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MODELLING OF SOME STEALTH FEATURES FOR A SMALL NAVY SHIP AT THE CONCEPT DESIGN STAGE - PART II

Natalia Szulist

Gdańsk University of Technology
11/12 Narutowicza Str.
80-233 Gdańsk, Poland

Abstract

In the paper a few problems associated with modelling the basic stealth features for a small ship at the concept design stage are introduced. One problem concerns the modification of the immersed ship hull using the rapid change of the ship loading condition. The second is associated with the modification of the ship boundary layer by the hull skin cover. The other stealth features of the ship are not presented in this paper. The research method is based on the risk assessment and assessment of the ship performance. The risk may be estimated according to a proposed risk model. The risk assessment can be done according to the risk matrix criteria. The ship performance assessment is based on modification of the ship hull position on the water surface and modification of the ship boundary layer. Some elements of the research method and mathematical model for estimating the ship performance are introduced in the paper. Generally, the research is associated with the interdisciplinary investigations and multi-criteria ship design. The problems presented in the paper follow from the a Ph.D. research conducted at the Faculty of Ocean Engineering and Ship Technology Gdańsk University of Technology.

Keywords: *small navy ship, stealth technology, ship hydromechanics, ship performance, risk assessment*

1. Introduction

The navy operations at sea often require to apply more and more advanced multi-task ships. The following paper regards the problems associated with modelling some stealth features for a multi-task small navy ship at the concept design stage. The ship should enable to perform the general tasks, reconnaissance and combat operations, to support the safe and rescue operations, to launch the water drones, etc. Despite of the size the multi-task navy ships may be the platforms for the flying drones and unmanned water vehicles including the autonomous water drones.

The main objective of the research is to work out a functional model of the multi-task small navy ship having some stealth features. To obtain the stealth features the modification of the immersed ship hull form and modification of the ship boundary layer may be used.

The research method combines the navy ship risk assessment and assessment of the ship performance.

The risk assessment requires first of all to estimate the ship susceptibility, vulnerability and killability and consequences. Then the risk may be assessed using the risk matrix criteria. The risk assessment is associated with the ship killability which may be understand in the opposite way as the ship survivability. According to the risk estimation for the data scenario development the safety assessment of the ship may be done for the given operational conditions.

The ship performance assessment requires to define the operational conditions first of all and next to estimate the ship floatability, stability, resistance and propulsion characteristics. Before the ship performance may be started the ship weight should be estimated according to the data operational condition. At this stage of design the operational conditions concern mainly the ship loading condition than the sea state. The seakeeping of the ship will be considered at the preliminary stage of design.

2. The research problem

The aim of this paper is to outline a study into a feasibility of an advanced multi-task small navy vessel having some stealth features enabling to The main objective of the research is to work out a functional model of the multi-task small navy ship having some stealth features. The ship should be able to move on the water surface in two different operational conditions with the range of speed up to 30 knots. When the operational conditions have to be changed the ship speed may be substantially decreased.

To obtain the stealth features the modification of the immersed ship hull form by the relatively rapid change of the loading condition and modification of the ship boundary layer by the hull skin cover may be used.

It is proposed that the modification of the immersed ship hull form is done by the sequential rapid change of the loading condition. The loading condition very much depend on the quantity of water in the ballast tanks. It has been decided to take into account two loading conditions which have the impact on the ship stealth features. The first operational loading condition is called as the surface loading condition when the ship has no water or having the remaining quantity of water in the ballast tanks. The second is called as the immersed loading condition when the ballast tanks are full of water. The process of ballasting the ship should be rather fast or rapid in time. Therefore the dynamical stability of the ship is a very important problem to be solved during the research. The ship speed should be decreased during the ship ballasting.

It is proposed that the modification of the ship boundary layer by the ship skin cover would increase the stealth effect.

The influence of the ship hull immersion and ship boundary layer on the ship resistance and propulsion it may be investigated by estimating the flow around the ship hull. This may be checked using either the computational fluid dynamics technique or investigations using the circulating channel.

The study has been driven by the tactical advantages that such the ship could offer to the military authorities and for the commercial users as well.

The major assumptions concerning the multi-task small stealth navy ship have been defined as follows:

- main dimensions (length x breadth x height): (60 meters) x (10 meters) x 8.4 (meters),
- displacement up to 900 tons,
- operational speed up to 30 knots.

