

Introduction of Personal Watercrafts AquaTrax F-12/F-12X Installing a 4-Stroke Engine

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ABSTRACT

The AquaTrax F-12 and F-12X Personal Watercraft (PWC) were developed with design goals of excellent driveability and environmental suitability superior to the existing 2-stroke engine PWCs. A 4-stroke engine and turbo charger were installed for the first time in PWCs. As a result, they passed the EPA 2006 emission regulation and the CARB 2004 emission regulation for the first time in PWCs, and driveability exceeded that of the existing 2-stroke engine PWCs. The turning ability of these PWC, like that of a motorcycle, was realized through a newly developed water jet pump suitable for the characteristics of a 4-stroke engine, and the hull bottom of Honda's original shape. Thus, the level of existing PWCs was changed completely.

1. Introduction

Personal watercraft (PWC) are presently marketed for one to four riders. PWCs are popular for offering a greater degree of maneuverability than boats, and in 2001, approximately 110,000 units were sold in the US market. In response to concerns about the environment and market trends demanding increased controllability and stability and higher speeds in PWC, Honda has developed a PWC fitted with a 4-stroke engine.

The 2002 AquaTrax F-12 (F-12X) is shown in Fig. 1. The AquaTrax is highly stable, and offers a level of rider comfort new to PWC. It is a three-person PWC, which takes into account the needs of inexperienced users, and is fitted with an Off-Throttle-Steer (OTS) system⁽¹⁾, and features a limit mode that controls the maximum speed of the engine. The F-12X is fitted with a turbo-charger, and is the most

powerful three-person PWC on the market. This paper will describe the major technologies utilized to achieve the performance targets set for these PWC.



Fig.1 AquaTrax F-12

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2. Development Concept

Development of the AquaTrax F-12/F-12X did not restrict itself to the conventional paths taken in PWC design. Designers adopted a users' perspective and considered the requirements of a PWC for family use and the features of a PWC which most contribute to rider enjoyment. The development concept established for the craft was to achieve a product which is safe, friendlier to the environment, sporty, and easy to use. Fig. 2 shows details of the development concept.

3. Engine

In addition to the existing U.S. Environmental Protection Agency (EPA) marine exhaust emissions regulations, the California Air Resources Board (CARB) has recently issued

a set of strict regulations, and the US Water Quality Bureau has also commenced consideration of regulations. All of these regulations place severe restrictions on marine engine design. Given these environmental considerations, Honda has chosen a 4-stroke engine as its PWC engine. The base engine is a CBR1100XX motorcycle engine. This engine was modified for aquatic use, and the stroke was increased by 5 mm. The engine has a displacement of 1,235 cm³. Table 1 shows the main engine specifications for the F-12/F-12X. A target of 100 PS/L at 7,000 rpm was set for the natural aspiration AquaTrax F-12. Reduction of pressure loss and mechanical loss in the exhaust system has enabled the achievement of performance in the middle class of the PWC market. The AquaTrax F-12X adds a turbo-charger to the F-12 engine, and features the highest power output of any PWC on the market. A biaxial secondary balancer ensures safe, comfortable high-speed cruising.



Fig. 2 Development concepts and features for AquaTrax

Table 1 Major specifications of engines

Items	AquaTrax F-12X	AquaTrax F-12
Engine type	4-stroke inline 4 cylinder	4-stroke inline 4 cylinder
Valve train	DOHC 16 valve	DOHC 16 valve
Displacement (cm ³)	1 235	1 235
Bore x stroke (mm)	79 x 63	79 x 63
Compression ratio	8.5	11
Cooling system	Water cooled, open loop	Water cooled, open loop
Lubricating system	Dry sump	Dry sump
Fuel supply system	Programmed fuel injection	Programmed fuel injection
Intake system	Turbocharger and intercooler	—
Balancer shaft	Applied	—
Maximum power (kW/ r/min)	121.4 / 6 100	91.9 / 7 000
Maximum torque (N-m/ r/min)	191.8 / 5 500	125.5 / 7 000

