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Assessing a method of incorporating jetting in the HS model and its commercial implications

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Abstract

At the time that the heat stress risk estimate methodology embodied in HotStuff was developed, the fact that jetting had an effect on heat stress was recognised. A jetting factor is included in the risk estimate calculations, but not currently used. The reason for this is the difficultly in developing a metric for evaluating the effectiveness of a particular jetting geometry.

The purpose of this study is to develop an understanding of how the jetting characteristics of a particular pen or deck might affect the heat stress risk for livestock. This understanding is then used to develop guidelines for preferred approaches to jetting as well as a jetting factor suitable for use in heat stress risk estimate calculations. The study should both help to guide the development of improved jetting configurations and allow fairer treatment of jetting in HotStuff.

Executive Summary

This study uses a first principles approach based on heat transfer analysis to understand the effect that the jetting of supply air has on heat stress in livestock. The approach relates pen geometry, jet geometry and pen air turnover to a jetting factor, which describes the change in the heat rejection from livestock for a given difference between skin temperature and air wet bulb temperature. A velocity field is calculated from a given supply, pen geometry and jet configuration. A corresponding heat transfer field is then calculated from the velocity field. The heat transfer field is then aggregated into a jetting factor, which considers the difference in heat transfer between the pen under jetting and the pen with only a drift velocity as well as the proportion of the pen area over which the jetting is effective.

The existing heat stress model has been calibrated against historical heat stress events. In order for the application of jetting factors to the existing heat stress model not to alter the average calculated risk over the fleet, the jetting factors need to be normalised against the industry average. This requires assessment of the jetting configuration on ships in the existing fleet.

Even without calculating the industry average for jetting in the current fleet there is still benefit in providing a relationship between jet configuration, PAT and pen configuration to assist the ship owners to maximize the benefits of jetting. Table E.1 specifies the preferred jet configuration for a given PAT and pen configuration. Specifications are based on assumptions which are detailed further in section Table E.1. The supply velocity is fixed at 12m/s which was chosen as a good compromise between jet effectiveness and power consumption. For jets distributed along one side of a rectangular pen and the exhaust along the opposite side, the fixed outlet velocity means that for a given PAT and pen length the jet spacing and jet outlet diameter are related. Table E.1 gives the optimum spacing/diameter combination for each pen length and PAT, together with the raw jetting factor which is exceeded for 85% of the pen area.

Table E.1 **Optimum jet spacings and outlet diameters for each PAT value and pen length, for a jet velocity of 12m/s**

Pen Air Turnover (m/hr)	Supply to exhaust distance across the pen: 5.0 m	7.5 m	10.0 m	12.5 m	15.0 m	17.5 m	20.0 m	
100	0.382 m	0.707 m	1.039 m	1.374 m	1.414 m	1.745 m	2.078 m	Jet Spacing
	75 mm	125 mm	175 mm	225 mm	250 mm	300 mm	350 mm	Outlet Diameter
	1.093	**1.098**	**1.100**	**1.101**	**1.098**	**1.099**	**1.100**	Jetting Factor
150	0.452 m	0.679 m	1.145 m	1.368 m	1.593 m	2.068 m	2.290 m	Jet Spacing
	100 mm	150 mm	225 mm	275 mm	325 mm	400 mm	450 mm	Outlet Diameter
	1.111	**1.111**	**1.116**	**1.116**	**1.115**	**1.118**	**1.116**	Jetting Factor
200	0.530 m	0.905 m	1.060 m	1.434 m	1.810 m	2.187 m	2.121 m	Jet Spacing
	125 mm	200 mm	250 mm	325 mm	400 mm	475 mm	500 mm	Outlet Diameter
	1.126	**1.129**	**1.126**	**1.128**	**1.129**	**1.130**	**1.126**	Jetting Factor
250	0.611 m	0.916 m	1.221 m	1.527 m	1.832 m	1.939 m	1.696 m	Jet Spacing
	150 mm	225 mm	300 mm	375 mm	450 mm	500 mm	500 mm	Outlet Diameter
	1.139	**1.139**	**1.139**	**1.139**	**1.139**	**1.136**	**1.129**	Jetting Factor
300	0.693 m	0.942 m	1.195 m	1.634 m	1.885 m	1.616 m	1.414 m	Jet Spacing
	175 mm	250 mm	325 mm	425 mm	500 mm	500 mm	500 mm	Outlet Diameter
	1.145	**1.147**	**1.146**	**1.149**	**1.147**	**1.139**	**1.131**	Jetting Factor
350	0.594 m	0.977 m	1.363 m	1.750 m	1.616 m	1.385 m	1.212 m	Jet Spacing
	175 mm	275 mm	375 mm	475 mm	500 mm	500 mm	500 mm	Outlet Diameter
	1.153	**1.156**	**1.157**	**1.157**	**1.150**	**1.141**	**1.133**	Jetting Factor
400	0.679 m	1.018 m	1.357 m	1.696 m	1.414 m	1.212 m	1.060 m	Jet Spacing
	200 mm	300 mm	400 mm	500 mm	500 mm	500 mm	500 mm	Outlet Diameter
	1.162	**1.162**	**1.162**	**1.162**	**1.152**	**1.142**	**1.134**	Jetting Factor

*note that for very high flows, the jet size is limited to 500mm jets for practical considerations

Red text shows jet spacing >1.5m. This highlights the effect of constraining the jet diameter.

Contents

1 Introduction

Jetting refers to a component of the ships ventilation where a controlled and measurable air velocity is directed across a specified area, in this case an individual pen on the deck of a ship. Shipowners and exporters believe that the HS model in its present form does not factor in the benefits of pen jetting that occurs on some livestock vessels. The argument is that Pen Air Turnover (PAT) reflects the ventilation efficiency on a deck but ignores the additive heat transfer effect of jetting and this is not accounted for in the HS model. If true, this has obvious animal welfare impacts and commercial implications.

A review (LIVE.234) was undertaken to establish the scale of effect that a jetting factor in the HS model might have on allowing increased stocking rates. Using a simplified and broad model based on some actual ship deck observations, the LIVE.234 report identified that, for many vessels, the stocking rate could only be jetting-affected for a small part of the year.

The LIVE.234 report also highlighted a likely wide discrepancy between jetting measurements by different people. This would make experimental determination of a jetting factor not only costly, but also imprecise and subject to dispute. The purpose of this project is to look more closely at the feasibility of including a workable jetting allowance into the HS model.

It is recognised that the HS model will never be able to precisely include a jetting factor for all circumstances, however a first order correction is warranted as currently the HS model has no allowance for air speed. Assessing the likely commercial impact required running a number of sample shipments with typical livestock types. The inclusion of a jetting factor will be determined on a deck-by-deck basis and will be based on current, best knowledge and where necessary conservative estimates. The inclusion of a jetting factor on a deck-by-deck basis will require only minimal upgrading of the current HS version 3 to adjust the existing HS jetting factor of 1.0.

The purpose of this study is to develop a first order understanding of how the jetting characteristics of a particular pen or deck might affect the heat stress risk for livestock. A first principles approach is taken. The approach is:

1) Develop an understanding of the influence of velocity, cross-sectional area and exit velocity of jets on the velocity fields in a pen
2) Develop and understanding of the relationship between velocity fields and heat transfer fields
3) Relate the heat transfer fields to a jetting factor
4) Test the jetting factors derived through the above work with HotStuff-generated charts to show the effects of implementing a jetting factor

The desired outcome for the study is to develop a means for calculating a jetting factor based on simple jet geometry and other parameters, which may be able to be used in conjunction with the heat stress estimates provided by HotStuff. The jetting factor is the minimum ratio between the heat transfer with jetting and without jetting over a specified proportion of the pen area. A higher jetting factor means that it is easier for livestock to lose heat at a particular temperature and has the effect of reducing the risk of heat stress.