The ship stealth domain has been defined as a combination of the ship features as follows:

- feature 1: ship hull form enabling to change the efficiency of the ship detection in the air and in the water,
- feature 2: materials including the ship hull skin cover enabling to change the efficiency of the ship detection in the air and in the water,
- feature 3: radiation of the noise and vibrations,
- etc.

The research problems to be solved are as follows:

- development of a model for estimating the influence of the ship hull form on the efficiency of the ship detection in the air and in the water depending on the loading condition,
- development of a model for estimation the influence of the ship hull skin cover on the boundary layer, wake and ship resistance.

The challenges associated with the research are significant. It follows from the fact as an example that the loading condition and boundary layer (wake and resistance) have divergent design requirements in general.

3. The research method

The research method is a kind of risk-based performance-oriented method which enables to assess the safety and performance of a ship at the design stage and in operation, Gerigk (2010). The method enables to take into account the influence of factors following from different sources including the design, operational and safety management related factors. The risk assessment and performance assessment may be done for all the possible design scenarios and sequences of events. All the above describe the so-called holistic approach to ship safety.

Within the method the risk assessment is based on application of the risk model which may be modified according to the scenarios of events under consideration. The risk assessment requires first of all to estimate the ship susceptibility, vulnerability and killability and consequences. Then the risk may be assessed using the risk matrix criteria. The risk assessment is associated with the ship killability which may be understand in the opposite way as the ship survivability. According to the risk estimation for the data scenario development the safety assessment of the ship may be done for the given operational conditions.

The risk assessment. The risk model associated with the different hazards and scenarios regarding a multi-task small navy ship should be estimated according to the well known general formulae, Gerigk (2010):

$$R_i = P_i \times C_i \tag{1}$$

where:

P_i - probability of occurrence of a given hazard;

C_i - consequences following the occurrence of the data hazard and scenario development, in terms of fatalities, injuries, property losses and damage to the environment.

In the case of the multi-task small navy ship depending on a hazard occurred a general formulae for estimating the risk may be presented as follows:

$$R_i = P_{HO}\ P_{SD/HO}\ (1-P_{SNSS})\ C \tag{2}$$

where:

P_{HO} - probability of the data hazard occurrence,

$P_{SD/HO}$ - probability of the data scenario development conditional on the data hazard occurrence,

P_{SNSS} - probability of small navy ship survivability conditional on the data scenario development and conditional on the data hazard occurrence,

C - consequences regarding the fatalities C_{HF} (HF - Human Factor), property (ship) C_{SNS} (SNS - Small Navy Ship as a whole), environment C_E (E - Environment), estimated at each stage of an accident (catastrophe).

A major hazard taken into account during the research is the killability of the small navy ship under consideration. The probability of the data hazard occurrence, probability of the ship killability may be written as follows:

$$P_{HO} = P_K = P_S\ P_{K/S} \tag{3}$$

where:

P_K - probability of the ship killability,

P_S - probability of the ship susceptibility,

$P_{K/S}$ - conditional probability vulnerability in the case of the ship damage.

The probability of the ship susceptibility P_S is the measure of the ship inability to intercept any of the threats: detecting, classifying, targeting, attacking or hitting. The key issue from the interception point of view are the stealth features the multi-task small navy ship may possess.

The probability P_{SNSS} may be estimated using the following methods, Gerigk (2010):

- binary method;
- method based on definition of the ship hydromechanic characteristics,
- method based on definition of the ship performance including the ship dynamics in waves.

In the case of the last method the sway, heave, roll and pitch functions in time domain have been anticipated as the major characteristics enabling the risk assessment, Gerigk (2010). The risk analysis requires to estimate the conditional probabilities concerning the major events (initial events, hazards), intermediate events and final events (consequences). The typical additional events may concern the water on deck, air cushions, cargo leakage, additional heeling moments, etc. The above risk model should be prepared in such a way to enable to consider many of the possible scenarios using the event tree analysis ET

The performance assessment. The performance assessment may be done using either the physical model (towing tank or circulating channel investigations) or numerical simulation techniques. It has been assumed that the computer simulation will be used during the research. Within the research the ship performance require to estimate the ship floatability, stability, dynamical stability and resistance and propulsion.

