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THE OBLIQUE WATER ENTRY IMPACT OF A TORPEDO AND ITS BALLISTIC TRAJECTORY SIMULATION

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Abstract. To study the water entry ballistic trajectory of a torpedo, the wind tunnel experiment has been done based on the similarity principle. Then the drag coefficient of the torpedo is got when it enters the water, which is amended by the introduction of continuous supercavitation factor and local cavity effect factor. The vertical plane motion equations are established to get the torpedo's trajectory. The large scale nonlinear transient finite element commercial software MSC. dytran is also used to simulate the initial water entry impact of the Disk-Ogive-Head[1] torpedo, including four special high-speed water entry attitude angles. Then the kinematics parameters as the tail of torpedo submerges in water are input into the motion equation as the initial conditions. Finally, two parts of the data are combined to get the whole kinematic and kinetic parameters. During the calculation, the ballistic modeling uses the cavitation number to determine the torpedo's moving status: in the supercavitation stage, in partial cavity stage or in full wet navigation stage. The simulation results will do reference use to the following trajectory design. In addition, the water impact load and over load calculation of high-speed oblique water entry impact will help to design the intensity of torpedo's shell.

Key words. Water entry, MSC. dytran, FE simulation, torpedo, over load, trajectory, impact drag coefficient.

1. Introduction

In modern naval warfare, torpedo and anti-torpedo confrontation is growing more fiercely, improving the concealment of torpedoes is a key issue to be researched, conventional air-dropped torpedo or rocket assisted torpedo usually enters water with a parachute [2]. As the target is so large that it can be easily found by the enemy. In addition, when a torpedo enters water with a buffer cap, if the buffer cap couldn't fully come to pieces, the relic would affect its streamline, and thus affect the torpedo's hydrodynamic characteristic. So high speed torpedo's entering water without a parachute and a buffer cap is a trend.

However, water entry of high-speed naked torpedoes will face enormous fluid impact force. Perhaps the load could cause damage to its structure, so failure and even damage of internal components cannot be ignored. It is necessary to accurately compute the fluid and solid interaction and its effect. Therefore, research on water entry impact of high speed torpedoes and their ballistics trajectory have an important significant background.

As computer-aided engineering technology rapidly develops, finite element analysis software has been widely used in the transient dynamics analysis [3], which could be applied in the process of special transient dynamics simulation analysis, especially in high speed torpedo's water entry impact issues, and it can greatly improve the efficiency and save the spending [4]. In practical work, the experiment research of water entry impact is not only costly but also difficult to operate. Sometimes the results may not be entirely accurate. The transient nonlinear finite element commercial analysis software MSC. dytran can effectively deal with

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multi-material fluid-solid coupling problems, it is very appropriate to simulate the dynamic response when a torpedo hits the water.

In the current investigation, the wind tunnel experiment has been done to get the drag coefficient of the torpedo based on the similarity principle. The continuous supercavitation factor and local cavity effect factor are introduced to amend the drag coefficient, which is combined with the vertical plane motion equations to get the torpedo's tracks. The finite element software MSC. Dytran is used to simulate the initial water entry impact of a Disk-Ogive-Head[1] torpedo, including four special high-speed water entry attitude angles. When the kinematics parameters are got, they are input into the motion equation as the initial conditions. Then two parts of the data are combined to get the whole kinematic and kinetic parameters.

2. Dytran program

2.1. Software description. MSC. Dytran[5] is a large nonlinear transient finite element commercial software, which could be used in aviation, aerospace, marine and automotive fields, as well as a wide range of applications. In MSC. Dytran the solid structure uses Lagrange elements; fluid (including air, water) uses Euler elements. The interface between the two is defined as fluid-solid coupling surface. The coupling algorithms include general coupling algorithm and Arbitrary Lagrangian-Eulerian (ALE) Coupling. By directly grid-coupling Lagrange mesh and Euler mesh the kinematics parameters and motion parameters on the coupling surface can be automatically and accurately calculated and outputted at each time step. In this process, on one hand, Euler pressure caused by material flow through the coupling algorithm automatically loads on the structure grid; on the other hand, the deformation of the structure grid will in turn affects the flow of Euler material and pressure values. So the interaction of structure deformation and fluid makes it possible to get the solution of fluid-solid coupling problem.

2.2. Numerical model. In this paper, all the output parameters and model use the International Units. The finite element model of the torpedo is shown in figure 1. Euler fluid region is divided into two parts, the upper part is air domain, with the size of 1.2m∗1.2m∗0.8m. It is divided into 200,000 Euler elements, filled with ideal compressible gas. The air domain is described by Gamma state equation [6]:

$$p = (\gamma - 1)\rho e, \tag{1}$$

where p is the air pressure, γ is the ratio of specific heat, taken as 1.4, ρ is the air density, taken as 1.2, e is the specific internal energy of unit mass. The initial pressure for the air region takes a standard atmospheric pressure of $0.1013Pa$. According to Eq. (1) the initial e of air domain could be calculated as $211{,}041J/g$.

The lower part is the water domain, with the size of 1.2m∗1.2m∗1.5 m, which is divided into 300,000 Euler elements. Non-viscous and compressible fluid medium is used to fill these elements. The pressure of the water region is described by the polynomial equation of state [6], shown as

$$p = \begin{cases} a_1\mu + a_2\mu^2 + a_3\mu^3 + (b_0 + b_1\mu)\rho_0 \\ \mu > 0, incompression \\ a_1\mu + (b_0 + b_1\mu)\rho_0 e \\ \mu < 0, intension \end{cases}, \tag{2}$$

where p is the pressure of water, $\mu = \rho/\rho_0 - 1$, ρ is the density of sea water, ρ_0 is the reference density of water. The true density of sea water takes 1020 m/s^3, the reference water density takes 1000 m/s^3, e is specific internal energy per unit mass.