SEALAB: Aero-hydro mechanics of a three-wings jumping vehicle

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ABSTRACT: The paper presents an overview on the SEALAB project, a technology platform to develop new concepts in design of high-speed marine vehicles. In particular in this paper the aero-hydro-mechanics of the new vessel is discussed, with the aim of developing analytical and numerical models to describe its response and to optimize the navigation performances.

1 INTRODUCTION

HSMVs increasingly attract the attention of the scientific and technical community. In fact, the increasing speed of such vehicles becomes competitive with aircrafts and ground transportation in the presence of dedicated infrastructures, and with the advantage of higher payloads, thus stimulating their increasing commercial use. The technical related problems open a wide spectrum of challenging scientific questions on the propulsion plants, sea-keeping performances, shock structural resistance, guidance and control systems, with aerodynamic effects cooperating with hydrodynamic forces (Faltinsen 2006, Fossen 1994, Collu et al. 2008, Collu et al. 2010, Collu et al. 2007, Kandasamy et al. 2009, Bruzzone et al.).

In this context HSMV investigation appears to belong to a multidisciplinary field where the integration of the different technology components and their optimization represent driving concepts (Peri & Campana 2003, Pinto et al. 2004).

This paper illustrates the concepts behind an innovative high-speed marine vehicle (HSMV) in the context of a large project named SEALAB and developed at the Sapienza University of Rome.

The new challenging vehicle is a technology platform with many new technologies hosted on board. The vehicle presents innovation in several fields, involving the whole architecture of the vehicle, the propulsion, transmission and control systems, the shock attenuation devices and the structural real-time monitoring and damage detection system based on optical technology.

The present paper is mainly addressed to the new architecture of the vehicle equipped with three types of control surfaces closed in the same loop: submerged foils, aerodynamic surfaces and a special interface system with skids equipped with a suspension device that contributes to the vehicle lift, large mitigation of the of water-impact phenomena (slamming) (Carcaterra & Ciappi 2000, Carcaterra & Ciappi 2004, Carcaterra et al. 2000, Iafrati et al. 2000, Dessi & Mariani 2008), and to the trim-keeping at high speed (over 150km/h).

Figure 1. SEALAB: front view

The paper presents the basic theory for the unusual way of navigation of the vehicle, together with some numerical simulations. Moreover, an overview on the SEALAB project is shortly presented in the next section.

2 SEALAB: SHORT OVERVIEW

SEALAB is a project conceived to develop new technologies for marine vehicles. Two main strategies are used; on one hand innovation from other fields is imported into the marine context, through a strong contamination from automotive and aerospace technology; on the other hand specific advances are obtained for the extreme operating conditions characterizing this high-speed vehicle and the produced innovation transferred to the previously mentioned fields.

The financial support to the project comes from mixed sources: regional research funds (EU related), university research projects together with the involvement of private companies and other research institutions. Since part of the funds have public nature, mitigating the financial risk for the companies involved, these are admitted to be part of the project only if they contribute on non-standard technologies, those implying a possible step innovation and not only incremental advances.

The project splits into several sub-projects, each finalized to the development of specific technologies to guarantee a step innovation in any specific area of interest.

The activated sub-projects are:

1. New vehicle architecture
2. Stability, control and intelligent suspension system
3. New propulsion devices – compound water-jet and turbo-jet
4. On-board smart structures to reduce vibrations and shock
5. Self-diagnosis of structural element failures
6. New materials (low environmental impact)
7. Intelligent drive-train systems

The construction process of SEALAB is started and the vehicle assembly in progress in a dedicated lab of the Sapienza Univeristy.

3 VEHICLE DYNAMICS SIMULATION

The general model of the system comprises the equations of the rigid body motion of the vessel, coupled to the equation of motion of a set of *N* suspension systems.

For the vessel one has in the vehicle reference system :

$$\begin{cases} \mathbf{M}_G^{hydr} + \mathbf{M}_G^{skids} = \mathbf{\Omega}\,\mathbf{J}\,\boldsymbol{\omega} + \mathbf{J}\,\dot{\boldsymbol{\omega}} \\ \mathbf{F}^{hydr} + \mathbf{F}_G^{skids} = M_0\left(\mathbf{\Omega}\,\mathbf{v} + \dot{\mathbf{v}}\right) \end{cases}$$