1.1 Assumptions

In order to adopt a simple model of the development of an air jet, a number of assumptions are made:

- Air jets are above the back height of the livestock in the pens. The blocking effect of the animals therefore has little effect on the velocity fields created by the jets. For pens where this is not the case and livestock can block the air jets then the effect of the air jets on increasing heat transfer is assumed to be negligible for the majority of the animals in the pen. The associated reduction in heat stress is therefore also assumed to be negligible.
- Air jets are assumed to be equi-spaced and positioned along one side of the pen only
- The axes of the air jets are assumed to be angled perpendicularly to the walls of the pen
- Jet outlets are assumed to be circular, with no vanes to affect the angle of the flow.
- For the jetting factor calculations it is assumed that livestock in a fully stocked pen can access the best 85% of the pen in terms of the achievable jetting factor or heat transfer. The jetting factor quoted is then the one that applies to the least dominant animal.

Table 1.1 lists the assumptions used in the calculations outlined in this study.

Table 1.1 Assumptions for Calculation

Variable	Value	Units
Pen Geometry		
Pen Width	5	m
Pen Length (in jetting direction)	5 (varied)	m
Pen Height	2.4	m
Ventilation configuration		
Required PAT	200/ 400	m/hr
Total Volume Flowrate	5000/ 10000	m^3/hr
Jet Exit Velocity	12	m/s
Min/Drift Velocity	0.06	m/s
Jet Half Angle of Expansion	7	deg
Heat Transfer Values		
Ambient Wet Bulb Temp	30	degC
Skin Temp	40	degC
Conductivity	0.024	W/m K
Air Density	1.2	kg/m3
Characteristic Length	1	m
Absolute Viscosity	2.50e-05	Pa.s
Prandtl Number	0.7	

2 Relating Jet Parameters to Velocity Fields

The interaction of the flows from air jets in a pen is potentially very complex, both at a small scale and at a large scale, where asymmetries in the flow could lead to the development of large scale eddies. The treatment of velocity fields here ignores these complex secondary interactions and concentrates on developing a first order understanding of the primary jets.

The approach assumes that all air jets are equi-spaced (i.e. with a full space between each jet and half a space each side of the outer jets) along one wall of the pen, and high enough relative to the back height of the livestock that the jets remain relatively unaffected by the position of the livestock. A constant pen air turnover (PAT) and therefore a constant volume flowrate for a given pen area is assumed. A constant outlet velocity is also assumed (12 m/s in the examples shown), meaning that the outlet diameter for each of the circular jet outlets is determined by the number of jets specified for the pen.

The spreading rate of the jet is assumed to be 7° to each side along the axis of the jet. Once adjacent jets meet, the mode of expansion is assumed to change. At the point where the jet diameters meet, the cross-sectional area of the jet influence is assumed to continue to expand at 7° at the top and bottom only. The velocity within the region influenced directly by the jet is assumed to be uniform. Using the described jet geometry assumptions and assuming conservation of momentum, the velocity at any given distance from the outlet may be calculated.

Entrainment effects on the velocity of air surrounding the jet are also considered. With the assumption of conservation of momentum, a decreasing velocity as the jet expands corresponds to an increase in mass flowrate inside the jet. The velocity of the air entrained into the jet is calculated by discretising along the axis of the jet and matching the mass flowrate of the entrained air with the increase in mass flowrate inside the jet. The velocity of the entrained air decreases with increasing distance perpendicular to the axis of the jet and is assumed to decrease to zero midway between adjacent jets.

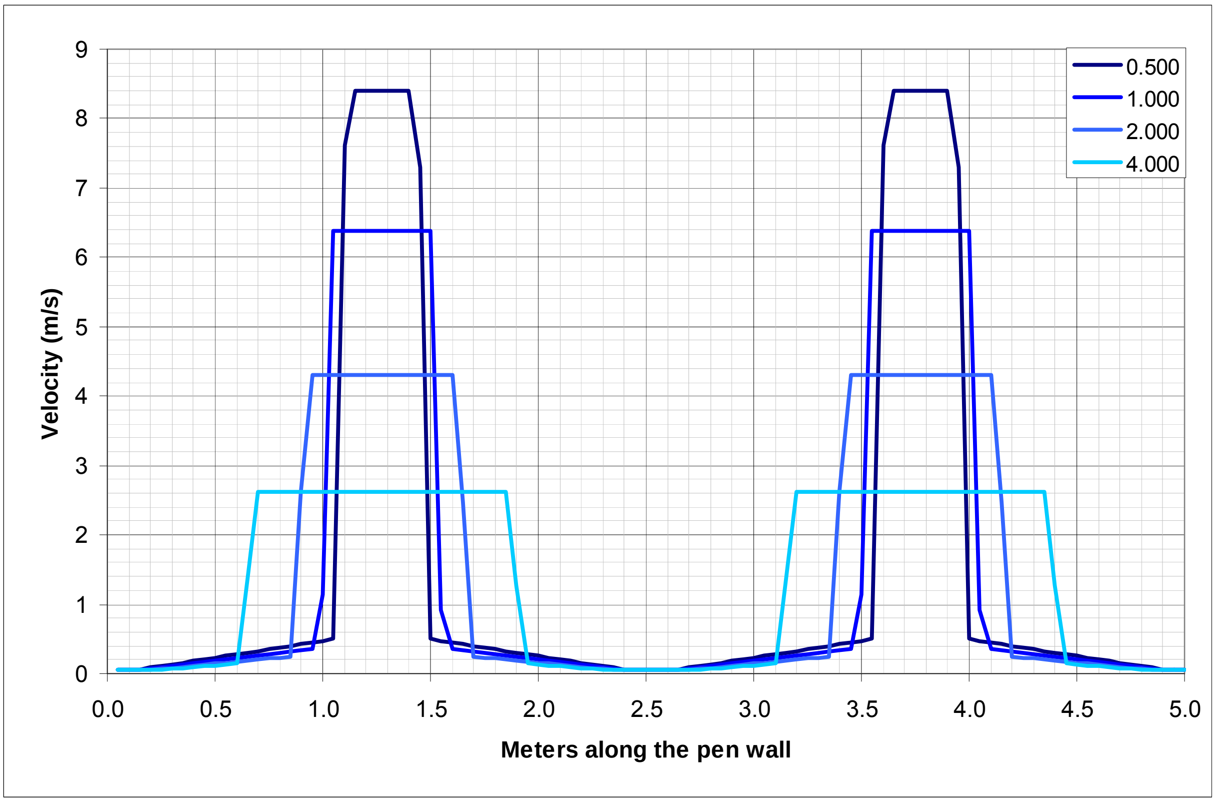


Figure 2-1 **Velocity profiles at increasing distances from the outlet**

The velocity fields are calculated using a finite element approach programmed within Excel. The air velocity for elements at the boundary of the jet is interpolated to minimise inaccuracies due to the grid resolution. Figure 2-1 shows velocity profiles at 0.5m, 1m, 2m and 4m from the jet outlet. The profiles show the air velocity inside the jet, the velocity profile at the boundary layer and the decreasing velocity of the entrained air with increasing distance from the jet centreline.

Figure 2-2 shows example velocity fields over a horizontal pen cross section taken at the axis of the jets. The example is based on a 5m x 5m pen with two equi-spaced jets. The figure shows both the entrainment of air into the jet and the change in velocity at the boundary layer of the jet.

