

Establishment of an Aero-Dynamic Simulation System for Motorcycles and Its Application

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ABSTRACT

A numerical simulation system for motorcycles was constructed aiming at predicting aerodynamic-characteristics of the bodies at the early stage of development. In order to shorten the time for constructing a complete model of a motorcycle, which have fairly complicated shapes, and to generate meshes on the model as quickly as possible, an orthogonal mesh with porosity for each cell was adopted. An evaluation of this system regarding accuracy and time needed for analysis was carried out by applying the system to some motorcycles actually under development. As a result, we found that a sufficient level of accuracy was obtained in predicting aero resistance forces and wind protection performances.

1. Introduction

Amidst increasing demands for shorter development periods, various computer simulations (CAE) have been introduced to development in recent years as a means of meeting these needs. Fluid analysis has conventionally required significant time for the creation of calculation models, and the enormous calculation time has lowered its practicality compared to the field of structural analysis. In the automotive field, aerodynamic simulations came to be frequently used for automobiles from around 1990⁽¹⁾. This is thought to be because the spread of super-computers first made these types of calculations possible. However, the calculations at that time took up to 150 hours of computation time using these expensive super-computers⁽¹⁾,

and appear to have been done more for the purpose of demonstrating that such aerodynamic calculations were possible. Since that time computer performance and software have improved, and aerodynamic calculations have become fairly well established in the automotive field.

On the other hand, there are extremely few reports thus far of these calculations in the field of motorcycles, and although there are some cases of calculations for part units such as the flow around the wheels⁽²⁾, there are as yet no reports of overall calculations for the completed vehicle.

The reasons for this are as follows.

- (1) Motorcycles generally have a more complicated body shape compared to automobiles, and the human body must also be modeled, which makes it quite difficult to create 3D CAD data.

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- (2) A mesh of some type must be generated to perform fluid calculations, but it is technically difficult to generate a mesh that allows calculations for a complicated body shape such as a motorcycle.
- (3) Motorcycles have a short development period compared to automobiles, so it is difficult to create a model and conduct simulations within the development period.

Therefore, in light of its position as a development tool, establishment of a simulation system for motorcycles requires a different perspective from that of automobiles.

2. Development Aim

Motorcycle design items related to air flow span a wide range, including for example even the hot exhaust wind produced by the engine and wind noise. However, this study narrowed the focus to the following two items.

- Reducing aero resistance force
- Optimizing the way the wind strikes the rider (wind protection performance)

Conventionally, these items were evaluated by manufacturing a test vehicle and then conducting wind tunnel tests. This study aimed to create aerodynamic simulation tools capable of evaluating the above two items in the initial development stage prior to completion of a test vehicle. Simulation prediction accuracy for the evaluations items is of course important, but emphasis was also placed on allowing simulations that do not take too much time.

3. Technical Investigations

3.1 Two Issues for Decreasing the Process Time

In order to shorten the simulation modeling process as much as possible, the first point to be considered is that the data must flow smoothly between each system on which 3D shapes are created or modified. To achieve this, the following points should be taken into account.

- The 3D data created by the Design Department should be usable as upstream data.
- The data should be linked with CATIA.
- Mesh generation should not take much time.

In order to create 3D shapes of completed motorcycles and allow simulations amidst this data flow, the following two issues must be considered.

- Motorcycle models are comprised of 20 to 40 components, and interference between components must be eliminated to achieve a single volume.
- A mesh for calculation must be created for complicated shapes.

These issues were handled by the methods described below to reduce the process time.

3.2 Issues for Achieving a Single Volume

Normally, large amounts of upstream data are created for each component as surface data. In order to perform simulations, the intersecting parts of these surfaces must be completely eliminated to achieve a single volume. Normally the unnecessary parts of surfaces must be removed manually on a CATIA or CAD system, or the shape must be converted to a solid and Boolean operations performed.

Therefore, the method actually used achieved a single volume in the later stage when the mesh for the calculation area was created without any merging of intersecting portions by CATIA. This is made possible by using the mesh for calculation area types described below. This reduced the overall modeling process time.

