close to the outlets of the air distribution system. These peaks dominate the evaluation of the average pen velocity.

It can be seen that the velocity ratio for pen three is significantly lower than the other two pens. The data indicates that this results from the fact that this pen was not bounded by a wall, running parallel to the air distribution system. It also results from significantly less peak velocity close to the outlets of the air distribution system, as for the other two pens.

One final set of measurements was taken, in the centre of pen three. The hot wire probe was left to continuously record velocity for 2 minutes. The highest velocity measured during this time was 0.66 m/s and the lowest was 0.09 m/s. The difference between these two numbers is in excess of a factor of 7, which indicates the extent of the blustery flow. This gives rise to a point of caution in relation to modelling such a flow. Blustery flows are inherently difficult to model, and most models need some empirical data to calibrate the level of variation. This data typically comes from experiments conducted on the actual sample or an equivalent sample. In this case, it is considered that the requirement to include a "Jetting Factor" may give rise to the necessity to include one more factor to describe the blustering levels, with a concern that the list of complexity may continue. Furthermore, the cost associated with experimentally evaluating a ship, is expected to be prohibitively high making it difficult to objectively evaluate the level of blustery flow.

The last two columns of Table 1 were included to quantify how blustery the flow was. The intention of including these columns was to flag the level of this factor, to future personnel that may be asked to include jetting parameters in the HS model. It would be prudent to at least make some evaluation of the significance of this factor, and if necessary provide some weighting to it, in the HS model.

5. EFFECTIVE TEMPERATURE INDEX (ETI) CALCULATION

A set of climatic data was chosen that corresponds to identifiable dates within the HS model. A nominal arrival date of August 15th was chosen as it corresponds to a nominal wet bulb temperature of 28.2 degrees. A nominal relative humidity of 65% was chosen which corresponds to a dry bulb temperature of 34 ^{o}C. ETI represents the effective animal body temperature when exposed to the nominated climatic parameters and was derived experimentally from studies of dairy cows and it can effectively be viewed as a measure of animal comfort.

The ETI was calculated for each case where ETI is given as:

$$ETI = 27.88 - 0.456\, T_{db} + 0.01754\, T_{db}^2 - 0.4905\, RH - 0.00088\, RH^2 + 1.1507\, V - 0.126447\, V^2$$

$$+ 0.019786\, Tdb\, RH - 0.046313\, Tdb\, V$$

Tdb = Dry Bulb Temperature, RH = Relative Humidity, V = Velocity

The ETI was initially calculated for the case of a velocity ratio of 3, with the nominated temperatures above. The ETI was then calculated with the standard PAT as the velocity, and the dry bulb temperature lowered, until the ETI gave the same value as for the case with the velocity ratio of 3. In this way, an effective dry bulb temperature was calculated that gave the same ETI as the increased velocity. This process was repeated for the case where the velocity ratio was 10. This approach gave a low sensitivity to velocity, for values below 5 m/s. As such, it is considered that either ETI does not fully describe the potential benefit of air velocity or that air velocity below 5 m/s is of limited benefit in terms of cooling of animals. The form of the equation would indicate that velocity has been included from a regression analysis that did not couple the velocity to a convective heat transfer parameter. This would suggest that the ETI may not well model the potential benefits of air velocity, however it does not preclude the possibility that low air velocity may be of limited benefit.

6. CONVECTION POTENTIAL CALCULATION

A second approach was then used, that accords to a Convective Potential method as follows: $P_c = 10\, V^{1/2}\, (Tskin - Tambient)\, A$

Pc = Cooling due to convection and represents the heat loss from the animal due to convection

V = Velocity,

Tskin = Skin Temperature, Tambient = Ambient Temperature, A = Area

This is the approach used by Qvarnstrom [1], and a nominal skin temperature of 37 ^{o}C was used. This temperature was chosen as it represents a moderately high value. From the studies, it appears that animals with this skin temperature are not yet in the critical region but are close to this point. As such, it is thought that this would represent a marginal condition and aligns to the aim of this investigation. Again, Pc was calculated for a velocity ratio of 3 with the standard temperature and then it was calculated with the standard PAT and the ambient temperature was adjusted to give the same Pc as for the higher airflow. This was repeated for the velocity ratio of 10. This method is expected to over-predict the benefit as it only describes the convective cooling and ignores the other methods of cooling, which may show little benefit from increased velocity. Moreover, it ignores relative humidity and shows no asymptote at 40 ^{o}C body temperature.

The effective temperatures generated by the ETI and the Convective Potential approaches were then averaged in order to cancel out the potential shortcomings of each. The results are presented in Table 2. The ETI and Convective Potential methods give quite different results. There is insufficient information within the open literature to give confidence in making a determination as to which of the two methods is most likely to best model the current circumstance. Moreover, the development of such a model is considered to fall outside the scope of this evaluation. Therefore, the simple averaging approach was adopted. This gives rise to a point of caution to those that may include such a model into the HS program. The lack of models in the open literature would necessitate the development of such a model, as part of the program to include jetting into the HS model. Moreover, the variable sensitivity of the existing crude models indicates that caution should be used when developing this model to ensure that its sensitivity is appropriate.