The ship hydromechanic characteristics associated with the above features are the base for estimation how much the modification of the immersed ship hull form by the sequential rapid change of the loading condition affects the ship stealth characteristics like the ship detection in the air and in the water. The latest concerns the modification of the ship boundary layer by the ship skin cover as well.

The ship performance assessment requires to define the operational conditions first of all and next to estimate the ship floatability, stability, resistance and propulsion characteristics. Before the ship performance may be started the ship weight should be estimated according to the data operational condition. At this stage of design the operational conditions concern mainly the ship loading condition than the sea state. The seakeeping of the ship will be considered at the preliminary stage of design.

It is proposed that the stealth features of the ship will be delivered by the modification of the immersed ship hull form and modification of the ship boundary layer.

How big is the influence of the ship hull immersion and ship boundary layer on the ship resistance and propulsion is the may aim of the research.

From the formal point of view the aim of research is to work out a method for analyzing two basic features deciding if a ship may be considered as a stealth ship. The first feature is the modification of the immersed ship hull form by a relatively rapid change of the loading condition. The second feature is the modification of the ship boundary layer by the ship hull skin cover. Both the features are closely connected with the ship hydromechanics. The research contains the method, models, numerical computations, validation and verification of results obtained and conclusions.

The problems associated with the ship performance should be precisely considered for the multi-task small navy ship under consideration during the Ph.D. studies carried out at the Faculty of Ocean Engineering and Ship Technology Gdańsk University of Technology. The problems regarding the ship maneuverability and seakeeping will be investigated according to a methodology of another research project.

As it was mentioned before the research method combines the navy ship risk assessment and assessment of the ship performance.

The method. The method is based on the following main steps:

- setting up the requirements, criteria, limitations, safety objectives,
- defining the ship including the hull form, arrangement of internal spaces, ballasting, weights and centre of gravity, loading condition,
- defining the environment,
- identifying the hazards and sequences of events (scenarios),
- assessing the ship performance including the ship floatability, stability, dynamic stability (research task1: modification of the immersed ship hull form is done by the sequential rapid change of the loading condition), ship flow and resistance (research task 2: modification of the ship boundary layer by the ship skin cover),
- estimating the risk according to the event tree analysis ETA and risk model (risk value is estimated for each scenario separately),
- assessing the risk according to the risk acceptance criteria (risk matrix) and safety objectives, (Abramowicz-Gerigk 2006, Abramowicz-Gerigk 2008b, Abramowicz-Gerigk & Burciu 2013, Arangio 2012, Burciu & Grabski 2011, Gerigk 2004, Gerigk 2005, Gerigk 2006, Gerigk 2008, Gerigk 2010, Gerigk 2012, Nowakowski & Werbińka 2009).

The structure of the method is presented in Figure 1, Gerigk (2010).

The criteria within the method is to achieve an adequate level of risk using the risk acceptance criteria, risk matrix, Gerigk (2010). Providing a sufficient level of safety based on the risk assessment is the main objective. It is either the design, operational or organizational objective. Safety is the design objective between the other objectives. The measure of safety of the object is the risk (level of risk). The key drivers during the ship design and during the research on the multi-task small navy ship are the research task 1 and research task 2.