3.3 Selection of a Mesh for Calculation

Meshes used for fluid calculations are classified into the following three types.

- (1) Body Fitted Coordinates (BFC) (curvilinear mesh that follows the shape)^{(2), (3)}
- (2) Unstructured mesh⁽⁴⁾
- (3) Orthogonal and straight line mesh + porosity

Type (1) is the method conventionally used for aerodynamic simulations of automobiles, but application to motorcycles which have a complex shape is difficult.

Type (2) can also support complex shapes, and recently this method is being used with increasing frequency in various areas. This method has the potential to become an effective method for aerodynamic simulations of motorcycles, but it assumes that the data for motorcycle bodies that are comprised from multiple objects are converted to a single volume by solid Boolean operations. However, this work requires an enormous amount of process time.

The authors adopted method (3). This mesh uses straight lines, so object shapes cannot be expressed by the mesh. Therefore, object shapes are expressed by the concept of the porosity of each constituent element (cell) according to the mesh. The porosity in each cell method first determines whether each cell is empty or filled with matter. Furthermore, when a part of a cell is empty, the shape is approximated by the area ratio of the empty and matter portions at the three surfaces (two surfaces for two dimensions) that enclose the cell. Fig. 1 (a) shows the approach toward porosity for two dimensions. Here, P_x and P_y are porosity values, and these values are defined for all the cells. Fig. 1 (b) shows an entire motorcycle body shape expressed in terms of porosity. Each element is expressed by a color according to the P_x and P_y values. Cells that are completely occupied by matter are indicated in red, and cells partially occupied by matter are indicated with varying colors according to the degree.

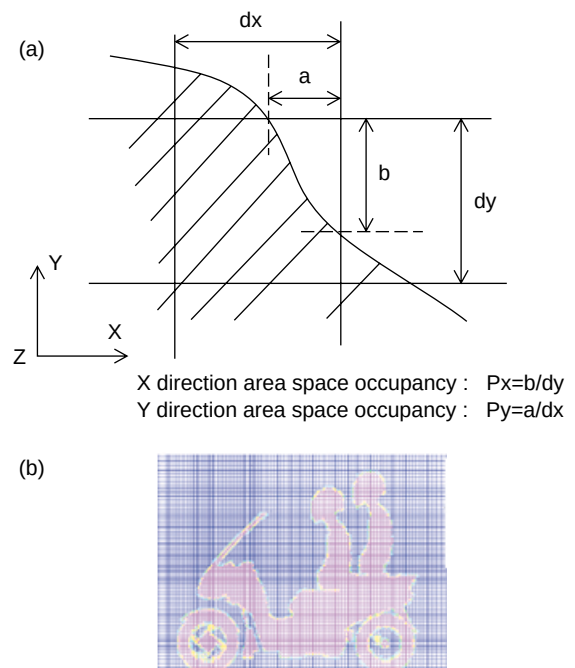


Fig. 1 (a) Concept of porosity; (b) Representation of an entire motorcycle model by porosity