where: $\mathbf{M}_G^{hydr}, \mathbf{F}^{hydr}$ are the hydro-aero-dynamic moments and forces including those generated by the control surfaces and by the propulsion system; $\mathbf{v}, \mathbf{\Omega}, \boldsymbol{\omega}, \boldsymbol{\tau}, \mathbf{J}$ are the center of mass velocity, the angular velocity tensor, the angular velocity vector, the control vector (like rudders trim, propulsion thrusts angles etc.) and the inertia tensor, respectively; finally:

$$\mathbf{M}_G^{skids} = \sum_i \mathbf{M}_G^{skids(i)}, \mathbf{F}^{skids} = \sum_i \mathbf{F}^{skids(i)}$$

are the moments and the forces transmitted to the vessel by all the suspension systems of the skids. These last are indeed controlled by analogous equations of motion:

$$\begin{cases} \mathbf{M}_G^{hydr(i)} - \mathbf{M}_G^{skid(i)} = \mathbf{\Omega}_i\,\mathbf{J}_i\,\boldsymbol{\omega}_i + \mathbf{J}_i\,\dot{\boldsymbol{\omega}}_i \\ \mathbf{F}^{hydr(i)} - \mathbf{F}_G^{skid(i)} = M_{0i}\left(\mathbf{\Omega}_i\,\mathbf{v}_i + \dot{\mathbf{v}}_i\right) \end{cases}$$

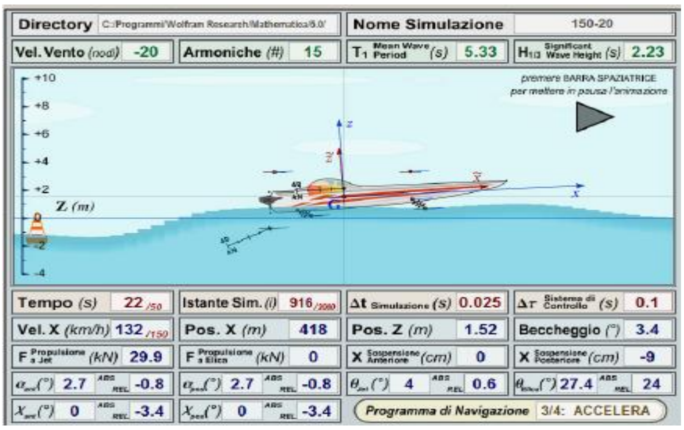
In general, the hydrodynamic and aerodynamic forces $\mathbf{M}_G^{hydr}, \mathbf{F}^{hydr}$, have a nonlinear nature in terms of the variables $\mathbf{v}, \mathbf{\Omega}, \boldsymbol{\omega}$ and $\mathbf{x}, \mathbf{R}(\alpha_1, \alpha_2, \alpha_3)$, centre of mass position and rotation matrix (depending on the three angles α_i), respectively, and also depend on the random surface elevation *w* in a complicated fashion, not last the presence of intermittent contacts between the skids and the sea surface, once a threshold speed is crossed. The same is true for $\mathbf{M}_G^{hydr(i)}, \mathbf{F}^{hydr(i)}$. The skid forces (forces transmitted between suspensions and vessel) depend in general in a nonlinear way on both $\mathbf{v}, \mathbf{\Omega}, \boldsymbol{\omega}$ and $\mathbf{x}, \mathbf{R}(\alpha_1, \alpha_2, \alpha_3), \mathbf{v}_i, \mathbf{\Omega}_i, \boldsymbol{\omega}_i$ and $\mathbf{x}_i, \mathbf{R}_i(\alpha_{1i}, \alpha_{2i}, \alpha_{3i})$, because of form of the kinematic linkages and because of on nonlinear constitutive relationship of the elastic components and of the dampers.

Therefore, the whole set of equations of motion of the system are in general nonlinear stochastic differential equations in terms of the unknown vector:

$$\mathbf{z} = \left[\mathbf{x}, \alpha_1, \alpha_2, \alpha_3, \mathbf{v}, \boldsymbol{\omega}\right]$$

$$\mathbf{z}_{si} = \left[\mathbf{x}_i, \alpha_{1i}, \alpha_{2i}, \alpha_{3i}, \mathbf{v}_i, \boldsymbol{\omega}_i\right],\ i = 1,2 \ldots N$$

