IMAGE-BASED METHOD FOR THE AERODYNAMIC CHARACTERISTICS OF A MOTOR CYCLE

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Abstract. In this paper, a simple image-based method for the analysis of aerodynamic characteristics is discussed. In the practical CFD, most of the efforts are wasted for grid generations. Body-fitted grid was often used for the flow calculation around the vehicle until today. When computing flow around the object, CAD data of the object is necessary. In this research, digital photo is used as a substitute for CAD data. In order to insert this image into Cartesian grid, the object is clipped from the base image by image processing. The resolution is reduced to fit the grid size. For the model of three dimensions, the object images are obtained from multi directions and the object is clipped as the same as two dimensions. In this image-based method, flow around a motor cycle with a person and aerodynamic characteristics of the motor cycle were successfully obtained.

1 INTRODUCTION

In general, the discussion about the numerical methods of how to solve the Navier-Stokes equations and their approximation formula are centered in CFD field. In the practical applications most of the efforts are wasted for the grid generations. In these days, two types of typical grid systems are body-fitted grid and Cartesian grid. Body-fitted grid was often used for the flow calculation around the vehicle and the airplane and so on until today. When simulation around the airplane, time to execute the calculation of Navier-Stokes equations is several to tens of hours, while the grid generation requires longer time, for instance, weeks to months, even by an expert. In this manner, grid generation around the complex object involves an immense amount of time and effort. Now, Cartesian grid is in focus. This approach is one solution to save time for grid generation. In the recent years, accuracy of
Cartesian grid approach has been raised by increasing the number of grid points with the progress of computers.

When computing flow around an object, CAD data of the object is necessary. However, CAD data has not always had to be prepared. In the present approach, flow computation is done based on a digital image of a motor cycle with a person, instead of the CAD data which is generally required to represent the object shape. When analyzing aerodynamic characteristics of the motor cycle, human body data are necessary as well as that of the motor cycle. Unlike the motor cycle, human CAD data is not easily obtained. Besides the human takes different postures and they definitely affect to aerodynamic characteristics. In the present paper, we propose a new approach to incorporate the human body and the motor cycle shapes into Cartesian grid without any CAD data, but with digital images.

2 EXPRESSION OF OBJECT SHAPE

Usually CAD data of a vehicle is necessary to analyze the flow around the vehicle to generate grid. On the contrary we propose the solution method of flow around a vehicle without the CAD data. Instead of CAD data, a digital photo image is used here. As an example of two-dimensions, an image of a real motor cycle is prepared as shown in Fig. 1.

![Figure 1: Shape model of motor cycle](C) Honda Motor Co.,Ltd., http://www.honda.co.jp/motor/.

In order to insert this image into Cartesian grid, the image is manually binarized and the resolution is reduced to fit the grid size as Fig. 2.
How to make a three-dimension model is explained as follows. The photograph taken from three directions is prepared. As the same as two-dimensions, these digital photos are manually binarized. Resolutions of these images are lowered to fit the grid size. Then the three images should fit to the three sides of the Cartesian grid. Viewing from one side, the three-dimensional object is indicated by black pixels, or in other words, the object does not exist in the area indicated by white pixels. The same processes can be done from the other two sides. Finally the logical product of areas indicated by black pixels composes the three-dimensional model. Figure 3 shows a simplified example of the idea above.

3 NUMERICAL METHOD

3.1 Governing equations

Here we solve incompressible Navier-Stokes equations (1) and the equation of continuity with pseudo-compressibility term as Eq. (2).
\[
\frac{\partial u}{\partial t} + (u \cdot \nabla) u = -\nabla p + \frac{1}{\text{Re}} \nabla^2 u
\]

(1)

\[
\frac{1}{\delta} \frac{\partial p}{\partial t} + \nabla \cdot u = 0
\]

(2)

Where \( \delta \) is called pseudo-compressibility coefficient, and it is related to density \( \rho \) and pseudo-speed of sound \( c \) by the pseudo-compressible state equation of

\[
p = c^2 \rho = \delta \rho
\]

(3)

In this case, only at the steady state, or only when \( \frac{\partial p}{\partial t} = 0 \) is achieved, Equation (2) satisfies the equation of continuity. Then, equations (1) and (2) are rewritten to Eqs. (4) and (5) for the time accuracy, using the pseudo-time \( \tau \) as

\[
\frac{\partial u}{\partial \tau} + \left[ \frac{\partial u}{\partial t} + (u \cdot \nabla) u + \nabla p - \frac{1}{\text{Re}} \nabla^2 u \right] = 0
\]

(4)

\[
\frac{\partial p}{\partial \tau} + \delta (\nabla \cdot u) = 0
\]

(5)

When the solution converges with \( \tau \to \infty \), the equation of continuity is satisfied in every time step.