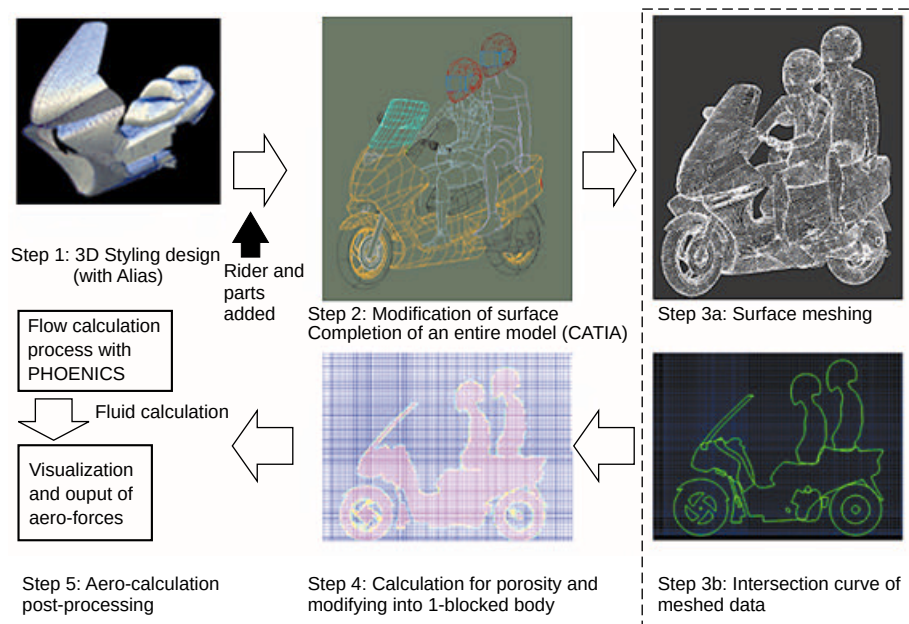


Fig. 2 Outline of system flow

3.4 Selection of a Solver

Selection of a solver was based on the premise that method (3) described in section 3.3 could be used. The solver actually used was PHOENICS developed by CHAM Inc. (England). This code is not equipped with functions for method (2), but is appropriate for using method (3). Note that the following calculation options were used.

Turbulence model : Standard k-ε model
 Convection term : Hybrid method
 Numerical scheme: Simplest method

4. System Outline

When constructing the system, commercially available software and in-house programs were combined as appropriate. Fig. 2 shows an outline of the system flow. Each step is described below.

- Step 1: 3D design data is created using Alias.
 Step 2: The step 1 data is transferred to CATIA and 3D surface data for small components is added.
 Step 3: Mesh models for each component are created by the in-house mesh generator incorporated into CATIA. Then, the individual mesh models are combined into a completed vehicle condition as shown in step 3a. At this time, intersecting portions between components may still remain such as shown in the sectional drawing in step 3b.
 Step 4: Porosity data corresponding to the orthogonal mesh for calculation data and shape data are created, and the intersecting portions between components are merged to achieve a single volume.
 Step 5: Calculations are performed using PHOENICS with the step 4 data as the input data. The calculation results file is read and calculations for the six components of aero-force are performed. To visualize the results, the file format is converted and then the data is displayed on a commercially available post-processor FIELDVIEW.

5. Application to Development Models

The developed system was applied to models for mass-production to verify the calculation accuracy. The accuracy was verified by comparing aero resistance force, streamline, pressure distribution and other factors with wind tunnel test results using the actual vehicles. Two types of test vehicles were used: (a) sports type motorcycle and (b) large-size scooter.

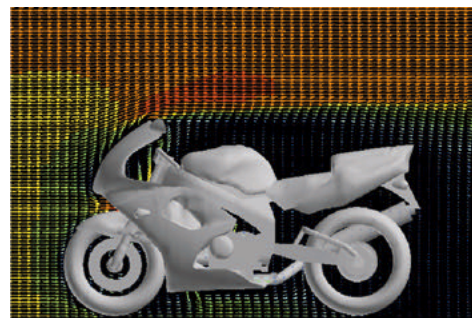


Fig. 3 Calculation results without rider

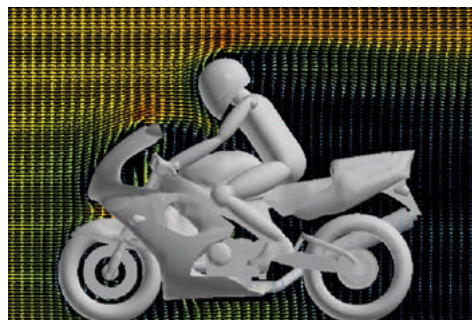


Fig. 4 Calculation results with rider

(a) Sports type motorcycle

The simulation results and wind tunnel test results for the aero resistance force and the forces acting at the front tire and rear tire contact points were compared for the cases of the motorcycle alone and the motorcycle with a rider. Fig. 3 and Fig. 4 show the simulation results for air flow speed using vectors. Fig. 5 and Fig. 6 compare the aero resistance force and the forces acting at the front tire and rear tire contact points, and show that each of these values match closely. Note that this model used 980,000 meshes for calculation and the calculation time was approximately 72 hours on an sgi ORIGIN2000 (180 MHz *8 CPU).