Despite their numerous advantages, 4-stroke engines generally have a lower specific power than 2-stroke engines. To achieve top performance, high engine speed and high output, supercharging, and a large displacement were each examined as possibilities in the design of the F-12X engine. At high engine speeds, cavitation in the water jet pump causes a noticeable decline in pump efficiency. Reduction was therefore examined as a method of ensuring that engine speed did not exceed the limit for impeller use, but it was not adopted due to the fact that it caused over revving feel. Higher displacement would increase weight, and the power/weight ratio would prevent the achievement of performance targets. Supercharging, through the adoption of an exhaust turbo-charger, proved to be the method allowing achievement of the targets set for the F-12X.

Fig. 3 shows an external view of the F-12X engine, Fig. 4 shows a cutaway drawing of the same engine, and Fig. 5 gives an idea of the power performance of the F-12/F-12X. Both engines are set to deliver maximum power under 7,000 rpm, and the engine and water jet pump are coupled by a simple direct crank connection. To prevent a drop in intake efficiency in the jet pump intake duct, it was necessary to position the propeller shaft as far as possible below the bottom surface of the hull. For this reason, the crank center height has been lowered by fitting a dry sump with a shallow oil pan. The oil tank has been integrated with the front cover, and the oil pump has been built in. The oil pump is directly driven by a semi-Oldham coupling from the tip of the ACG flywheel, and features a simple mechanism dispensing with a chain and drive gears.