suitable for direct Montecarlo simulations and related statistics, or approached by different methods as those presented in (Carcaterra et al. 2005, Bisplinghoff et al. 1962, Culla & Carcaterra 2007).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Nome Simulazione 150-20
Vel. Vento (nodi) -20
Armoniche (#) 15
T_1 Mean Wave Period (s) 5.33
$H_{1/3}$ Significant Wave Height (s) 2.23
premere BARRA SPAZIATRICE per mettere in pausa l'animazione
Tempo (s) 22 /50
Istante Sim. (i) 916 /2000
Δt Simulazione (s) 0.025
Δτ Sistema di Controllo (s) 0.1
Vel. X (km/h) 132 /150
Pos. X (m) 418
Pos. Z (m) 1.52
Beccheggio (°) 3.4
F Propulsione a Jet (kN) 29.9
F Propulsione a Elica (kN) 0
X Sospensione Anteriore (cm) 0
X Sospensione Posteriore (cm) -9
α_{ant} (°) 2.7 ABS REL -0.8
α_{post} (°) 2.7 ABS REL -0.8
θ_{jet} (°) 4 ABS REL 0.6
θ_{elica} (°) 27.4 ABS REL 24
χ_{ant} (°) 0 ABS REL -3.4
χ_{post} (°) 0 ABS REL -3.4
Programma di Navigazione 3/4: ACCELERA

Figure 2. SEALAB simulation software (screen view)

A dedicated software has been developed, aimed at solving the equations of motion of the vessel at different sea-state and with different navigation programs. In fact, the designer can select the propulsion program, the different parameters for the automatic control for the hydrofoils and aerofoils, the suspension system setup etc. As a result the software produces an animation of the vessel in navigation, together with a complete report of all the relevant physical quantities monitored during the running test.

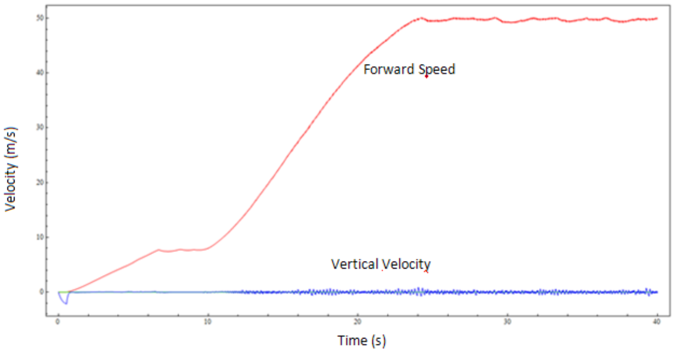

Figure 3. Time history of the velocity

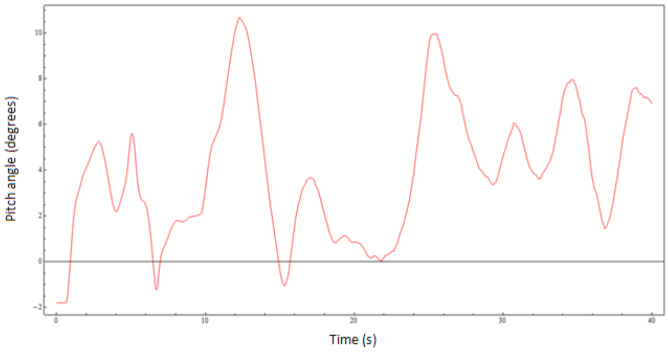

Figure 4. Time history of the pitch angle

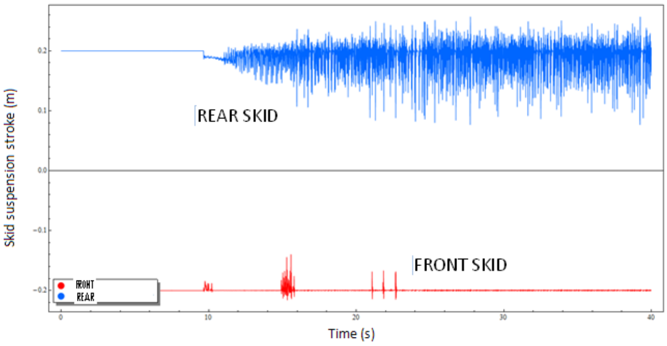

Figure 5. Time history of the skid strokes (front and rear)

The figures show the velocity, the pitch angle and the skids vertical displacements for a simulated acceleration of the vehicle up to 50m/s, with a Jonswap spectrum with wind speed at 10 knots. Although the simulations provide an exceptional help in predicting and with a good degree of realm the system performances, beside this tool the SEALAB team has developed also simplified linear models of the vehicle dynamics.

