

# Development of an Ultra Flat Torque Converter by Applying Three-dimensional Computational Fluid Dynamics

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## ABSTRACT

A method has been created to optimize design parameters using three-dimensional CFD to analyze the internal flow condition of a flat torque converter, and one-dimensional angular momentum theory. This method has been used to design a torus and blade configuration which reduces flow loss, and to optimize the specifications of the stator, which has a great affect on torque capacity characteristics. This has allowed the development of the thinnest ultra flat mass production torque converter in the world without sacrificing torque converter performance.

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## 1. Introduction

The trend toward increased steps in automatic transmissions (AT) and continuously variable transmissions (CVT) with the aim of improving comfort and fuel economy has accelerated in recent years. The development of an ultra flat torque converter that is thin and which delivers high performance is essential to meeting these demands.

Regarding analysis of the internal flow condition of torque converters, actual measurements of internal pressure and flow distributions around the stator<sup>(1)(2)</sup> and the results of characteristic predictions using three-dimensional computational fluid dynamics (CFD)<sup>(3)</sup> have been reported thus far. However, in order to develop an ultra flat torque converter, it was necessary to analyze factors causing performance deterioration when the torus section is flattened and the stator is made thinner, and to find a way to shorten the development period for verifying the design parameters.

This study created a method for verifying design parameters that is based on analysis of the internal flow condition of a flat torque converter using three-dimensional viscous CFD and one-dimensional angular momentum theory. This method was then used to design a torus and blade configuration that reduces flow loss and to optimize the flat stator specifications. This made it possible to develop the world's thinnest ultra flat torque converter. A 15% reduction in the axial dimension and a 3% improvement in transfer efficiency compared to the conventional Honda 2-liter engine class torque converter was achieved without sacrificing torque converter performance.

## 2. Development Issues

When attempting to design a flat torque converter, the main design restrictions are on flattening the torus section and making a thinner stator, which are known to influence torque converter performance as follows.

- (1) Flattening the torus section causes the torque capacity characteristics and the transfer efficiency to drop.
- (2) Making the stator thinner creates torque capacity characteristics with peaks.

Of these, (1) influences the fuel economy, and (2) influences the drivability of a vehicle at launch by creating a discrepancy between the engine torque characteristics and the torque absorption characteristics of the torque converter.

## 3. Development Targets

The following development targets were set in consideration of the above technical issues and the need to shorten the overall AT axial dimension.

- To achieve torque capacity characteristics and a transfer efficiency equal or superior to the current model.
- To reduce the overall torque converter width by 15% compared to the current model.

To achieve these targets it was necessary to analyze factors causing and quantitatively evaluate changes in torque converter performance caused by flattening the torus section and using a thin stator. Therefore, the following torque converter tests and three-dimensional viscous CFD were performed. The CFD tool used was a general-purpose code,

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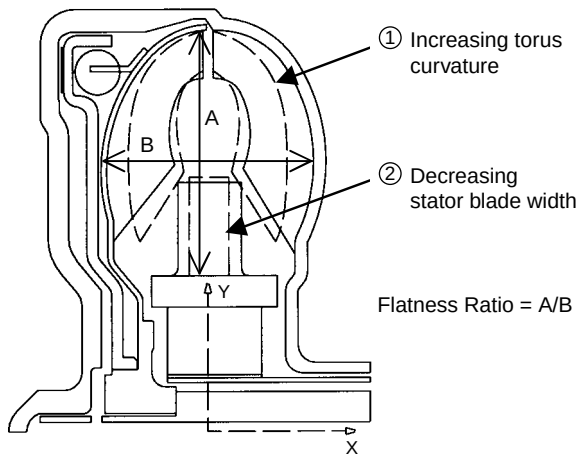


Fig. 1 Restrictions on the design process

which applied the finite volume method for digitizing, the CFD turbulence kinematic model was applied as the standard  $\kappa$ - $\epsilon$  model, and the SIMPLE method was used as the analytic algorithm.