Fig. 3 F-12X Engine appearance

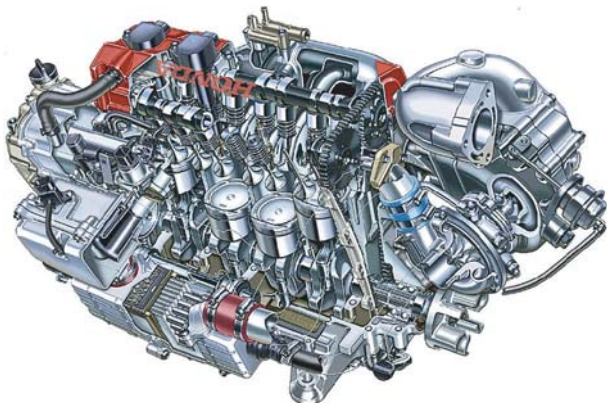


Fig. 4 Cutaway drawing F-12X engine

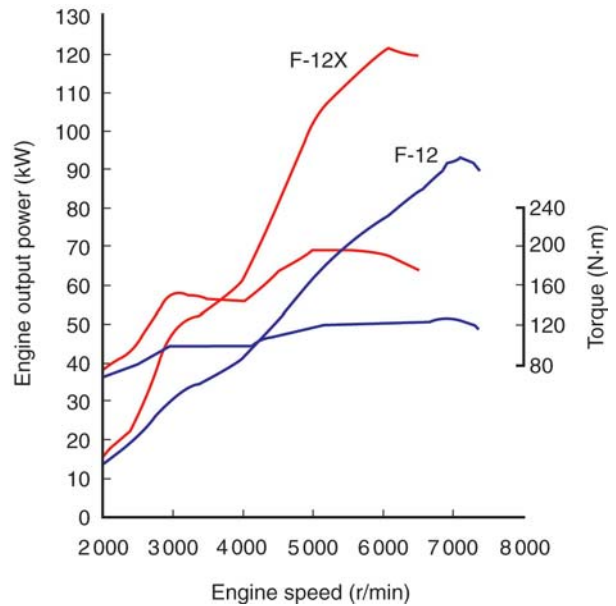


Fig. 5 F-12/F12X Engine performance

The turbo-charger utilized in the F-12X was designed specifically for this craft, and is manufactured by IHI. It is the world's first seawater direct cooling exhaust turbo-charger with an attached waste gate in this class. Fig. 6 shows a structural diagram of the turbo-charger. Because a high level of throttle response was required from the engine, low inertia mixed flow turbine blades were adopted. As Fig. 7 shows, this enabled a 22% reduction in turbine weight, and a 20% increase in acceleration of turbine speed. It has also been possible to significantly decrease turbo lag. The turbine housing is made of seawater corrosion-resistant niresist cast iron, and is provided with a water jacket which maintains surface temperature below 85 °C, even at full power with the throttle fully engaged. Turbo supercharging generates a mean effective pressure in cylinder of 2.14 MPa. To resist this pressure, the high-rigidity, fully rounded pistons are made of forged aluminum. An oil jet cooler positioned below the pistons maintains low piston temperature, and alumite treatment of the top ring channels ensures continuous high-load operation.

It was necessary to adopt measures to deal with oil flow from the breather, because of the possibility that a PWC may overturn. As Fig. 8 shows, in the AquaTrax F-12/F-12X, vertical breather chambers are located within the vertical type oil tank on the engine side and the tank side. When the craft is overturned, the oil level in the breather chambers falls below the height of the separator. This configuration ensures that oil does not flow into the breathers even when the craft is not immediately righted. Because this is a simple structure utilizing no special devices, it is highly reliable. The engine cooler is a direct-cooling type utilizing jet pump water pressure rather than a cooling water pump. The same resin top-coating corrosion-resistant treatment used for outboard motors is applied to the inner surface of the water jacket. To ensure that the cooling water jet injected into the exhaust system does not flow back when the craft is overturned, the mechanism shown in Fig. 9 was adopted to prevent flow-back from the water muffler into the engine.

