Supersport of watercraft Jet Ski ULTRA 300 Series

What riders seek in a personal watercraft are powerful acceleration, greater maximum speed and excellent maneuverability on rough water. To meet these demands, Kawasaki developed the Jet Ski ULTRA 300 Series powered by a high-power engine featuring an ultra-efficient supercharger. Kawasaki then added further improvements in the ULTRA 310 Series, developed as the 2014 model.

This paper discusses the structures and distinct features of the high-powered engine and hull of the Jet Ski ULTRA 300 Series — a supersport of watercraft.

Preface

In recent years, the market for personal watercraft including Jet Ski (Fig. 1) has become increasingly polarized into high price range models (high power and high functionality) and low price range models (relatively low power with basic functions only) as shown in Fig. 2. The low price range models are mainly used for rentals at resorts, while personal riders are increasingly drawn toward the high price range models featuring high power and high functionality.

In order to respond to the demands of these riders, such as "powerful acceleration," "greater maximum speed" and "excellent maneuverability on rough water," recent personal watercraft have been equipped with a supercharged engine. Kawasaki has offered the Jet Ski ULTRA 250X equipped with a supercharged engine since 2007.

However, engines have rapidly become increasingly more powerful in recent years, and in order to respond to the demands of the riders, it became necessary to develop an engine with an even higher power. Under such circumstances, Kawasaki adopted a highly efficient supercharger to develop the higher power Jet Ski ULTRA 300 Series, without increasing the size of the engine or the hull.

Fig. 1 Jet Ski ULTRA 300X

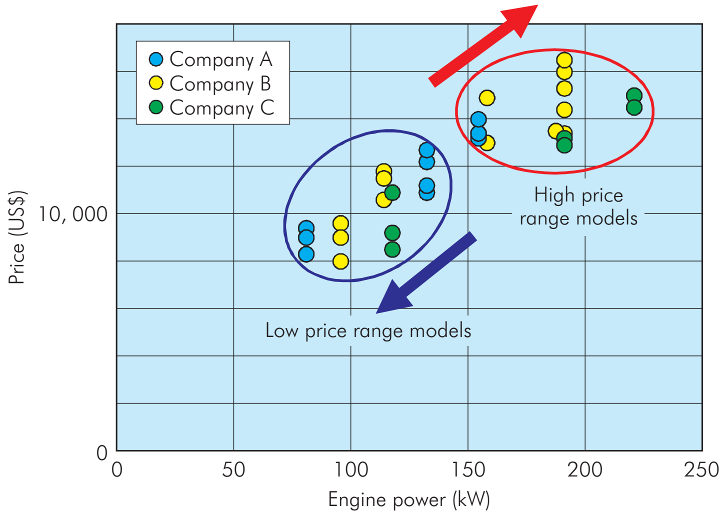


Fig. 2 Engine power and price distribution

1 Development of high-power engine — Pursuit of superior supercharged pressure

(1) Selection of supercharger

The pressure ratio of the ULTRA 250X engine is 1.8. This ratio is the same as conventional supercharged engines including automobiles, etc., equipped with a centrifugal type or roots type supercharger or turbocharger.

First, we selected an ideal supercharger aiming for a pressure ratio of 2.2 or more. In order to acquire powerful acceleration, it is necessary to have a large engine torque which can efficiently rotate the jet pump from a low rpm range. For this reason, a supercharger which can discharge a sufficient flow rate from a low rpm range was required, and thus we adopted a roots type supercharger.

Unlike other types of supercharger, the roots type can generate high supercharged pressure constantly over the entire rpm range from very low speeds to the maximum speed range, and achieve a flat and heavy torque curve. However, a common roots type supercharger could only achieve a pressure ratio of up to 1.8 due to structural limitations. Therefore, we adopted the TVS (Twin Vortices Series) supercharger (Fig. 3) newly developed by Eaton of the U.S. This TVS is the latest type of supercharger which can achieve high pressure-charging at a pressure ratio of 2.4. However, since this product was originally developed for automobiles and was never before used in a marine product, various modifications had to be performed.