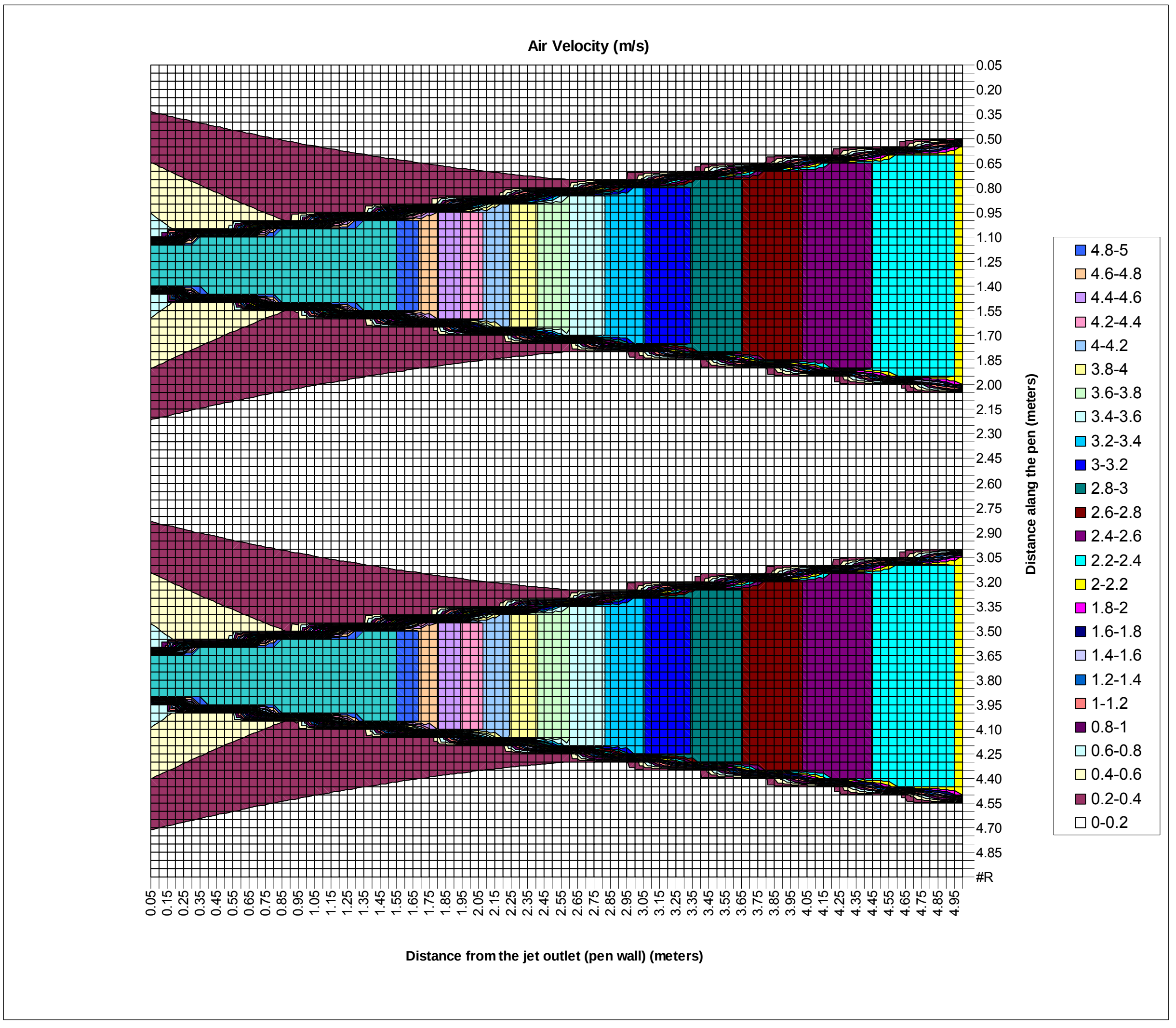


Figure 2-2 **Example velocity fields for a horizontal cross section**

For these calculations the pen is divided into smaller calculation cells. The velocity given for each of these cells is calculated to be the average for the cell. A resolution of 100x100 cells is used for the spreadsheet calculations. These velocity values are used for further calculations.

2.1 Comparison of first order approach with CFD test case

A simple computational fluid dynamics (CFD) test case has been developed to provide a comparison with the first order approach described above. The CFD test case is set up with geometry and boundary conditions as follows:

- 1.5m high and 5.0m wide and 10.0m long
- The jet inlet velocity is 12m/s
- Approximate cross sectional area of jet at inlet is 0.03m^2 (0.2m wide and 0.15m high).
- A symmetry boundary used (4 jets are present but only two need to be modeled).
- Boundary conditions are a wall at the top/bottom/inlet and open to atmosphere elsewhere.

The simplified geometry is illustrated below in Figure 2-3.

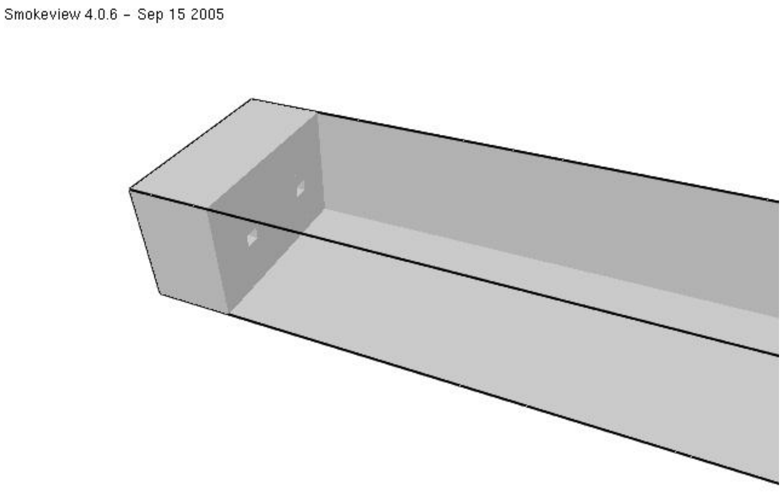


Figure 2-3 **Simplified pen geometry for CFD test case**

The velocity contours developed by the jets are shown in Figure 2-4. The figure shows the velocity field at an instant in time. The 7 degree expansion angle is also illustrated with respect to the jet centerline (model reference JT-1-2).

A comparison between the velocity field developed in the CFD test case and the first order approach suggest that the assumptions using in the first order approach are reasonable. In particular, a comparison between the assumed spreading rate and the spreading rate in the CFD test case is illustrated in Figure 2-4. The decay of velocity with distance from the jet outlet shown in Figure 2-2 also compares well with the velocity decay evident in Figure 2-4.

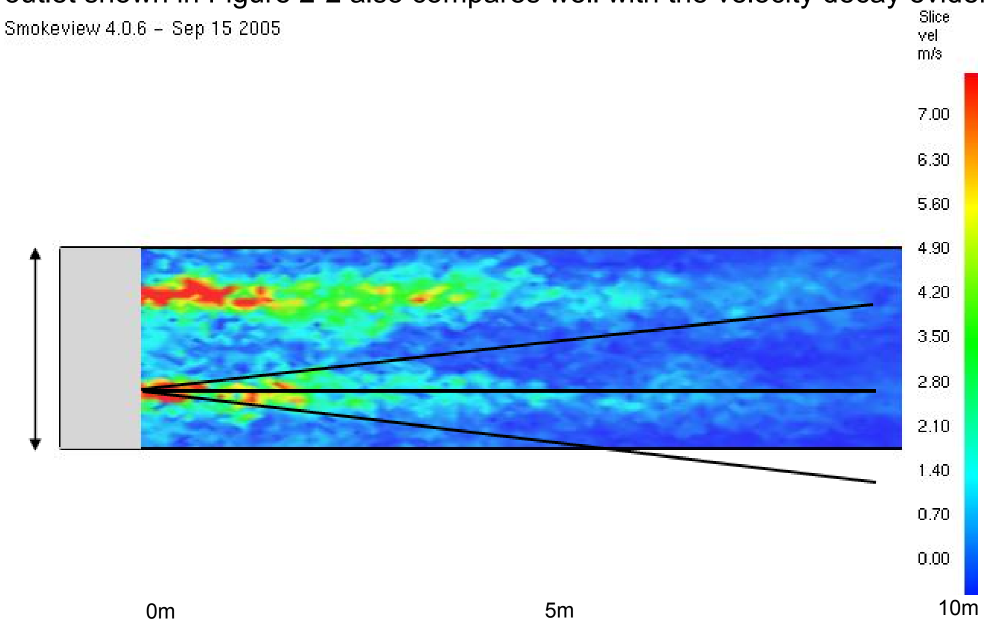


Figure 2-4 **Snapshot of velocity contours for developed example jet flows**

3 Relating Velocity Fields to Heat Transfer

In order to relate the air velocity in the jet to the ability of an animal to reject heat, it is necessary to make a number of assumptions about the nature of the heat transfer.

