

## Improving the Efficiency of a High Speed Catamaran Through the Replacement of the Propulsion System

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**ABSTRACT:** The high speed vessels are primarily designed for short distances services as public transport of passengers and vehicles. The range of high speed, according to the Code of high-speed vessels begins at 20 knots, which depends on the cruise speed you desire for your vessel; you will have to use the most appropriate type of propellant.

In general, in the past 20 years, they have been building high-speed vessels with speeds above 33 knots, which meant installing water jet propellants coupled to powerful engines and therefore of high consumption of fuel, increasing operating costs and causing increased air pollution.

Although the prices of fuel have been reduced to half, due to the sharp fall in oil prices, the consumption of fuel and the air pollution remains high at these speeds and powers used, in addition to that the reduction of the time spent on each trip is not excessive, mainly in short routes that are less than an hour.

This article is about adapting a ship of high-speed service, with a maximum speed in tests of 34 knots and to reduce its operating costs (fuel, maintenance, etc.) and make it economically viable; before the transformation, this vessel was operating with a service speed of 22 knots, and with a consumption per mile of 135 liters of MGO.

The transformation process has consisted by:

- Replacement of the two original water jet with four shaft lines with fix pitch propeller.
- Replacement of the two original main engines (2 x 6500 kW = 13000 kW) by four engines (4 x 1380kW = 5.520 kW).
- Changing the underwater hull shape to fit the new propellers and maximize its efficiency.
- Relocation of auxiliary engines, to achieve the most efficient trim.
- Installation of two lateral propellers to improve maneuverability and shorten the total time of journey.

After the reform and the return to service of the vessel with a service speed of over 22 knots, it has been verified that the consumption per mile is of 45 liters MGO, representing a reduction of 65% of consumption and even more reduction of emissions as the new engines comply with the latest regulations.

### 1 INTRODUCTION

High speed vessels are primarily designed for short distance services as public transport of passengers and vehicles. The range of high speed, according to the Code of high-speed vessels begins at 20 knots,

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## 2 TRANSFORMATION REQUIREMENTS

Trasmapi is a shipping company that has dedicated more than thirty years to the transport of passengers between the islands of Ibiza and Formentera, with high-speed vessels. In 2013 it was decided to incorporate to the service the transport of vehicles that is when the process of finding a unit that could satisfy the requirements began:

- The journey between Ibiza and La Savina (11 nautical miles) should be done in less than 30 min. Therefore the service of speed would have to be 22 knots.
- The fuel consumption should be less than 50 l per mile navigated and operation should be respectful with the environment.
- The navigability and maneuverability skills should be appropriate to the route.

The High Speed Vessel Castavi Jet was found together with her twin (hulls 54 and 55) in the second hand market, they were built in the shipyard Austal Ships Pty Ltd in 1997. It was an aluminum catamaran used for the transport of passenger and vehicles.

These catamarans were purchased by the municipal transport company Istanbul (IDO) and operated across the Sea of Marmara, until the increase of fuel made the operation not viable economically.

The original propulsive system, figure 5, consisted in two diesel engines MTU 20V 1163 TB73L with a total power capacity of 13,000 kW actuating through two waterjet, with which they obtained a maximum speed in tests of 34 knots, on the commercial route between Yenikapi (Istanbul) and Yolava it operated at a service speed of 22 to 23 knots, well below the design, yet fuel consumption was excessive, as well as the power used, operating below 80% MCR, makes the consumption increases substantially.



Figure 1. Image of the catamarans taken during the sea trial done in Australia

## 3 ANALYSIS AND STUDY OF THE NEW PROPULSIVE SYSTEM

After a detailed technical study we came to the conclusion that the way to meet the requirements of the shipping company TRASMAPI was to purchase the high-speed vessel type Castavi Jet and make it go through a transformation that basically consists in:

Table 1. Propulsion Change

Item	Current	Proposed
Main Engines	2 x MTU 20 V 1163 engines	4 x Mitsubishi S16R MPTK
Gearbox	2 x Reintjes VLJ 4431	4 x ZF 5355
Means of Propulsion and steering	2 x KaMeWa 125 SII water jets	4 x Fixed Pitch propeller 4 x spade rudder