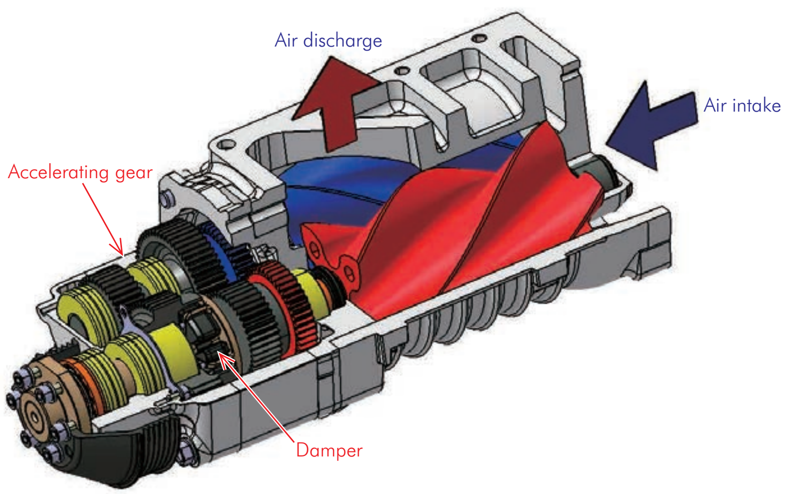


Fig. 3 Internal structure of the TVS supercharger

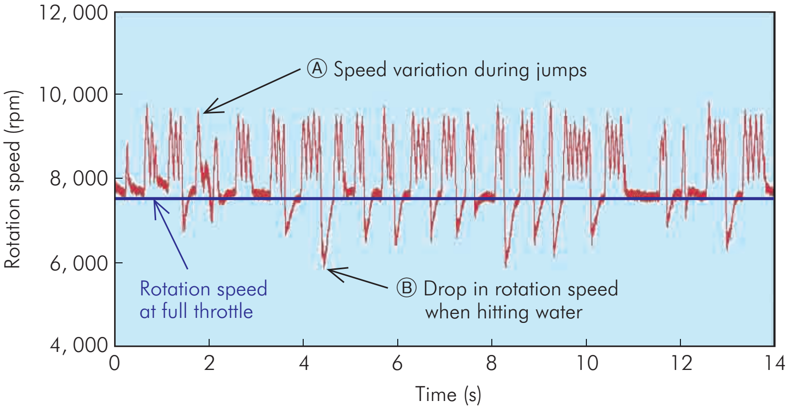


Fig. 4 Engine speed variation data

(2) Application of TVS supercharger in a marine product

Personal watercraft jump over waves as they are propelled forward. While jumping, the load is released since water is not supplied to the jet pump, and the engine runs in an overspeed range beyond the rated rpm (Fig. 4 Ⓐ). This is like making an automobile jump repeatedly. In this overspeed range, the engine speed rises and falls repeatedly in a short cycle. When a watercraft hits the water, a load is suddenly applied as the water enters the pump, which causes the engine rpm to drop suddenly (Fig. 4 Ⓑ), and the load on the engine becomes extremely high. Similarly, a large load is also applied to the supercharger, as it is linked with the engine to rotate the internal rotors. In order to reduce the load, various investigations were performed on the drive of the supercharger.

First, as shown in Fig. 5, a belt drive was adopted. It was arranged so that the belt slips during overspeed to release the load, while maintaining an appropriate belt load with an auto belt tensioner. However, since this is not enough to absorb the large load when the watercraft hits the water, a special damper was additionally provided inside the TVS as shown in Fig. 3. As shown in Fig. 6, these two mechanisms reduced the load transmitted to the TVS, and it became possible to mount it on a personal watercraft.

