A New Escort Tug Family Designed To Anticipate New Safety Requirements And Operational Needs

Massimo FIGARI[a,1], Luca MARTINELLI[b], Michele MARTELLI[a], Lucia ENOIZI[b], Benedetto PIAGGIO[a]

[a] *Università degli Studi di Genova, DITEN - Genova - Italy*

[b] *Rosetti Marino SpA – Ravenna - Italy*

Abstract. The aim of the paper is to describe an industry-academic collaboration to conduct a research project whose main goal is the design of a new escort tug family characterized by high intact/damage stability margins, good maneuvering capability and stable behavior during escort indirect assistance. The project is focused on three main research areas: hydrodynamic design and internal subdivision of the hull, simulation of the escort capabilities in different operational scenario, development of control logics that will allow autonomous or unmanned operations. The paper describes the methodological approach adopted for the design and will show some preliminary results. The tug has been designed to be in compliance with new amendments of the 2008 Intact Stability Code (Res. MSC.415(97)) which will enter into force on 1st January 2020) both for towing and for escort operations. Furthermore, a significant step towards enhancement of ship's safety is granted by tug's capability to withstand a damage in accordance with criteria applicable to OSVs. This paper describes the prototype hull and its stability characteristics. CFD calculations and towing tank tests have been performed in order to assess the hull design and to infer simulation models able to describe the behavior of a family of vessels. In particular, the propulsion and maneuverability aspects in escort operations are deeply investigated. Results of the project will form the bases for the conceptual application to a remotely controlled or autonomous escort tug.

Keywords. Tug, Escort tug, Simulation, Maneuvrability

1. Introduction

With the aim of developing a new generation of tugs, Rosetti Marino and University of Genoa started the design of a new tug's hull that shall be the basis for a multipurpose tugs family, embedding high intrinsic safety (i.e.: high hydrostatic stability; escort dynamic stability; damage survivability for side damages) and good overall performance.

This new concept design will be supported by a new simulation tool, developed and fit for the new tug's family. A maneuvering simulation model and a computational tool will provide maneuvering capability forecasting of ASD tugs during design phase. The same simulation model can be the basis of an integrated automation system, acting as a decision support to help the master during the most challenging escort/assistance

[1] Corresponding Author, Massimo Figari, Università degli Studi di Genova, DITEN, Via Montallegro 1, 16145 Genova, Italy; E-mail: massimo.figari@unige.it.

maneuvers, as well as to control the autonomous sailing of the tug (at least during non-emergency maneuvers).

Tugs represent a challenging market for workboat designers and operators. The general increase in size of merchant vessels requires the use of tugs with increasingly better performances in terms of bollard pull. This design goal is achieved by increasing tugs power and size, but this increase of bollard pull/size produces also some disadvantages. Ships of medium size are not prepared to safely sustain high push forces onto the side shell, or extremely high wire pulls onto the vessels' bollards. Large size tugs are not optimal for assistance in restricted/busy harbor waters and, last but not least, tugs of large size/power implies, for the operators, high overall capital investments and high daily costs. Furthermore, the development of large hydrodynamic forces for steering or braking an assisted ship is a matter of hull and propulsion system integrated design.

The idea behind the project is the development of a medium size tug's hull, capable of good performance in ahead/astern directions (maximum achievable speed, low wave pattern), fulfilling the requirements for tugs stability with large margins (RESOLUTION MSC.415(97) entering into force on 1st January 2020). The presence of a medium size skeg has the aim to achieve good escort performance without impairing low speed maneuvering readiness. A double hull configuration (side protection) allows hull damages survivability in accordance to requirements of RESOLUTION MSC.235(82) for OSV ships.

In the next paragraphs a description of the development of this study will be summarized, with evidence of the preliminary results and with an overview on the future activities, expected to be completed within 2019.

This study is a cooperative initiative of Rosetti Marino and University of Genoa, and it is being partially funded by the Italian Ministry of Infrastructures and Transport.

2. Tug design approach by innovation & research

To face the above-mentioned challenges, a research project has been established in order to develop a design of a new tug family. The shipyard-university partnership has the aim to achieve sound engineering results by merging the existing robust shipyard background with a new, simulation oriented, scientific approach.