The proposed conversion, figure 6, will be archived by addressing the following areas:

- 1 Weight Analysis
- 2 Hull form development
- 3 Shaft line arrangement
- 4 Regulatory impacts

Other aspects of the reconfiguration involve:

- Removal of the existing ride control forward T-Foils,
- Relocation of Auxiliary engines (generating sets) from auxiliary engine room to main engine room
- Addition of tunnel side thruster into the ride control room of each hull.
- Replacement of the two original water jet with four shaft lines with fix pitch propeller.
- Replacement of the two original main engines (2 x 6500 kW = 13000 kW) with four engines (4 x 1380kW = 5.520 kW).
- Changing the underwater hull shape to fit the new propellers and maximize its efficiency.
- Relocation of auxiliary engines, to achieve the most efficient trim.
- Installation of two lateral propellers to improve maneuverability and shorten the total time of journey.

The extensive experience of TRASMAPI's technical director and the people who design high-speed vessels have been the main basis for the creation of this reform project. The fact that twin boats could be operated, as it occurs with the Fjellstrand 38.8 catamarans, equipped with water jet propulsion and fix pitch propeller, has allowed us to gather first-hand information to be able to determine the efficiency of the different propulsion systems in directly comparable models and at full-scale.

After studying the different propulsion systems, the most effective for the new service speed of 22 knots was shown with full submerged propellers with free actuation. For this reason it was decided to replace the original jet propulsion propeller with the conventional format.

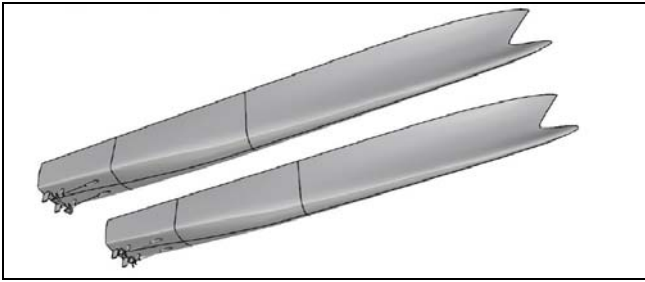


Figure 2. Image 3D model of the catamaran hulls with the new propulsive and steering.

By modifying the propulsion system investigations have been made to improve the ship's hull, so a study has been done to compare the new hull with the old one. In order to reduce the maximum the hull resistance, it was decided to extend it to 3600 mm, increasing the waterline length. As there is no need to protect the original water jets, which are changed by the new system of conventional propellers, it is possible the extension of the hull to the transom (FR 50), this modification provides a reduction in the hull resistance of 4 , 6%.

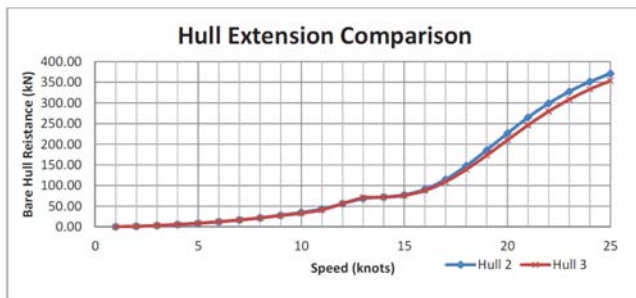


Figure 3. Hull extension comparison

In the new aft blocks, the shaft brackets and the steering system have been installed, this allows to simplify the changing process, and that can be developed in a modular way. In order to reduce the maximum the hull resistance it is decided to install single arms brackets and suspended rudders.

According to calculations performed and according to the graph of Figure 3, it was estimated that the propellers should provide approximately 350 kN, to make the first approach to the propellers, two alternatives were evaluated:

- Install two propellers, one in each hull, was the most efficient solution. But this option was discarded, the size and the weight of the propeller can generate excessive level of vibrations and noise decreasing the comfort of passengers, and increasing the loads over the aluminum structure. And the hull depth was close to the maximum depth in the route.
- Finally, four propellers was installed, two in each hull. Even it is not the optimal solution, is a workable option and the numerical models show that comply with the project specifications.

