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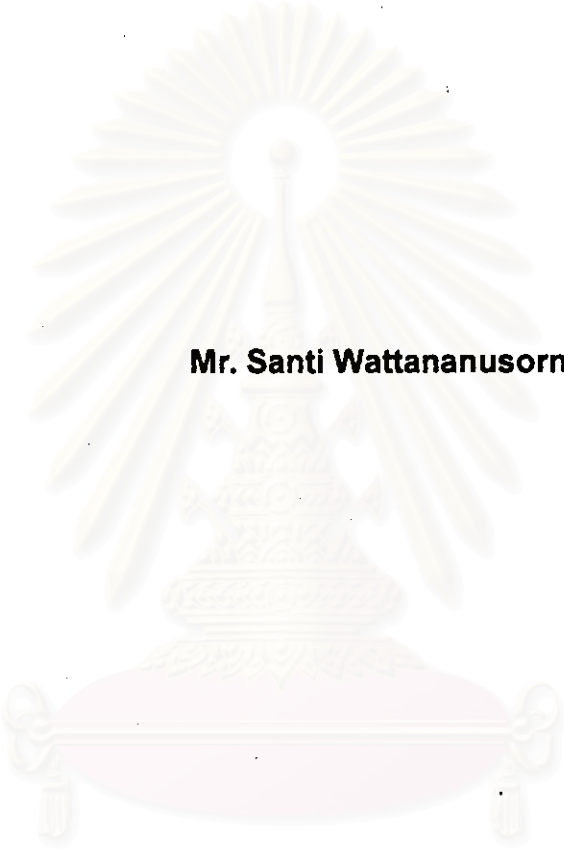
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**SIMULATION OF AIR FLOW PAST THE PARALLEL  
INCLINED FLAT PLATES IN A SQUARE DUCT**



**Mr. Santi Wattananusorn**

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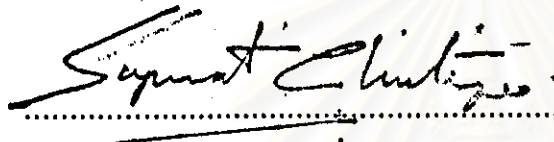
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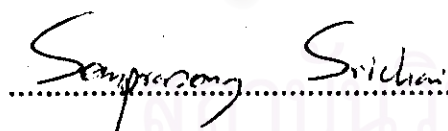
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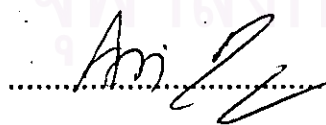
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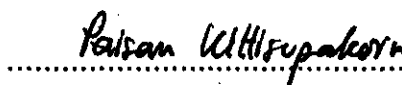
  
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ปรากฏการณ์การไหลของอากาศผ่านแผ่นแบนเรียบที่เอียงขนานกันในท่อรูปสี่เหลี่ยมจัตุรัสถูกศึกษาผ่านวิธีแก้ไขเชิงตัวเลขโดยใช้เทคนิคการคำนวณพลศาสตร์ของไหล (CFD) โปรแกรมคอมพิวเตอร์ที่ชื่อ ฟีนิกซ์ (PHOENICS) ถูกนำมาใช้เพื่อหาคำตอบสำหรับการไหลแบบปั่นป่วนที่สถานะคงตัวในสามมิติ ภายใต้หลักการของไฟไนต์โวลุ่ม สมการควบคุมคือ สมการนาเวียร์-สโตกส์ในรูปค่าเฉลี่ยของอิทธิพลทั้งหมดที่ไม่สามารถยึดตัวได้ ความเค้นเรย์โนลด์ถูกกำหนดด้วยแบบจำลองความปั่นป่วนเค-อีพิลลอน โดยใช้สมมติฐานความหนืดที่หมุนวนของบูสซิเนสค

เพื่อตรวจสอบความถูกต้องเชิงตัวเลขและสภาพที่ใช้ได้ของแบบจำลองความปั่นป่วน ในขั้นแรกผลของการคำนวณถูกนำไปเปรียบเทียบข้อมูลของความเร็วซึ่งได้มาจากการทดลอง การเปรียบเทียบระหว่างผลที่ได้มาจากการวัดและผลที่ได้มาจากการคำนวณ โดยทั่วไปเป็นที่น่าพอใจถึงแม้จะพบความไม่ตรงกันบ้างในบางแห่ง ในตอนท้ายผลกระทบของจำนวนแผ่นแบนเรียบ ความเอียงของแผ่นแบนเรียบ และการไหลในท่อด้วยค่าตัวเลขเรย์โนลด์สูง ที่มีต่อระยะทางซึ่งใช้ในการปรับตัวเข้าสู่ภาวะการไหลคงรูป ตลอดจนการลดลงของความดันรวม ถูกตรวจสอบ

