Multimaterial bird model for bird impact simulation using SPH method

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Abstract. Bird strike case is a part of the passenger aircraft certification requirements. The numerical calculation of bird crash cases can ease the burden and time of testing to be performed. The definition of a valid bird model is often a problem in modeling bird impact cases. One of the modeling approaches that can be used is the smooth particle hydrodynamic method. In this method, birds are modeled as fluid particles that have a certain number of parameters. There are a number of geometry variations and bird model parameters that can be used, including physical properties of fluids, materials, and various other controls. The paper focuses on building the multimaterial bird model that is more representative than traditional bird model, but simple to make.

1. Introduction

Bird strike incidences have caused many financial losses and threats to the safety of aviation around the world. Based on the USA Bird Strike Comittee page data, on 2013, 250 people have died worldwide due to bird strike since 1988. The losses caused by the case are estimated at 700 million dollars per year [1]. The case of bird impact in Indonesia occurred on September 27, 2007 on the B737-200 PK-YRT aircraft with the Surabaya-Mataram route, so the plane was forced to make a two-minute landing after takeoff from Juanda airport [2]. The resistance of aircraft components to birds strike has become one of the requirements of aircraft certification.

The certification of bird impact on aircraft components can be done by testing. In addition, finite element method can also be used to simulate cases of bird impact. The use of finite element method is intended to reduce the cost and time required for testing. The exact definition of bird models is often a major problem in the numerical simulation of bird strike. There are several different techniques that can be used to simulate bird impact, among them Lagrangian, Eulerian, Arbitrary Lagrangian-Eulerian (ALE), and Smooth Particle Hydrodynamic (SPH). Each of these approaches has advantages and disadvantages. SPH method is considered to be best representative of the case of bird impact because majority of birds consist of fluid. [3] The focus of this research is building bird model using SPH method. The SPH method is a modeling method of a continuum as fluid particles that have a certain number of properties.

In order to produce a valid bird model, a comparison with the bird model is made with the experimental results. The experimental results used as a comparison were the results of a bird carcass collision experiment on a plate performed by Liu, in the form of displacement points at the location of sensors mounted on the target plate [4]. Bird models used in bird impact simulations can be unimaterial bird models and multimaterial bird models. The unimaterial bird model is made by simplifying the true bird shape into a simple single shape. The model of multimaterial birds is made by
maintaining the main body parts of birds, such as head, neck, torso, and wings. Most researchers use the unimaterial bird model (also called the traditional bird model) because it is simpler than the multimaterial bird model.

In this paper, a multimaterial bird model is created to review the possibility of obtaining a model that is more accurate than the traditional bird model, but simple enough to make. The bird model used refers to the FAR / CS 25 regulation of bird impact, which weighs 1.8 kg [5]. The speed used in the modeling is adjusted to the collision speed in the experiment. Both models are compared to determine the model closer to the experimental results.

2. FEM modeling and simulation setup

The bird model validation was carried out according to the experiment in reference [4]. The bird model crashed into a 600x600x10 mm aluminum plate. The bird model validity test was performed by comparing the displacements occurring at the point where the sensor D1 (-50.0) and D2 (-150.0) were placed. The experiment used a 1.8 kg bird carcass that hit the target plate at a speed of 116 m/s. The mass of birds according to experiment is 1.8 kg [4]. The bird was folded and placed in a sabot before launched to the target. The experimental scheme is shown in figure 1, while the sensor location is given in table 1.

![Figure 1. Scheme of bird collision experiment on plates.](image)

**Table 1. Location of the sensor on the target plate.**

| Sensor | x (mm) | y (mm) |
|--------|--------|--------|
| D1     | -50    | 0      |
| D2     | -150   | 0      |

Previous unimaterial bird models have been used to compare Liu's experimental results. Traditional bird model geometries used include a straight-ended cylinder model, a hemispher-tipped cylinder, and an ellipsoid. Traditional bird model density is based on references [3] and [6] of 950 kg/m³. The aspect ratio or the ratio between the length of the bird model and the diameter of the bird model is adjusted by references [3] and [6], i.e. 2. The size of the bird model is determined by the relation of mass, density, volume, and aspect ratio. The diameter of the bird model is determined using equations (1), (2), and (3). The sectional shape of the unimaterial bird model is shown in figure 2. The size and number of SPH particles in the bird model are found in table 2.

