밀페된 슬롯 환기공간의 방해물이 공기유동에 미치는 영향
Modelling the effects of Obstructions in Slot-Ventilated Enclosures

최 홍 림* 루이스 디 알브라이트**
H. L. Choi, Louis D. Albright

적 요

축사나 환기시스템은 슬롯 환기시스템(slot-ventilation systems)으로 설치되어 있는 경우가 많으며, 이의 공기 流動을 2차원으로 해석할 수 있다. 직사각형 슬롯 환기 밀폐공간의 공기혼합 형태와 속도분포의 추정을 위해서 K-E 난류 전이모형을 기초로 한 TEACH-T 프로그램을 변형, 적용하였다. 이 모형을 이용하여 얻은 기류분포 형태는 실측한 기류분포 형태와 매우 잘 맞았으며 추정한 공기속도의 크기는 비교적 잘 맞는 편이었다. 그러므로 TEACH-T 프로그램을 변형해서 환기시스템 설계의 기초자료가 되는 여러 형태의 슬롯 밀폐공간의 공기분포와 공기속도의 크기를 추정하는데 TEACH-T 프로그램을 변형해서 적용시킬 수 있다.

I. Introduction

Air quality in confinement animal housing is important to production and health. Obstacles play in important role in determining air flow directions and velocities, and air mixing. Since a typical agricultural building will have obstacles of significant sizes, their effects on air velocity fields must be determined to predict the ventilation dilution effect via mixing.

Numerous studies have described modeling air flow within a ventilated space having no obstructions. Examples are: Nielson, et al.(1), Murakami, et al.(2) and Choi, et al.(3) each of whom applied the k-Epsilon (k-ϵ) method of attaining closure in the solution of the turbulence transport equations. As a contrast, Timmons, et al.(4) modeled distribution of vorticity within a ventilated space as a method to predict air flow directions and velocities. These researchers, and numerous others, have shown significant success in developing models able to predict air flow patterns, especially in spaces having no obstructions.

Choi, et al.(3) provided details of modifying the k-ϵ based TEACH-T computer model (Gosman and Ideriah(5)) in application to the prediction of air mixing within a rectangular, slot-ventilated enclosure. The governing equations were developed and predicted air velocities are compared to data available in research literature. Reasonably good agreement was found, which is encouragement to apply the technique to the problem of determining the effects of obstructions within a ventilated air space. For this study, a rectangular air space was chosen to approximate the shape of many agricultural buildings, and rectangular obstructions were assumed for computational ease in solving the

---

This paper was presented in the 1st International Symposium on "Building Systems: room air and air contaminant distribution" at the University of Illinois through 5-8 December, 1988.

* 경상대학교 농과대학 농공학과
** Department of Agricultural and Biological Engineering, Cornell University.

governing differential equations.

II. Mathematical Model

Standard equations for flow continuity and momentum transport were used. See Choi et al.(3) for a more complete development. Turbulent stress was modeled as (Rodi(6))

$$-<uv>=\nu_t[U,y+V,x]\cdots\cdots\cdots(1)$$

and turbulent viscosity was determined by local values of k and ϵ,

$$\nu_t = c_\mu k^2/\epsilon.\cdots\cdots\cdots\cdots\cdots\cdots(2)$$

The turbulent parameters, k and ϵ, were derived from their respective transport equations (Rodi(6)). At boundaries, conditions were imposed of no slip and no flux normal to the boundaries. A uniform velocity profile was imposed at the inlet in the direction of entry (U component), with zero velocity in the V direction. Similar conditions were imposed at the outlet. Standard values of coefficients were used in the euqations, c_μ=0.12 or O. 15 (depending on flow geometry); C_D=1; c_{e1} = 1.44; c_{e2} = 1.92; Φ_k = 1; and Φ_e = 1.3.

Near wall surfaces, the wall function method (Launder and Spalding(7)) was imposed. The numerical values, κ = 0.4, and E = 5.1, as recommended by Monin and Yaglom(8), were used.

