Design support for outboard motors for small vessels using computational fluid dynamics

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Abstract

Part-design support was provided to the Marine Division of Yamaha Motor Co., Ltd. using computational fluid dynamics (CFD) technology that our company built through the development of automatic transmissions. Our knowledge of fluid dynamics, technologies of simulation, and data processing was fully utilized through the selection of CFD software, data processing ingenuity and a detailed analysis of the flow field. Consequently, we were able to satisfy the needs of our customers, and we received excellent customer feedback.

1. Introduction

Various studies have been conducted on heat and fluid dynamics to develop automatic transmissions for automobiles. The thermal and fluid phenomena inside transmissions are complex and diverse. For example, in a hydraulic system, there exist multiscale problems in which phenomena ranging from several micrometers to several hundred millimeters must be solved simultaneously. Additionally, problems exist regarding hydraulic response delays and pressure wave propagation when air is mixed with oil. Lubrication systems suffer from problems such as oil agitation by gears, forced lubrication, and cooling of high-speed rotating clutches, pulleys, and bearings. Hence, a wide range of advanced simulation and analysis techniques is required to understand and visualize these phenomena.

This report describes our recent application of fluid analysis technology to support the design of parts for the Marine Division of Yamaha Motor Co., Ltd.

2. Overview of Design Support

2.1 Overview of Simulation

The object of the simulation is the gearbox (red frame) of an outboard motor for small vessels, as shown in Fig. 1.

The oil behavior was analyzed in detail to reduce churning loss. Considering the purpose of the analysis and possibility of the future refinement of the study design, air needed to be considered to computationally reproduce this phenomenon. Hence, the simulation was conducted using SIMULIA XFlow (hereafter referred to as XFlow)[1], which is a general-purpose thermal fluid dynamics simulation software that can accurately calculate gas-liquid two-phase flows.

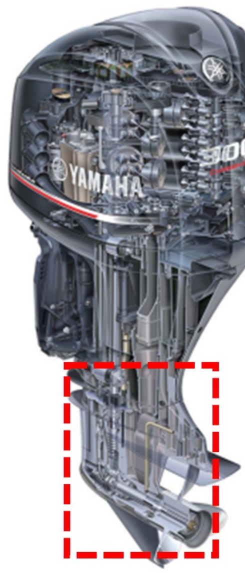

Fig. 1 Outboards for Small Vessels

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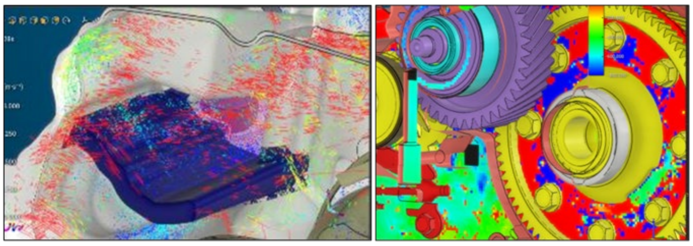
XFlow has good analytical accuracy, but it also has drawbacks in detailed post-processing, including display problems, such as the velocity vectors being too small to see and the pressure distribution being drawn roughly (Fig. 2).



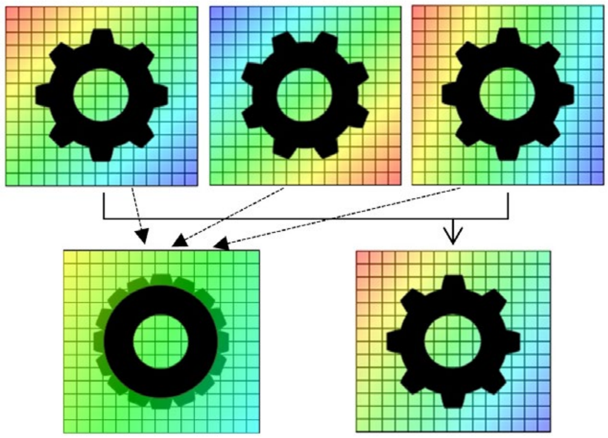
(a) Velocity vector (b) Pressure distribution

Fig. 2 XFlow results display example

In the development of automatic transmissions, these drawbacks did not present any issues, as the main outputs were the macroscopic behavior of the oil and churning loss caused by the gears. However, for current purposes, these drawbacks pose a major issue. We attempted to solve this problem by loading the XFlow output into STAR-CCM+[(2)], which is another CFD software that has excellent visualization and data processing functions.