![Figure 2. The shape of the unimaterial bird model.](image)
\[ D_{\text{hemispher-tipped cylinder}} = 3 \left( \frac{8m}{\pi \rho \left( \frac{4}{3} + 2(AR - 1) \right)} \right) \]
\[ D_{\text{straight-ended cylinder}} = 3 \left( \frac{8m}{\pi \rho AR} \right) \]
\[ D_{\text{ellipsoid}} = 3 \left( \frac{6m}{\pi \rho AR} \right) \]

Table 2. The size of a traditional bird model.

| Shape                   | L (mm) | D (mm) | SPH particle numbers |
|-------------------------|--------|--------|----------------------|
| Hemispher-tipped cylinder | 226    | 113    | 6552                 |
| Straight-ended cylinder  | 268    | 134    | 6656                 |
| Ellipsoid               | 244    | 122    | 6567                 |

The multimaterial bird model is built by maintaining the head, neck, torso, and wings. Each part of the bird's body is approached by a single form. The internal organs, bones and feathers in each body section are not modeled and incorporated into each of the substitution geometrics. The torso is substituted with a hemispheric cylindrical tipped shape. The neck is substituted with a straight-cylindrical shape. Wing is replaced with rectangular shape. The head is replaced with a hemispheric cylindrical tipped shape. The beak is not dotted and is combined with the head by raising the density of the head model. The multimaterial bird model is shown in figure 3.

The size of each body part of the bird is adjusted to the measurement of the average non-dimensional aspect ratio in geese. The size of the aspect ratio for the torso, neck, and head of the bird is calculated as the ratio of length to diameter. The non-dimensional size of the wing is determined by the halfspan ratio with the root chord. Bird wings are considered straight rectangular so root and tip chords have the same length. The non-dimensional size of each part of the bird's body is found in table 3.
Table 3. Non-dimensional sizes of bird model parts.

| Part  | Shape                  | Aspect Ratio |
|-------|------------------------|--------------|
| Head  | Hemispher-tipped cylinder | 1.35         |
| Neck  | Straight-ended cylinder  | 2.5          |
| Torso | Hemispher-tipped cylinder | 1.57         |
| Wings | Rectangular             | 2.64         |

The multimaterial models are varied based on the mass distribution of each part of the bird's body, into models M1, M2, and M3. The mass distribution of each part of the bird's body is modified from reference data [7] and [8]. The variation of mass distribution is shown in table 4.

Table 4. Percentage distribution of mass on the part of the bird model.

| Part  | Mass percentage (%) |
|-------|---------------------|
|       | M1  | M2  | M3 |
| Head  | 4   | 3   | 2  |
| Neck  | 6   | 5   | 3  |
| Torso | 70  | 72  | 75 |
| Wings | 20  | 20  | 20 |

The distribution of the density of each bird body is adjusted by reference [7]. The density distribution is shown in table 5.

Table 5. Density of each part of the bird.

| Part  | Density (kg/m³) |
|-------|-----------------|
| Head  | 900             |
| Neck  | 1500            |
| Torso | 1150            |
| Wings | 590             |

The size of each part of the bird's body is determined using the relation of mass, density, volume, and aspect ratio according to equation (2) for a straight-cylindrical shape and (1) for a hemispher-tipped cylinder shape. The size of the bird's head is found in table 6. The size of the bird's neck is found in table 7. The size of the bird's torso is found in table 8. The size of the bird wings is shown in table 9. The number of particles in the M1, M2, and M3 models is shown in table 10.

Table 6. The size of bird head model.

| Size  | M1   | M2   | M3   |
|-------|------|------|------|
| D (mm)| 46.4 | 42.1 | 36.8 |
| L (mm)| 62.85| 57.03| 49.85|

Table 7. The size of bird neck model.

| Size  | M1   | M2   | M3   |
|-------|------|------|------|
| D (mm)| 41.9 | 38.9 | 33.2 |
| L (mm)| 104.75| 101.14| 83  |

Table 8. The size of bird torso model.

| Size  | M1   | M2   | M3   |
|-------|------|------|------|
| D (mm)| 104  | 105  | 106.4|
| L (mm)| 163.75| 165.32| 167.53|
Table 9. The size of bird wings model.

| Size          | M1   | M2   | M3   |
|---------------|------|------|------|
| Chord (mm)    | 79.9 | 79.9 | 79.9 |
| Halfspan (mm) | 211.2| 211.2| 211.2|
| Depth (mm)    | 36.2 | 36.2 | 36.2 |