- It is assumed that approaching the heat stress threshold, 85% of heat is lost through respiration (latent heat loss), with only the remaining 15% lost through the skin (sensible and latent heat loss). It is assumed that respiratory heat loss remains constant while the cutaneous heat loss varies with the effects of jetting. This means that a doubling of the amount of heat lost through the skin due to jetting effects will only relate to a 15% increase in the total amount of heat lost.
- A simplified animal geometry is assumed with 4 x $1m^2$ surfaces, and only the uppermost surface affected by jetting. That is; only ¼ of the animals surface benefits from jetting. The drift velocity (which is the volume flowrate divided by the cross sectional area of the pen perpendicular to the jet axis and 0.06m/s in the examples shown) is used for all other sides.

The following approach is used to relate air velocity fields to the heat transfer from livestock positioned in the air flow.

1. Calculate the Reynolds number $\mathrm{Re}_L = \frac{\rho V L}{\mu}$ where ρ is the density of air ($1.2 kg/m^3$), V is the air velocity, L is the characteristic length (1m) and μ is the absolute viscosity.
2. If the Reynolds number < 5 x 10^5 (approximately 10.5m/s) then assume the flow is laminar, otherwise use laminar-turbulent equations
3. Calculate the Nusselt number $Nu_L = 2 \times \left(0.332\,\mathrm{Re}^{\frac{1}{2}}\,\mathrm{Pr}^{\frac{1}{3}} \right)$ if the flow is laminar or $Nu_L = \mathrm{Pr}^{\frac{1}{3}} \left(0.037\,\mathrm{Re}^{\frac{4}{5}} - 871 \right)$ if the flow is laminar-turbulent. The Prandlt number *Pr* is assumed to be 0.7 in both cases.
4. The heat transfer is then calculated using $q = Nu_L K_f \left(T_s - T_\infty \right)$ where the conductivity K_f is assumed to be 0.024W/mK, T_s is the skin temperature and T_∞ is the ambient temperature. The examples shown assume a 10K difference between the ambient temperature and skin temperature.

Figure 3-1 shows the heat transfer field that is calculated from the velocity field shown in Figure 2-2. Note that the field is only shown for the top left-hand corner of the area shown in Figure 2-2. The heat transfer contours indicate that while the entrainment effects do induce low velocity airflows outside the expansion angle of the jet, the increase in heat transfer in these areas is small.

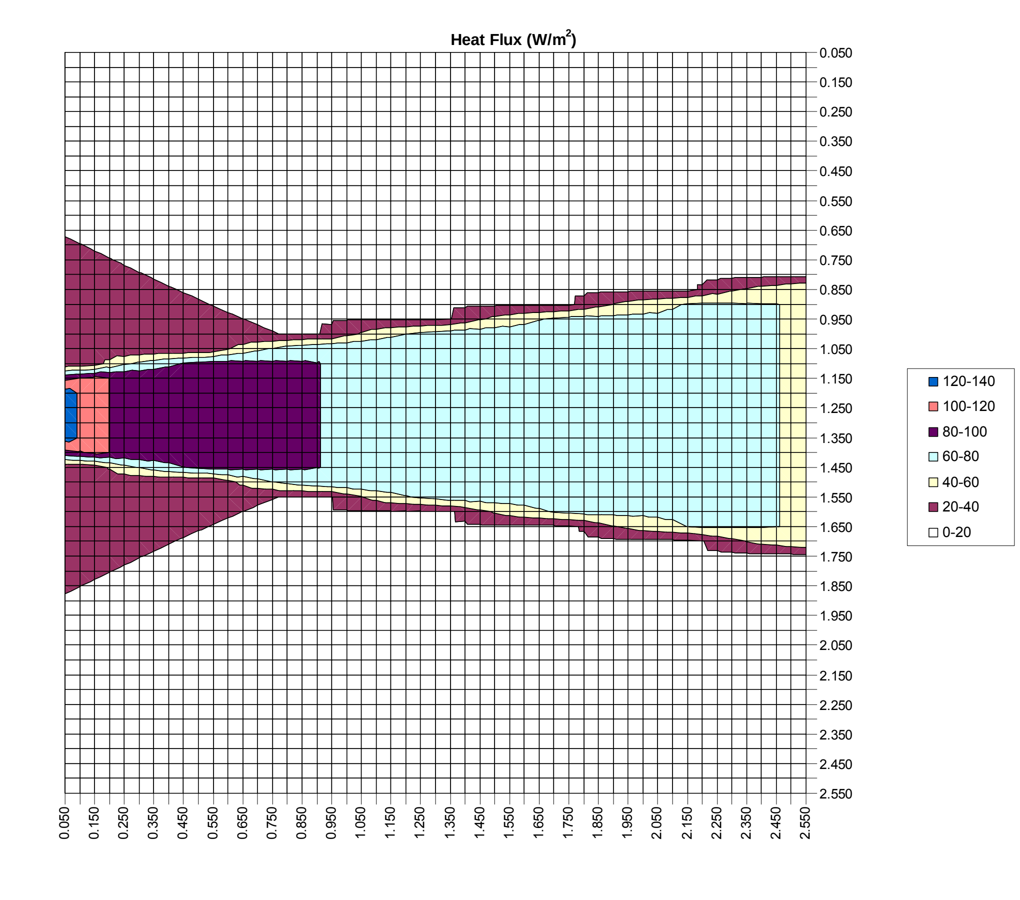


Figure 3-1 **Example heat flux fields for a horizontal cross section**

4 Relating Heat Transfer to a Jetting Factor

The previous section outlined the approach for converting a velocity field over a pen to a heat transfer. The next step it to calculate a jetting factor from the heat transfer calculated for each discrete element in a grid imposed over the pen. The jetting factor is an evaluation of the effectiveness of the jets for the whole pen and not for each discrete element. To do this, it is necessary to assume a stocking density for the pen (in terms of a percentage pen area fill) and to assume that all of the livestock in the pen will move to the best possible location in the pen in terms of the ability to transfer heat. The percentage of the area of the pen that is occupied by livestock is assumed to be 85% at full stocking and 85% x the 'stocking fraction' at other stocking densities.

The jetting factor for a point in the pen is then calculated as a ratio between the heat transfer achieved at the drift velocity and the heat transfer achieved at the velocity with the jet/s present. Under drift velocity only (no jets) the jetting factor is set to 1. Comparing the new total heat loss with the drift-only case will give the jetting factor. At this stage, the jetting factor is still a representative heat transfer ratio for a discrete element of the pen area.

By considering the jetting factor for each discrete element in the pen, a relationship can be developed between jetting factor and the fraction of the pen covered by that jetting factor or higher. Details of the assumptions behind the examples shown are provided in section 1.1.

Figure 4-1 shows the relationship between jet configuration, the jetting factor and the percentage of the pen area over which the jetting factor indicated is achieved or bettered. The coloured bands on the figure show regions where a particular range of jetting factors is achieved. For example, with 6 equi-spaced jets along one side of the pen, greater than 90% of the pen area experiences heat transfer improvement of 10% or better under the conditions detailed in section 1.1. The figure shows the important result that there is a preferred number of jets to achieve the greatest advantage from jetting effects. Too few jets give high heat transfers, but fail to achieve the required coverage, while too many jets will give good coverage, but fail to sustain sufficient air velocity with greater distance from the jet outlets.