The focus of the project is the maneuverability prediction at design stage for a family of hull shapes equipped with a family of propulsion and steering systems. Although the maneuvering capabilities, together with stability margins, are the main characteristics required to any tug to adequately use the available pull performances, especially when facing emergency assistance services, the present state of the art tug design does not normally involve maneuverability simulation tools, instead used with very good feedback in naval applications (Altosole & Martelli, 2017; Martelli, 2015). The idea behind the project is the development of a dedicated simulation design tool able to predict powering/maneuverability characteristics of a range of design solutions/main ship's dimensions. The tool will enable the shipyard and the potential client to converge to reliable design solutions by anticipating with reasonable accuracy the dynamic behavior of new tug's design.

From a scientific point of view, the main challenge is to fill the existing gap in low speed and high-speed maneuverability models. Three main key engineering aspects of the tug maneuvering performance are under investigation: hydrodynamic design of the hull with escort capability, simulation of the escort capabilities in different operational scenario, development of control logics that will allow autonomous or unmanned operations.

The project is divided into five main work packages:

1) Tug preliminary and detailed design;
2) Model scale tests and full scale trials;
3) Maneuverability simulator design;
4) High speed and low speed CFD computations;
5) Numerical models validation and design applications.

The preliminary design result is shown in Figure 1, where the sketch of the longitudinal view of the RM2812 escort tug is presented. The main overall characteristics are reported in Table 1.

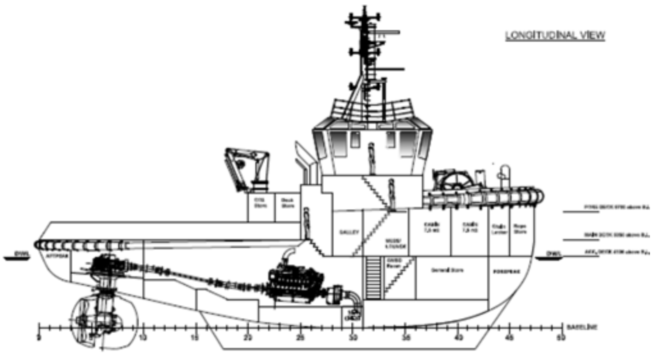

Figure 1. GENERAL ARRANGEMENT.

Table 1. Main tug characteristics

L [m]	B [m]	D [m]
28.40	12.00	4.95
V [kn]	**P_B [kW]**	**Bollard Pull [t]**
12.5	2x2000	>65

2.1. Intact and damage stability

The hull's stability is the ability through which tugs may safely assist ships. Safe operations are deeply dependent from the tug's righting arm curve in operational load conditions.

This prototype has been designed to get righting arms always larger than 0.8 m in any operational condition, thus allowing to comply with the large margins required by new amendments of the 2008 Intact Stability Code (Res. MSC.415(97), mandatory on 1st January 2020, both for towing and for escort operations.

The tank plan is studied to achieve a double hull configuration capable to withstand a damage in accordance with criteria applicable to OSVs. Double bottom arrangement extended all over the length also allow safety margins against possible flooding for grounding. These characteristics, peculiar of this new design, realize a significant step towards enhancement of tug's safety.

2.2. Towing tank tests

A wide spectrum test campaign was arranged to address several scientific and technical issues related to escort hulls. The objective of the tests was twofold: to get measured values for the tug design and to gather data for the numerical simulation of the escort activity.

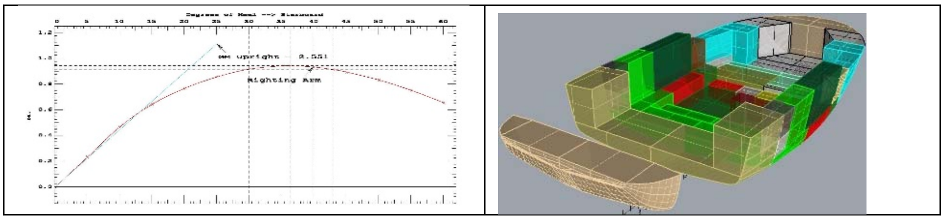

Figure 1. Stability analysis.