การทำนายแสดงให้เห็นว่าระยะทางสำหรับการพัฒนาเข้าสู่ภาวะการไหลคงรูปจะยืดออกไป เมื่อลดจำนวนของแผ่นแบนเรียบลง อย่างไรก็ตามระยะทางนี้จะถูกทำให้สั้นลง เมื่อความเอียงของแผ่นแบนเรียบลดลง ในกรณีของตัวเลขเรย์โนลด์ที่อยู่ในช่วงของการศึกษานั้น ผลลัพธ์เชิงตัวเลขทำนายว่าการไหลของอากาศที่ตัวเลขเรย์โนลด์มีค่าสูงกว่า จะต้องการระยะทางสำหรับการพัฒนาเข้าสู่ภาวะการไหลคงรูปยาวกว่ากรณีของตัวเลขเรย์โนลด์ที่มีค่าต่ำกว่า นอกจากนี้ยังพบว่า แคมเปอร์ชนิดแผ่นเดี่ยวจะทำให้เกิดการลดลงของความดันรวมสูงกว่าแคมเปอร์ชนิดหลายแผ่นอย่างมีนัยสำคัญ

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KEY WORD: SIMULATION / COMPUTATIONAL FLUID DYNAMICS / AIR FLOW / FLAT PLATES  
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The phenomena of air flow past the parallel inclined flat plates in a square duct is studied through the numerical solution by using computational fluid dynamics ( CFD ) technique. A computer program called PHOENICS , is adopted to solve for three-dimensional steady turbulent flow under the finite volume method. The governing equations are incompressible ensemble-averaged Navier-Stokes equations. The Reynolds stresses are modeled by the  $k - \epsilon$  turbulence model with Boussinesq's eddy viscosity assumption.

To verify the numerical accuracy and validity of the turbulence model , the results are first compared with experimental velocity data. Comparisons between measured and calculated results are in general satisfactory , although some discrepancies are found. Finally , the effects of the number of flat plates , the inclination of flat plates and high Reynolds number in the duct flow , to the distance for fully developed flow , as well as total pressure drop , are investigated.

The predictions show that the development length extends when the number of flat plates decreases , however , such length is shortened when the inclination of flat plates becomes smaller. In case of Reynolds number within the range of study , the numerical results predict that the air flow at higher Reynolds number requires the development length to be longer than the lower Reynolds number condition. Furthermore , it is found that the single blade damper causes total pressure drop to be significantly higher than the multi-blade damper.

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## LIST OF SYMBOLS

### ALPHABETICAL SYMBOLS

|            |   |
|------------|---|
| A          | section area of body at right angles to motion direction          |
| a          | longitudinal spacing between two consecutive vortices in same row |
| B          | test-section width  |
| b          | plate breadth   |
| $C_D$      | drag coefficient  |
| $C_L$      | lift coefficient  |
| $C_P$      | pressure coefficient  |
| $C_{Ps}$   | separation pressure coefficient                                   |
| $C_\mu$    | empirical constant  |
| $C_1, C_2$ | coefficients in approximated turbulent transport equation         |
| D          | drag force  |
| D          | duct diameter   |
| D          | diffusion conductance   |
| $D_h$      | hydraulic diameter  |
| $D_i$      | constants in tridiagonal system                                   |
| E          | roughness parameter   |
| F          | strength of convection  |

## LIST OF SYMBOLS ( continued )

|                 |  |
|-----------------|--|
| $f_x, f_y, f_z$ | body forces per unit mass in x , y , z directions        |
| G               | rate of production of turbulence from mean motion        |
| I               | turbulent intensity                                      |
| J               | integrated total fluxes over control-volume faces        |
| $J_x, J_y, J_z$ | convection plus diffusion fluxes in x , y , z directions |
| k               | kinetic energy of turbulence                             |
| L               | mixing length  |
| L               | lift force   |
| $L_s$           | development length                                       |
| $L_i, M_i, U_i$ | finite coefficients on lower- , main- , upper-diagonal   |
| P               | local static pressure                                    |
| $P_0$           | free-stream static pressure                              |
| $P'$            | fluctuating component of pressure                        |
| $P'$            | pressure correction                                      |
| $P^*$           | guessed pressure   |
| $\bar{P}$       | mean value of pressure                                   |
| $\bar{P}'$      | mean value of pressure fluctuation                       |
| R               | resistance coefficient                                   |
| Re              | Reynolds number in duct flow ( = $\rho V D_h / \mu$ )    |