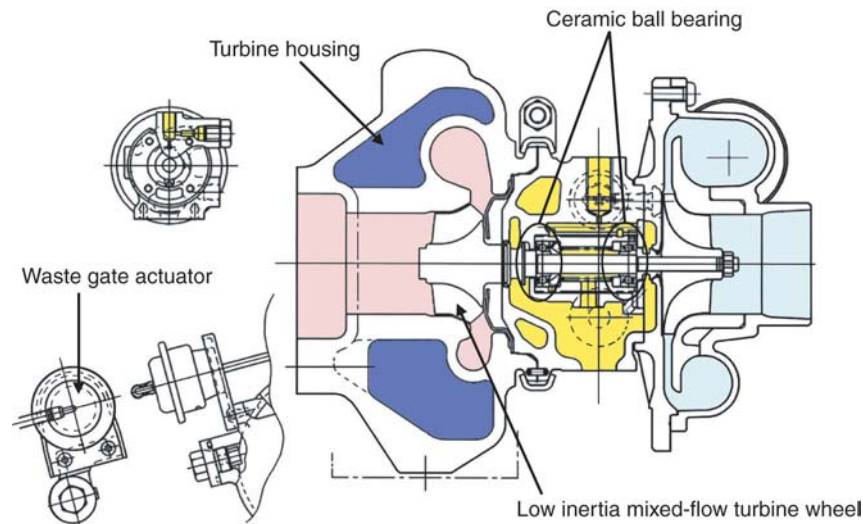


Fig. 6 Layout of turbo charger for F-12X

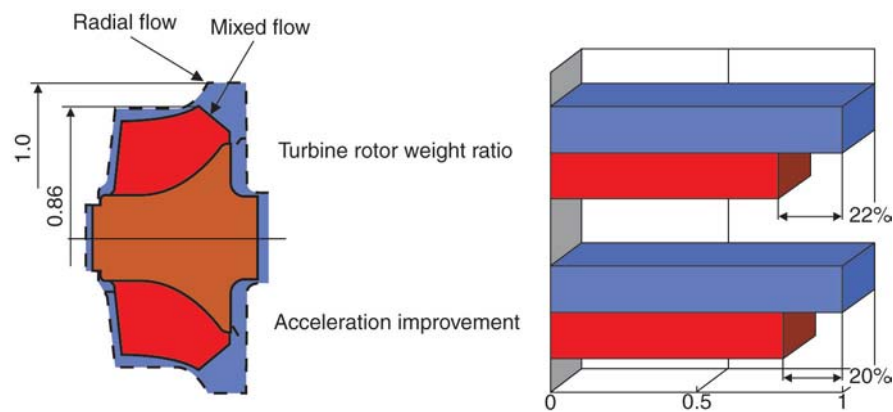


Fig. 7 Improvement of acceleration

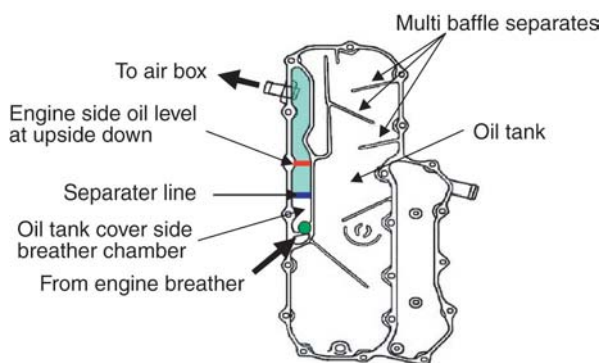


Fig. 8 Engine breather system

4. Hull

To give the craft a banking turn similar to a motorcycle, a multi-chine deep-V hull shape was adopted for the basic rise of the hull bottom (dead rise) as shown in Fig. 10. The dead rise angle was established with consideration of a balance between maneuverability and running resistance. The two left and right strakes generate buoyancy while the craft is running, and contribute to the reduction of running resistance in the hull. The design of the keel, positioned in the center and representing the lowest point of the hull, is different than that found in conventional PWCs. The curvature of the section connecting the left and right sides of the hull has been increased to enable the craft to bank easily when turning, and

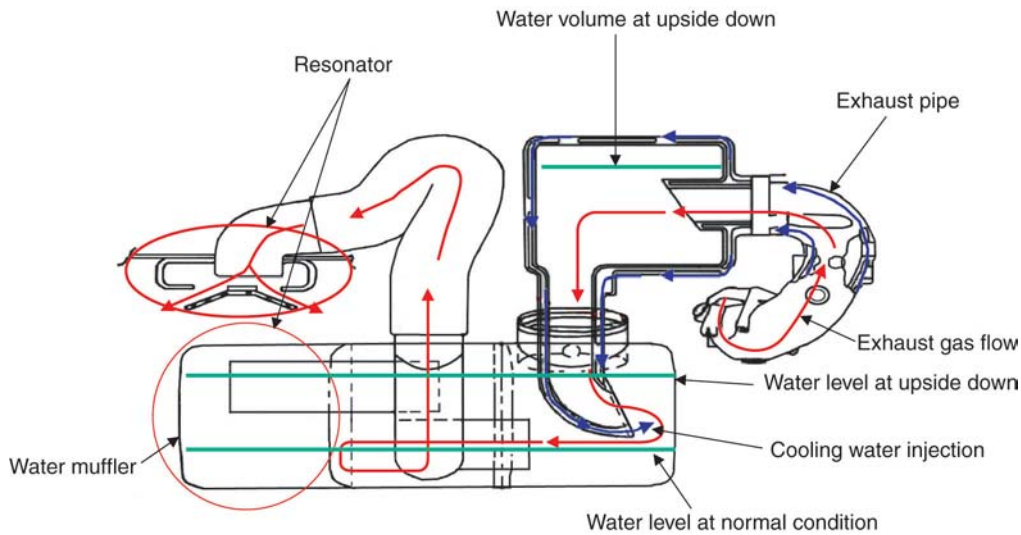


Fig. 9 Layout of exhaust system



Fig. 10 3-D Hull design

5.2 Side Panels

As shown in Fig. 12, a section of the deck underneath the seats on both sides has been designed to make it removable for easy access to the inside of the hull for maintenance. This design enables a higher level of maintenance to be carried out than has been the case in the available 2-stroke PWC.