(b) Large-size scooter

Fig. 7 shows the 3D simulation model for calculation, Fig. 8 shows the wind tunnel test conditions, and Fig. 9 shows a comparison of calculated and actually measured aero resistance force. Here as well an excellent correlation was obtained for aero resistance force.

Fig. 10 shows the calculation results for surface pressure distribution and an image of the pressure measurement condition in the wind tunnel. Fig. 11 shows



Fig. 7 Calculation model of a scooter



Fig. 8 Wind tunnel test

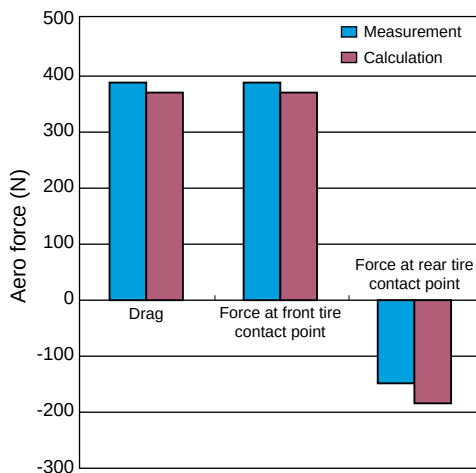


Fig. 5 Comparison of aero-dynamic forces between calculation and measurement (without rider)

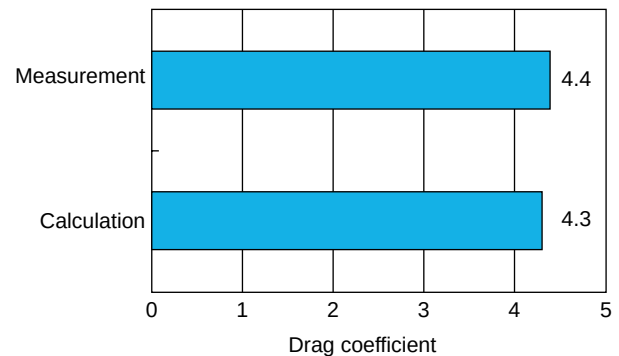


Fig. 9 Comparison of drag coefficients between calculation and measurement results

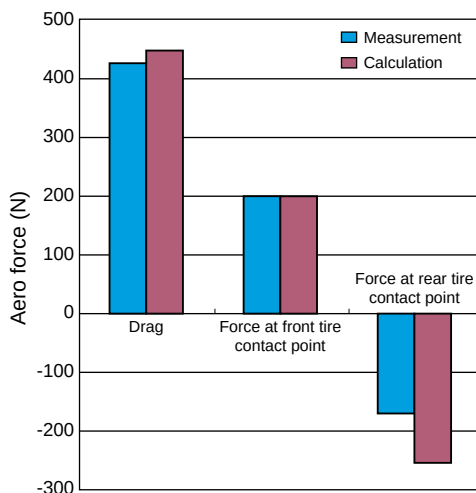


Fig. 6 Comparison of aero-dynamic forces between calculation and measurement (with rider)

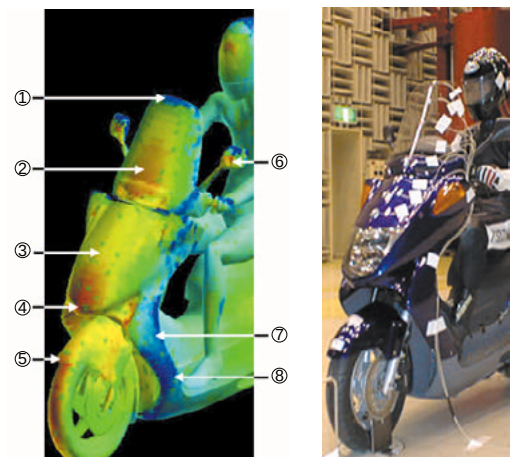


Fig. 10 Pressure distribution from the calculation results and a measurement scene in a wind tunnel