In general, equations for U-momentum, V-momentum, turbulent kinetic energy of the fluctuating motion, and the kinematic rate of turbulent energy dissipation obey a generalized conservation principle. If the dependent variable of interest is denoted by ϕ, the generalized differential equation in vector form is

$$\mathrm{div}\,(\rho U\phi) = \mathrm{div}\,(\Gamma_\phi \mathrm{grad}\phi) + S_\phi \cdots(3)$$

The convective term is balanced with diffusive and source terms. Although the source term may be nonlinear, it may be linearized so the set of discretized equations can be solved by methods for linear algebraic equations. When the source term, S_ϕ, depends on ϕ, the dependence may be linearized by (Patankar(9), where S_C and S_P depend themselves on ϕ):

$$S_\phi = S_C + \phi S_P.\cdots\cdots\cdots\cdots\cdots(4)$$

Any desired value of ϕ may be prescribed to be the solution at an internal node point by setting S_C and S_P for that point as, for example, $S_C = 10^{30}\phi_P$, desired, and $S_P = -10^{30}$, numbers sufficiently large to make the other terms in the discretized form of the equation negligible. This procedure was used to represent internal obstacles in the calculation domain by, in effect, inserting "internal" boundary conditions.

The governing mean flow equations and turbulent equations with appropriate boundary conditions were formulated by a staggered grid and hybrid numerical scheme. Difference equations were solved by the SIMPLE procedure. Details of the method may be found in Patankar(9). The TEACH-T program is based on this solution procedure (Gosman and Ideriah(5)) and was modified to apply to steady, two-dimensional, turbulent recirculating air flow in a rectangular enclosure having a slotted ventilation inlet on one wall, and a slot outlet on the other.

III Comparison to Experimental Data

Data provided by Timmons(10) was used to explore the ability of the model and solution procedure to predict realistic air flows. The airspace had an aspect ratio (length to width) of 2, with inlet and outlet placed on the end walls. Inlet width to wall height was 0.1, and the inlet width was twice that of the outlet. The obstacle was on one long side ("floor"), centered in the space. Obstacle height was 30% that of the space height, and its width was 20% that of the space length. The geometry of the air space, except for the obstacle, was identical to one described by Choi et al.(3) in an initial application of the TEACH-T model to recirculating air flows in slot-ventilated enclosures. In Figure 1 is shown, (vector form) air velocities for two inlet arrangements, and the resulting pressure fields. In each case the outlet is located at the midpoint of the outlet wall. In Figure 1a, the inlet is also midway on the left wall, while in lb the inlet is centered at the three-quarters point. Jet attachment, recirculation areas, and expected relative velocities all agree with experience and data provided by Timmons(10).

This leads credence to using the TEACH-T program to model air flows in spaces having obstacles.

When the inlet is at the center of the left wall (Figure 1a) the jet deflects downward and attaches to the top of the obstacle. When the inlet is nearer the "ceiling", attachment is to the ceiling and the recirculation zone to the left of the obstacle shows little air movement. Both air flow patterns show good agreement with the data of Timmons(10). Calculated pressure fields clearly show the effects of the obstruction, and the strong Coanda effect in the upper left corner of Figure lb. Space limits in this report preclude a thorough development of this comparison, and others, and explanations of results. Such will be published in the future.