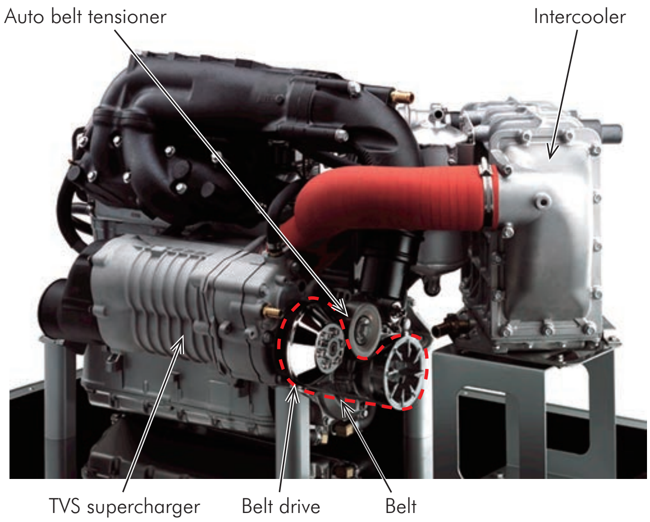


Fig. 5 Engine layout

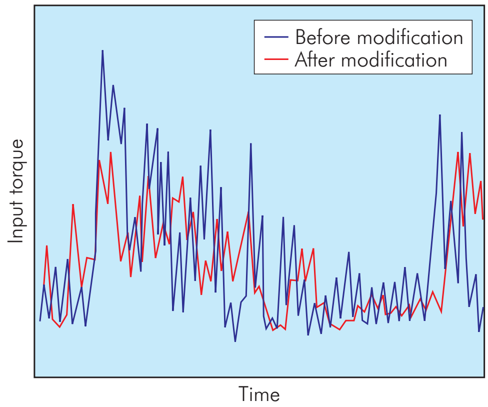


Fig. 6 Torque input to the supercharger

(3) Increasing the efficiency of supercharging

To obtain high power by an efficient supercharge, the following improvements were added. First, a large size water-cooled intercooler was provided to increase the charging efficiency by cooling the supercharged intake air. The temperature of the intake air which increased during the supercharging was substantially reduced by utilizing the abundant surrounding water. In order to prevent the sufficiently cooled intake air from being warmed up by the engine heat no matter how slightly, a resin intake manifold was adopted for the first time in a supercharged engine. In order to efficiently burn the highly supercharged intake air, the appropriate valve timing, fuel injection volume and ignition timing were selected, while checking the actual combustion condition based on an analysis of the combustion and power.

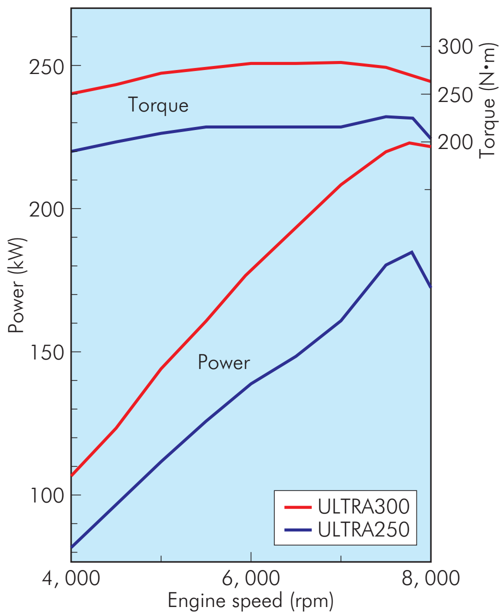


Fig. 7 Engine power properties

These improvements realized the highest power in the personal watercraft industry, with a pressure ratio of 2.2 and a maximum power of 221 kW, even with an engine displacement of 1.5 L. The engine power properties are shown in Fig. 7. In addition to the high power, this new engine also realized a huge reduction in discharged gas. It is an environmentally friendly engine that cleared the U.S. EPA (Environmental Protection Agency), CARB (California Air Resources Board), which is the most severe standard in the world, and EU standards.

2 Optimum hull for the high power engine — Pursuit of acceleration

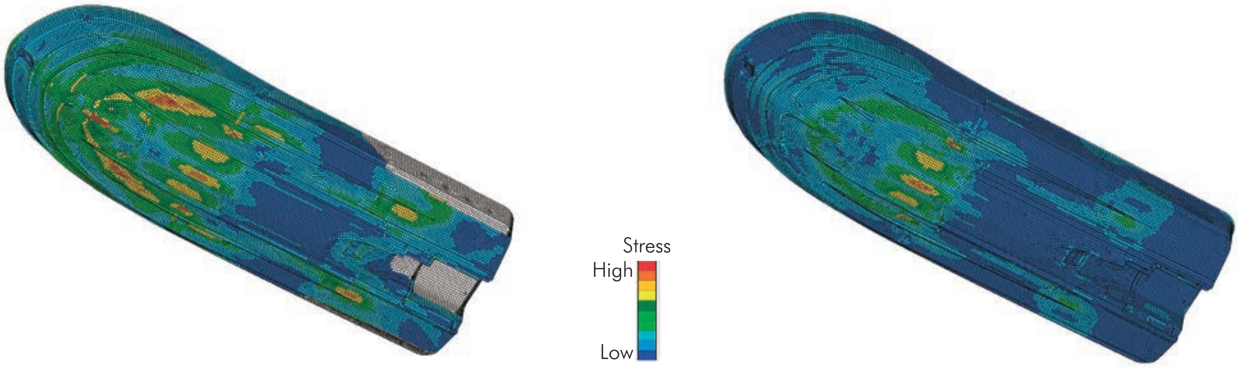
Personal watercraft do not always cruise over a smooth water surface; they are also driven over rough water. Moreover, "fast" not only means "maximum speed" but also often refers to "acceleration," as in various other vehicles. Therefore, in the ULTRA 300 Series, the development target was to realize "high acceleration performance" on "any water surface."

(1) Hull (bottom) form

The hull form was designed as a deep V type warped hull with a 22.5 degree dead rise (Fig. 8). As well as improving wave cutting performance, this form eased wave shocks and improved riding stability on rough water.

Normally, if the V form of the hull is sharpened to improve wave cutting performance and ease wave shocks, the drag of the hull will increase, and as a result, the maximum speed and acceleration performance will deteriorate. However, since this can be compensated by the high power engine, we focused on riding stability on rough water and adopted this form.