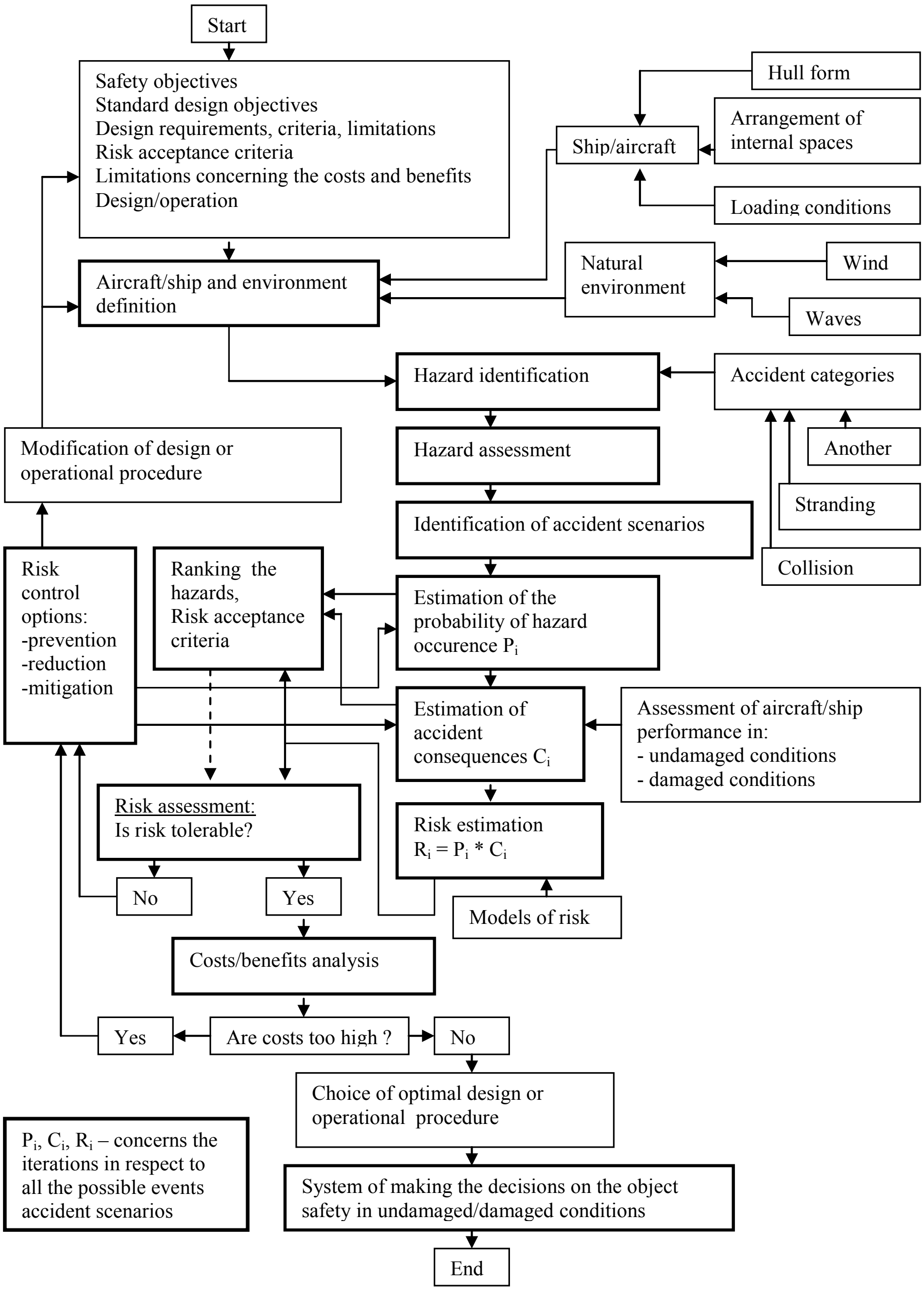

Figure 1. The structure of the research method combining the risk assessment and performance assessment of the multi-task small navy ship.

From the design point of view the main research tasks associated with development of the small stealth ship concept are as follows:

- development of ship hull form and arrangement of internal spaces,
- development of ship structure and ship hull skin nano-cover,
- selection of ship devices and subsystems,
- estimation of ship mass and centre of gravity,
- investigations of ship performance,
- investigations of selected problems associated with the ship performance during the towing tank or circulating channel investigations,
- investigations of influence of the ship hull skin nano-cover on the boundary layer

using both the computer simulation and physical model investigations.

4. Basic information on the model for modification of immersed hull form by sequential rapid change of loading condition

I has been assumed that modification of the immersed ship hull form should be achieved by the sequential rapid change of the loading condition. The buoyancy of the ship increases and decreases according to the efficiency of the ballasting pumps. Two options have been considered regarding the speed changing the loading condition form the floating loading condition to the immersed loading condition and in the opposite way. It is connected with the rate of flow of the ballasting pumps. The maximum quantity of the ballast water (volume of the ballast tanks) is of about 200 tons. Two pumps of the rate of flow 10 cubic meters per minute or two pumps of the rate of flow 25 cubic meters per minute may be applied. It means that the ballast tanks may be full of water in 10 minutes in the first case and in four minutes using the pump of efficiency 25 cubic meters per minute.

