Multisection approach for the vertical water impact of a fuselage

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1 INTRODUCTION

Although aircraft ditching is a rare event in the aeronautical field, it needs to be considered in the design phase to guarantee safety and ensure the certifications' respect. Besides experimental tests [1, 2] and high-fidelity approaches [3], the use of fast and efficient solvers, albeit of lower fidelity, is of primary interest to aircraft manufacturers to have a quick but at the same time accurate estimate of the hydrodynamic loads acting on the aircraft, to be effectively exploited in its conceptual and preliminary design phases. This is particularly true during the aircraft optimization process where many different configurations have to be analyzed. In this perspective, fully non-linear potential flow models, although remaining low fidelity approaches but being fully non-linear, provide accurate details, like pressure distribution, and should allow capturing some hydrodynamics phenomena occurring in ditching problems like cavitation and ventilation [1]. An idea should be developing a 2D+t procedure which exploits a 2D fully non-linear potential flow model [4, 5] to describe the hydrodynamics of the aircraft ditching phenomenon. The 2D+t approach is based on a slender body approximation and reduces the 3D problem into a series of 2D cross section problems, with the shape of the section changing in time, in an earth-fixed frame of reference. As a first step through the implementation of a 2D+t approach, this paper presents a multisection procedure for computing the vertical water impact of a fuselage. Differently from the 2D+t method, in the multisection procedure the forward velocity in the longitudinal direction is not considered and the shape of the 2D sections don't change in time during the immersion. The proposed multisection procedure is based upon a 2D fully non linear potential flow hybrid BEM-FEM solver proposed in [6, 7]. The hybrid BEM-FEM approach has shown in the past good capabilities in describing the hydrodynamics of 2D water impact problems both in water entry with constant velocity [6, 7] and in the combined water entry/exit with varying speed [8]. The numerical investigation aims to preliminarily verify the procedure here proposed through its application to a guided drop test of a scaled fuselage.

2 MULTISECTION PROCEDURE

The vertical water impact of a fuselage is here faced with a multisection approach where the 3D water entry problem is approximated by a series of the 2D water entry problems of the different fuselage cross sections. In this way the 3D problem is split into a series a 2D boundary value problem which are solved independently by using the hybrid BEM-FEM solver. The multisection algorithm is based on a three-step procedure, described in the following, and shown in figure 1.

- Step 1. Let consider the impacting fuselage on the x-z plane. Starting from the point where the fuselage touches the water the first time, a number of equally spaced vertical space-fixed cross planes intersecting the fuselage are introduced.
- Step 2. When the body reaches a fixed initial depth, necessary to start the numerical simulation [8], the first space-fixed plane is activated. The corresponding 2D section on the y-z plane is derived by linear interpolation between the fuselage sections closer to the

activated plane. This is the 2D body geometry that the hybrid BEM-FEM solver uses to solve the 2D water entry problem.

- Step 3. After certain time steps, other space-fixed sections are activated as the lower intersection with the fuselage contour reaches the fixed initial depth. The corresponding 2D sections are derived and the water entry simulation starts on each new activated section.

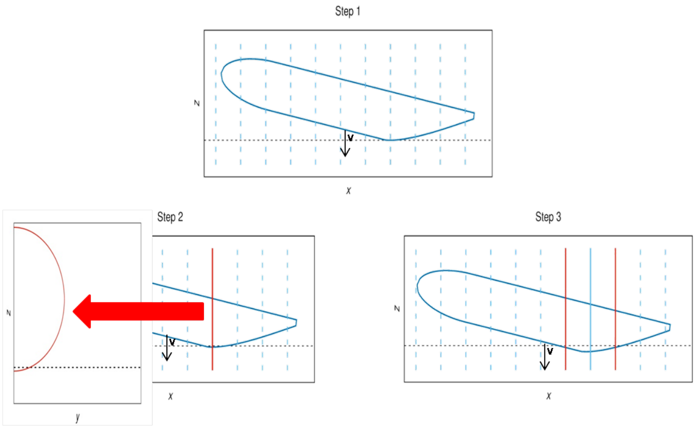

Figure 1: Multisection procedure.

The third step of the multisection procedure described above is the most critical one from a numerical point of view. It requires paying particular attention to the choice of the initial discretization of the new activated section. Indeed, in this work, during the firsts numerical test on the multisection procedure, it was observed that an inadequate discretization does not allow the formation of the jet and the evolution of the solution. This critical aspect is similar to what was observed in [9] for the water entry of an asymmetric body. In that case, the criticality was the correct definition of the initial discretization, in particular the choice of the amplitude of the first panel on the two sides of the free surface. To overcome this criticality, in [9] the initial discretizzation was defined by considering the relationship on the velocity singularity at the intersection point between the body contour and the free surface

$$u_z \propto \sigma r^{\sigma-1}, \quad \sigma = \frac{\pi}{2(\pi-\beta)}, \tag{1}$$

where r is the distance from the intersection point (*i.e.* the half width of the firsts panel on the free surface, $r = dx/2$) and β is the deadrise angle. Thus fixing the amplitude of the first panel on one side, the amplitude of the first panel on the other side is chosen to have the same order of the vertical velocity at the two intersection points. In this way, the discretization guarantees the formation of the jet on both sides of the body and the evolution of the solution [9]. In this paper, in order to define the size of the first panel for the new activated section, the relationship (1) is coupled with the Courant number, C,

$$C = \frac{udt}{dx}, \tag{2}$$

used to determine the time step dt. In equation (2) u and dx are the flow velocity and the amplitude of the panel, respectively. Setting $dx = 2r$, considering $u \simeq u_z$ at the initial step of new activated section and being dt governed by the previous activated sections, the following relationship is proposed for the choice of the first panel amplitude of the new activated section

