"A-TIRMA G2: An Oceanic Autonomous Sailboat"

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A-TIRMA G2: an oceanic autonomous sailboat

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Abstract

This paper describes a new design of a 2 meter LOA (Length Over All) autonomous sailboat conceived for sailing in an ample set of weather conditions. The design has been focused on robustness and on achieving some degree of redundancy on critical components like sails and rudder. Accordingly, it is equipped with two light-weight carbon fiber wing sails and two slanted rudders protected by skegs. Its stability curve is fully positive, so she is capable of recovering autonomously from capsizing.

1 Introduction

The design of an unmanned sail boat, specifically conceived for sailing in an ample set of weather conditions, implies to take into account many particular factors to make it adaptable and flexible enough for distinct situations without human intervention. This could be done using complex and costly electromechanical systems, simulating the maneuvers typically performed by a crew. All this to keep the necessary balance between sail surfaces and and wind speed. But, in the typical conditions found at sea, the probability of something going wrong is really very high. To minimize problems or the effect of complete breakdown of some elements, we might look for a flexible design and duplicate all elements and systems on board, in order to keep the boat sailing, even in precarious conditions. In addition, there are other problems to

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take into account, like avoiding marine traffic, or encountering floating debris or algae which might diminish the navigation capacities of the sailboat.

On the other hand, when designing an unmanned sailboat, there are some meaningful requirements present in a traditional vessel which are not necessary to fulfill, mainly those aimed to guarantee the habitability and maneuverability of the boat for the crew.

In this paper we will describe the design principles that have guided the design of the next generation of our boat A-Tirma [1, 2]: A-Tirma G2 (Generation 2). A-Tirma, on its first generation [1] was based on a commercial one-meter low cost RC boat (in Figure 1 we can see both sailboats side by side in our laboratory). The motivation behind this initial approach was to get an affordable open experimental platform which could serve as test bed for the development of navigation algorithms for sailboats. A-Tirma G2 design tries to surpass some of the limitiations of the previous prototype, specially a better behavior in harsh conditions. On the other side, we got to a point with the fist prototype where there was no more room for payload on it. A-Tirma G2 is bigger in size having a length of 2 meters, allowing for loading more equipment on board. And in relation to its physical design, it is a new design developed from the scratch, where not having a deck and being provided with two wing sails are its main feaures.

2 Vessel's description

The length of a vessel, not devised for gliding, conditions strongly the speed it can reach, as the speed is a function of the resistance by wave formation, and inversely proportional to the vessel's length. A greater length improves sailboat's navigation behavior, being less influenced by the impacts and thrust waves produce. Being said that, the length chosen for our design is mainly restricted by the practical aspects of having a prototype at a lesser scale, more manageable and economical. In Table 1 we can see the main dimensions of A-Tirma G2, and in Table 2 the more important properties related to its design. Figure 2 a perspective of the design is shown, and in Figure 3 a profile and the curve of sectional areas and other hydrostatic data.

Dimension	Value
Sketch length	2.000 m
Total length	1.985 m
Sketch beam	0.370 m
Maximum beam	0.488 m (including skegs and rudders)
Sketch draught	0.628 m

Table 1: A-Tirma G2's main dimensions

Fig. 1: A-Tirma G1 and G2

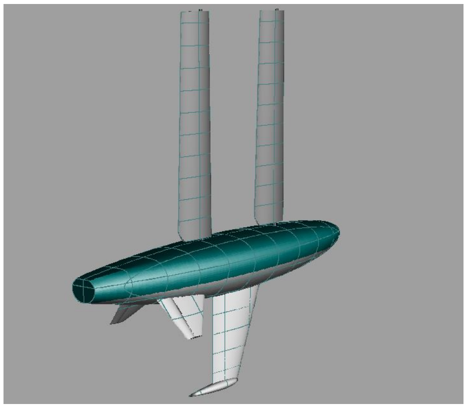

Fig. 2: A-Tirma G2 perspective. Cilindric section, two wing sails and two 40º rudders with skeg

A-Tirma G2 has a length overall (LOA) of two meters, and in opposition to A-Tirma first generation, it is provided with two wing sails. In Figure 4 is shown a stern view of the boat. Its design has been conceived with a stability curve which is positive for all heel angles, as we can observe in Figure 5. Furthermore, its smooth slope produces a relatively soft behavior when an increase in wind speed makes her heels. Due to its nearly cylindric hull shape, the curve has a relatively smooth slope, and it does not has a large righting moment for the first 85 degrees of heeling, obtaining a relatively smooth response to heeling efforts due to the action of wind on the sails. This contributes to reduce the stress on rigging.