#### 4. Effects of Flattening the Torus Section

##### 4.1 Confirmation of Torque Converter Performance

Torque converter performance was confirmed using torque converters having the same design parameters of flow channel area, blade angle, number of blades, bias angle, and blade inlet/outlet radius, with the only difference being the torus section flatness ratio. Table 1 shows the main torque converter specifications and test conditions. Fig. 2 shows the torque converter characteristic measurements. Note that Type A and Type B in Table 1 were designed based on conventional design methods<sup>(4)</sup>, and that the Type A torque converter is currently used in 2-liter engine class vehicles.

As shown in Fig. 2, the transmission capacity factor  $\tau$  and the torque ratio  $K$  decrease for all speeds. The transfer efficiency was also confirmed to drop by approximately 7% as the torus section flatness ratio decreased from 84% to 75%.

##### 4.2 Analysis of Flow Conditions inside the Torque Converter by Computational Fluid Dynamics (CFD)

It is known that the turbulence kinematic energy  $\kappa$  determined by solving the two-formula  $\kappa$ - $\epsilon$  model can be applied to predict separation flow and secondary flow, the factors which degrade flow performance, in other fluid devices. These predictions are accurate to a degree appropriate for practical application. Therefore, the turbulence kinematic energy  $\kappa$  at the speed ratio  $e = 0.8$ , which occurs frequently while driving, was calculated for the Type A and B torque converters shown in Table 1 in order to analyze factors causing and quantitatively evaluate changes in characteristics due to flattening. The calculation results shown in Fig. 3 confirmed local rises in the turbulence kinematic energy value when the flatness ratio was decreased from 84% to 75%.

Table 1 Torque converter specifications and test conditions

|                                     |          | Type A | Type B |
|-------------------------------------|----------|--------|--------|
| Hydraulic diameter (mm)             |          | 232    |        |
| Number of blades                    | Impeller | 27     |        |
|                                     | Turbine  | 23     |        |
|                                     | Stator   | 15     |        |
| Flattening rate (%)                 |          | 84     | 75     |
| Stator blade width (mm)             |          | 13.5   |        |
| Rotation speed of input shaft (rpm) |          | 2500   |        |
| ATF temperature (°C)                |          | 85     |        |

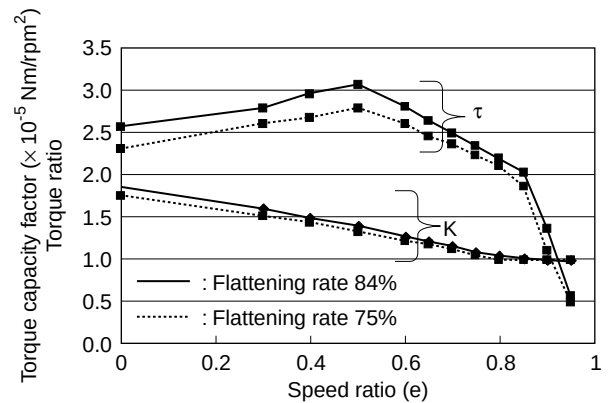


Fig. 2 Affect of flattening rate on torque converter performance

Next, the flow direction and velocity were analyzed for the AA' section of the Type B converter shown in Fig. 3 which exhibited a rise in the turbulence kinematic energy value. The flow visualization in Fig. 4 shows that a secondary flow occurred and the flow velocity dropped on the suction side of the turbine blades where the turbulence kinematic energy value increased.

In addition, Fig. 5 shows the relationship between the length of the fluid circulation passage and the turbulence kinematic energy in order to determine locations where separation and secondary flow increase in the torus section. The horizontal axis represents the ratio between the overall length of the fluid circulation passage and the distance from the pump inlet to some set location. This shows that the turbulence kinematic energy at the turbine inlet, turbine outlet, stator inlet and pump inlet were all higher for the Type B converter than for the Type A converter.

These torque converter tests and numerical calculations confirmed that the factors causing a drop in the torque capacity characteristics and transfer efficiency due to the flattening of the torus section are the secondary flow and separation occurring around each blade inlet on the flattened torus section. In addition, it was confirmed that the value of the turbulence kinematic energy  $\kappa$  could be used for quantitative evaluation of flow loss.