The following tests were performed: resistance, self-propulsion, thruster open water and oblique flow, thruster behind hull, bollard pull. PMM tests were performed at light draught, including static drift tests, pure sway, pure yaw and drift+yaw oscillating tests; While the most of the tests were carried out in upright condition and without thrusters, some repetitions with thrusters and with 10° heel angle were studied. Finally Free-Model Escort tests were designed to explore the whole behavior of the hull-propulsion systems. Table 2 shows the speed ranges and the thruster angle or hull headings of the different tests.

Due to the project focus to compare model tests with CFD calculations, raw and preprocessed model scale results were kindly provided by FORCE Technology, for an independent data processing.

Table 2. Towing tank tests programme

Tests	V [knots]	Heading/Thruster angle [°]
Thruster Open water	9	0, 15, 30, 45, 60, 75, 90, 105, 120, 135, 150, 165, 180
Resistance - Ahead	4-14	
Resistance - Astern	4-13	
Self-propulsion - Ahead	4-14	
Self-propulsion - Astern	4-13	
Bollard pull	0	
PMM tests	0, 3, 9	0, 2, 4, 6, 10, 20, 30, 40, 50, 60, 70, 80, 90, 100, 110, 120, 130, 140, 150, 160, 170, 174, 176,178, 180
Escort tests	9	20, 30, 45, 55, 120, 140

A scale model of the 28.4 m escort tug was tested in the towing tank at FORCE Technology, [Rieu, 2017]. The model was fitted with two ducted azimuth thrusters, a center skeg, bow fenders, deck, bulwarks and superstructure for escort tests.

Performance Tests with Stock Propellers. For still water resistance, self-propulsion and bollard-pull tests, the model was mounted underneath the towing carriage in the specific FORCE Technology set-up for tests with small models. The model was free to heave and pitch and constrained for all other motions. Two gauges measured the forces at the center of the vessel and at the second fixation point. Figure 3 shows respectively ahead and astern resistance tests at design speed.

PMM Tests. In the maneuverability tests, the model was mounted underneath the Planar Motion Mechanism system (PMM), which constrains the motions of the model in the horizontal plane (surge, sway, yaw) and at a prescribed heel angle. The forces and moments in the constrained directions were monitored by the gauge system installed in the PMM setup.

AHEAD ASTERN

Figure 3. Resistance tests.

Free Model Escort Tests. For free-sailing escort tests the model was fully released in all motions; the connection to the carriage was granted only through a towing line fitted with a gauge measuring the forces. Towing line forces were monitored at both extremities, both in X and Y direction on the tested vessel, in X, Y and Z direction on the mooring point attached to the towing carriage. Instrumentation cables were connected vertically above the model to prevent any type of pulling forces. The model motions were monitored by use of inclinometers and the optical tracking system. Escort tests were performed at 20, 30, 45, 55, 120 and 140 degrees thrusters heading, at two sets of RPMs.

Figure 4. ESCORT FREE MODEL TEST.

Figure 4 shows a free model run, the test is simulating an escorting at fixed ship speed, fixed thruster speed and thruster angles, in a steady heading position. For all the runs, the heading equilibrium configuration was rapidly achieved after the beginning and it was maintained for all the carriage run. The heeling angle ranged from 8 to 10 degrees. This heading and heeling stability during escort is an important property of the hull.

2.3. PMM data analysis and hydrodynamic force estimation

The hydrodynamic derivatives of the maneuverability mathematical models are evaluated following two different methodological approaches, described in the following.

Single Run Method (SR). The single realization (carriage-run) of PMM test is adopted to feed the model: depending on the selected regression model, the solution to the problem can be explicit in closed form (Fourier Series Approach) or must be fitted in a minimum optimization problem sense (Time-Domain Approach). The method is not suitable to the identification of a unique maneuvering model, moreover, the single realization fit is subjected to major estimation uncertainty without any possibility of global fairing if the measurement is not long enough or repeated.

Multiple Run Method (MR). The derivatives are inferred by exploiting data acquired from series of PMM tests (complete set or subsets).

The optimization problem of regression is hence approached across three parallel methodologies commonly adopted in tank facilities (ITTC 2014), gradually increasing in mathematical effort: a simplified regression model, a time-domain approach and a frequency domain scheme. Systematically all the regression methods are compared all-over the experimental domain of observations in terms of local and mean global RMS error. Figure 5 shows the inferred response surface and the experimental values.