To calculate required power a conservative propulsive efficiency of 60% which encompasses both propeller and mechanical losses is used until further information is available from the propeller manufacturer.

Knowing the brake power delivered, the resistance is interpolated to obtain a speed using the following equation

$$\text{Power (kW)} = \text{Resistance (kN)} \times \text{Velocity (m/s)}$$

The new main propulsion engines to be Mitsubishi S16R-MPTK producing 1380 kW at 1650 rpm to archive the vessel speed requested of 22 knots, four off engines will required to deliver sufficient power.

For full load condition a vessel speed of 22, 39 knots is predicted at 100% MCR (5520 kW) in sea state 0 at level trim.

The following appendages have been included in calculation of total resistance:

- 4 off rudder
- 4 off shaft
- 4 off shaft support brackets with strut boss
- 2 off bow thruster

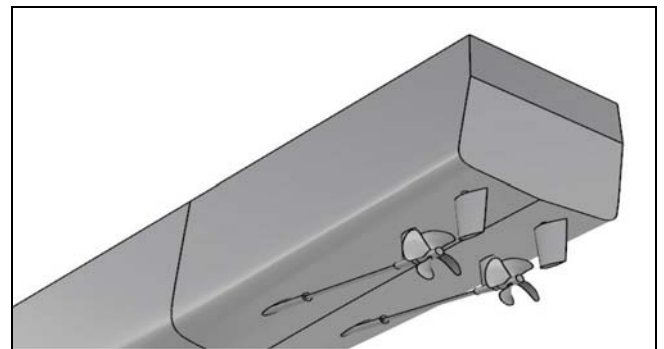


Figure 4. Image 3D model of the propulsive system layout and steering.

By installing two propellers per hull special attention is required so no undesirable interactions occur between them, decreasing their performance and generating unwanted effects like noise or vibrations. It is determined that the optimal diameter for each propeller is 1575 mm and the minimum shaft separation has to be of 2200 mm.

As it is a vessel designed to have a single propeller per hull, the problem that arises is that the two motors do not fit in the engine room with a separation of 2200 mm between crankshafts. In order to accommodate the engines is decided to reduce the distance between them in 300 mm by using a drive shaft between the gearbox and the main engine.

