KEELCRAB™

Keelcrab MaxiCrab, theory and practice: differences between design and testing

Regione Lombardia PSR 2014 2020

July 27th 2022. On a torrid summer afternoon, the Keelcrab R&D team moves to Genoa for the first day of testing of MaxiCrab; after months of hard work, tests, calculations, prototype design and simulations, the fateful day of truth has arrived; will it work?

Having acknowledged that all the preliminary test phases in laboratory and in a simulated environment gave positive results, we know from experience that the difference between testing our robots in a simulated environment or actually on the hull of a vessel is similar to the difference between attempting to land a Boeing 737 in DastyFlySim (perhaps one of the leading flight simulators in Europe) or on the Malpensa runway on a foggy day in December.

First of all, a couple of due clarifications:

MaxiCrab is the new underwater drone for cleaning yacht hulls; it is the evolution of another product, Keelcrab, the drone for cleaning pleasure boat hulls, already produced and sold by Aeffe srl in more than 50 countries in the first five years since market launch.

The maxiCrab prototype, built and ready for testing, is a new model of underwater drone with enlarged dimensions and advanced functions, designed for cleaning yachts long from 24 to 50 m. This new prototype is therefore characterised first and foremost by greater physicality and relative cleaning capacity, but also by greater adhesion power to the hull thanks to a dual suction pump system, new electronic board, additional digital functions to support the operator, and a revised design following new modelling.

Tech Fast: a financing program proposed by the European Regional Development Fund in Lombardy; Aeffe S.r.l.'s project was awarded as the best bidder in the region, confirming its desire to bring Lombardy's excellence in the mechatronics sector to the world. The MaxiCrab project, ID 3156753, was 50% co-financed with public funds from the Tech Fast call of the ERDF 2014-2020 in partnership with the Lombardy Region and the European Union.

Returning to the group heading to Genoa on the day of truth, the debate centred on a commonplace of mechanics and design according to which "in general terms" a proportional and total reduction of

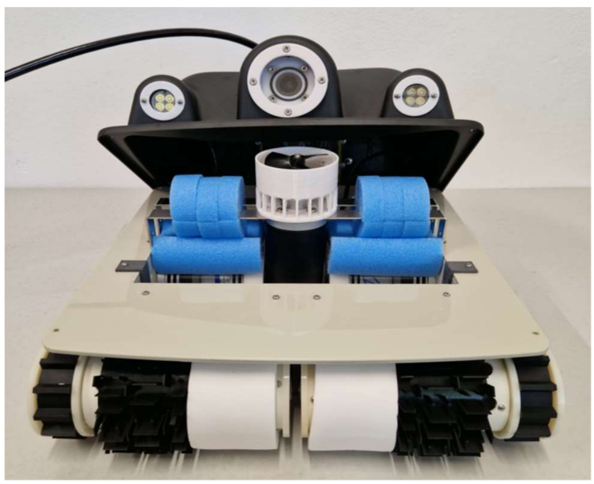
Aeffe srl
sede legale a Como 22100, Via Rezzonico 39
Sede operativa a Bulgarograsso 22070, Via Ferloni 28
P.IVA & CF: 03385790138
Codice SDI: W7YVJK9
www.keelcrab.com

the physicality of a complex mechanical object generates a far greater design and prototype effort than its enlargement; in simple terms, in our case a MiniCrab would be far more difficult and sweaty than a MaxiCrab, or in other words: the mechanical multiplication factors in the enlargement would

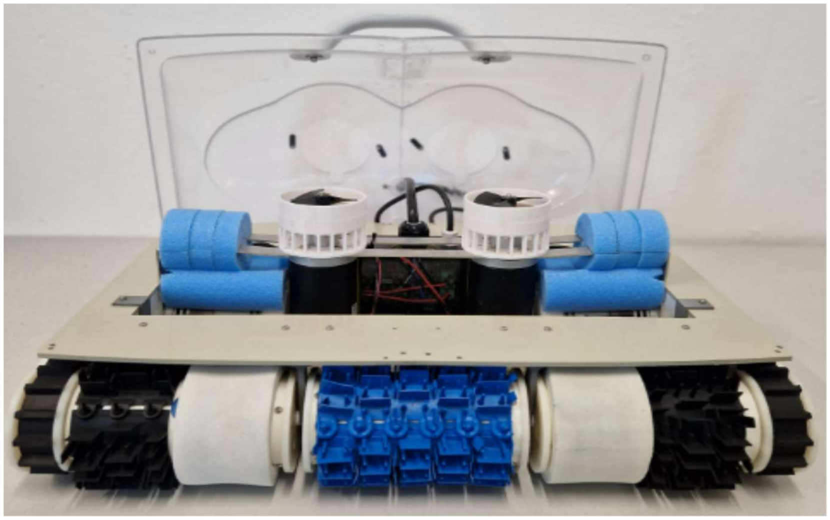
be less complex to manage with respect to divisive factors in downsizing a precisely mechanical complex object.

