Commun. Comput. Phys.
doi: 10.4208/cicp.231113.290914a

Vol. 17, No. 2, pp. 564-593
February 2015

Multiple-Body Collision Algorithms for Computational Simulation of High-Speed Air-Delivered Systems

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Received 23 November 2013; Accepted (in revised version) 29 September 2014

Communicated by Rho Shin Myong

Abstract. Currently, there exists a lack of confidence in the computational simulation of multiple body high-speed air delivered systems. Of particular interest is the ability to accurately predict the dispersion pattern of these systems under various deployment configurations. Classical engineering-level methods may not be able to predict these patterns with adequate confidence due primarily to accuracy errors attributable to reduced order modeling. In the current work, a new collision modeling capability has been developed to enable multiple-body proximate-flight simulation in the Loci/CHEM framework. This approach maintains high-fidelity aerodynamics and incorporates six degrees of freedom modeling with collision response, and is well-suited for simulation of a large number of projectiles. The proposed simulation system is intended to capture the strong interaction phase early in the projectile deployment, with subsequent transfer of projectile positions and flight states to the more economical engineering-level methods. Collisions between rigid bodies are modeled using an impulse-based approach with either an iterative propagation method or a simultaneous method. The latter is shown to be more accurate and robust for cases involving multiple simultaneous collisions as it eliminates the need to sort and resolve the collisions sequentially. The implementation of both the collision detection methodology and impact mechanics are described in detail with validation studies to demonstrate the efficiency and accuracy of the developed technologies. The studies chronologically detail the findings for simulating simple impacts and collisions between multiple bodies with aerodynamic interference effects.

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AMS subject classifications: 76

Key words: Submunition, projectile, ballistic, CFD, 6-DoF, solid body collision, contact force, hypersonic, aerodynamic, interference effects.

Nomenclature

a,b	Center of gravity locations for colliding bodies
$[A]$	Matrix of mass and inertial properties for colliding system
$\{B\}$	Vector of motion properties for colliding system
e	Coefficient of restitution for collision
J	Inertia tensor expressed in inertial reference frame
L	Length of projectile dart
m	Mass
M	Total number of bodies in contact during simultaneous collision
M_C	Total number of contact points during simultaneous collision
$\hat{n}$	Unit normal vector at contact point
N	Number of bodies in active contact during simultaneous collision
N_C	Number of active contact points during simultaneous collision
p	Collision contact point
P	Collision impulse magnitude
$\{P\}$	Vector of collision impulses for colliding system
$\vec{r}$	Distance vector from mass center to contact point
V_{REL}	Normal relative velocity at contact point
V_0	Initial velocity of colliding sphere
$\vec{V}$	Velocity of mass center
$\vec{\omega}$	Angular velocity
z_0	Distance from dart CG to ground for static dart drop case
α_0	Angle between dart axis and horizontal for static dart drop case
ε	Separation distance between two colliding spheres

1 Introduction

A variety of weapon systems consist of carrier vehicles that dispense submunitions over a target area such as a mine field. The submunitions are typically unguided darts that rely on aerodynamic forces for achieving stable projectile flight with high kinetic energy