Their design relevance is related to the chance of modifying the design of the vehicle, and especially of the suspension systems, in a more effective way. In fact, simpler linear models, permit a better understanding of the response properties of the system, identifying more clearly the parameters controlling the vehicle stability and minimizing the undesired motion components.

4 SIMPLIFIED LINEAR MODELS

In its simplest modelling, the vehicle is idealized as a three-wings system: the first is an aerofoil, the second a hydrofoil and the third consists of a system of skids with a related elastic suspension and control. The three components are associated to the physical systems: (i) the lifted hull and the airfoils control surfaces, (ii) the submersed hydrofoil control surfaces, (iii) and the surfing skids attached to a rather sophisticated suspension with semi-active controls and special kinematic linkages.

The navigation of the new vessel follows different regimes depending on the operating speed and sea states. It starts as a displacement ship, then a planning hull behaviour is observed. As the speed increases, the hull is lift over the sea surface, and for almost still water conditions, it behaves as a hydrofoil, with additional cooperation of the aerofoil, both for lift and trim control purposes. To overcome the limits of a traditional hydrofoil, when large amplitude waves are encountered, the vehicle is equipped with a system of skids, a third interface-wings, surfing on the sea surface and attached to the hull structure by a suitable suspension system.

Figure 6. View of SEALAB

The interface-wings permit the navigation of the vessel at high speed even in the presence of large amplitude waves, the suspended skids acting as a filter between the sea surface and the hull structure and as trim-holders, in a manner analogous to an off-road wheeled vehicle approaches a rough road.

The navigation in the presence of the suspended skids, presents two different regimes: (i) the first is characterized by a permanent contact between skids and sea surface, (ii) the second indeed by an intermittent contact of the two. The modalities of navigation are completely different, and the second regime implies the vehicle jumps over the waves. More precisely, a critical speed is recognized in the range of intermittent contact, that when crossed produces the vehicle jumping from crest to crest, with smaller fluctuations in the pitch motion and a smaller average resistance due to the impacts, with the vessel centre of mass trajectory close to the sea surface envelope.

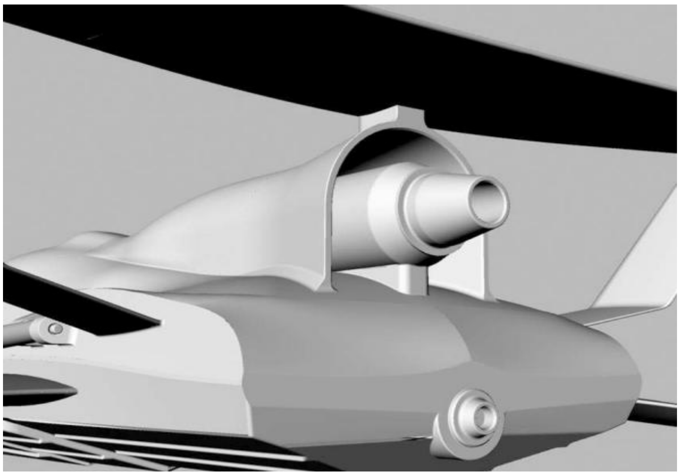

Figure 7. SEALAB: details of the gas-turbine exauste and of the water-jet

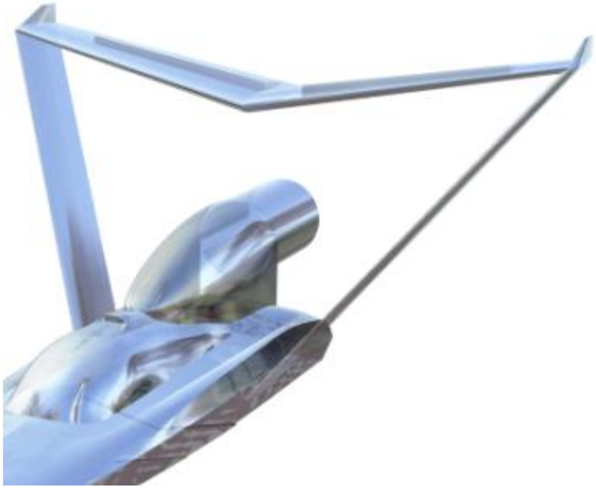

Figure 8. SEALAB: detail of the jet-engine and wing

During the design process, the SEALAB team developed several tools of analysis. The first was the brute force of numerical simulations, able to predict the expected response of the vehicle at different speeds of navigation and at different sea conditions, and presented in the previous section. Together with this approach, a theoretical modeling of the system, allows a more systematic understanding of the navigation properties of the vessel, including stability, together with a more clear identification of its key design parameters, and a more appropriate development of the control system characteristics.