Table 2: Results for equivalent conditions calculations

Standard PAT				**Equivalent Conditions with 3 x PAT**				**Equivalent Conditions with 10 x PAT**			
V (m/s)	Tdb (C)	Twb (C)	RH (%)	V (m/s)	Tdb (C)	Twb (C)	RH (%)	V (m/s)	Tdb (C)	Twb (C)	RH (%)
.047	34	28.2	65	0.141	33	27.2	65%	.469	31	25.5	65%
ETI = 48.196 for standard conditions				ETI = 48.153 for standard Conditions				ETI = 47.988 for standard conditions			
				ETI = 48.154 for v = 0.047 m/s & T = 33.98 ^{o}C				ETI = 47.97 for v = 0.047 m/s & T = 33.89 ^{o}C			
Pc/(10 A) = 0.650 for standard conditions				Pc/(10 A) = 1.126 for standard conditions				Pc/(10 A) = 2.054 for standard conditions			
				Pc/(10 A) = 1.126 for T = 31.8 ^{o}C and V = 0.047 m/s				Pc/(10 A) = 1.126 for T = 27.52 ^{o}C and V = 0.047 m/s			
Tdb,av = 34 ^{o}C				Tdb,av = 32.9 ^{o}C				Tdb,av = 30.71 ^{o}C			
				Twb,effective = 27.2 ^{o}C @ 65% RH				Twb,effective = 25.5 ^{o}C @ 65% RH			

The approach above uses an equivalent temperature whilst maintaining the same velocity. This approach was adopted because it is intuitively incorrect to artificially adjust the PAT in order to give the same animal comfort. This follows as PAT also controls the rate of heat removal from the vessel, and so by artificially increasing this level, it would be expected to lead to very high levels of improvement. On the other hand, by adjusting wet bulb temperature, it would give the same overall level of heat removal from the vessel as the PAT would remain the same.

6. POTENTIAL STOCKING BENFITS

The results for the equivalent conditions calculations were used as the input for the HS model. A fictitious vessel was set up with a PAT that was very close to the nominal PAT as listed in Table-2. The arrival date was chosen to be the 15th of August as this nominally corresponds to a wet bulb temperature of 28.2 °C, the same as the value used for the nominal PAT case for Table-2. The additional data relating to the voyage is as follows:

Breed: 25% Bos Indicus **Weight**: 220 kg **Arrival Port**; Kuwait

Departure Port: Port Hedland **Fat Score:** 3

The equivalent conditions with a 3 x PAT gave an equivalent wet bulb temperature of 27.2 °C, which corresponded to an arrival date of September 15th. The HS program was then run with this as the arrival date, but all other parameters held the same. Finally the equivalent wet bulb of 25.5 °C was interpolated as an arrival date of September 30th, corresponding to the case of 10 X PAT. The HS program was run with this condition also. The results are presented below, in Table 3.

Table 3: Stocking levels for the given case

Case	**Max Stock no. /% risk of 5% mortality**	**Stock no. for 2% risk of 5% mortality**
Nominal PAT	2983 / 3.57%	2540
3 x PAT	2983 / 1.36%	2983
10 x PAT	2983 / 0.7%	2983

Table 3 identifies some benefits for the nominated conditions. These show that for the marginal month of September, a reduced stocking fraction would need to be used in order to meet a 2% risk of 5% mortality, based on the standard PAT. When the elevated PAT is used, the allowable stocking fraction returns to 100%. The difference represents some 15%.

Importantly, this case was chosen to specifically represent a marginal episode. The results indicate that there is no specific benefit for those months in which the allowable stocking fraction is 100% as these voyages are at maximum potential already

In terms of additional sailing dates, this information can be gleaned from the equivalent wet bulb temperature values. At an equivalent condition of 3 x PAT, the equivalent wet bulb temperature went from 28.2 down to 27.2 °C. This means that all months of the year would be acceptable, for 100% stocking fraction, for the particular class of animals, given in the example. This can be seen in the values of wet bulb temperatures presented in Table 2.1 of the report LIVE.116 “Development of a Heat Stress risk Management Model” of October 2003.

7. CONCLUSIONS

Intuitively, increased air movement should give improved cooling potential to animals. The methodology used for this report is acknowledged as being only a first order estimate and is intended to give a general interpretation of the magnitude of the potential benefits.

The estimate of increased stocking density indicates that during the most critical month of August, potential stocking density may increase by up to 15%. There is also a potential to increase stocking density in the months from June – September, however the increases would be less in June, July and September, compared to August. In the months from October – May, there would be no potential benefit, as 100% stocking fractions can be maintained in these months, with the standard calculation of PAT.

The potential improvements listed above are only applicable for the class of animal given in the example, for the nominated conditions. It is expected that different classes of animals, at different conditions would show different results.

It is acknowledged that a very simplified approach was taken to the determination of the average pen velocity. This simply gave an arithmetic mean to all the velocity measurements. It would be prudent for a true evaluation, to make some value judgements concerning the locations at which readings were taken. That is, readings in the centre of the pens, remote from the air outlets, would carry less cooling potential as they may have already been heated by the animals. This also means that caution should be used when interpreting the results above.

8. REFERENCES

1. Malin Qvantrom: “Estimation of production losses and measures to reduce thermal stresses in dairy production under tropical conditions”, JBT thesis, Swedish University of Agriculture, 2002.

2. LIVE.116 “Development of a heat stress risk management model.” MLA publication, October 2003.