Fig. 11 Sponson

to ensure that the direction of yaw is not excessively affected by transversal waves, etc., when the craft is in operation. The sponson fitted at the rear of the hull is effective in ensuring static stability and grip when turning. Fig. 11 shows the side flow sponson. This configuration allows the current produced under the lower surface of the sponson when the craft is turning to flow freely around the side flow section. This prevents the occurrence of sudden excess yaw rate when the craft commences its turn, and balances slide and grip during turning.

5. Deck

5.1 High Nose Form Design

To reduce the amount of splashing of the rider during operation, the craft was designed so that the bond line at the front is higher than the bond line at the rear. This design makes the external appearance of the AquaTrax different to other PWCs, giving the craft an individual identity.



Fig. 12 Side panel

5.3 Riding Position

To enable safe, comfortable steering with a sporty feel, the seat on the new PWC has been positioned higher than on other models. Fig. 13 shows the riding position for the new PWC. The height of the seats gives a riding position which makes the craft easier to control, and has increased hull turning ability, realizing the above mentioned safe, comfortable steering with a sporty feel.

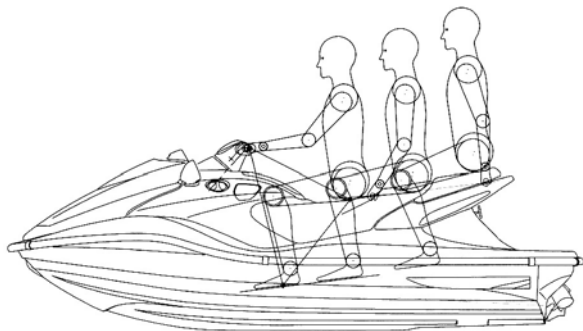


Fig. 13 Riding position



Fig. 14 Glove box

5.4 Storage Space

The AquaTrax F-12/F-12X features a 74.6 liter storage space at the front of the craft, and a 10.3 liter glove box in front of the rider. The glove box, shown in Fig. 14, has the largest capacity of any PWC, increasing ease of use.

5.5 Stern Deck

The long stern deck of the F-12/F-12X, has a flat surface making it easier to board the craft from the water, and is also convenient for towing and a variety of other uses.

6. Water Jet Pump

The AquaTrax F-12/F-12X is propelled by a single-stage axial flow water jet pump⁽²⁾ independently designed by Honda. Fig. 15 shows the structure of the water jet pump. The intake section was designed to achieve a balanced performance from low to high speeds using cavitation tunnel tests and computational fluid dynamics (CFD). The pump section features a three-blade stainless steel impeller, with a stainless steel housing. This steel has excellent wear durability. The stator has six vanes; the vanes and the impeller blades were designed with careful consideration of cross-sectional characteristics. The size of the rear internal bearings in the F-12X has been increased to accommodate the greater engine power, and these bearings also receive thrust. The jet nozzle is a straight type, and the craft is also provided with a bilge pump operating on negative pressure.

Pump matching was optimized on the basis of running tests. To respond to rapid pickup from the 4-stroke's characteristic idling to high engine speeds and sudden increases in power generated by the turbo-charger, the engine was tuned to increase absorption power in the transients. In combination with changes in engine power characteristics, this was intended to allow for the continuousness of acceleration and the feeling of initial acceleration.