During the ballasting process the dynamic stability of the ship should be permanently controlled. It is very important to the location of the centre of gravity and ship centre of buoyancy in each step time.

Thus the restoring moments M_R (transversal or longitudinal) at small changes of heel is composed of the moment due to the ship buoyancy and moment due to the ship weight:

$$M_R = M_B + M_W \tag{4}$$

where:

M_B - moment due to the ship buoyancy, $M_B = V \rho g GZ_{quasi\text{-}static}$,
V - immersed buoyancy of the ship,
ρ - density of water,
g - gravity acceleration,
$GZ_{quasi\text{-}static}$ - righting arm of buoyancy for the quasi-static condition at each buoyancy increase and time step,
M_B - moment due to the ship weight, $M_W = \sum (\rho g \Delta V_{Ti}) r_i$,
ΔV_{Ti} - volume of ballast water in the ballast tank under consideration,
r_i - heeling arm following from the ballast water in the data ballast tank.

The scheme of modification of immersed ship hull by sequential rapid change of loading condition is presented in Figure 2.

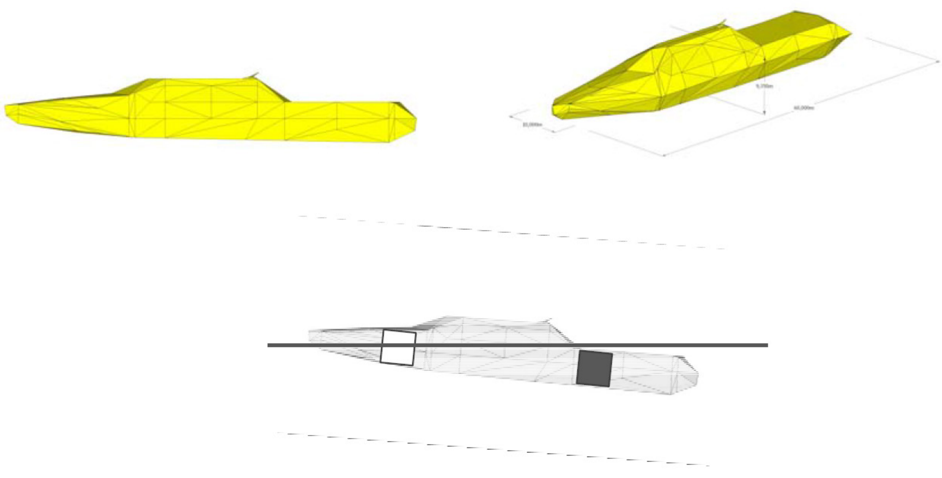

Figure 2. The scheme of modification of immersed ship hull by sequential rapid change of loading condition.

5. Some remarks on modification of the ship boundary layer by the ship skin cover

It is prepared that the simulation of the ship flow will be based on the RANSE (Reynolds Averaged Navier-Stokes Equations) flow model, implemented in the STAR-CCM+ solver. It has been assumed that the simulation in the calm sea condition will be considered first of all. Later the problems of the ship motion in waves will be analyzed.

The simulation of the ship motion includes the following problems:

- taking into account the free surface of water;
- solving the equations of motion for the floating ship in calm water and in waves;
- preparing the dynamic (i.e. moving) mesh; the floating ship is moving during the simulation; it means that the nodes of mesh in which the flow is being solved should move as well.

The Volume of Fluid (VOF) model will be used to capture the flow of two fluids (air and water) on the free surface of water. It means that the fluids (air and water) filling the domain are treated as single fluid. An additional variable is introduced for each of the components: “volume fraction” c_i. The parameters of the resulting multiphase fluid (e.g. density ρ) are then computed as follows, by Kraskowski, Gerigk et al. (2012): $\rho = \sum_i \rho_i \cdot c_i$, where c_i and ρ_i are the volume fraction and density for each of the components, respectively. Note that $\sum_i c_i = 1$ in each point of the domain.

Solving the motion of the floating ship it is necessary to integrate the Newton equations using the forces due to weight of the structure and forces exerted by the fluids (these are updated in each time step). It has been assumed that the sway, heave, roll and pitch motions are the crucial characteristics from the ship performance point of view. A simplification is used: only the motion in the mentioned degrees of freedom are considered. In the case of using the “sliding mesh” approach introducing such a simplification greatly simplifies the mesh generation, by Kraskowski, Gerigk et al (2012).