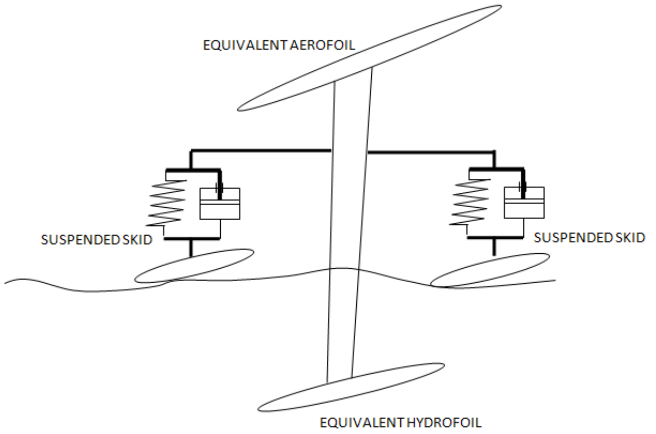

Figure 8. Simplified scheme of the SEALAB vehicle

In the present paper, the attention is mainly addressed to a general presentation of the skid-suspension effects, since the other navigation characteristics (like planning-hull and hydrofoil behaviors) are widely investigated in the existing literature (Faltinsen 2006, Collu et al. 2008, Collu et al. 2010, Collu et al. 2007, Kandasamy et al. 2009, Bruzzone et al.).

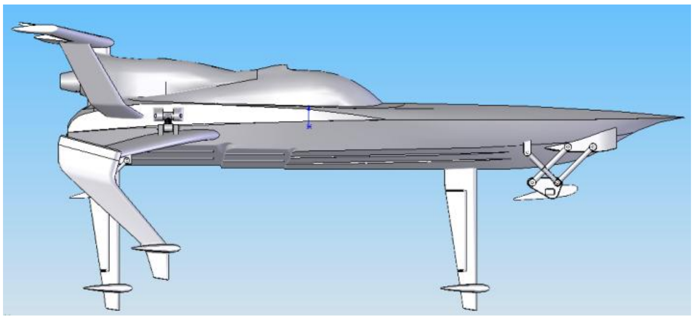

Figure 9. SEALAB: side view of one of the concept prototypes

The model here considered is a prototype three-wings system, with minimal complication, but able to include also stability properties. The vessel has two degrees of freedom: heave motion z and pitch angle θ. Two skid-suspension systems are introduced, each characterized by its own vertical displacement. The aerofoil and the hydrofoil are modeled as usual in aeroelasticity by using Theodorsen theory (Bisplinghoff et al. 1962), that provides for a wing in unsteady motion, the lift L and the moment M in terms of differential characteristics of the absolute vertical displacement u and the angle of attack α with respect to the inflow velocity:

$$\mathbf{F}_i = \mathbf{A}_i\,\dot{\mathbf{q}}_i + \mathbf{B}_i\,\mathbf{q}_i$$

$$\mathbf{F}_i = \begin{Bmatrix} L_i \\ M_i \end{Bmatrix}, \quad \mathbf{q}_i = \begin{Bmatrix} u_i \\ \alpha_i \\ \dot{u}_i \\ \dot{\alpha}_i \end{Bmatrix} \tag{1}$$

The matrices $\mathbf{A}_i$, $\mathbf{B}_i$ depend on geometrical and constructive characteristics of the system, and on the inflow velocity U_i for the wing. Equation (1) is derived in the context of wing theory in potential flow (Bisplinghoff et al. 1962), but with suitable replacement of the matrices $\mathbf{A}_i$, $\mathbf{B}_i$, it remains still valid for the skid, well fitting the results of experimental tests. Note that, both for the wings as well as for the skids, the inflow velocity U_i has a random character. In fact, in the presence of random sea waves, the surface elevation w produces a random velocity disturbance also under the free surface. This implies the velocity field encountered by the hydrofoil as well as by the skid, are random variables. As a general result, we conclude equation (1) provides a random force and dynamic effects involving random operators $\mathbf{A}_i$, $\mathbf{B}_i$. The analysis of such effects, even in the context of stability, strictly would need the help of rather complicated stochastic methods as those proposed in (Carcaterra et al. 2005, Culla & Carcaterra 2007). This opens an interesting theoretical perspective for the investigation of the models describing the new vehicle, actually under development by the SEALAB team.

