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Novel particle distributions for SPH bird-strike simulations

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Abstract

This paper is concerned with bird-strike numerical simulations using the Smoothed Particle Hydrodynamics method to represent the bird model. A comparison between bird models with classical mesh-based particle distributions and bird models with initial particle distributions generated using a technique based on the Weighted Voronoi Tessellation algorithm is presented. The adopted iteration technique to fill the bird model with particles is described. Particle distributions generated using this new technique are assessed in comparison with reference bird models commonly used in the literature. Results of generic bird-strike simulations on a flat target structure indicate the superiority of the proposed bird models over the bird models with classical mesh-based particle distributions in terms of flow behavior, conservation of total energy, normal forces, pressures, and computational efficiency.

Keywords: Bird-strike; Numerical simulation; Smoothed Particle Hydrodynamics; Weighted Voronoi Tessellation; Particle distribution

1. Introduction

Birds frequently collide with aircraft during near-airport operations, especially during take-off and landing. In general, all parts of an aircraft facing in the direction of motion are exposed to this threat (e.g. leading edges of wing and empennage, cockpit windshields, radome, landing gear, engines, rotors). Due to the high exposure with approximately 170.000 bird-strikes recorded between 1990 and 2015 in the US and by US-registered aircraft abroad [1], bird-strikes account for one of the largest every-day threats to aviation safety and are a relevant issue for both fixed- and rotary-wing aircraft. An exemplary incident that caught wide public attention is the 2009 Hudson River accident, where an Airbus A320 was forced to undertake an emergency landing on the Hudson River near Manhattan after experiencing a double engine failure due to a number of birds impacting both engines shortly after take-off [2,3]. Fortunately, there were no fatalities among the 155 occupants of flight US1549, yet this accident pointed out the importance of bird-strike analyses.

With the objective to develop a substitute bird model for the use in bird-strike experiments, the fundamentals and physical phenomena involved in bird-strike events have been investigated starting in the 1960s [4–9]. These pioneering investigations pointed out the typical impact pressure response, which is characterized by (a) a sharp

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rise up to the peak pressure (Hugoniot pressure), (b) a subsequent decay of the pressure, and (c) a steady pressure level [7]. Furthermore, they found that birds essentially behave fluid-like during a bird-strike at the characteristic impact velocities. Thus, substitute birds are typically modeled using gelatine, which replicates this behavior very well[1] and the fluid-like behavior can be simulated by a hydrodynamic model [6,7]. Generally speaking, substitute birds allow for improved reproducibility in bird-strike experiments compared to experiments with real birds because of the absence of species-dependencies, individual-specific mass and shape (for instance depending on age and gender), heterogeneous material properties, difficulties in targeting, and controlling the bird's shape and attitude upon impact [10,11]. Nevertheless, the reproducibility of the substitute bird's shape and its attitude upon impact still remains challenging [12]. Although substitute birds cannot be employed for certification yet, they are of value for the design of new aircraft structures. Today, experimental and numerical analysis methods are employed to investigate the bird-strike resistance of new aircraft structures. Due to the high cost associated to experimental testing (need for detailed test articles that usually are destroyed after a bird-strike test), there is a large interest in using numerical analyses. The latter can contribute to design bird-strike resistant structures and to prepare the experimental setup before undergoing first experimental testing, which still is mandatory within bird-strike certification. Among several computational approaches to simulate bird-strike, see e.g. [10,13–15], the Smoothed Particle Hydrodynamics (SPH) method [16,17] is widely used to simulate the bird as it has been proven that SPH can reproduce the main physical effects of the bird-strike phenomenon [11,18–21]. SPH is a mesh-free numerical method; therefore, the bird model is discretized with particles that are not interconnected as in mesh-based methods. The mesh-free nature of SPH enables large deformations and splitting of the bird model without additional care. The method can be coupled to the Finite Element (FE) solution typically employed for the structural models using a penalty contact algorithm since both methods are based on the Lagrangian formulation. Furthermore, the SPH method is incorporated in several commercial FE codes, which eases its application within structural analyses. Contrary to these advantages, the SPH method is computationally expensive because it frequently requires redetermining which particles interact.

Besides the frequent use of SPH for bird-strike simulations and the studies on representative bird model shapes [10,11,19,22,23], there are no studies on the effect of the particle distribution to the knowledge of the authors. Commonly, SPH bird models are generated based on volume element meshes from which the elements are converted to particles [11,18,24–26] or on cubic lattice arrangements [20,27–30]. This, however, comprises several drawbacks as it will be discussed in this paper. The present work investigates novel particle distributions in the context of bird-strike simulations. In particular, a technique to generate superior, quasi-isotropic initial particle distributions within arbitrary domains is introduced.

First, the adopted numerical approach for the bird-strike simulations is presented in Section 2. The paper continues in Section 3 with a brief review of typical bird geometries as well as approaches employed to generate SPH bird models. Next, the Weighted Voronoi Tessellation technique, which is used to fill arbitrary bird geometries with equidistant uniform particles, is described. Means to analyze the quality of particle distributions are demonstrated. Section 4 presents the bird-strike simulation model adopted for the benchmark studies. The simulation results as well as a profound assessment and discussion are given in Section 5. Finally, conclusions are drawn in Section 6.

2. Numerical simulation approach

The presented numerical bird-strike simulations adopt an approach where the Smoothed Particle Hydrodynamics and the Finite Element method are coupled within one simulation with explicit time integration. Fig. 1 provides an overview of the SPH-FE bird-strike simulation approach with schematic explanations, while further details of the bird modeling, the structural modeling, and the fluid–structure interaction are described hereafter.

2.1. Bird modeling

For the bird model that in a bird-strike behaves fluid-like (cf. Section 1), the weakly-compressible SPH method as described by Monaghan [17] is employed. It uses the Lagrangian formulation, i.e. where the motion of the material points and the discretization are tied, to discretize the continuum using particles. Each particle represents a volume

[1] Besides gelatine, there are other materials, see [5].