Table 10. Number of particles in the model of multimaterial birds.

| Part   | Particle numbers |
|--------|------------------|
|        | M1   | M2   | M3   |
| Head   | 1288 | 1032 | 636  |
| Neck   | 2464 | 1976 | 476  |
| Torso  | 17084| 20784| 9360 |
| Wings  | 21200| 21200| 21200|

The bird material is modeled using Null material code [9]. The aluminum plate material is modeled using Plastic Kinematic code [9]. Contact between the bird model and the target model using the Automatic Node to Surface code [10]. The mechanical parameters of the bird material and the aluminum plate are adjusted by reference [9][11]. The parameters of the model material of birds and the target plates sequentially are found in table 11 and 12.

Table 11. Bird model property.

| Parameters               | Value          |
|--------------------------|----------------|
| Mass (kg)                | 1.8            |
| Density (kg/m³)          | 950            |
| Pressure cutoff (Pa)     | -1000          |
| Dynamic viscous coefficient | 0.001         |
| Material code            | Null           |
| EOS                      | Gruneisen      |

Table 12. The model property of the target plate.

| Parameters               | Value         |
|--------------------------|---------------|
| Boundary condition       | clamped       |
| Side lenght (mm)         | 600           |
| Depth (mm)               | 10            |
| Material code            | Plastic kinematic |
| Density (kg/m³)          | 2923          |
| Yield stress (MPa)       | 345           |
| Failure strain           | 0.18          |
| Elastic modulus (GPa)    | 71            |
| Target modulus (MPa)     | 460           |
| Poisson’s ratio          | 0.3           |
| D Constant of Cowper Symonds (s⁻¹) | 118000 |
| P Constant of Cowper Symonds | 4            |
| Element type             | shell         |

Equation of state (EOS) used for the bird model is EOS Gruneisen model. This EOS parameter is adjusted by reference [3]. The value of $C = 1483$ m/s is the bulk speed of sound (intersection between the $v_s - v_p$ curve). Value $S_1 = 1.92$; $S_2 = 0$; and $S_3 = 0$ are the gradients of the $v_s - v_p$ curve. The value of $\gamma_0$ (Gruneisen gamma) is 0.1.

3. Results and discussions
The results obtained in post-process using LS Prepost and MS Excel.
3.1. Impact visualization
Visualization of impacts on traditional bird models is shown in figure 4. Visualization of impacts on traditional bird models is shown in figure 5.

Figure 4. Visualization of traditional bird model collisions: (a) hemisphered-capped cylinder, (b) straight-angled cylinder, (c) ellipsoid.
Figures 4 and 5 show that both the model of the unimaterial bird and the model of the created multimaterial bird have resulted in an impact profile with particles spreading radially. This has fulfilled the hydrodynamic theory of bird crashes according to reference [3].

3.2. Result of displacement at sensor location
The result of displacement at location D1 is compared with the experimental results as shown in figure 6. The result of displacement at location D2 is compared with the experimental results as shown in figure 7.
Figure 6. Comparison of the results of the three model forms on nodal D1.

Figure 7. Comparison of the results of the three model forms on nodal D2.

Figure 6 and figure 7 show that the model of the unimaterial birds and the model of the multimaterial bird made has shown compatibility with the experimental results. Figure 7 also shows that the multimaterial bird model in general, gives results closer to the experiment at nodal D2 than the unimaterial bird model. However, in figure 6, at nodal D1, the closer to the impact center, the straight-ended cylinder model is better at capturing the maximum deflection than the other model, either the unimaterial model or the multi-material model. It is because the shape of the sabot used to carve the carcass in Liu experiment is a straight-tipped cylinder. In the experiment, the carcass is bent (folded)
so it is more like a cylinder, not in the condition of the wings stretching (in flight). In addition, even though at D1 the straight-ended cylinder capturing the maximum deflection better than the other model, as shown in figure 6, the simulation with straight-ended cylinder model gave the result of plastic deformation in the target structure (the final displacement differs too far from the starting position). However, the experiment results show that the deformation is not plastic. In summary, the straight-ended cylinder model does not correlate better to the experiment result than the multi-material model.

4. Conclusion

The model of multimaterial birds created in the simulation has given deflection results that are closer to the experimental results. However, improvements need to be made to better capture a higher deflection as in the use of folded carcas in experiments. In general, for simulated bird impact cases under in-flight conditions (wing stretches), the multimaterial bird model has been representative.

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