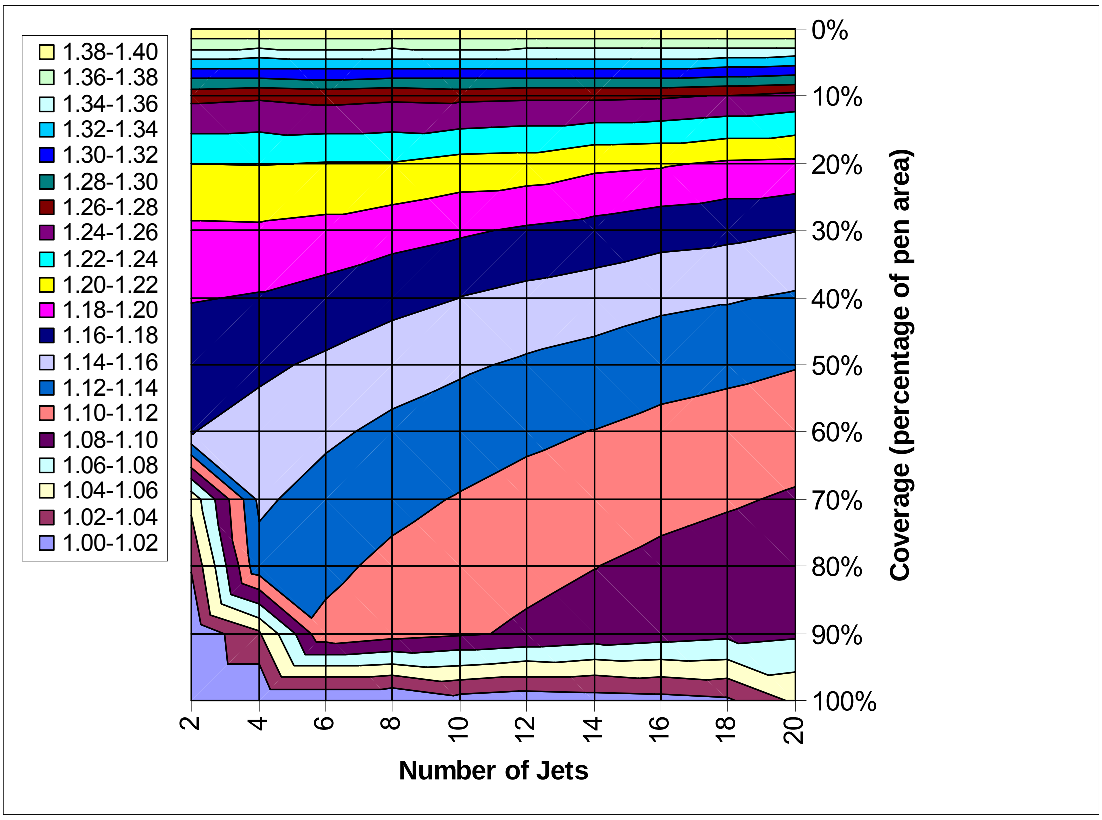


Figure 4-1 **Relationship between jet configuration, jetting factor and coverage for PAT = 200m/h**

Figure 4-2 shows the relationship between jet configuration, jetting factor and pen area coverage for a PAT of 400m/hr. The higher PAT requires a higher volume flowrate, which, for a given number of jets is increased by increasing the outlet area of the jets rather than the outlet velocity. An increase in PAT gives a significantly higher jetting factor for many areas in the map of Figure 4-2 compared to the same areas in Figure 4-1.

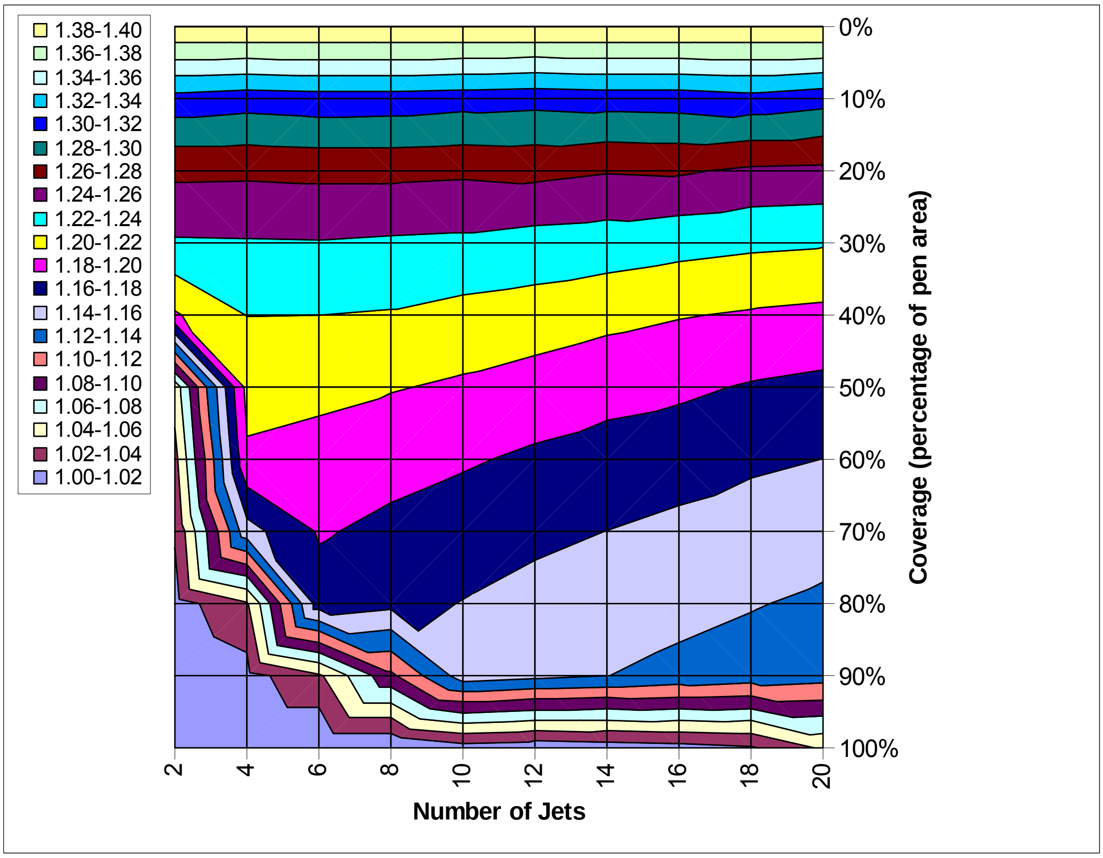


Figure 4-2 **Relationship between jet configuration, jetting factor and coverage for PAT = 400m/h**

Figure 4-3 shows the fraction of the pen area over which a specified jetting factor is achieved with a variety of different jetting configurations. The cumulative distributions show the limited coverage of jetting configurations with a small number of jets. Also evident are the effects of the limitations in the ability for larger numbers of jets to maintain high air velocities over the pen area and therefore achieve high heat transfers and jetting factors. The distributions for higher than optimal jet numbers maintain higher minimum jetting factors for 85% pen coverage, but the jetting factors aren't as high as for jetting configurations with lower jet numbers for lower pen area coverage requirements.

It is also apparent that in seeking an optimal number of jets, it is better to err on the side of too many jets, as the drop off in jetting factor from the optimal case is more gradual than if too few jets are installed.

4.1 Normalisation of the Jetting Factor

The HS heat stress risk estimate software currently uses a jetting factor of 1.0 for all decks on all vessels. While the constant factor doesn't allow for more favourable treatment of pens with good jetting characteristics or harsher treatment for pens with poor or no jetting, the current heat stress estimations produced by the model, taken overall, has been shown to agree well with available mortality data. For this reason, the range of jetting factors achievable for the range of vessels servicing the live export industry needs to be normalised about the current jetting factor. In this way, heat stress risk estimates will be affected by the jetting characteristics of the pen, but the average estimates, which agree well with current voyage data, will remain relatively consistent.