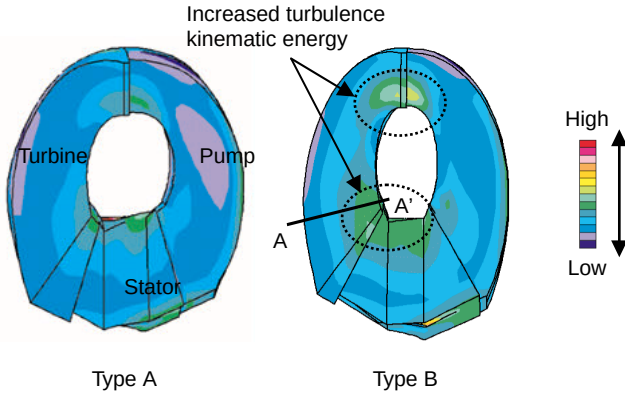


Fig. 3 Calculation results of turbulence kinematic energy

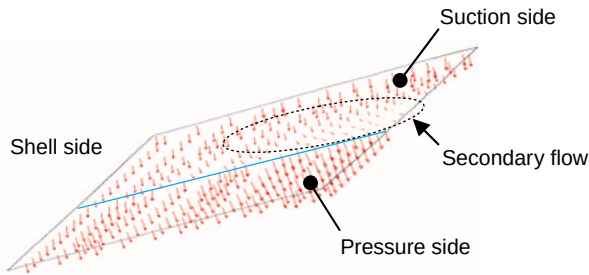


Fig. 4 Flow visualization at section AA'

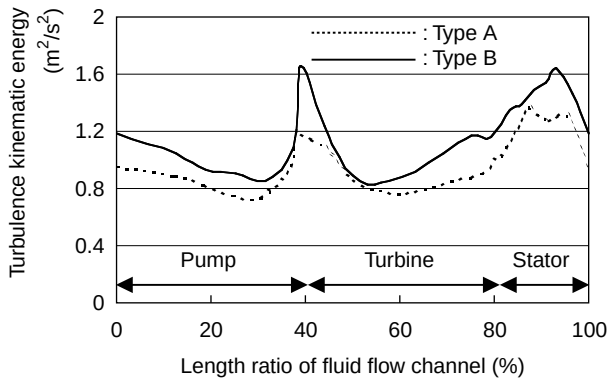


Fig. 5 Relationship between turbulence energy and length ratio of fluid flow channel

## 5. Effects of Using a Thin Stator

### 5.1 Confirmation of Torque Converter Performance

Torque converter tests were conducted by varying only the stator blade width based on the Type A converter shown in Table 1. The torque converter specifications and test conditions are shown in Table 2. The Type C stator has the same number of blades as the Type A stator, but the blade width is 2 mm shorter in the axial direction and the blade shape is reduced the same ratio as the blade width reduction ratio. Fig. 6 shows the torque converter characteristic measurements. These results show that reducing the stator blade width causes the torque capacity factor to increase centering around a speed ratio of 0.5 as well as causing the transfer efficiency to decrease.

Table 2 Torque converter specifications and test conditions

|                                     | Type A | Type C |
|-------------------------------------|--------|--------|
| Hydraulic diameter (mm)             | 232    |        |
| Flattening rate (%)                 | 84     |        |
| Stator blade width (mm)             | 13.5   | 11.5   |
| Rotation speed of input shaft (rpm) | 2500   |        |
| ATF temperature (°C)                | 85     |        |

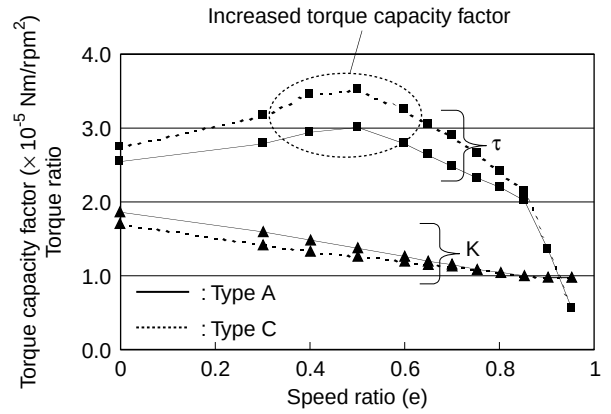


Fig. 6 Affect of decreasing the stator blade's width on torque converter performance

### 5.2 Analysis of Flow Conditions around the Stator by Computational Fluid Dynamics (CFD)

The flow conditions around the stator were analyzed at the speed ratio of 0.5, which showed the greatest change in torque capacity for the Type A and Type C stators in Table 2 using the three-dimensional CFD described in section 4.2 above. The numerical calculation method is the same as that described in section 4.2. Fig. 8 and Fig. 9 show the calculation results for the flow conditions around the stator. Fig. 8 shows the turbulence kinematic energy and Fig. 9 shows the velocity vectors for the plane corresponding to the center between the stator shell and core as shown in Fig. 7.