The doubt is substantial, well-founded and legitimate, and especially when I think of a multiplier of overall effort on a possible MiniCrab, compared to the huge efforts made to put our first MaxiCrab in the water, I feel like changing the company's core-business... but let's get back to the test: we are ready on the jetty with MaxiCrab already extracted from its ip67 transport case, the power cable promptly unrolled on the jetty, electronics box connected to the column and remote control tested and ready to use. We lower the drone into the water using the Kevlar-reinforced power cable, and here the first big test: is MaxiCrab's hydrostatic trim correct? Our 'zero', the gold standard, yardstick and reference for the validation of the prototype is clearly the-Keelcrab (the 'starting' version already on the market, dedicated to smaller boat hulls). Keelcrab has a neutral-positive hydrostatic buoyancy (studied and improved over the years) since it is equipped with a calculated and correct quantity of closed-cell foam material inside some of the drone's mechanical components, to balance those with a negative specific weight in immersion and guarantees a correct neutral-positive buoyancy for us; this is fundamental for the specific activities that the drone actually performs: going straight while advancing (more generally, obeying commands) without being subject to exogenous thrust vectors that modify trajectories while it is engaged in cleaning an irregular surface such as a boat hull all at varying depths.

In the design of MaxiCrab we mainly varied the X-axis (its width) by increasing it by 60% and generating an overall weight increase out of the water of 35%; so, we started by adding +35% floating foam (in the handling and frame rollers / as for the-keelcrab) applying a simple mathematical proportion. Result: as soon as it was lowered into the water, our MaxiCrab, instead of proving to be a neutral-positive object, sank like a submarine, immediately making us realise that reflection was necessary, a robust correction of the amount of floating foam installed in the mechanical components and the study of the correct relative application (in order to avoid problems of variation in the centre of gravity) before proceeding with the engine start-up and hull adhesion tests. What in the mathematical proportion of hydrostatic trim calculation have we missed? The answer is complex and certainly lies in the concept of specific weight and the difference in the behaviour of a body surfaced or immersed in liquid; the difference is between the simplicity of the theoretical model adopted and the complexity of the real environment. Having become aware of the problem, we began with changes to the robot's hydrostatic buoyancy by adding buoyant material, taking great care with the relative positioning (so as not to vary the barycentre and metacentre of our prototype and thus anticipating and avoiding buoyancy problems in a state of navigation with suction pumps active) increasing proportionally by +10% at a time (testing the result step by step every time in immersion) until reaching the desired hydrostatic buoyancy only on the third attempt. Result = weight of Maxicrab +35% (compared to the-keelcrab) buoyant material added +65%; to compensate for the hydrostatic buoyancy, more than twice the amount of buoyant material initially assumed was added.



Having thus found an apparently correct hydrostatic set-up, we set about to recalculate the robot in the water and operate the pump motors in order to test its centre of gravity with active pumps, but above all its overall suction on the hull. In the MaxiCrab version, unlike the basic version the-keelcrab, there are 2 suction motors installed:



Even in this case, although we relied on a reasoned mathematical proportion according to which the increase in the flow rate of the pumps must not be double (maxiCrab is not twice as large as the-keelcrab) but parameterised this time on the X-axis basis of maxiCrab (i.e. its width), there was no shortage of surprises. Following the above-mentioned criterion, the decrease (in volts) in the electronic management of the single motor led to an overall increase of 70% in the water flow rate of the pumps, compared to the-keelcrab (since it was generated by 2 combined motors). Result: once the pumps were switched on and the drone was positioned just below the waterline of the test yacht, the suction generated was so high that the drone could not be moved by the traction motors. In fact, MaxiCrab was so attached that the traction motors struggled to move the drone on the surface of the hull, as if there was an arm above the hull compressing the drone towards the hull and sending the motors into protection because they were overcurrent. In this case, as in the previous one, there could have been a functional response at a theoretical level, but this was not supported by the actual analysis of the behaviour in hull tests. Result: 50% reduction in the overall pump flow rate (estimated 30%) compared to the nominal flow rate at 24 volts with a clear advantage in terms of efficiency of the drone's current consumption function and MaxiCrab in correct suction with traction motors slightly under stress but within the limits of use.

After modifying the firmware and adjusting the power delivered to the pumps, we proceeded to the start of the planned test session by verifying and filming the prototype both by means of visual behavioural analysis (especially during the phases in which the drone was working on the waterline) and by means of display and in ARA trim (with tanks and GAV).

In spite of the brush changes, some additional electronic set-up in the handling of the vertical parts of the hull, we experimented a slight heating of the traction motors after more than 4 constant hours of use, problem resolved with the installation of brushless traction motors on the subsequent prototype version. After that, the test session was very positive overall. MaxiCrab turned out to be well controllable, not subject to any particular exogenous thrust vectors during navigation, with excellent cleaning capabilities; suction factor was well balanced, with appealing marketing terms, the child of the economies and hydrostatic advantages obtained through the use of the combined dual pump system.

Despite the fact that the day enlightened us on how theory alone is never enough to reach the effective results, or even before that the product concept, the most comforting element of this positive test session certainly remains the speed with which the Keelcrab team understood and promptly solved all the operational problems highlighted during the tests.

This skill for immediate reaction is very strong if compared to the birth of the first the-keelcrab for which it took months and years. This is certainly a fortifying and motivating factor, symptomatic of a group maturity that over the years, on the basis of the continuous creation of new submarine mechatronic products, consolidated know-how and experience, a factor that perhaps in the short-term economic cycle is difficult to highlight but which certainly in the long term is the company's primary added value.

Fabio Terzaghi CEO