### 3.2 Discretization

About scheme, higher-order upwind difference is used for the convection terms and second-order central difference is used for the viscous terms. The temporal difference is Crank-Nicholson of second-order. And internal repeat is Lower Upper-Symmetric Gauss Seidel (LU-SGS) employed for the convergence calculation of \( \tau \).²

### 3.3 Object boundary

Flow around a motor cycle is computed with the image of a digital photograph. As an object shape is based on a binarized image, a body surface would be expressed like stairs as shown in Fig.4. In this research, simple boundary condition is posed. As shown in Fig.4, the velocity in a body cell which is adjacent to the body surface is given with the velocity of the neighboring cell as \( u_1 = -u_0 \) and \( v_1 = -v_0 \) to satisfy the condition of \( u = v = 0 \) at the body surface. Similarly pressure value is copied from the neighboring cell to satisfy the condition that the normal pressure gradient is zero.
4 RESULTS

4.1 Computed result of two-dimensions

First of all, the photograph of the target object for the calculation is taken. Three kinds of postures are examined here to compare the difference of aerodynamic characteristics when the motor cycle is running. These postures are normal position, standing position which is susceptible to wind drag, and forward-bent position that less receives air drag. Initial condition is uniform flow. At the in-flow boundary, velocity is fixed and the pressure is extrapolated from the interior points. At the out-flow boundary, the pressure is fixed, while the velocity is extrapolated. The grid points are 500×300. The Reynolds number (Re) is set 1,000,000.

First example is a normal position of a motor cycle. The original picture is shown in Fig. 5. The flow field is plotted in Fig. 6. The number of pixels of original photographs was too large, and the resolution was reduced to fit the memory of computer. The height of the motor cycle with a person is represented with 50 grid cells. The vector length represents the velocity magnitude. The vector color represents the pressure. Secondly, forward-bent position is calculated with the picture of Fig. 7. The flow field is plotted in Fig. 8; the height of the object is represented with 45 grid cells. Thirdly, we conduct the computation of a standing position. The original picture is shown in Fig. 9. The flow field is plotted in Fig. 10; the height of the object is represented with 60 grid cells. The drag coefficients of three types of position are compared. Figure 11 shows the relation between time steps and drag coefficients. Figure 12 shows the relation between time steps and lift coefficients. The difference of posture is made clear though Karman-like vortex is remarkably observed because there is no ground surface. Mean values and the ranges of each coefficient indicated in Table 1.
Figure 5: Prepared image (Normal style) Figure 6: Flow around a motor cycle (Normal style)

Figure 7: Prepared image (Forward-bent style) Figure 8: Flow around a motor cycle (Forward-bent style)

Figure 9: Prepared image (Standing style) Figure 10: Flow around a motor cycle (Standing style)
Table 1: Aerodynamic coefficients

<table>
<thead>
<tr>
<th>Style</th>
<th>Drag Coefficient</th>
<th>Lift Coefficient</th>
</tr>
</thead>
<tbody>
<tr>
<td>Normal style</td>
<td>1.376±0.013</td>
<td>-1.118±0.13</td>
</tr>
<tr>
<td>Forward-bent style</td>
<td>1.532±0.011</td>
<td>-0.997±0.16</td>
</tr>
<tr>
<td>Standing style</td>
<td>1.814±0.065</td>
<td>-1.096±0.37</td>
</tr>
</tbody>
</table>

4.2 Computed result of three-dimensions

Only normal riding style is presented here. Figure 13 is a photograph taken from side. In a similar way, Figure 14 is taken from front, and Figure 15 is taken from above. Preparation to the calculation is done by the method of Fig.3. Complete model is shown in Fig.16. The shape of the motor cycle is well-represented though the resolution is low. The grid points are 160×70×130. The Reynolds number (Re) is set 1,000,000. Figure 17 shows computed result of three-dimensions. The vector length represents the velocity magnitude. The vector color represents the pressure. The height of motor cycle with a person in the area is the same as two-dimension computed with 50 grid points. Although the resolutions of the object are the
same, three-dimensional model looks rougher (or more a stair-like shape). It might be an optical illusion, or be a true three-dimensional effect. In any case, three-dimensional effect makes two flow fields completely different. Six component forces around a motor cycle are shown in Table 2. Six component forces are drag coefficient, lateral force coefficient, lift coefficient, rolling moment coefficient, yawing moment coefficient, pitching moment coefficient. The center of gravity to calculate the moment is set near the center of the object.
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Table 2: Six component force around a motor cycle

<table>
<thead>
<tr>
<th>$C_D$</th>
<th>$C_Y$</th>
<th>$C_L$</th>
<th>$C_{RM}$</th>
<th>$C_{YM}$</th>
<th>$C_{PM}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.286</td>
<td>-0.133</td>
<td>-2.904</td>
<td>-0.056</td>
<td>-3.016</td>
<td>0.112</td>
</tr>
</tbody>
</table>

5 DISCUSSION

In this paper, the image-based method for aerodynamic analysis was demonstrated. Most of the preparation time is image processing and half a day is enough to set up the computation. There are many issues related to accuracy of the image-based computations left for the future research. About accuracy of three-dimensional model obtained from pictures, four error sources are possibly considered. The first is a distortion of the lens. Second is the setup of three cameras. Their directions should be crossed in the right-angle but not in practice. Thirdly the process to lower the resolution may introduce another error. Finally the present idea can only be applied for convex shapes. We may have virtual object around a concave space. These errors should be evaluated for practical applications.

The accuracy of Cartesian grid approach is beyond the present scope. However, the number of grid points used in the present research should not be sufficient. More number of grid points around the object is necessary and multi-resolution method would be introduced for quantitative analyses.

6 CONCLUSIONS

- Flow around a motor cycle was successfully simulated with the digital photo image, instead of object CAD data. This approach is applicable to any kind of object and will be useful for the design without CAD data.
- It is concluded that the present method can be used for the evaluation of a running motor cycle with a person and, moreover, be applied to various flow problems.
- Accuracy evaluations of both image-based modelling and the Cartesian grid approach are the future works.

REFERENCES