Fig. 8 Hull form



(a) Conventional structure

(b) New structure

Fig. 9 Stress analysis results of the hull

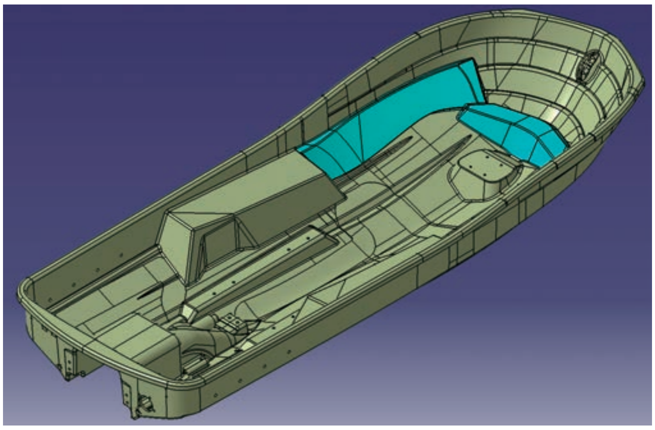


Fig. 10 Structure of the new lightweight hull

(2) Hull weight reduction

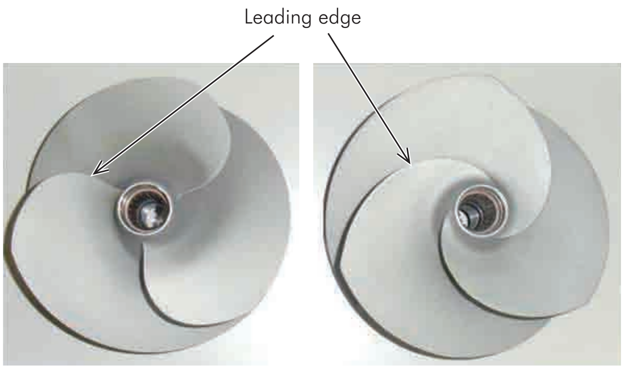
The weight of the hull greatly affects acceleration performance and riding stability on rough water. For this reason, we have reduced the weight of the hull, which makes up the largest portion of the weight.

The analysis results of the stress which is generated on the bottom of the hull during a ride is shown in Fig. 9, and the new hull structure where the thickness and reinforcement structure were changed based on the analysis results is shown in Fig. 10. By adding reinforcement (light blue portion in Fig. 10) to the portion where high stress is generated in the conventional structure (red portion in Fig. 9) and reducing the overall thickness, the new structure achieved high rigidity and reduced the weight of the hull to 85 kg, approximately 17 kg lighter than the conventional model ULTRA 250X.

3 Optimum jet pump for the high power engine

We designed a new jet pump along with improvements in the engine power, and the inner diameter was set at 160 mm, which is larger than the conventional model. We also made substantial changes in the shape of the impeller on the leading edge side, and by increasing the surface area of the impeller blades by about 13%, we were able to efficiently convert the torque of the high power engine into propulsive force without generating cavitation*. The conventional shape and new shape of the impeller are shown in Fig. 11, and a comparison of the standing start acceleration performance is shown in Fig. 12.

* Phenomenon where foam is generated in a short period of time by the pressure difference in the flow of a liquid.



(a) Conventional shape (b) New shape

Fig. 11 Shape of the impeller

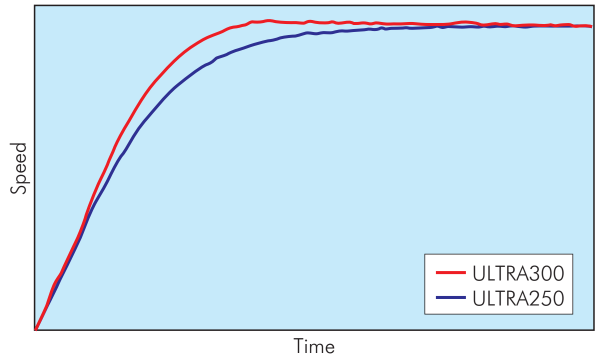


Fig. 12 Starting acceleration performance

Fig. 13 Jet Ski ULTRA 310LX

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Concluding remarks

Kawasaki developed the ULTRA 300 Series based on the concept of "powerful acceleration," "greater maximum speed" and "excellent maneuverability on rough water," which riders seek in a personal watercraft. This ULTRA 300 Series is equipped with excellent functionality, including a high supercharging, high power engine, and a hull which maximizes the engine performance. This series was the center of all attention at the Japan International Boat Show 2013. Moreover, for the 2014 model, we developed the ULTRA 310 Series with further improvements added (Fig. 13). As well as clearing the U.S. and EU standards, we also achieved great reductions in emission gas, and great improvements in fuel consumption. We wish to change the image of personal watercraft in society by paying full consideration to the environment, and contribute to the revitalization of the global market.