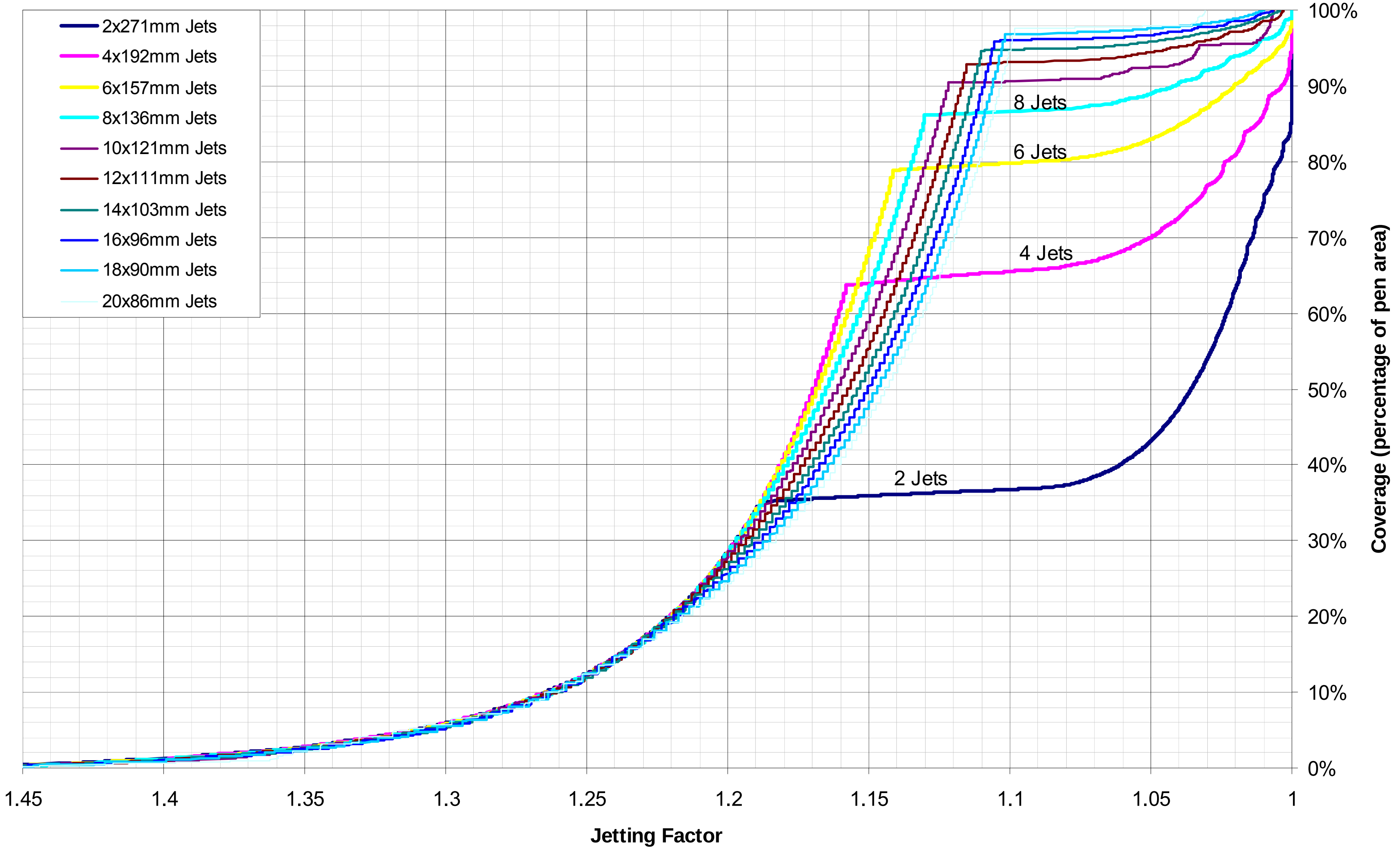


Figure 4-3 **Cumulative probability distributions relating jet configuration to jetting factor and pen coverage for a 5m wide, 5m long pen**

5 Heat Transfer Benefits and Commercial Impacts

Previous sections discussed the range of jetting factors achievable given the assumptions outlined in section 1.1. This section looks at the effects of heat transfer on the allowable stocking densities for representative livestock and voyages. This is done by varying the jetting factor in HotStuff. The HotStuff database and algorithm already incorporates a jetting factor, which can be varied on a deck by deck basis. Changing the jetting factor has the effect of scaling the heat loss for a given difference between the ambient temperature and the core temperature of the animal (i.e. as the jetting factor is increased the heat lost for a given temperature difference increases proportionally). The current jetting factor for all decks on all vessels used with HotStuff is set to 1.0.

In order to demonstrate the effects of varying the jetting factor, an example voyage to the Gulf in the northern summer has been used. Table 5.1 provides details for the voyage characteristics and livestock characteristics used for the voyage.

Table 5.1 Voyage and livestock characteristics used in examples

Voyage Parameters

Vessel Name	MV Example
Last Port of Departure	Fremantle
Departure Month	August
First Port of Arrival	Arabian Gulf
Arrival Date	19/08/2007

Livestock Characteristics

	Wether Description	Steer Description
Breed	Merino	25% Bos Indicus
Weight (kg)	40	250
Quantity	862	239
Fat Score	3	3
Coat Description	New shorn to 10mm	Only one coat type
Acc. Zone	3	3
Wet Bulb Temp	10.6	10.6

Figure 5-1 shows the number of livestock able to be carried within acceptable risk under varying jetting conditions. The risk of a 5% mortality event for the number of livestock shown is kept constant at 2%, where possible. The stocking density limitations from the ALES tables restrict the maximum number of livestock for the assigned pen area to 4310 wethers and 1310 steers for the given animal characteristics. In cases where the ALES limitations are more restrictive than restrictions imposed by heat stress limitations, the ALES stocking density and associated heat stress risk (≤ 2%) are shown. In cases where it is not possible to carry any livestock with a 2% risk of a 5% mortality event, the number of livestock is shown as zero and the risk of a 5% mortality event is shown (in this case only a comparative measure). Note that the extremes of the jetting factors shown are likely to be outside the range practically achievable.

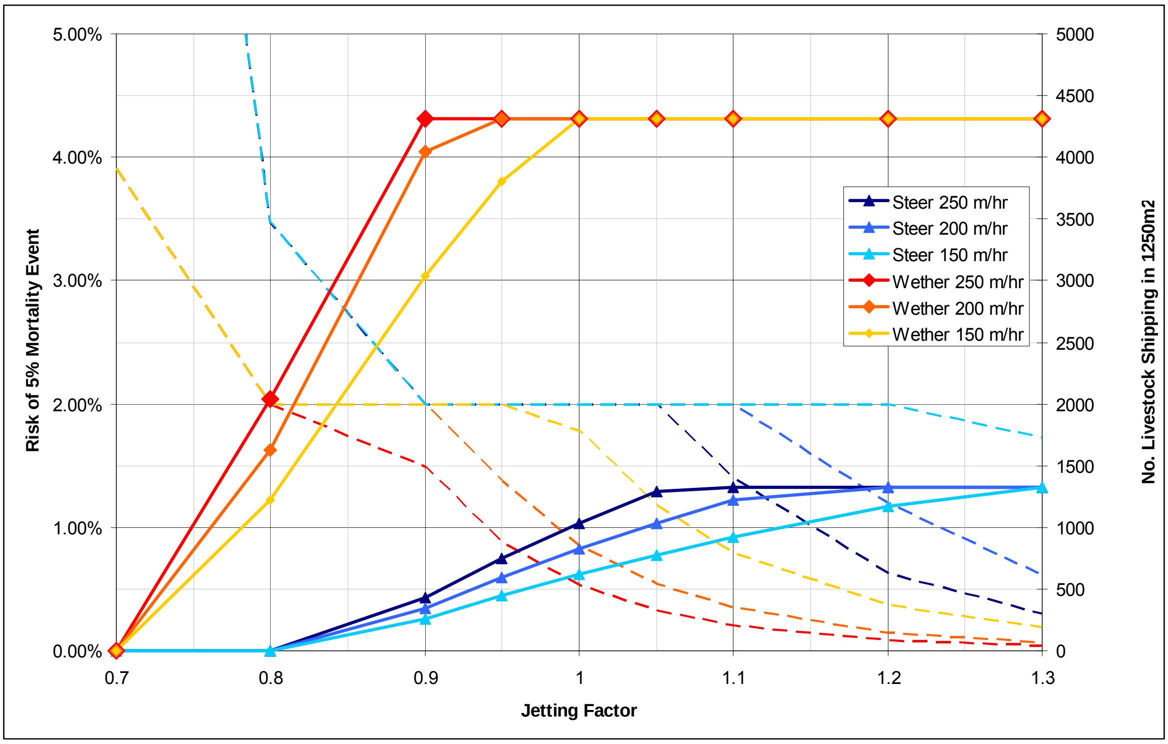


Figure 5-1 **Relationship between normalised jetting factor, risk and de-stocking rates. Solid lines are stock numbers with the dotted lines showing the risk in colours matched to the solid stock lines.**

Table 5.2 shows the risk of a 5% mortality event for a range of jetting factors on decks with different PATs for the August Gulf discharge detailed in Table 5.1. Note that the range of achievable jetting factors for a given pen or deck is related to the PAT.