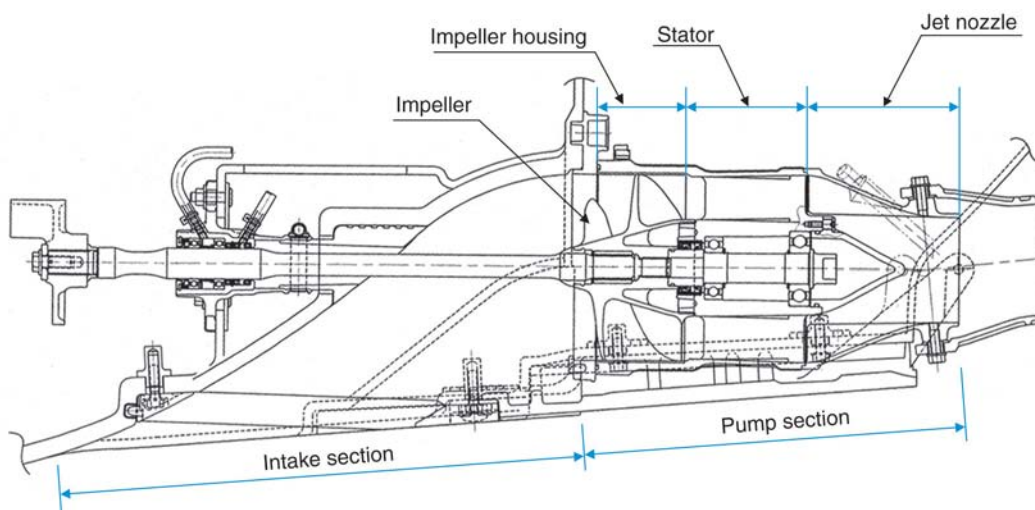


Fig. 15 Water jet pump for AquaTrax

7 Off-Throttle-Steer (OTS) System

The structural characteristics of PWC cause thrust to drop when the throttle is closed (off throttle). There are therefore situations in which riders may not be able to turn the craft in the intended direction. To provide a solution, the new PWC has been designed with an OTS system to help eliminate this possibility when turning with the throttle off. Fig. 16 shows a structural diagram of the AquaTrax F-12/F-12X throttle body.

There are two types of OTS systems: the rudder type, and the type which increases engine speed. The type adopted for the AquaTrax F-12/F-12X makes turning possible by increasing engine speed at full steering with the throttle closed. Fig. 17 shows an operational diagram for the OTS system. In this system, full turning of the steering handle with the throttle released switches on a steering switch located on the handle shaft, which activates a solenoid valve. A diaphragm releases the negative pressure built up in the surge tank, which opens the throttle valve, increasing engine