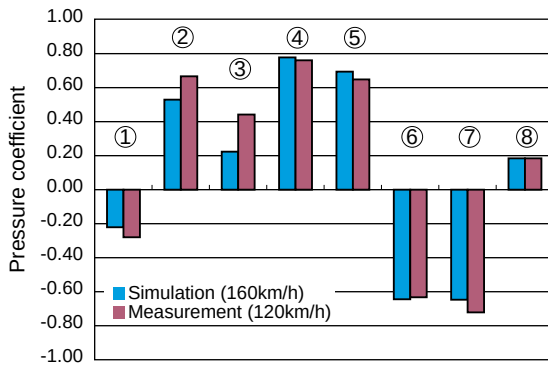


Fig. 11 Comparison of a calculation and measurement results of pressure on specified points

a comparison of these calculated and measured values. In this figure, the quantitative values matched closely except for case (3), and the overall distribution trend also matched closely.

Fig. 12 shows the calculated streamline, and Fig. 13 shows the streamline in the wind tunnel test. These results match fairly closely.

The remaining figures show a comparison of calculation results when the motorcycle body specifications are changed. Fig. 14 and Fig. 15 show the surface pressure distribution calculation results for two types of motorcycle bodies with different lower fairing outer edge shapes. Red indicates higher pressure, and means a stronger wind force. Focusing on the lower limb (from the knee downward) portion of the rear riders, Fig. 15 shows that the wind force is weaker and the wind protection performance has been improved compared to Fig. 14. Fig. 16 and Fig. 17

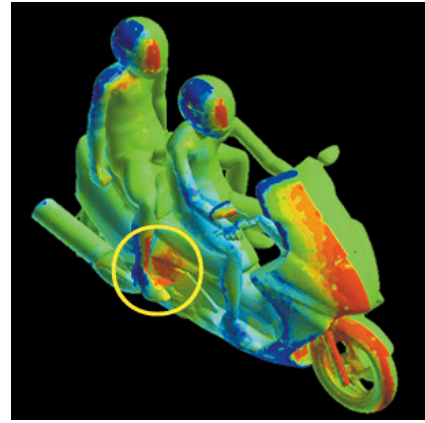


Fig. 14 Pressure distribution (Original fairing)

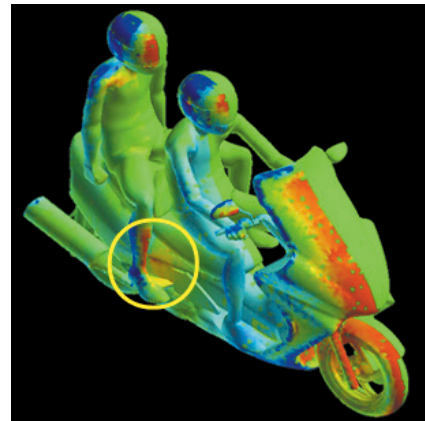


Fig. 15 Pressure distribution (Improved fairing)

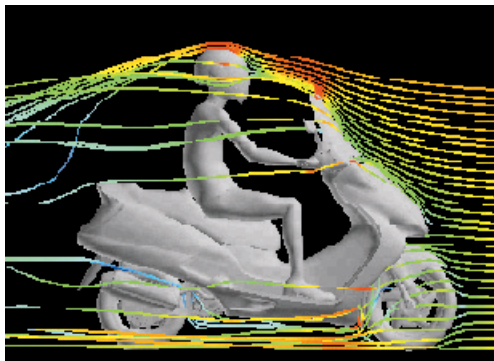


Fig. 12 Calculated stream line of a scooter model

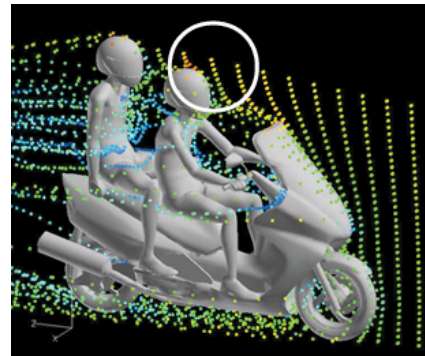


Fig. 16 Air flow pattern with riders (low windscreen)