As mentioned above, solving the flow in the domain with moving boundaries (in the considered case – the boundaries of the floating object), requires using the dynamic mesh. Different approaches are possible here: rigid mesh (no relative motion between nodes), deforming mesh, overlapping mesh and sliding mesh, by Kraskowski, Gerigk et al (2012).

Such an approach provides good compromise between the accuracy, robustness and computational time. The ship hull is closed into the cylindrical sub-domain located in larger rectangular domain. The inner sub-domain undergoes angular and translational motion, while the outer domain undergoes only translational motion, by Kraskowski, Gerigk et al. (2012).

For the presented analysis the sliding mesh approach was selected and its simplified example is presented in Figure 3.

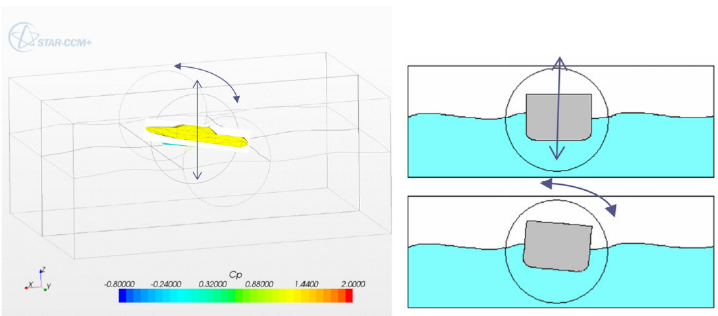

Figure 3. The simplified example how the sliding mesh approach will be applied for the motion analysis of the small navy ship under consideration (by M. Kraskowski, Ship Research and Shipbuilding Centre, 2012)

6. A concept of a small stealth ship

The primary aim of the research is to work out a functional model of functional model of the multi-task small stealth navy ship which should be able to move on the water surface with two different operational (loading) conditions with the range of speed up to 30 knots. The novel solutions have been applied regarding the hull form, arrangement of internal spaces, materials and propulsion system. The ship is defined as a mono-hull having an unconventional arrangement of internal spaces.

The major factors to obtain the stealth features of the ship are: hull form, hull skin cover, limited boundary layer (nano-skin) and wake, limited vibration and acoustic emission.

A visualization of the second version (2nd design version) of the multi-task small navy ship MTSNS under consideration is presented in Figure 4.

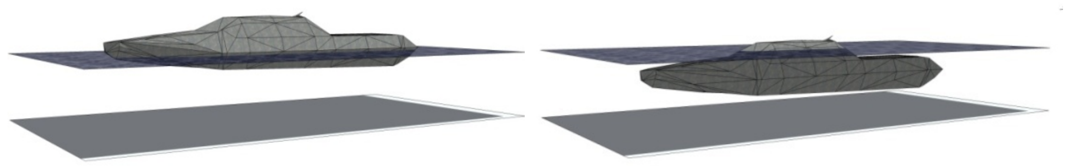

Figure. 4. A visualization of the second version (2nd design version) of the of the multi-task small navy ship MTSNS.

The MTSNS has the following main dimensions:
- Length L = 60 m,
- Breadth B = 8 m,
- Maximum speed v = 30 knots.

The main technical data of the MTSNS are as follows:
- a multi-purpose vessel for the combat or/and logistic tasks,
- innovative solutions applied: multi-fuel main engine, lift for launching the water drones and air drones, stealth technology features.

7. Conclusions

The problems presented in the paper are connected with the research on the modelling of the stealth features for the multi-task small navy ship MTSNS at the concept design stage. The research itself seems concerns the application of an advanced approach to the stealth technology problems presented in the paper.

The major research problems from the stealth technology application point of view have been defined as follows:

- research task1: modification of the immersed ship hull form is done by the sequential rapid change of the loading condition, ship flow and resistance,
- research task 2: modification of the ship boundary layer by the ship skin cover.

The research presented in the paper is divided into a few parts. One of them is associated with submitting the projects to be supported by the NCBiR Ministry in Warsaw. The whole research is performed by a team of Ph.D. students.

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