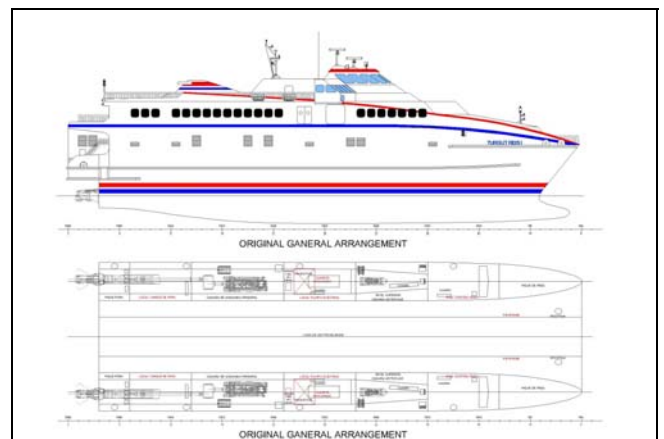


Figure 5.-Original general arrangement

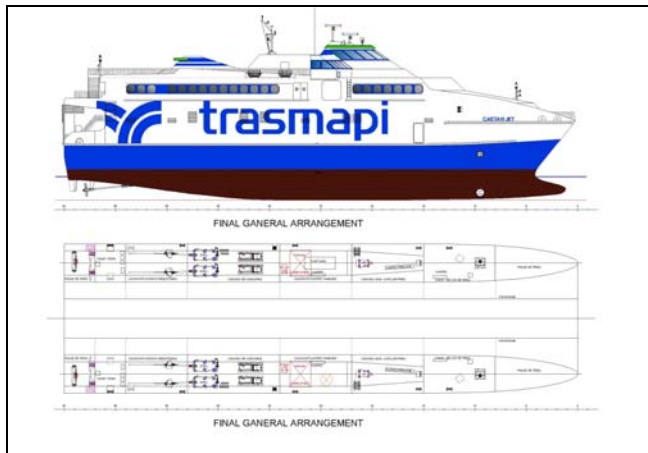


Figure 6.-Final general arrangement

#### 4 RESULTS OBTAINED WITH THE TRANSFORMATION

The new propulsive system ( four fixed pitch propellers ) two per hull, combined with the four rudders and the side thrusters, gives the boat a remarkable maneuverability, allowing it to perform the docking and undocking maneuvers safely in conditions with adverse weather, achieving that the operation is done in a reduced time. Keep in mind that the ship can carry out daily about 20 maneuvers in narrow docks, with congested traffic and with little depth. Therefore in order to be able to perform efficiently and safely the vessel requires to have a great maneuverability.

By reducing the propulsion power there has been a weight saving with the four new engines MHI S16R with regards to the two existing motors MTU 20V1163, yet even having a new equipment (engines and side thrusters, loading facilities, etc.) a reduction in weight has been obtained in the light weight of around 2%, leaving the light displacement in 490 t.

The sum of different factors like:

- The installation of a propulsion system (FPP) optimized for the service speed.
- The increase of the waterline length and therefore on the number of Froude.
- To improve the hull shape to maximize the propeller performance.
- To reduce the light weight.

Optimizing the energy efficiency of high-speed craft covered by this article has been feasible.

That vessel, in its original conception, obtained in trials sea with maximum speed test of 34 knots, although to contain its operating costs (fuel, maintenance, etc.) and make it economically viable, their owner operated by a service speed of 22 knots, with a consumption of 135 l per mile of MGO, this consumption comprising consumption of main and auxiliary engines .

After the return to service of the vessel after the reform and with a service speed of over 22 knots, it has verified that the consumption per mile is 45 l MGO, this include consumption of main engines and the auxiliary, which represents a 65% reduction in

fuel consumption and emissions even as new engines comply with the latest regulations of MARPOL Annex VI.

#### 5 NEW EEIO

As regards the Energy Efficiency Operational Index EEOI the ship before and after transformation would be:

$$EOI = \frac{\sum FC \cdot EF}{GT \cdot D}$$

where:

- FC : Fuel consumption of main and auxiliary engines
- EF: Emission factor of the fuel used in kg CO<sub>2</sub> / GT x NM.
- GT : Vessel's tonnage in tones.
- D: Distance in nautical miles.

EEOI for the ship before the transformation, for fuel consumption of main and auxiliary engines per nautical mile, gives a value of 0.1381 kg CO<sub>2</sub> / GT x NM.

The ship EEOI once transformed and changed its propulsion system for new fuel consumption of engines and auxiliary engines, gives a value of 0.0452 kg CO<sub>2</sub> / GT x NM.

This means that the transformed ship produces three times less CO<sub>2</sub> per GRT and nautical mile sailed than the ship with the original propulsion power.

Given that the ship has approximately 2,000 hours effective work with the new propulsion system, the vessel would consume approximately 3406 t of fuel less, which for the purposes of pollution greenhouse gases such as CO<sub>2</sub>, stop polluting the year about 10100 t of CO<sub>2</sub>.

#### 6 CONCLUSIONS

- 1 The high-speed vessels with water jet propulsion systems in order to maintain a high propulsive efficiency have to navigate at speeds above 33 knots, making unviable operation at lower speeds to reduce fuel consumption.
- 2 The high speed for short and medium distances is insufficiently substantiated by the high level of pollution produced and the short time savings.
- 3 High-speed vessels that were built in times of low fuel cost can be converted to operate at a slower speed, and keeping the classification of high-speed vessels, changing their propulsive water jet system by the traditional propeller pitch fixed and with a high reduction of fuel consumption.
- 4 Reducing the speed of high-speed vessels changing the propulsive system, allows a more economical operation of the vessel and meets the objective of the IMO to reduce the production of greenhouse gases on ships.
- 5 Maintaining a minimum consumption of the propulsion plant and auxiliary engines, it allows prolong the life period of high-speed vessels,

without being affected, too much, due to the increase in fuel prices.

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