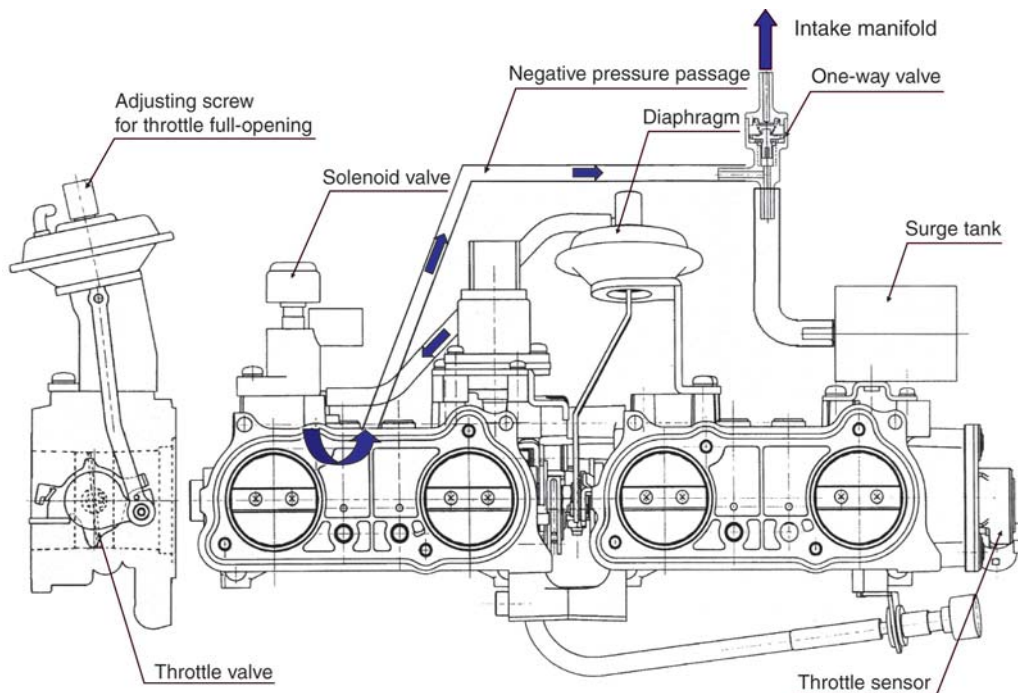


Fig. 16 OTS Construction

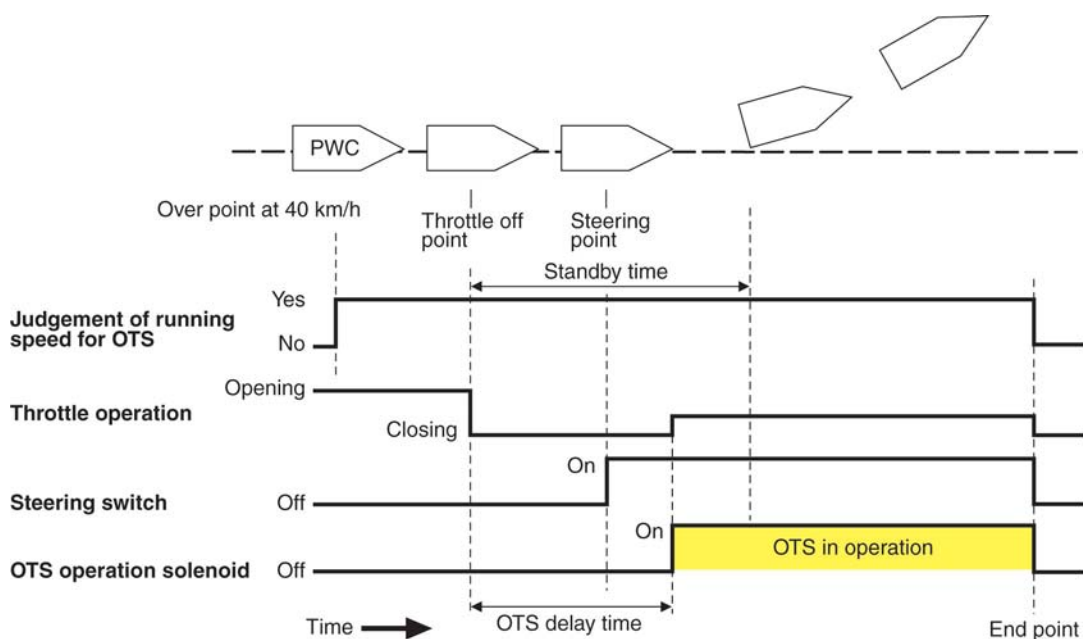


Fig. 17 OTS System operation

speed and therefore ensures turning ability. The estimated craft speed at which control will take effect is calculated in the ECU on the basis of engine speed and the degree of openness of the throttle. The craft running locus with and without OTS is shown in Fig. 18. Utilization of the OTS system ensures that the craft will continue to turn when the steering handle is being turned with the throttle closed.

8. Electrical System

The AquaTrax F-12/F-12X has achieved a balance between excellent throttle response on the one hand and high power and low emissions on the other by utilizing electronically controlled fuel injection and ignition to provide optimal control of fuel injection and ignition timing in response to running conditions. In the AquaTrax F-12X, fine waste gate control provides stress-free transients from natural aspiration at low engine speeds to high engine speeds with turbo-charger-enhanced power, in addition to incredible power at high engine speeds. The AquaTrax F-12 engine has been provided with settings to ensure ease of handling and a high level of response across the entire range of engine speeds, and offers a different but no less pleasurable experience than the turbo-charged F-12X.

The AquaTrax F-12/F-12X features a limit mode to help inexperienced users in learning to control the craft. This function can be engaged using the mode button on the multi-function meter shown in Fig. 19. Setting the limit mode limits the maximum engine speed, enabling inexperienced users to gain an understanding of the behavior of the craft under limited speed. The combination meter shows running speed, engine speed and remaining fuel on an LCD display. The multi-function meter shows time, total running time, time over a section and distance over a section. Various



Fig. 19 Multi function meter

warnings are displayed on red LED indicators and also appear on the LCD display. At the same time, the rider's attention is attracted by a buzzer. The types of warnings include fuel remaining, low battery level, abnormal oil pressure and fuel injection system malfunction. When a malfunction is detected in the fuel injection system, the LCD warning symbol and the red LED display a diagnostic code.