2.2 Overview of Analysis

When analyzing the flow in a gearbox, the turbulence components must be handled carefully. When the flow is stirred by the gears, the flow changes constantly owing to interface fluctuations and vortices of various sizes. Therefore, the same procedure cannot be repeated. Moreover, an accurate analysis cannot be performed if only the flow field is used at a particular moment; such an analysis may lead to erroneous judgments. In this study, the turbulence components were removed by averaging the data. As simple time averaging cannot correctly preserve the data on the gear surface, we focused on the gear phase and performed ensemble averaging by extracting and averaging only the data obtained when the gear teeth were in exactly the same position (Fig. 3).



Simple time average = no good for analysis Ensemble average = good for analysis

Fig. 3 Data processing method

This allowed only the time-averaged components corresponding to the phase of the gears to remain, thereby ensuring that the phenomena of interest were captured.

However, the following issues must be overcome when transferring the XFlow results to STAR-CCM+.

1) The data output from XFlow was not in a format that could be read using STAR-CCM+.
2) Even if the phases of the gears are the same, the phases of the bearings, shafts, and so on may not be aligned. These differences result in variations in the sequence of the output data in the result file at each time point, which impedes ensemble averaging. That is, the lines written in each file are different, even though the data are taken from the same location.

These issues were addressed using data processing programs. For Issue 1), the data format was rewritten using AWK, which is a language that specializes in processing text data. Next, Issue 2) was addressed using the data-mapping function in STAR-CCM+. First, a unified mesh was prepared, in which rotators with different phases were removed from the model. The resulting files written at each time point were read, mapped, and output sequentially. As there were 200 result files, Java programming was used to automate the entire process to accelerate and improve the work efficiency.

Consequently, data from the same location are always written on the same line, which makes data processing easier. In addition, a simple program was written using AWK to perform ensemble averaging.

Figure 4 shows an example of the flow analysis. Using data with minor turbulence components, it was possible to perform a detailed analysis and evaluation of the pressure distribution, velocity distribution, and their relationship with the torque loss. This analysis enabled the identification of the design parameters that were closely related to the loss of torque, which led to the clarification of the design guidelines.

3. Overview of Design Support

For the first time, fluid dynamics technology has been used to provide design support for components outside the automotive industry. Although this study involved a component with which we had no previous experience, we were able to satisfy the needs of our customers by fully utilizing our knowledge of fluid dynamics, analytical technology, and data processing technology with programming, which we acquired through the development of automatic transmissions. Consequently, we achieved a high level of customer satisfaction. We will continue to refine our technology and make technical contributions to a wide range of customers.

(1) SIMULIA is a European company (Societas Europaea) incorporated under the laws of France, and is a trademark or registered trademark of Dassault Systèmes that is registered with the Commercial Court of Versailles under registration number 322 306 440, or a trademark or registered trademark of any of the subsidiaries of Dassault Systèmes in the United States or other countries.

(2) STAR-CCM+ is a registered trademark of Siemens AG.

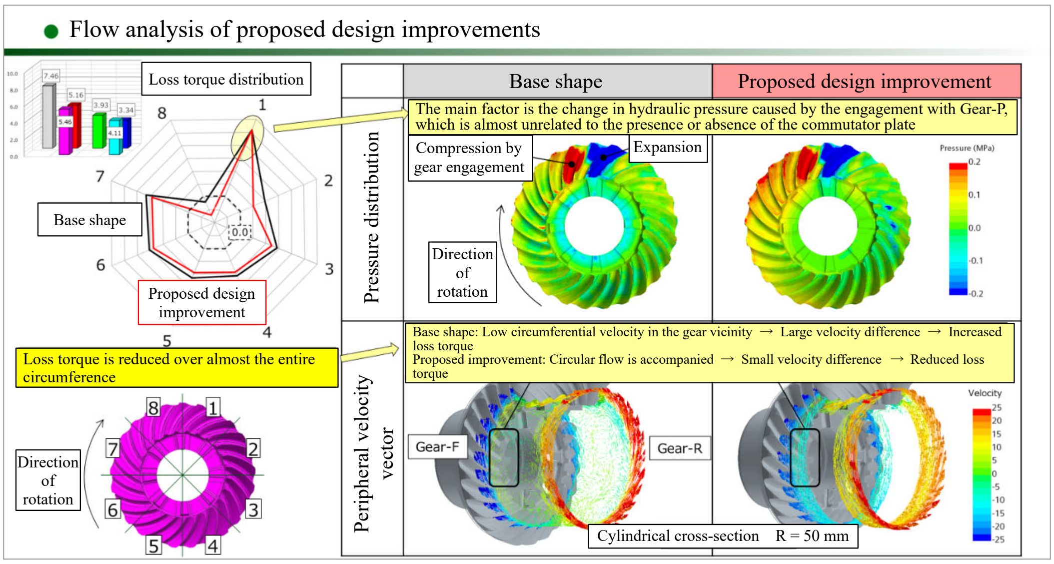


Fig. 4 Example of data analysis

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