Fig. 8 and Fig. 9 show that compared to the Type A stator, the increase in the turbulence kinematic energy is larger at the Type C stator suction face, and separation also occurs at the Type C stator suction side. Furthermore, all flow from the outlet of the Type C stator was confirmed to be offset from the designed stator blade angle. The one-dimensional angular momentum theory<sup>(4)</sup> also clearly showed

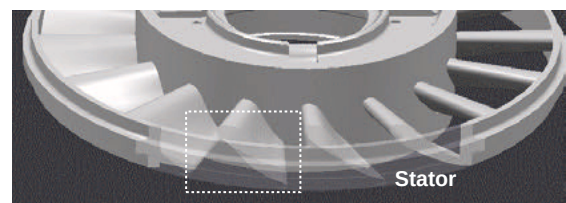


Fig. 7 Visualization area

that this change in stator outlet flow angle applied a rotational load to the pump, which resulted in a drop in transfer efficiency.

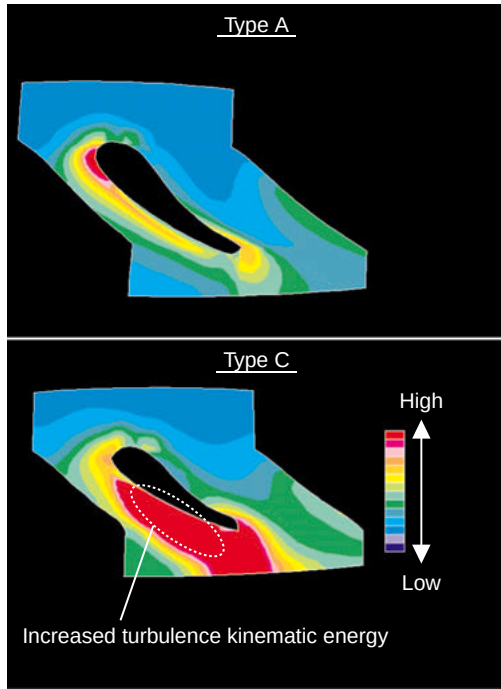


Fig. 8 Calculation results of turbulence kinematic energy

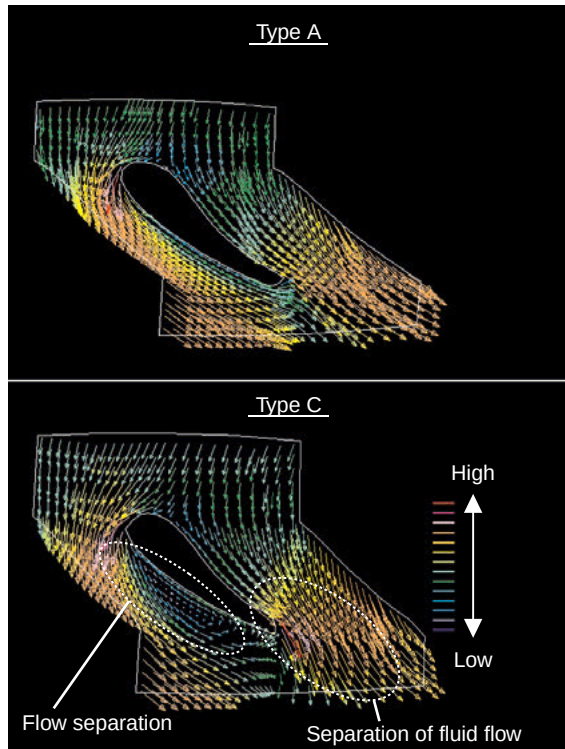


Fig. 9 Calculation results of fluid velocity

The above torque converter tests and numerical analysis confirmed that the change in outlet flow angle induced by separation occurring at the stator suction face was the main factor causing peaked torque capacity characteristics and lower transfer efficiency when a thin stator is applied.