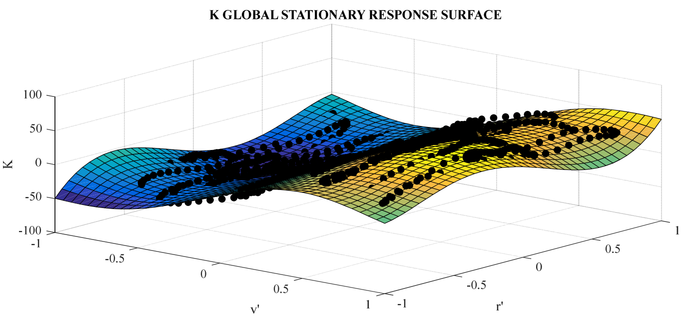

FIGURE 5. 5th order stationary roll response surfaces vs PMM sample cycles

3. Simulation for Design

For several years, University of Genoa has been involved in the development of propulsion control systems for naval and patrol vessels (Donnarumma et al. 2017; Martelli et al. 2017). The increasing complexity of these propulsion systems requires control system functions able to manage high power in several propulsion configurations and during critical ship maneuvers i.e. slam start, crash stop, severe turning (Geertsma et al. 2017; Stapersma et al. 2017). Optimizing the whole propulsion control system of the vessel, also in critical conditions, means finding an optimal compromise between performance and safety. Simulation techniques can be a very useful tool in representing marine propulsion dynamics, based on which automation or propulsion designers can develop and test propulsion options. Several works are available in the literature, dealing with modelling and simulation techniques for marine applications. (Baldi et al. 2015; Cichowicz et al. 2015; Altosole et al. 2017). In particular, a simulation application for the representation of the towing operations by tugs is shown in Altosole et al. (2013).

The ship simulator consists of a set of differential equations, algebraic equations and tables that represent the various elements of propulsion and control systems, ship maneuverability and the mutual interactions among them.

From the mathematical point of view, the problem can be summarized by solving the following differential equations system:

$$\boldsymbol{M\dot{\nu} + C(\nu)\nu = \tau_H + \tau_P} \tag{1}$$

$$\boldsymbol{2\pi I \frac{dn(t)}{dt} \;=\; Q_{eng}(t) + Q_{fric}(t) + Q_P(t)} \tag{2}$$

$$\boldsymbol{S_i(t) = K_{P\_i}\ e_i(t) + K_{I_i}\int_0^t e_i(t)dt + + K_{D\_i}\frac{d}{dt}e_i(t)} \tag{3}$$

The ship motion, Equation (1), is expressed in vectorial form where ν represent speed, τ_H and τ_P represent hull hydrodynamics and propeller forces. The propulsion plant dynamics is described through the differential equation of the shaft line, Equation (2), where n represent shaft speed, Q_{eng}, Q_P and Q_{fric} represent engine, propeller and friction torque. The propulsion control system is represented by a set of equations, whose form is, in many cases, like the one presented in Equation (3), describing a PID controller where e_i represent a generic error function.

While Equations (1), (2) and (3) represent the normal navigation mode, the peculiarity of the escort mode requires additional effort to well understand the challenging governing principles behind it. When dealing with a multi-vessel towing scenario then the dynamics double and the modelling of the towing line arises: the modelling adopts an elastic catenary scheme (Piaggio et al. 2017). Figure 6 represents the main breakthrough required to escort simulation were not only the escort tug but also the assisted ship and the towing line have to be carefully modelled.

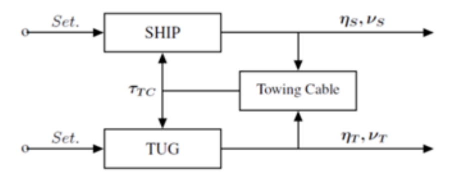

Figure 6. Simulation model scheme

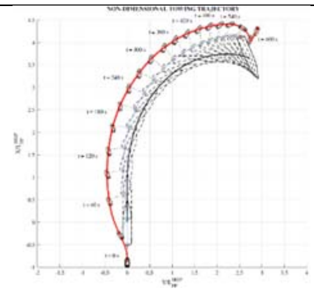

Figure 7. Simulation results of an escort braking assistance

4. Results and Discussion

The paper presented an all-round approach to escort tug design actually in phase of deployment across an ongoing research project, whose aim is to develop a new tug family and a simulation tool helpful for ASD tug design. The design process is somehow traditional for the prototype definition, however the new simulation and CFD approach tools, are devoted to develop size/skeg variations of the prototype hull, thanks to the wide experimental data collection.