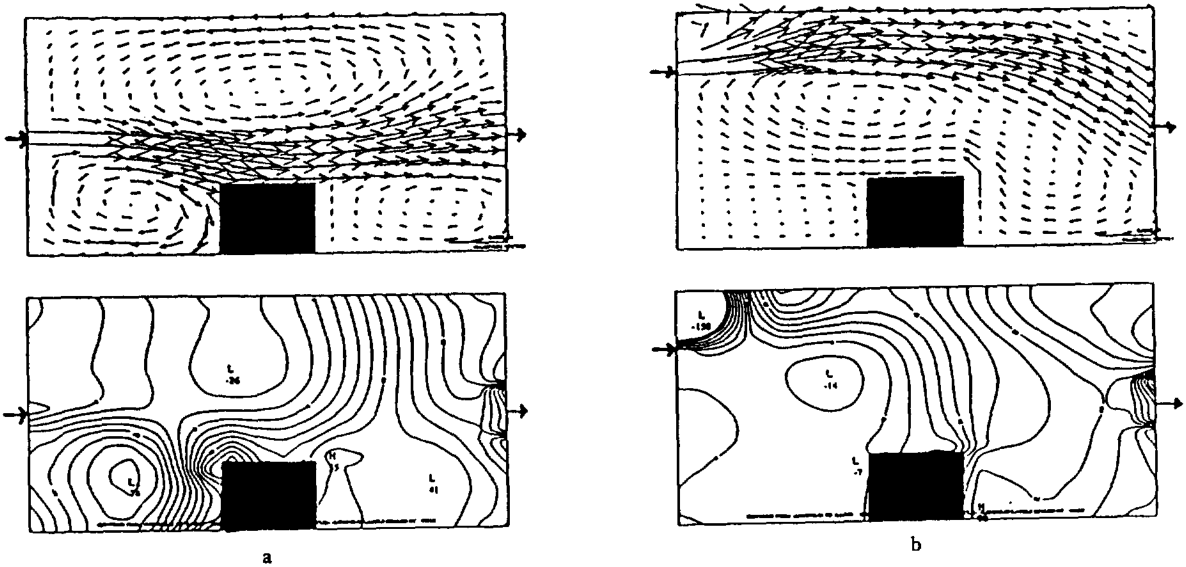
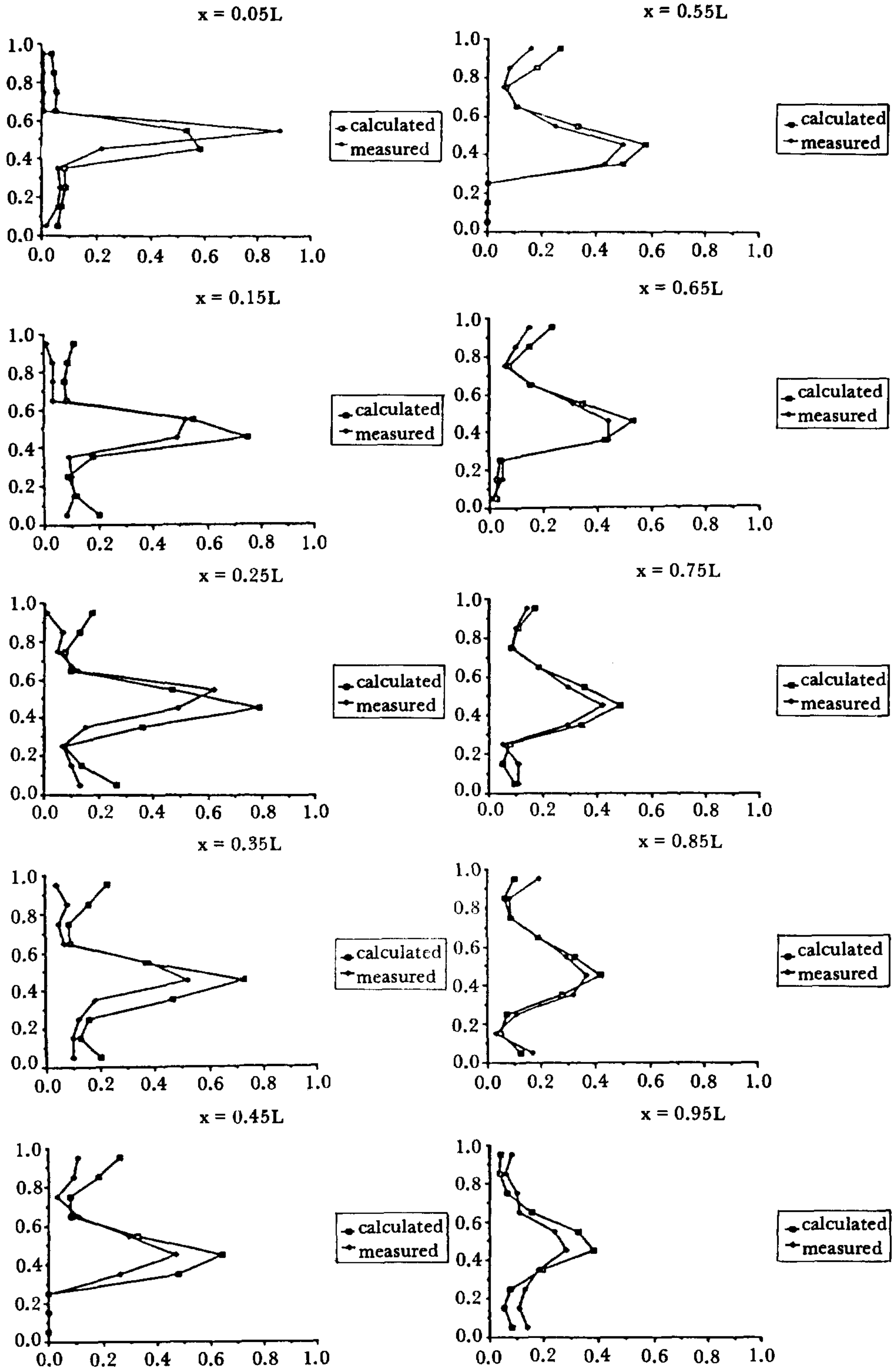