Figure 10. SEALAB: detail of the wing system of the concept prototype

However, note the response of the wings are weakly affected by the surface elevation w in comparison with the effect w produces on the skids response. Therefore, in this paper, we assume (i) the random variability of U_i for the hydrofoil (and for the aerofoil) is negligible, so that the matrices $\mathbf{A}_i$, $\mathbf{B}_i$ become deterministic and none random parameter appears in equation (1) for the wings (ii); for the skids, in equation 1, the force produces a random time-dependent component $\mathbf{f}$ proportional to w, while the matrices $\mathbf{A}_i$, $\mathbf{B}_i$ are again approximated as deterministic. Therefore:

$$\begin{aligned}
\mathbf{F}_{aero} &= \mathbf{A}_a\,\dot{\mathbf{q}}_a + \mathbf{B}_a\,\mathbf{q}_a \\
\mathbf{F}_{hydro} &= \mathbf{A}_h\,\dot{\mathbf{q}}_h + \mathbf{B}_h\,\mathbf{q}_h \\
\mathbf{F}_{skid\ 1} &= -\mathbf{f}_1 + \mathbf{A}_{s1}\,\dot{\mathbf{q}}_{s1} + \mathbf{B}_{s1}\,\mathbf{q}_{s1} \\
\mathbf{F}_{skid\ 2} &= -\mathbf{f}_2 + \mathbf{A}_{s2}\,\dot{\mathbf{q}}_{s2} + \mathbf{B}_{s2}\,\mathbf{q}_{s2}
\end{aligned}$$

The two wings are integral with the vehicle. Therefore, their state vectors are the same, and coincide, except for initial settings of the trim $\mathbf{z}_{0a}$ and $\mathbf{z}_{0h}$, with the state vector $\mathbf{z}$ of the vessel:

$$\begin{aligned}
\mathbf{F}_{aero} &= \mathbf{A}_a\,\dot{\mathbf{z}} + \mathbf{B}_a\left(\mathbf{z} - \mathbf{z}_{0a}\right) \\
\mathbf{F}_{hydro} &= \mathbf{A}_h\,\dot{\mathbf{z}} + \mathbf{B}_h\left(\mathbf{z} - \mathbf{z}_{0h}\right)
\end{aligned}
\qquad
\mathbf{z} = \begin{Bmatrix} z \\ \theta \\ \dot{z} \\ \dot{\theta} \end{Bmatrix} \tag{2}$$

The hydrodynamic skid forces also depends on the state vector $\mathbf{z}$, since

$$\mathbf{F}_{skid\ i} = -\mathbf{f}_i + \mathbf{A}_{si}\left(\dot{\mathbf{z}} - \dot{\mathbf{z}}_{si}\right) + \mathbf{B}_{si}\left(\mathbf{z} - \mathbf{z}_{si}\right)$$

$$\mathbf{q}_{si} = \mathbf{z} - \mathbf{z}_{si}, \quad \mathbf{z}_{si} = \begin{Bmatrix} \delta_i \\ \theta_{0si} \\ \dot{\delta}_i \\ 0 \end{Bmatrix} \tag{3}$$

where δ_i are the relative displacements of the suspension system. The mass matrix of the vehicle is $\mathbf{M}$, while mass, damping and the stiffness matrices of the suspensions are described by $\mathbf{M}_1$, $\mathbf{M}_2$, $\mathbf{C}_1$, $\mathbf{C}_2$, $\mathbf{K}_1$ and $\mathbf{K}_2$, respectively.

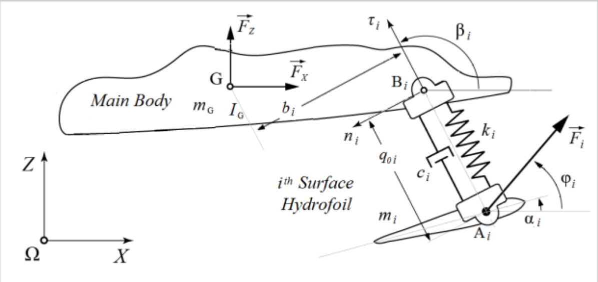

Figure 11. Scheme of the suspension system

In fact, the equations of the vehicle, for heave and pitch motion (forward motion is at constant speed *V*), are:

$$\mathbf{Q}\dot{\mathbf{z}} + \mathbf{R}\mathbf{z} + \mathbf{S}_1\mathbf{z}_{s1} + \mathbf{S}_2\mathbf{z}_{s2} = \mathbf{F}_a + \mathbf{F}_h \qquad (4)$$