The keel is a trapezoidal NACA63-009 [3] profile with a retracted bulb with a NACA 0012 [3] section, optimized to avoid entanglement with floating debris and seaweeds.

For heeling angles of 90 degrees or more, wing sails contribute to prevent capsizing and facilitate the boat to get to an upright position, in case of capsizing due to a wave. In addition, in order to have a better resistance to capsize and more directional stability, A-Tirma G2 presents a proportional bigger lateral surface resistance than many actual boats due to its skegs and keel, although at the cost of sacrificing some speed due to an increase in drag.

The efforts to improve the directional stability for all wind intensities and heeling angles, allow to optimize the power consumption dedicated to govern the sailboat.

The behavior of the torque produced on a classic sailboat with a single rudder is different from A-Tirma G2. The *LEAD*, longitudinal distance between the center of lateral resistance and the center of efforts on the sails, should

Volume properties	
Displaced Volume (Vol.)	0.042 m^3
Displacement (Dsp.)	0.043 tonnes
Area of wet surface (Sw)	1.224 m^2
Length pos. of hull center (LCB)	1.021 m
Length pos. of hull center (LCB)	2.458
Transverse pos. of hull center (TCB)	0.000 m
Vertical pos. of hull center (KCB)	0.562 m
Middle section properties	
Middle section area (Sm)	0.077 m^2
Waterline properties	
Length in waterline (Lwl)	1.946 m
Beam in waterline (Bwl)	0.367 m
Waterline surface (Swl)	0.543 m^2
Length pos. center of waterline (XF)	1.008 m
Transverse pos. center of waterline (TF)	0.000 m
Entry angle (Beta)	1.434^o
Transverse moment of inertia (It)	0.003 m^4
Longitudinal moment of inertia (Il)	0.099 m^4

Initial stability	
Transverse metacentric height (KMt)	0.637 m
Transverse metacentric height (BMt)	0.075 m
Longitudinal metacentric height (KMl)	2.907 m
Longitudinal metacentric height (BMl)	2.345 m
Lateral plan	
Lateral area	0.322 m^2
Longitudinal pos. of center of efforts	1.040 m
Vertical pos. of center of efforts	0.436 m
Features of hull above waterline	
Lateral wind exposed area	0.720 m^2
CoG's z coordinate of wind exposed area	1.063 m
CoG's x coordinate of wind exposed area	1.050 m
CoG's x coordinate of wind exposed area	1.050 m
Distance from bow of wind exposed area CoG	0.896 m
Weight: 0.043 t	
CoG X: 1.021 m CoG Y: 0.000 m CoG Z: 0.469 m	

Table 2: A-Tirma G2's properties

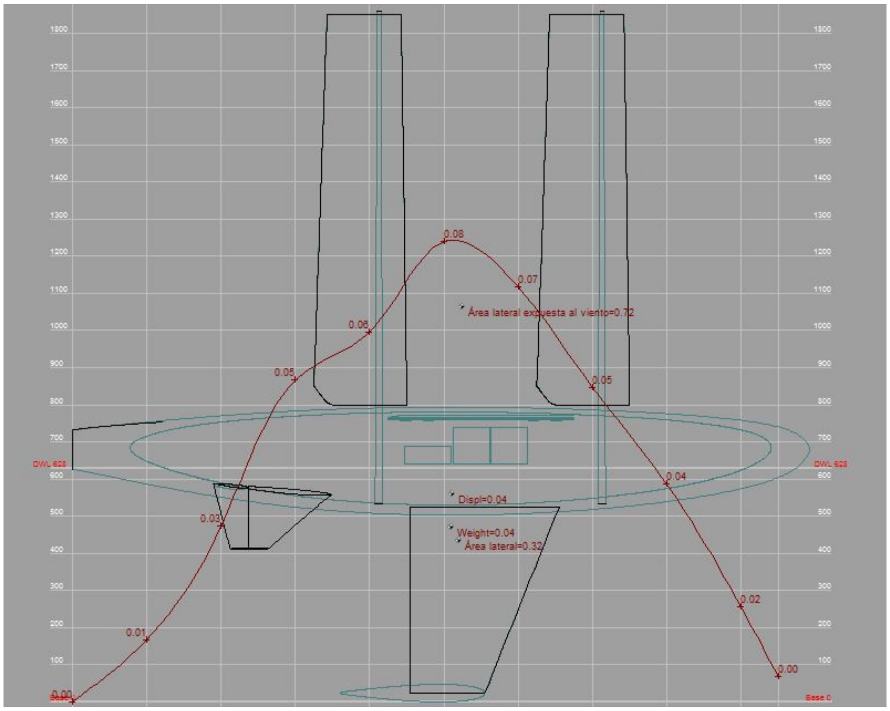

Fig. 3: A-Tirma G2 profile view and its curve of sectional areas and other hydrostatic data