Figure 1. Air velocity vectors and the resulting pressure fields for two different inlet locations. On the left, the inlet is at the midpoint of the wall; on the right the inlet is at 0.75 of the wall height.



x = 0.05L

x = 0.55L

x = 0.15L

x = 0.65L

x = 0.25L

x = 0.75L

x = 0.35L

x = 0.85L

x = 0.45L

x = 0.95L

Figure 2. Predicted and measured normalized velocities for the geometry of Figure 1a. The dimension x is in the horizontal direction, measured from the left, and L is the total length of the space. Velocities are normalized to the inlet velocity.

Timmons(10) recorded air velocity data using the configurations of Figures 1a and 1b, at an inlet Reynolds number of 6400. A sample of predicted and measured velocities in the long dimension (measured from the inlet end) are shown in Figure 2, for the geometry of Figure 1a. Comparable differences and similarities were seen in comparisons for the geometry of Figure 1b.

Ⅳ. Conclusion

The TEACH-T program was modified and applied to a slot-ventilated air space having an internal obstruction. Qualitative and quantitative results were compared to available experimental data, and it was concluded that it is possible to predict overall flow patterns, velocity fields, and other flow features in an air space having an obstruction to air flow which represents typical ventilated animal housing structures.

Symbols

c_μ, c_{e1}, c_{e2}, C_D empirical constants
E : constant for logarithmic velocity profile
k : turbulent kinetic energy of motion, $(m/s)^2$
p : primitive pressure, Pa
S : source term
u : fluctuating U velocity component, m/s
U: steady horizontal velocity component, m/s
v : fluctuating V velocity component, m/s
V: steady vertical velocity component, m/s

E: turbulent diffusion coefficient
ϵ : kinematic rate of dissipation of turbulent energy, m^2/s^3
κ : constant for logarithmic velocity profile
ν_t : turbulent viscosity, m^2/s
ϕ : empirical constant

References

1. Nielson, P.V., A. Restivo and J.H. Whitelaw. 1978. The velocity characteristics of ventilated rooms. Trans. of the ASME J. Fluids Engr. 100:291-298.
2. Murakami, D.E., D.E. Kato and Y. Suyama. 1987. Three-dimensional numerical simulation of urbulent air flow in a ventilated room by means of a two-equation model. Trans. ASHRAE. 93(2).
3. Choi, H.L., L.D. Albright, M.B. Timmons and Z. Warhaft. 1989. Air velocity distribution in a slot-ventilated enclosure. Trans. ASAE 31(6): 1804-1814.
4. Timmons, M.B., L.D. Albright, R.B. Furry and K.E. Torrance. 1980. Experimental and numerical study of air movement in slot-ventilated enclosures. Trans. ASHRAE 86(1):221-239.
5. Gosman, A.D. and F.J.K. Ideriah. 1976. TEACH-T; A general computer program. Dept. Mech. Engr., Imperial College, London.
6. Rodi, W. 1980. Turbulence Models and Their Application in Hydraulics. Int. Assoc. for Hydraulic Research.
7. Monin, A.S. and A.M. Uaglom. 1971. Statistical Fluid Mechanics. The MIT Press, Cambridge MA.
8. Launder, B.E. and D. Spalding. 1974. The numerical computation of turbulent flow. Comp. Methods in Appl. Mech. and Engr. 3:269-289.
9. Patankar, S.V. 1980. Numerical Heat Transfer and Fluid Mechanics. McGraw-Hill, New York.
10. Timmons, M.B. 1988. Personal communication.