where:

$$\mathbf{Q} = \begin{bmatrix} \mathbf{C} & \mathbf{0} \\ \mathbf{0} & \mathbf{M} \end{bmatrix}, \ \mathbf{R} = \begin{bmatrix} \mathbf{0} & -\mathbf{C} \\ \mathbf{0} & \mathbf{0} \end{bmatrix}$$

$$\mathbf{S}_1 = \begin{bmatrix} \mathbf{0} & \mathbf{0} \\ \mathbf{K}_1 & \mathbf{C}_1 \end{bmatrix}, \ \mathbf{S}_2 = \begin{bmatrix} \mathbf{0} & \mathbf{0} \\ \mathbf{K}_2 & \mathbf{C}_2 \end{bmatrix}$$

$$\mathbf{F}_a = -\begin{Bmatrix} \mathbf{0} \\ \mathbf{F}_{aero} \end{Bmatrix}, \quad \mathbf{F}_h = -\begin{Bmatrix} \mathbf{0} \\ \mathbf{F}_{hydro} \end{Bmatrix}$$

Substitutions of equations (2) into equation (4) produces:

$$(\mathbf{Q} + \mathbf{T})\dot{\mathbf{z}} + (\mathbf{R} + \mathbf{U})\mathbf{z} = -\mathbf{S}_1\,\mathbf{z}_{s1} - \mathbf{S}_2\,\mathbf{z}_{s2} \qquad (5)$$

$$\mathbf{T} = \begin{bmatrix} \mathbf{0} \\ \mathbf{A}_a + \mathbf{A}_h \end{bmatrix}, \quad \mathbf{U} = \begin{bmatrix} \mathbf{0} \\ \mathbf{B}_a + \mathbf{B}_h \end{bmatrix}$$

The found set of equations is completed with the two equations for the suspension systems (skids):

$$(\mathbf{Q}_{si} + \mathbf{T}_{si})(\dot{\mathbf{z}} - \dot{\mathbf{z}}_{si}) + (\mathbf{R}_{si} + \mathbf{U}_{si})(\mathbf{z} - \mathbf{z}_{si}) - \mathbf{S}_i\,\mathbf{z}_{si} = \mathbf{f}_i \qquad (6)$$

$$\mathbf{T} = \begin{bmatrix} \mathbf{0} \\ \mathbf{A}_{si} \end{bmatrix}, \quad \mathbf{U} = \begin{bmatrix} \mathbf{0} \\ \mathbf{B}_{si} \end{bmatrix}$$

Combining equations (5) and (6), one obtains:

$$\mathbf{H}\,\dot{\mathbf{x}} + \mathbf{G}\,\mathbf{x} = \mathbf{F}$$

$$\mathbf{H} = \begin{bmatrix} \mathbf{Q} + \mathbf{T} & \mathbf{0} & \mathbf{0} \\ \mathbf{Q}_{s1} + \mathbf{T}_{s1} & -\mathbf{Q}_{s1} - \mathbf{T}_{s1} & \mathbf{0} \\ \mathbf{Q}_{s2} + \mathbf{T}_{s2} & \mathbf{0} & -\mathbf{Q}_{s2} - \mathbf{T}_{s2} \end{bmatrix}$$

$$\mathbf{G} = \begin{bmatrix} \mathbf{R} + \mathbf{U} & \mathbf{0} & \mathbf{0} \\ \mathbf{R}_{s1} + \mathbf{U}_{s1} & -\mathbf{R}_{s1} - \mathbf{U}_{s1} & \mathbf{0} \\ \mathbf{R}_{s2} + \mathbf{U}_{s2} & \mathbf{0} & -\mathbf{R}_{s2} - \mathbf{U}_{s2} \end{bmatrix} \qquad (7)$$

$$\mathbf{x} = \begin{Bmatrix} \mathbf{z} \\ \mathbf{z}_{s1} \\ \mathbf{z}_{s2} \end{Bmatrix} \qquad \mathbf{F} = \begin{Bmatrix} \mathbf{0} \\ \mathbf{f}_1 \\ \mathbf{f}_2 \end{Bmatrix}$$

Equation (7) allows both the analysis of the expected pitch and heave motion response of the vessel excited by the surface random forces, and permits as well as the optimization of the suspension parameters in order to minimize the ship response. Additionally, eigenvalues analysis of the matrix $\mathbf{G}^{-1}\mathbf{H}$, allows for stability considerations, selecting those suspension parameters making the better sea-keeping performances, by inspecting the trajectories of the roots of the characteristic polynomial in the complex plane. This analysis is actually made introducing special control systems for the skids and their coupling (hydraulic and electromagnetic managed by a suitable electronic control).