With respect to state of the art of tug design, the adopted work frame contains several methodological innovations:

- an extensive and multidisciplinary towing tank maneuverability test campaign combined with fully matched CFD computations, for validation purposes;
- a thorough investigation about thruster-thruster and hull-thruster interaction in oblique flow and drifting hull, which is often neglected but of remarkable importance;
- a complete coupled dynamics time-domain scenario simulation overcoming the classical escort steady-state assumption.

The time-domain simulation scenario is expected to become a design tool of great potentiality. Both at early design stage, able to predict manoeuvrability and escort performances of peculiar ASD tugs and at operative stage, as training instrument or a realistic scenario simulator.

Acknowledgments

The research project is partially funded by Italian Ministry of Infrastructures & Transports (MIT), Waterborne Transports, Division 4, under General Director Decree n.7883 on 13 October 2016.

References

[1] Altosole, M., Boote, D., Brizzolara, S., Viviani, M. Integration of numerical modeling and simulation techniques for the analysis of towing operations of cargo ships (2013) International Review of Mechanical Engineering, Vol 7 (7), November 2013, pp. 1236-1245.
[2] Altosole, M., Martelli, M. Propulsion control strategies for ship emergency manoeuvres. (2017) Ocean Engineering, 137, pp. 99-109.
[3] Altosole, M., Benvenuto, G., Campora, U., Laviola, M., Zaccone, R. Simulation and performance comparison between diesel and natural gas engines for marine applications. (2017) Proceedings of the Institution of Mechanical Engineers Part M: Journal of Engineering for the Maritime Environment, 231 (2), pp. 690-704.
[4] Baldi, F., Theotokatos, G., Andersson, K. Development of a combined mean value-zero dimensional model and application for a large marine four-stroke Diesel engine simulation. (2015) Applied Energy, 154, pp. 402-415.
[5] D. Bruzzone, D. Ruscelli, D. Villa, M. Viviani "Numerical Prediction Of Hull Force For Low Velocity Manoeuvring", Proceedings 18th International Conference on Ships and Shipping Research (NAV 2015), ISBN 978-88-940557-1-9, p.284-295, June 24th – 26th, Lecco, Italy, M. Altosole and A. Francescutto (Editors)
[6] Cichowicz, J., Theotokatos, G., Vassalos, D. Dynamic energy modelling for ship life-cycle performance assessment. (2015) Ocean Engineering, 110, pp. 49-61.
[7] Donnarumma, S., Figari, M., Martelli, M., Vignolo, S., Viviani, M. Design and Validation of Dynamic Positioning for Marine Systems: A Case Study. (2017) IEEE Journal of Oceanic Engineering.
[8] Gaggero, S., Villa, D., Viviani, M. An extensive analysis of numerical ship self-propulsion prediction via a coupled BEM/RANS approach. (2017) Applied Ocean Research, 66, pp. 55-78.
[9] Geertsma, R.D., Negenborn, R.R., Visser, K., Hopman, J.J. Design and control of hybrid power and propulsion systems for smart ships: A review of developments. (2017) Applied Energy, 194, pp. 30-54.
[10] Martelli, M. Marine propulsion simulation. (2015) Marine Propulsion Simulation, pp. 1-104.
[11] Martelli, M., Figari, M. Real-Time model-based design for CODLAG propulsion control strategies. (2017) Ocean Engineering, 141, pp. 265-276.
[12] Piaggio, B., Martelli, M., Viviani, M., Figari, M. Manoeuvring model and simulation of the non-linear dynamic interaction between tethered ship and tug during escort. (2017) IMAM, Lisbon, pp. 95-104.
[13] Rieu, V. Self-propulsion and bollard pull tests 30m Escort tug. (2017) FORCE 117-24115 Report N°1, FORCE TECHNOLOGY.
[14] Stapersma, D., Vrijdag, A. Linearisation of a ship propulsion system model. (2017) Ocean Engineering, 142, pp. 441-457.