Furthermore, the following method was incorporated to set the optimal torque converter parameters in a short period of time.

## 6. Method for Optimizing Design Parameters

When actually designing a torque converter, a large number of design parameters including the flow channel diameter, flow channel area, blade angle, bias angle and number of blades must be verified in combination. In consideration of matrix generation and calculation time, verifying all the design parameters using three-dimensional CFD would require enormous development time. A prediction method that reflects changes in the internal flow conditions due to the application of a flat converter is essential. Therefore, one-dimensional angular momentum theory was used as a basis to further improve the accuracy of the practical simulation method,<sup>(5)(6)</sup> which is currently used in the design stage at Honda.

In this simple performance prediction method, the torque converter internal loss is divided into impact loss and friction loss. The secondary flow, separation and other loss in the flow channel due to the flattening of the torus section is defined as the friction loss  $L_f$ , and expressed by equation (1) below. Here,  $\gamma$  is the specific weight,  $Q$  is the flow rate, and  $h$  is the head loss.

$$L_f = \gamma \cdot Q \cdot h \quad (1)$$

$h$  is further broken down as follows.

$$h = \sum_{i=1}^3 h_i \quad (2)$$

$$h_i = \zeta_i \cdot \left\{ \frac{1}{2g} \right\} \cdot \left\{ \frac{C}{\cos(\alpha_{i2})} \right\} \quad (3)$$

Here,  $\zeta_i$  is the loss coefficient,  $g$  is the acceleration of gravity,  $C$  is the circumferential velocity,  $\alpha$  is the blade angle, and the super- and subscripts 1, 2 and 3 indicate the pump, turbine and stator, respectively.

Focusing on the loss coefficient  $\zeta_i$ , which was formerly defined based on past test data, three-dimensional CFD was performed for each designed torus section.  $\zeta_i$  was then corrected based on the calculation results from the torque generated by the pump and turbine. Fig. 10 shows the design process incorporating this method.

## 7. Application Example

The knowledge obtained from this analysis and the ultra flat torque converter developed using the design process shown in Fig. 10 are described below. The flatness ratio of the newly developed ultra flat torque converter shown in Fig. 11 was set at 65% in consideration of torque converter performance and the target for reducing the overall torque converter width.

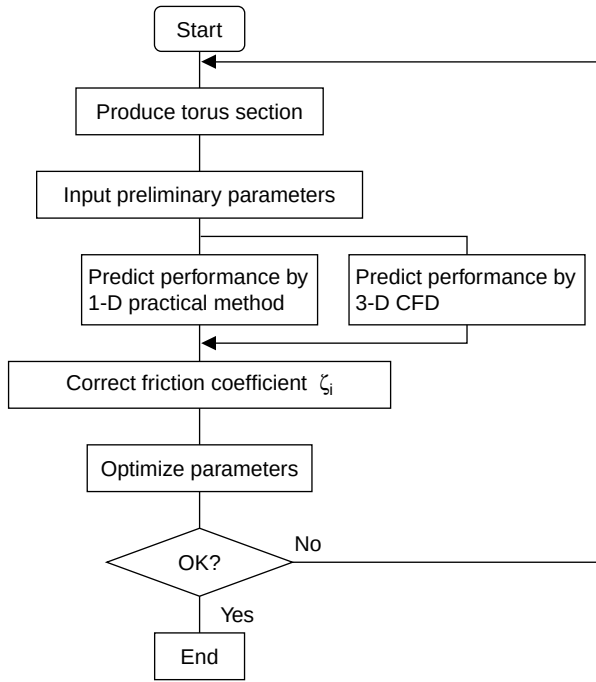


Fig. 10 Summary of design process



Fig. 11 Side view of developed torque converter

### 7.1 Torus Section and Blade Shape Design

The pump and turbine blade angle, bias angle, number of blades, and flow channel area were optimized with the aim of reducing flow loss. In order to illustrate the effects of this optimization, Fig. 12 shows a comparison of turbulence kinematic energy with the Type A converter currently used in the 2-liter engine class shown previously in Fig. 5. Note that the calculation conditions are the same as for Fig. 5. Fig. 12 clearly shows that the turbulence kinematic energy value and flow loss for the newly designed torus section decreased over the entire flow channel compared to the current model.