## LIST OF SYMBOLS ( continued )

|   |   |
|---|---|
| $S$   | source term   |
| $S_c$   | constant part of average value of $S$   |
| $S_p$   | coefficient of $\phi_p$   |
| $T$   | time interval   |
| $t$   | time  |
| $U$   | mean velocity upstream of body  |
| $U_j$   | mean velocity at vena contracta   |
| $U_s$   | velocity at separation  |
| $u, v, w$                                     | velocity components in $x, y, z$ directions   |
| $u', v', w'$                                  | fluctuating components of velocity in $x, y, z$ directions                                    |
| $u'', v'', w''$                               | velocity correction components in $x, y, z$ directions  |
| $u^*, v^*, w^*$                               | guessed velocity components in $x, y, z$ directions   |
| $\bar{u}, \bar{v}, \bar{w}$                   | mean velocity components in $x, y, z$ directions  |
| $\bar{u}_j$                                   | mean velocity component in $x_j$ direction  |
| $\bar{u}_{j,nw}$                              | absolute value of resultant velocity parallel to a wall at first grid node in $x_j$ direction |
| $\overline{u'}, \overline{v'}, \overline{w'}$ | mean value of fluctuating velocity components in $x, y, z$ directions                         |
| $V$   | fluid mean velocity   |

## LIST OF SYMBOLS ( continued )

|                    |   |
|--------------------|---|
| $\mathbf{V}$       | vector velocity field in cartesian space                              |
| $V_i, \tilde{V}_i$ | mean longitudinal velocity at same position of adjacent cross-section |
| $V_0$              | undisturbed air velocity relative to plate                            |
| $V_3$              | downstream velocity of individual vortices                            |
| $\bar{\mathbf{V}}$ | vector mean velocity field in cartesian space                         |
| $x, y, z$          | rectangular coordinates   |
| $x_j$              | coordinate direction  |
| $y_{mw}^+$         | normalized-coordinate near a wall                                     |

## GREEK SYMBOLS

|                                |  |
|--------------------------------|--|
| $\alpha$                       | angle of attack  |
| $\beta$                        | momentum coefficient                                   |
| $\Gamma$                       | diffusion coefficient of $\phi$                        |
| $\Delta$                       | designates a difference when used as a prefix          |
| $\delta x, \delta y, \delta z$ | spaces of adjacent grid points in $x, y, z$ directions |
| $\varepsilon$                  | dissipation of turbulent kinetic energy                |
| $\kappa$                       | Von Karmann constant                                   |
| $\lambda$                      | second viscosity coefficient                           |
| $\mu$                          | molecular viscosity coefficient                        |
| $\mu_t$                        | turbulent viscosity coefficient                        |

## LIST OF SYMBOLS ( continued )

|                                   |   |
|-----------------------------------|---|
| $\mu_{\text{eff}}$                | effective viscosity coefficient   |
| $\rho$                            | fluid density   |
| $\sigma_k, \sigma_\varepsilon$    | effective turbulent Prandtl numbers for transport of<br>k and $\varepsilon$ |
| $\tau_{xx}, \tau_{yy}, \tau_{zz}$ | normal stresses on y-z , x-z , x-y planes                                   |
| $\tau_{xy}, \tau_{xz}, \tau_{yz}$ | shear stresses on x-z , y-z , x-y planes                                    |
| $\bar{\tau}_{xx}^{(t)}$           | turbulent normal stress   |
| $\bar{\tau}_{xy}^{(t)}$           | turbulent shear stress  |
| $\tau_{w,j}$                      | shear stress at a wall in $x_j$ direction                                   |
| $\phi$                            | general dependent variable  |

### SUBSCRIPTS

|                     |   |
|---------------------|---|
| in                  | inlet value                                   |
| nw                  | near wall value                               |
| nb                  | neighbor grid points or control-volume faces  |
| P, E, W, N, S, L, H | grid points of a control volume and neighbors |
| e, w, n, s, l, h    | control-volume faces                          |

### SUPERSCRIPTS

|   |                                     |
|---|-------------------------------------|
| o | old value at beginning of time step |
|---|-------------------------------------|