# HYBRID SAILBOAT: PROPULSION MODELLING AND ENERGY GENERATION POSSIBILITIES

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*Abstract - This paper shows the modelling and energy generation results obtained during sailing with a hybrid ship in the generation phase. A normalized course and wind condition was settled. The different vessel components were mathematically modelled: hull, propeller and interaction between them. Several simulations were perform sailing to evaluate available power to use in energy generation, optimal propeller operation set point, ship speed variations, generated energy at different thruster speeds with every apparent wind angle. Sailing with 15 kt wind speed, the maximum generated energy was 0.924 kWh in 8.1 nautical miles. The ship speed reduction was 11 %. The maximum available power was 909 W. The propeller speed control can improve the generated energy. Presented energy recovery strategy, helps to reduce hybrid sailboat fuel consumption and emissions, compromising navigation speed about 10 %.*

*Keywords Control system, Hybrid, Modelling, Sailboat.*

## INTRODUCTION

A hybrid ship is a vehicle which can use, for propulsion purpose, two or more methods of energy storage: hydrocarbon, electric storage battery, hydrogen, inertial wheel, supercapacitors and so on. Really, one or several internal combustion engines (ICE) are coupled to electric generators and/or shaft propeller, using tank fuel energy. In addition, it is possible to use the storage energy in electric batteries by electric motors to rotate the propeller/thruster. Sometimes it is able to recover and storage the waste kinetic energy from stopping manouvers or when she is navigating under sail. Further, that energy will be used in propulsion or manoeuvring .

This paper shows the modelling and energy generation results obtained during sailing with a hybrid ship in the generation phase. Our reference ship was the University of the Basque Country training ship "Saltillo". A normalized course and wind condition was settled. The different vessel components were mathematically modelled: hull, propeller and interaction between them. Several simulation were performed sailing to evaluate available power to use in energy generation, optimal propeller operation set point, ship speed variations, generated energy at different thruster speeds at different wind angles.

## OBJETIVES

The aims of the work were:

- To establish a normalized course and wind condition to compare different generation strategies in the same scenario.
- To model mathematically the different vessel components: hull, propeller and interaction between them. Integrate all components by software for feed-forward simulations.
- To evaluate available power to use in energy generation
- To calculate optimal propeller operation set point
- To determine ship speed variations due energy generation.
- To compute generated energy at different thruster speeds with every apparent wind angle.

## RESULTS

Several simulations were performed to calculate the available power to generate energy with the propeller versus its rpm for different sailing conditions (Figure 6). A negative power value means energy flow from propeller to propulsion plant. The considered wind speed was 15 kt in all cases. Sailing between WP1-WP2 represent the condition close ridged 60º to true wind and the best generation situation was achieved at 112 rpm with Pmin=-375 W. Sailing beam reached (90º) to true wind (WP2-WP3) the best state of energy generation was Pmin =-590 W at 124 rpm. Finally, was evaluated sailing broad reached (150º) to true wind with Pmin =-909 W at 151 rpm.

After the best propeller operations points were calculated for each ship sailing direction, another set of simulations were performed over WP1, WP2 and WP3. For this sailing course was calculated total generating energy, ship speed, propeller thrust and hull required thrust. When the ship is arriving to WP1, just mechanical propulsion was used (section 1 in figure 7). The propeller thrust was equal to hull required thrust and the ship speed was constant. In section 2 only sail propulsion was used and propeller speed was adjusted to 112 rpm, being the propeller thrust negative. The available power to use in energy generation was -375 W in the axle of the prime mover and the vessel speed was 4.49 kt. Between WP2 and WP3 the wind thrust increase, the propeller set point was 124 rpm and achieved ship speed of 5.22 Kt. In section numbered as 4, the ship had the highest wind thrust, the propeller rpm was adjusted to 151 rpm, getting speed of 6,07 kt with -909 W. For each device of the ship energy chain, i.e., prime mover, power electronics, batteries, etc, efficiencies would be applied to get final energy storage.

The differences in ship speed (kt) between sailing with zero propulsion thrust and sailing with energy generation in best rpm set point are represented in the figure 8. The speed reduction was regarding 10-11 %.

The maximum available energy for the proposed wind speed and course was 0.924 kW over 8.1 nautical miles using previously calculated propeller optimum speed set points. For other thruster speeds, the obtained energy was less, being not much significant until 10 % rpm variation.

## CONCLUSIONS

As conclusion of the presented work can be say that the proposed experimental course and wind condition were very useful to compare different generation strategies in the same scenario. The mathematical model of sailboat based on integrated model approach architecture is a powerful tool to reduce developing time in the hybrid sailboat design. The available power to use in energy generation is significant and useful to energy generation, incremented in longer tracks sailing under sail exclusively. This power was highly dependent of the propeller rpm operation set point. An advanced control algorithm is necessary to maximize energy generation. The ship speed variations due energy generation were significant, about 10 %. Presented energy recovery strategy, helps to reduce hybrid sailboat fuel consumption and emissions, without compromise navigation speed. The positive results obtained from these simulations will be continued capturing navigational data by means of instrumentation already installed on board training ship "Saltillo". Tests at sea are going to be carried out on 2011.

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