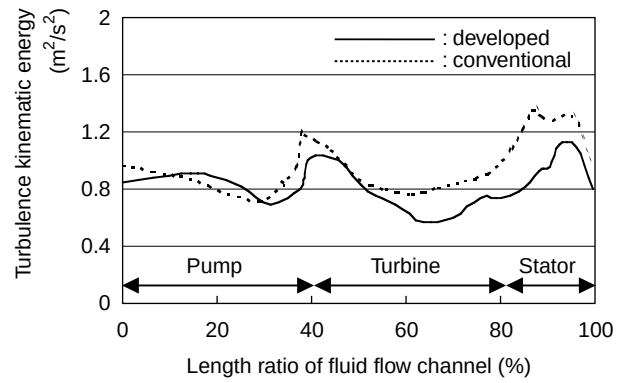


Fig. 12 Relationship between turbulence energy and length ratio of fluid flow channel

### 7.2 Optimization of the Stator

The number of stator blades, inlet/outlet angle and blade shape were newly designed as shown in Fig. 13 to suppress fluid slip caused by separation occurring at the thin stator suction face. Optimizing the stator suppressed fluid slip as shown in Fig. 14 and resulted in flat torque capacity characteristics.

In addition, torque converter characteristic measurements confirmed that the torque capacity characteristics for the developed torque converter are equal to those of the current model, and the transfer efficiency improved by 3%.

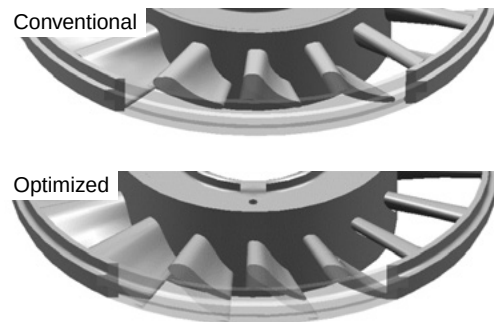


Fig. 13 Comparison between conventional and optimized stator blades

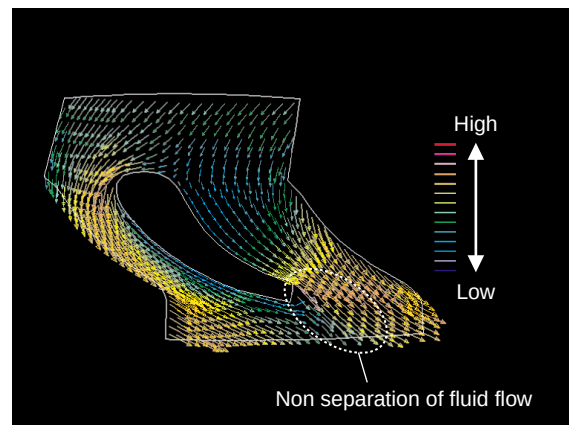


Fig. 14 Calculation results of flow velocity around optimized stator

## 8. Conclusion

The following items were clarified through torque converter tests and three-dimensional computational fluid dynamics. Furthermore, the axial dimension was shortened by 15% compared to the conventional Honda 2-liter engine class torque converter without sacrificing torque converter performance. This was achieved by creating a method for optimizing design parameters based on one-dimensional angular momentum theory.

- (1) The drop in the torque capacity characteristics and transfer efficiency due to flattening of the torus section is caused by secondary flow and separation occurring inside the flattened torus. Quantitative evaluation by the value of the turbulence kinematic energy  $\kappa$  is possible.
- (2) The peak torque capacity characteristics and the drop in transfer efficiency due to the application of a thin stator are mainly caused by changes in the outlet flow angle induced by separation occurring at the stator suction face.

Finally, the authors would like to express their deep thanks to Mr. Akira Kitajima, Mr. Kiyoshi Saitoh and other related parties at Yutaka Giken Inc., and to Mr. Akira Tsuboi, Mr. Satoshi Kawamura and other related parties at FCC Inc. for their participation in the joint development of this torque converter.

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