$$dx = \left(\frac{\sigma 2^{\sigma-1} dt}{C}\right)^{1/(2-\sigma)}. \tag{3}$$

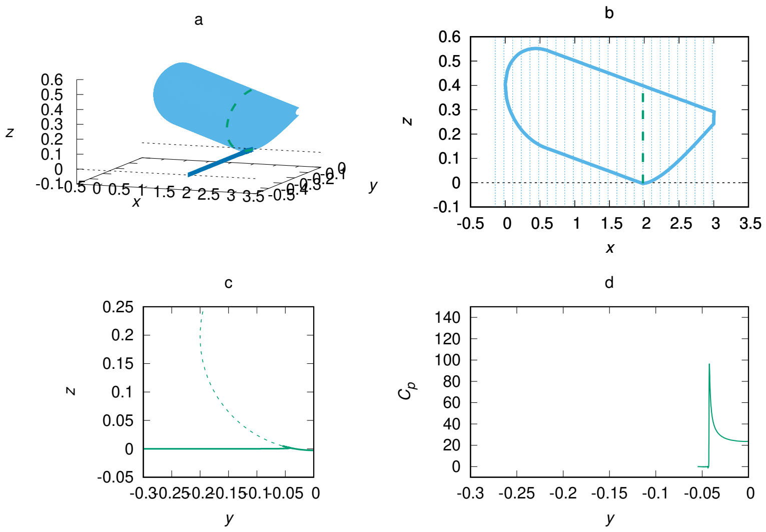

Figure 2: Overview at t=0.006s. a) 3D view. b) x-z plane: the dashed line represents the activated section. c) y-z plane: free surface (continue line) and 2D section (dashed line). d) pressure coefficient distribution acting on the activated section.

3 WATER ENTRY OF A SCALED FUSELAGE

A simple drop test case of a scaled fuselage has been chosen to verify the implemented procedure. The body is characterized by circular cross sections and impacts the water with a decelerated vertical velocity. At the beginning of the fuselage water entry, only the first fixed section is activated, which is represented by a green dashed line in figures 2a-b, where the fuselage on a global 3D view and on the x-z plane are respectively shown at time $t = 0.006s$. The light blue dashed lines in figure 2b represent the equally spaced vertical space-fixed cross planes introduced. The corresponding 2D water entry problem of the first activated section is solved and the results in terms of free surface shape and pressure coefficient distribution are depicted in figures 2c-d: as the solution is symmetrical, only the results on the y-negative side of the domain are shown. The flow rises along the body contour and a thin jet is formed (see figure 2c); moreover, the pressure coefficient on the wetted area is characterized by a peak just behind the jet root (see figure 2d). At a later time instant, $t = 0.027s$, the wetted area of the whole entering fuselage expanded and the second section has been activated: it is represented by a magenta dashed line in figures 3a-b. Also for the new activated section the corresponding 2D water entry problem is computed providing the free surface configuration and the pressure acting along the 2D section. Results in terms of the free surface shape and the pressure coefficient distribution for the two activated sections at time $t = 0.027s$ are shown in figures 3c-d. In the first one, green curves, the flow has continued rising the body contour and the pressure has decreased due to both the body deceleration and the increase of the local jet angle at the jet root. In the second one, magenta curves, a thin jet has been formed and a peak of pressure occurs at the jet root. The same behaviour in terms of free surface evolution and pressure coefficient distribution, can be observed by following other sections activated later, which will be shown during the workshop, thus highlighting that the algorithm in equation (3) works well.

4 CONCLUSION

The vertical water impact of a scaled fuselage with decelerated entry velocity has been presented. The problem was approximately studied with a multisection procedure exploiting a 2D fully non-linear potential flow solver based on a hybrid BEM-FEM approach. The test has shown that the formula for defining the initial discretizzation of the new activated sections works reasonably well. Indeed, in each section the jet is formed and the simulation updates as

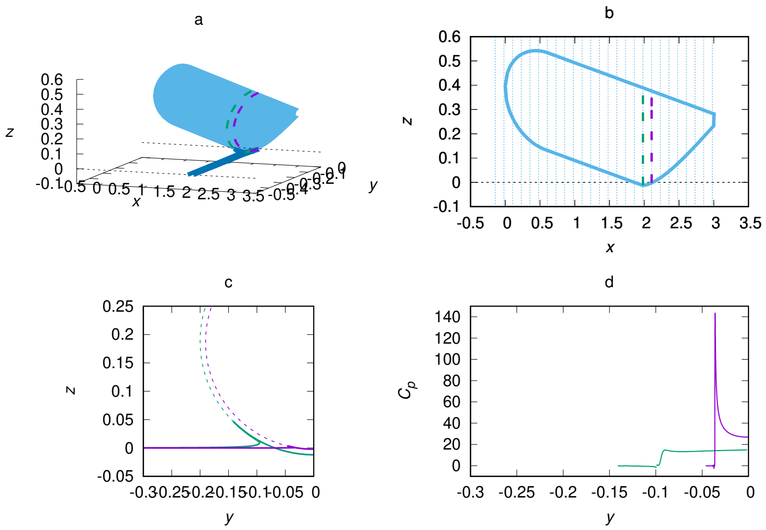

Figure 3: Overview at t=0.027s. a) 3D view. b) x-z plane: the dashed lines represent the activated sections. c) y-z plane: free surface (continue line) and 2D section (dashed line). d) pressure coefficient distribution acting on the activated sections.

expected, and the 2D solver provides, for each activated section, a hydrodynamics description in terms of free surface shape evolution and pressure distribution along the wetted area.

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