To provide added security, the user can also freely choose an ID number for keyless ignition, enabling him or her to lock the electronic system and prevent unauthorized use.

9. Sound Management

The AquaTrax F-12X is fitted with a biaxial secondary balancer, which in combination with the rubber mounting of the engine offers an extremely quiet and vibration-free riding experience. The turbo-charger contributes greatly to the quietness of the craft by absorbing exhaust energy, but the effect tends to be mitigated at low engine speeds until supercharging takes effect by sympathetic resonance in the water lock hose fitted to prevent infiltration of water into the exhaust system, which is a persistent difficulty encountered in PWC. To prevent these vibrations, the new PWC has been provided with a large-capacity 16.7 liter water muffler, one-third of which acts as a resonator to stop sympathetic resonance, and a water chamber fitted to the exhaust system outlet. Fig. 20 shows the water chamber when fitted, and Fig. 21 shows the resonator section. The form of the water chamber and the structure of the outlet were designed not merely to enhance driveability, but to prevent infiltration of water and increase ease of pump maintenance.

In order to achieve target performance in the natural aspiration engine of the AquaTrax F-12, it has not been fitted with a balancer. Because of this, the hardness of the rubber engine mounts has been reduced to decrease vibration. The mounts fit on to FRP plates which function like speakers to transmit vibration and noise, and therefore vibration cannot be isolated and generates noise in each section of the engine. Therefore the plate thickness of the hull side surface, the plate thickness and rib shape of the post cover, the plate thickness of the side panels and the structure and plate thickness of the rear grip were all reexamined to reduce vibration and noise.

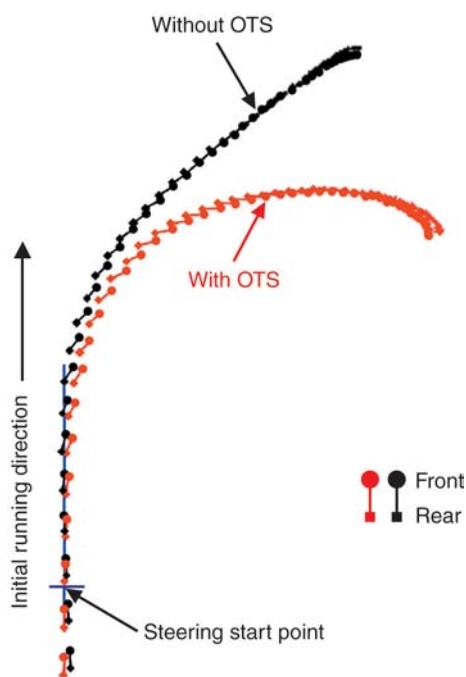


Fig. 18 Comparison of running locus



Fig. 20 Installed appearance of water chamber (Resonator)



Fig. 21 Upper view of water chamber (Resonator)

10. Conclusion

In designing its first PWC, the AquaTrax F-12/F-12X, Honda was not limited by the concepts utilized in the design of existing PWCs, and adopted a user's perspective to focus on safety, sportiness and ease of use.

- (1) A 4-stroke engine has been utilized in a PWC for the first time. This engine has been optimized for use with a jet pump, and balances superior drivability to other PWCs with environmental suitability which meet or exceed current regulations.
- (2) Honda's original hull design has realized a turning feeling like that of a motorcycle.
- (3) The F-12/F-12X features OTS and limit mode to help users to control the craft.
- (4) The F-12X engine is fitted with a turbo-charger and a biaxial secondary balancer. These features make the F-12X extremely quiet and vibration-free, giving the rider a comfortable high-speed cruising experience.
- (5) The F-12 engine's high throttle response at all engine speeds makes it easy to handle, and offers a different type of enjoyment to the turbo-charged model.

11. Acknowledgments

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