be studied for an optimal point of heeling, at which the torque is canceled and the rudder keeps amidships. A-Tirma G2 can not reef their sail to set her heeling. On the contrary, it has two rudders and skegs that move aft the

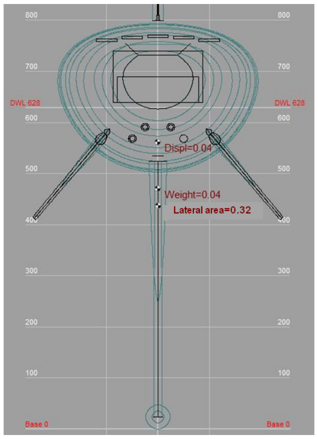

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Fig. 4: A-Tirma G2. Stations view

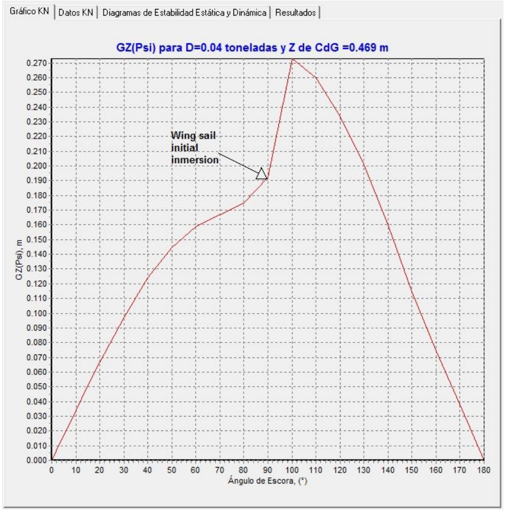

Fig. 5: Righting arms curve. At 90º of heeling, the wing sails touch water and the keel exists. Right arms increase rapidly (design created using FREE!Ship 3.30+)

CLR when the boat is heeling. This contributes to cancel the weather helm and improve course stability (Figure 6).

Each rudder will actuate in a given range of heeling angles at each side, overlapping its actuation at 5 degrees on each range. Both rudders, albeit effective only when sailing heeled on one side, allow to reach a long term final goal, even under precarious navigation conditions. In Figure 7 we can observe how only one rudder actuates for high heeling angles.

Wing sails have been built on carbon fiber using a symmetrical NACA 0009 [3] profile with a wingspan of 1.05m and mean of chord of 0.225m, equivalent to an aspect ratio of 4.6.

The choice of two semi-balanced or compensated wing sails follows several objectives. Namely, like using two rudders, they allow to keep navigating in case of breakdown of one of them. Moreover, two sails instead of one, with equivalent surface, produces less heeling moment as the sail plan center descends. Thus, the behavior downwind and in strong winds is improved. Also compensation contributes to minimize power consumption, as it reduces the torque needed to trim them.

Benatar et al [4] have demonstrated that a rudderless sailboat with a double mast configuration can be headed using only the sails. Considering this possibility, a rig of two wing sails may also be interesting as a final resource for steering the boat in case of total failure of the rudders.