Additional hints come considering a semi-active technology can be introduced for damping control, here called sea-hook dampers, that re-adapts to the case of a sea vessel, the sky-hook technology developed for wheeled vehicles. All these approaches are at the basis of the investigations in progress in the SEALAB project.

It appears, the previous model helps at the design stage of the vehicle under navigation conditions implying a permanent contact between the skids and the sea surface. However, direct numerical simulations show clearly how this condition holds only for speed below a certain threshold, given a certain sea-state. Once the speed overcomes this limit, the skids systematically come in and out from the water, the phenomenon becomes nonlinear, and the previous analysis is not valid anymore. For the response analysis in this condition, the tools described in section 3 are indeed used.

REFERENCES

O.M. Faltinsen (2006) *Hydrodynamics of high speed marine vehicles, Cambridge University Press, 2006.*

T. I. Fossen (1994) *Guidance and Control of Ocean Vehicles, John Wiley & Sons, New York, 1994.*

M. Collu, M H Patel, F Trarieux (2008) *"High speed marine vehicles with aerodynamic surfaces: development of a dynamic model for a novel configuration", Cranfield Multi Strand Conference, Cranfield, 2008.*

M Collu, M H Patel, F Trarieux (2010) *"The longitudinal static stability of an aerodynamically alleviated marine vehicle, a mathematical model", Proc. Of the Royal Society A, 466, 1055-1075, 2010.*

M Collu, M H Patel, F Trarieux (2007) *"A Unified Mathematical Model for High Speed Hybrid (Air and Water-borne) Vehicles", Second Int. Conf. on Marine Research and Transportation, Italy, 2007.*

M. Kandasamy et al. (2009) *"CFD Validation Studies for a High-Speed, Foil-Assisted, Semi-Planing Catamaran",* 10th Int. Conf. on Fast Sea Transp., FAST 2009, *Greece, 2009*

D. Bruzzone, P. Gualeni, P. Cassella, I. Zotti *"Motion and Added resistance of Multihull Marine Vehicles at high Speed : Numerical and Experimental Results"; Proc. Hydrodynamics VI – Theory and Applications, A.A. Balkema Publishers, 29 – 35, Australia.*

Peri, D., and Campana, E.F. (2003) *"Multidisciplinary Design Optimization of a Naval Surface Combatant", Journal of Ship Research, 47 (1), 2003.*

Pinto, A., Peri, D., and Campana, E.F. (2004) *"Global optimization algorithms in naval hydrodynamics", Ship Technology Research, 51 (3), 2004.*

A. Carcaterra, E. Ciappi (2000) *'Prediction of the Compressible Stage Slamming Force on Rigid and Elastic System Impacting over the Water Surface', Nonlinear Dynamics, 21(2), 193-220, 2000.*

A. Carcaterra, E. Ciappi (2004) *'Hydrodynamic shock of elastic structures impacting on the water: theory and experiments', Journal of Sound and Vibration, 271, 411-439, 2004.*

A. Carcaterra, E. Ciappi, A. Iafrati, E.F. Campana (2000) *'Shock Spectral Analysis of Elastic Systems Impacting on the Water Surface', Journal of Sound and Vibration, 229(3), 579-605, 2000.*

A. Iafrati, A. Carcaterra, A. Ciappi, E.F. Campana (2000) *'Hydroelastic Analysis of a Simple Oscillator Impacting the Free Surface', Journal of Ship Research, 278-289, 2000.*

D. Dessi, R. Mariani (2008) **"***Analysis and prediction of slamming-induced loads of a high-speed monohull in regular waves"***,** Journal of Ship Research*, 52(1), 2008.*

A. Carcaterra, D. Dessi, F. Mastroddi (2005) *'Hydrofoil vibration induced by a random flow: a stochastic perturbation approach', Journal of Sound and Vibration, 283, 401-432, 2005.*

R.L. Bisplinghoff, H. Ashley (1962) *Pinciples of Aeroelasticity, John Wiley & Sons, New York, 1962.*

A.Culla, A. Carcaterra (2007) *'Statistical moments prediction for a moored floating body in random waves', Journal of Sound and Vibration, 308, 44-66, 2007.*