Fig. 13 Stream line measured for an actual scooter

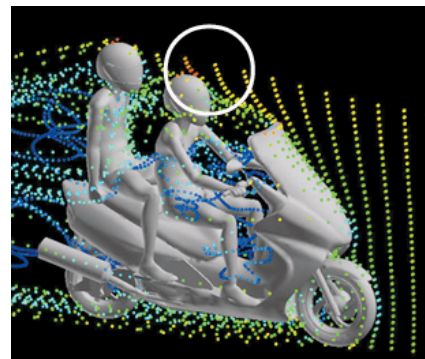


Fig. 17 Air flow pattern with riders (high windscreen)

compare the calculation results of the flow around a motorcycle body for two different windscreen specifications. The windscreen shape in Fig. 17 has a slightly longer top edge and also flares to the outside compared to the Fig. 16 windscreen shape. Fig. 17 shows that the wind force to the rider's head has been reduced.

These results showed that the developed system can be utilized for investigating the wind force to riders, that is to say the wind protection performance.

6. Reduction of Overall Simulation Process Time

In order to utilize aerodynamic simulations in the motorcycle development process, the time from modeling until the calculation results are obtained must be shortened as much as possible. Fig. 18 shows a breakdown of work process time for two years ago and at present. Modeling took approximately 45 days two years ago, but can currently be done in approximately 20 days when it is done by one person. The work item accounting for the largest percentage is model creation. This portion has been shortened from 40 days to 17 days due to improved staff modeling skills, and also because a greater percentage of the upstream data needed for modeling is 3D now compared to two years ago, which reduces the man-hours required to convert data to 3D. Thus, an environment where 3D data is available in advance is extremely important for promoting aerodynamic simulations.

The item accounting for the second largest percentage is computation time. Two years ago 900,000 meshes for calculation took approximately 3 days, but computer upgrades have presently made it possible to calculate 1.8 million meshes in 1.5 days. Tool advances have shortened the pre-processing (excluding model creation) from two days to one day, but post-processing remains almost unchanged at approximately one day. However, this accounts for a small percentage of the overall process time, so it is not a major problem.

7. Conclusion

A porosity-based aerodynamic simulation system was established and applied to development models, and the following results were obtained.

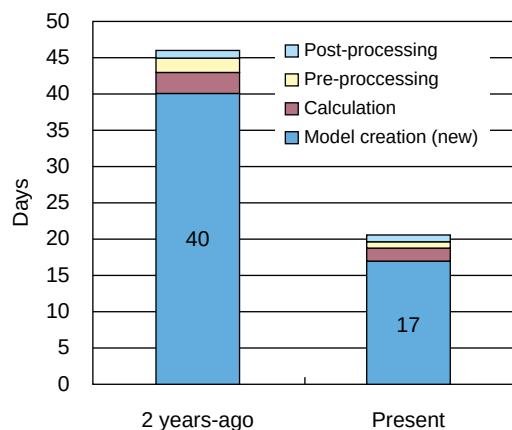


Fig. 18 Days required for an aerodynamic simulation of a motorcycle 2 years ago and at present

(1) It was confirmed that aerodynamic simulations using this method could be performed within a practical process time even for complex shapes such as completed motorcycle bodies.

(2) The calculation accuracy was confirmed for the overall aero resistance force and air flow pattern of completed motorcycle bodies, and found to be adequate for practical application.

In addition, further approaches are required for the following issues.

(1) Porosity is used to express shapes, so the air flow accuracy near walls is insufficient.

(2) When local shapes must be accurately expressed such as when checking the effects of small holes for example, the number of meshes required by the current method increases significantly, and it becomes difficult to obtain accurate calculations using a practical number of meshes.

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