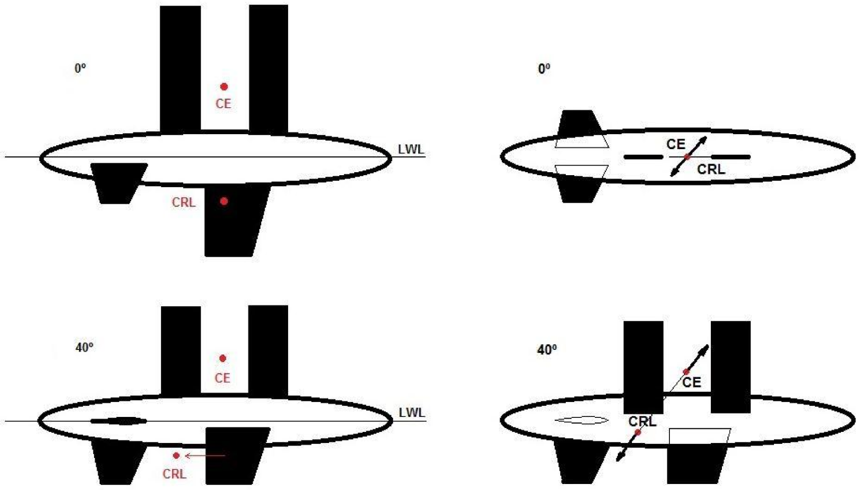

Fig. 6: A-Tirma G2. Sketch of the approximate equilibrium of forces, generated on the sails and the lateral resistance at 0º and 40º degrees of heeling. The configuration of skegs and rudders provides an equilibrium of moments in a wide range of heelling angles. On the figures, CE is the Center of Efforts on the sails, and CRL is the Center of Lateral Resistance

Note also that for navigating downwind, rigid sails are more efficient than cloth sails on any standard rig because at this point of sailing, cloth sails produce thrust entirely by drag, which clearly depends on the magnitude of the apparent wind. On the other hand, when sailing downwind using wing sails, thrust is obtained from lift and, maybe, also from drag. Figure 8 illustrates both situations.

In relation to the drive system for the wing sails, having a system under deck would have been preferible, being free of possible entanglements with floating debris and algae. Nevertheless, in this first operating prototype of A-Tirma G2, we have installed a traditional sheet system for RC (Remote Controlled) sailboats based on a servo with a drum.

3 Summary

This paper has described the main elements of the A-TIRMA G2 and the rationals that have determined the current design. We think that a 2 meter LOA offers a good balance between building costs and navigational capabilities, including the possibility of integrating interesting payloads. At the same

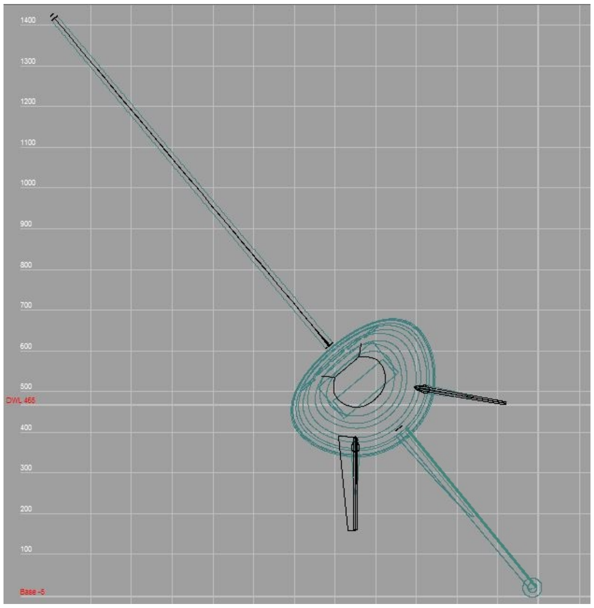

Fig. 7: A-Tirma G2. Only one rudder actuating for a heeling of 40º degrees

time, the 2 meter LOA starts to be considered as the legal limit for slow unmanned surface vehicles at sea.

At the moment, A-Tirma G2 has been built, finished and has passed initial sea trials in low wind conditions and RC mode (Figure 9). We are currently working in the adaptation of the A-TIRMA G1 control system to the new features of the G2. It will be running on an embedded real time operating system, ChibiOS/RT [5], where the control system of A-Tirma first generation has been improved and ported to a hardware platform with better computational resources [6].

Work in the close future will be directed towards validating the control system and the navigational capabilities of the new boat under different sea conditions.

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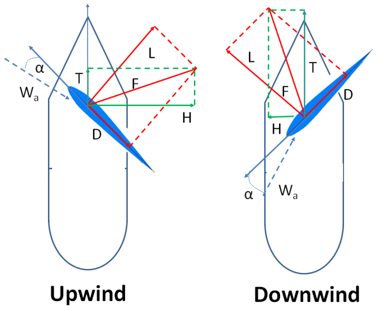

Fig. 8: Wing sail configurations for sailing upwind and downwind, where W_a is the apparent wind, alpha is the angle of attack of the profile with respect to apparent wind, L and D are the lift and drag produced by the wing profile. R is the resultant force that decomposes in H, a heeling component, and T, the thrust that effectively propels the vessel

Fig. 9: A-Tirma G2 prototype during its first trial at sea

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