Table 5.2 Relationship between PAT and jetting factor for the voyage outlined in Table 5.1

			5% Mortality Risk Table									Exp'd Mortality Table								
			Normalised Jetting Factor									Normalised Jetting Factor								
Deck	**Average Pen Air Turnover (m/hr)**	**Livestock Type**	0.7	0.8	0.9	0.95	1	1.05	1.1	1.2	1.3	0.7	0.8	0.9	0.95	1	1.05	1.1	1.2	1.3
1 Closed	300	Wether	12.99%	4.01%	1.11%	0.74%	0.38%	0.26%	0.16%	0.07%	0.03%	3.64%	1.06%	0.29%	0.19%	0.10%	0.07%	0.04%	0.02%	0.01%
2 Closed	250	Wether	15.54%	5.09%	1.49%	1.00%	0.53%	0.37%	0.24%	0.10%	0.05%	4.52%	1.38%	0.40%	0.27%	0.14%	0.10%	0.06%	0.03%	0.01%
3 Closed	200	Wether	19.96%	7.13%	2.26%	1.56%	0.85%	0.61%	0.40%	0.18%	0.08%	6.14%	2.03%	0.63%	0.43%	0.24%	0.17%	0.11%	0.05%	0.02%
4 Closed	150	Wether	28.81%	11.86%	4.29%	3.07%	1.78%	1.32%	0.89%	0.42%	0.21%	9.82%	3.68%	1.27%	0.91%	0.53%	0.39%	0.26%	0.13%	0.06%
5 Closed	100	Wether	50.37%	26.97%	12.51%	9.64%	6.27%	4.93%	3.57%	1.93%	1.10%	21.48%	10.14%	4.39%	3.34%	2.14%	1.68%	1.21%	0.66%	0.38%
6 Closed	90	Wether	57.88%	33.57%	16.84%	13.29%	8.96%	7.18%	5.33%	3.02%	1.78%	26.69%	13.53%	6.28%	4.88%	3.24%	2.58%	1.91%	1.08%	0.64%
7 Closed	70	Wether	77.03%	54.65%	33.74%	28.37%	21.13%	17.84%	14.17%	9.06%	5.93%	44.38%	27.10%	15.16%	12.47%	9.04%	7.55%	5.94%	3.75%	2.46%
8 Closed	50	Wether	95.67%	86.23%	71.04%	65.62%	56.83%	52.09%	46.07%	35.83%	27.87%	76.79%	61.05%	45.07%	40.47%	33.69%	30.32%	26.26%	19.83%	15.16%
1 Closed	300	Steer	39.71%	16.73%	5.81%	4.07%	2.26%	1.62%	1.05%	0.46%	0.21%	13.56%	4.99%	1.62%	1.12%	0.62%	0.44%	0.28%	0.12%	0.06%
2 Closed	250	Steer	42.16%	18.35%	6.58%	4.65%	2.62%	1.90%	1.23%	0.55%	0.26%	14.77%	5.59%	1.87%	1.30%	0.72%	0.52%	0.34%	0.15%	0.07%
3 Closed	200	Steer	50.58%	24.52%	9.75%	7.11%	4.20%	3.12%	2.10%	0.98%	0.49%	19.36%	8.04%	2.94%	2.11%	1.23%	0.91%	0.61%	0.28%	0.14%
4 Closed	150	Steer	64.37%	36.85%	17.31%	13.26%	8.47%	6.56%	4.65%	2.39%	1.28%	28.75%	13.81%	5.85%	4.39%	2.73%	2.10%	1.47%	0.75%	0.41%
5 Closed	100	Steer	85.90%	64.50%	40.74%	34.22%	25.26%	21.14%	16.54%	10.19%	6.38%	52.02%	32.24%	17.77%	14.47%	10.26%	8.44%	6.49%	3.91%	2.43%
6 Closed	90	Steer	90.52%	72.83%	50.07%	43.23%	33.34%	28.58%	23.07%	15.03%	9.89%	60.10%	40.10%	23.91%	19.95%	14.72%	12.37%	9.78%	6.19%	4.02%
7 Closed	70	Steer	97.65%	90.00%	75.04%	69.27%	59.62%	54.31%	47.51%	35.90%	26.96%	80.17%	63.78%	46.27%	41.14%	33.59%	29.84%	25.36%	18.37%	13.44%
8 Closed	50	Steer	99.93%	99.37%	97.05%	95.70%	92.74%	90.68%	87.51%	80.29%	72.55%	97.35%	92.69%	84.70%	81.55%	76.02%	72.78%	68.35%	59.84%	52.11%

6 Practical Recommendations for Industry

While the jetting analysis in previous sections provides some useful insights into the relationship between jetting configuration and the risk of heat stress, the results are not in a format than can be usefully applied to industry. A review of the jetting configurations for all of the existing fleet before the risk estimates are altered to use a jetting factor, before jetting factors (other than 1.0) are included in risk estimate calculations.

However, it is still possible to outline the most effective jetting configuration for a given PAT and pen configuration. This section provides some guidelines for industry best practice to achieve the best effect possible from jetting.

The factors used in the heat stress risk estimate calculations in HotStuff have been calibrated against historical events and have also been recently reviewed. In order to keep the estimates from HotStuff consistent, the jetting factor needs to be normalised such that there is no shift in the average risk estimates produced. Jetting factors need to be normalised about the industry average. This requires measurement of the jetting configurations across the fleet so that the industry average jetting factor can be estimated. While a jetting factor is coded into HotStuff and included in the database, and this report gives a formulation for jetting factor, the lack of normalisation prevents immediate use of the factors.

Without normalising jetting factors to ensure that risk estimates are consistent, it is still possible to calculate the most effective jetting configuration. Table 6.1 shows the spacing and outlet diameter to give the best jetting factor (over 85% of the pen area) for a given pen air turnover and pen configuration. It is important to note that the table is limited in its application to one type of pen and jet configuration. It is assumed that the jet supply is along one side of the pen, with the distance to the rear of the pen indicated at the top of the table. It is further assumed that livestock are able to move freely to any area of the pen to access the best 85% of the area for jetting. See section 1.1 for additional assumptions regarding pen configuration. The table does not apply to pens with no supply, although in cases where there are supply and exhaust pens, the distance at the top of the table is the total distance from supply to exhaust and the jetting factor has been assessed as if the animals had free run of the pens between the supply and exhaust. The jetting factors shown in the table are ‘raw’, and not normalised, but give an indication of the best possible improvement that jetting may have in the ability of livestock to lose heat.

Figure 6-1 extends the relationship between jetting factor, pen geometry, PAT and jet spacing to ranges where the jetting configuration is less effective. The figure can be used to estimate the jetting factor (not normalised) for any pen and jet configuration, provided that the jetting arrangement and pen geometry adhere to the assumptions provided in Section 1.1. For example; for a pen with 7.5m between air supply and exhaust and a jetting configuration providing a PAT of 200m/hr with equispaced jets on the supply side of the pen, a jetting factor (not normalised) of ~1.125 is achieved if the spacing between the jets is 750mm (ratio of 10). For this pen geometry and PAT, a jet spacing of greater than 900mm (ratio below 8) fails to achieve adequate pen coverage, while a jet spacing of less than 900mm (ratio greater than 8) (and correspondingly smaller jets) is less effective in sustaining higher air velocities across the pen.

HotStuff currently calculates risk estimates on a deck by deck basis. In some cases, existing vessel information is set up in such a way that different areas of the same deck are treated separately. Consideration for jetting in HotStuff is likely to require the extension of the separate treatment of different deck areas and the sub-division of deck spaces into areas with particular jetting properties.

A particular deck, for example, may be separated out into two or more different pen types for supply and exhaust pens. This approach will inevitably increase the number of deck entries and as a consequence, the number of different stocking entries. A significant increase in the number of stocking entries may result in the current process for adding stocking entries becoming unmanageable, particularly if jetting factors were to be assigned on a pen by pen basis. For this reason, the detail of the application of jetting factors in HotStuff requires further consideration on the best approach for an implementation that is easily used by industry. Enhancement of the graphical user interface to incorporate graphical representation of deck layouts and interactive stock assignment tools has been suggested in the past as a means of facilitating loading plans.

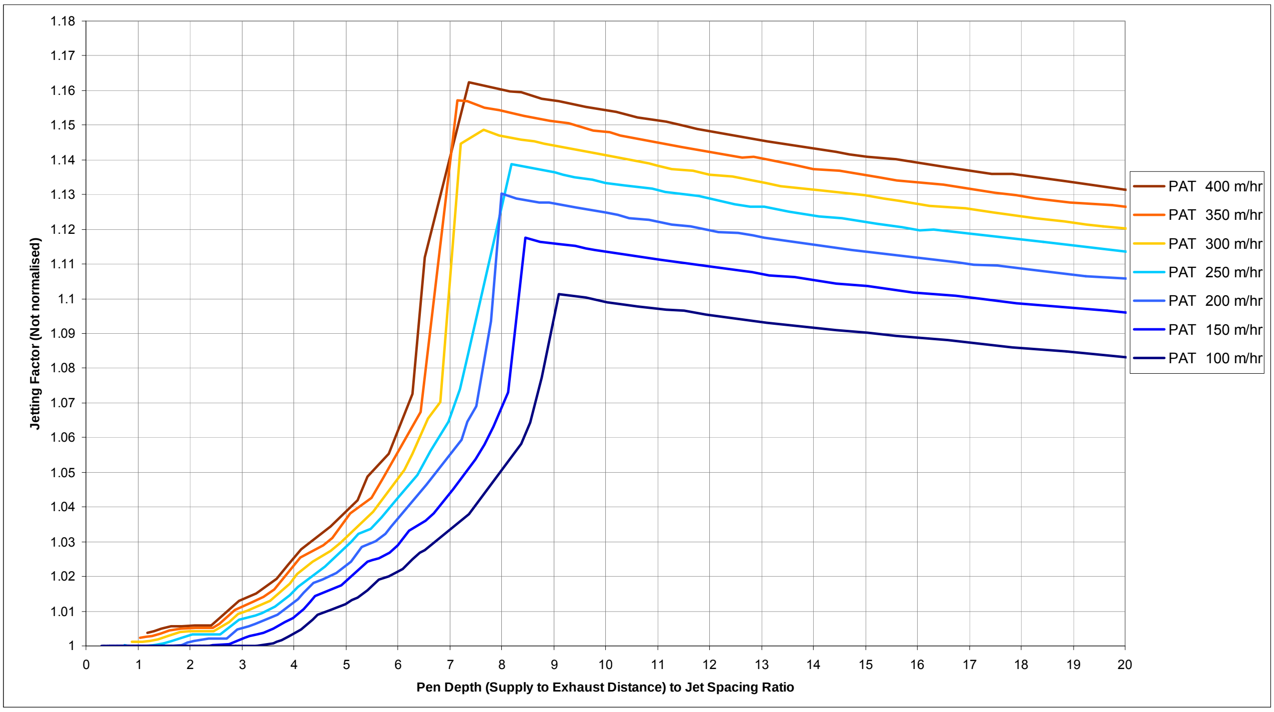
Table 6.1 Ideal jet size and spacing for a given PAT and pen configuration for 85% coverage

Pen Air Turnover (m/hr)	Supply to exhaust distance across the pen							
	5.0 m	7.5 m	10.0 m	12.5 m	15.0 m	17.5 m	20.0 m	
100	0.382 m	0.707 m	1.039 m	1.374 m	1.414 m	1.745 m	2.078 m	Jet Spacing
	75 mm	125 mm	175 mm	225 mm	250 mm	300 mm	350 mm	Outlet Diameter
	1.093	**1.098**	**1.100**	**1.101**	**1.098**	**1.099**	**1.100**	Jetting Factor
150	0.452 m	0.679 m	1.145 m	1.368 m	1.593 m	2.068 m	2.290 m	Jet Spacing
	100 mm	150 mm	225 mm	275 mm	325 mm	400 mm	450 mm	Outlet Diameter
	1.111	**1.111**	**1.116**	**1.116**	**1.115**	**1.118**	**1.116**	Jetting Factor
200	0.530 m	0.905 m	1.060 m	1.434 m	1.810 m	2.187 m	2.121 m	Jet Spacing
	125 mm	200 mm	250 mm	325 mm	400 mm	475 mm	500 mm	Outlet Diameter
	1.126	**1.129**	**1.126**	**1.128**	**1.129**	**1.130**	**1.126**	Jetting Factor
250	0.611 m	0.916 m	1.221 m	1.527 m	1.832 m	1.939 m	1.696 m	Jet Spacing
	150 mm	225 mm	300 mm	375 mm	450 mm	500 mm	500 mm	Outlet Diameter
	1.139	**1.139**	**1.139**	**1.139**	**1.139**	**1.136**	**1.129**	Jetting Factor
300	0.693 m	0.942 m	1.195 m	1.634 m	1.885 m	1.616 m	1.414 m	Jet Spacing
	175 mm	250 mm	325 mm	425 mm	500 mm	500 mm	500 mm	Outlet Diameter
	1.145	**1.147**	**1.146**	**1.149**	**1.147**	**1.139**	**1.131**	Jetting Factor
350	0.594 m	0.977 m	1.363 m	1.750 m	1.616 m	1.385 m	1.212 m	Jet Spacing
	175 mm	275 mm	375 mm	475 mm	500 mm	500 mm	500 mm	Outlet Diameter
	1.153	**1.156**	**1.157**	**1.157**	**1.150**	**1.141**	**1.133**	Jetting Factor
400	0.679 m	1.018 m	1.357 m	1.696 m	1.414 m	1.212 m	1.060 m	Jet Spacing
	200 mm	300 mm	400 mm	500 mm	500 mm	500 mm	500 mm	Outlet Diameter
	1.162	**1.162**	**1.162**	**1.162**	**1.152**	**1.142**	**1.134**	Jetting Factor

*note that for very high flows, the jet size is limited to 500mm jets for practical considerations

Red text shows jet spacing >1.5m. This highlights the effect of constraining the jet diameter.

Figure 6-1: Jetting factor (not normalised) given by a particular PAT, pen geometry and jet spacing



Past experience in attempting to assess how well a particular jet supports air movement over a pen suggests that measuring the effectiveness of jetting for a particular configuration is likely to be difficult. Particularly in regions with lower (approaching 0.5m/s) air velocities, air flow does not necessarily reach a steady state as slow moving, large-scale eddies in the flow are affected by moving livestock and opening and closing of hatches.

The primary aim of a good jetting configuration is to achieve a satisfactory air velocity over as much as possible of the pen. However, measurements of the air velocity fields in the pen are open to dispute. Specifications provided in Marine Orders Part 43 do not detail the proportion of time that the air velocity in a particular area of the pen must exceed 0.5m/s. Even relatively stagnant parts of a pen could receive occasional gusts at 0.5m/s if the measurement is taken for long enough. The conclusion is that measuring pen air velocities on a vessel for the purpose of assessment is too fraught with complications to be considered a practical approach. That is; it is considered infeasible to assess vessels by velocity measurement.

An alternative is to specify ventilation requirements at the jet outlets and provide guidelines for suitable jetting configurations. Measuring the velocity across jet outlets properly is still difficult and 96% pen coverage at 0.5m/s is not guaranteed. However, this approach is likely to be more practical to implement and regulate than measuring the velocities in the pen itself.

7 Conclusions

During the study described in this report, a method has been developed for relating jet configuration, pen/ deck geometry and pen air turnover to a jetting factor for the pen/ deck. A normalised jetting factor could be included in the heat stress risk estimate calculations, which means that HotStuff would then take jetting effects into consideration.

Measurement and categorisation of the jetting configuration needs to be completed for the existing live export fleet in order to provide sufficient information to allow normalisation of the jetting factor. The resulting estimates of heat stress would increase for some decks and ships but decrease for others, leaving the fleet average estimates consistent with existing estimates, which have been calibrated against historical shipping mortalities.

Without the measurement required to develop a normalised jetting factor, the method developed during the study is suitable for providing guidelines for the configuration of jets to provide the most effective outcome in reducing the risk of heat stress.