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An approach for treating contact surfaces in Lagrangian cell-centered hydrodynamics ☆

Nathaniel R. Morgan *, Mark A. Kenamond, Donald E. Burton, Theodore C. Carney, Daniel J. Ingraham

X-Computational Physics Division, Los Alamos National Laboratory, P.O. Box 1663, Los Alamos, NM, USA

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ABSTRACT

A new method is presented for modeling contact surfaces in Lagrangian cell-centered hydrodynamics (CCH). The contact method solves a multi-directional Riemann-like problem at each penetrating or touching node along the contact surface. The velocity of a penetrating or touching node and the corresponding forces are explicitly calculated using the Riemann-like nodal solver. The contact method works with material strength and allows surfaces to impact, slide, and separate. Results are presented for several test problems involving both gases and materials with strength. The new contact surface approach extends the modeling capabilities of CCH.

1. Introduction

We wish to simulate the motion of interacting deformable bodies that may be in full, partial, or no contact. In the general case, at the microscopic level in the boundary layer between the bodies, frictional and heat transfer mechanisms could be involved. In this work we simplify to the frictionless case in which the only coupling mechanism is the normal momentum component for the portion of the bodies in contact. Each of these bodies will be modeled with a Lagrangian mesh. Numerical schemes that address this interaction are termed *contact surface algorithms*.

Contact methods have been developed and used in Lagrangian staggered-grid hydrodynamic (SGH) calculations for many years. Early examples of contact methods are discussed in Wilkins [37] and Cherry et al. [7]. Hallquist et al. [17] provides an overview of multiple contact algorithms used in various Lagrangian SGH codes dating back to HEMP [37]. Of particular interest, Hallquist et al. [17] describes the contact surface scheme used in TOODY [31] and later implemented in DYNA2D [36]. The contact method of TOODY uses a *master–slave* approach. The goal of this approach is to treat the nodes on the contact surface in a manner similar to an internal node. The physical properties of the *slave* surface are interpolated to a ghost mesh (termed *phony elements* in [17]) that overlays the slave zones. The physical properties are interpolated from the slave surface to the ghost zones using surface area weights. The surface area weights are equal to the ratio of the ghost zone surface area to

* Corresponding author. Tel.: +1 5056670031.
E-mail address: nmorgan@lanl.gov (N.R. Morgan).

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the surface area of the master surface. The contact surface method for nodal-based Lagrangian cell-centered hydrodynamics (CCH) presented in this paper will use surface area weights similar in concept to those in TOODY. Following the area fraction approach of TOODY may seem retrospective; however, using surface area weights naturally extends to the new CCH methods that solve a Riemann-like problem at the node of a zone [10,24,25,3].

Lagrangian CCH differs significantly from the SGH approach. The differences arise because the CCH method solves the conservation equations for the zone on a single control volume. Lagrangian CCH was first proposed by Godunov et al. [15,16] and later by Ruppel and Harlow [1] resulting in the CAVEAT code [1]. The CCH approach in CAVEAT solved a Riemann problem at the center of the zone face. The nodal velocity was calculated from the neighboring face velocities. Recent work in Lagrangian CCH has focused on Riemann-like solutions at the node. Despres and Mazeran [10] were the first to introduce a method that solved a Riemann-like problem at the node. Maire et al. [24,25] improved upon the nodal solution approach developed by Despres and Mazeran [10]. Burton et al. [3] extended the seminal works of [10,24,25] by proposing a new nodal Riemann-like method that handles stress tensors and ensures the viscous stress tensor is symmetric.

In this work, a multi-directional Riemann-like problem is solved at every node in the mesh including along the contact surface. The Riemann-like problem for the nodes away from a contact surface use the nodal solution approach of Burton et al. [3]. A similar Riemann-like problem is solved at the penetrating or touching nodes along the contact surface that takes into account the appropriate contact physics. The Riemann-like problem at a penetrating or touching node includes information from both surfaces. The contact surface approach maps the properties from the contacting nodes to the penetrating or touching node. The corner impedance, corner velocity, and corner stress of the nodes on the contacting surface are mapped to the penetrating or touching node using surface area weights. The surface area weights are equal to the ratio of the contacting node surface area to the surface area of the penetrating or touching node. The mapped properties are used in the nodal Riemann-like problem. The process is repeated for every penetrating or touching node along the contact surface. We do not adopt a *master–slave* approach. Every penetrating or touching node on each side of the contact surface uses the same Riemann-like solver.

The layout of the paper is as follows. Section 1.1 defines the nomenclature and notational conventions used in the paper. Section 2 discusses the finite volume conservation equations, presents the nodal solution approach, and provides an overview of the CCH solution methodology. The new contact surface approach is discussed in Section 3. Test problem results are in presented in Section 4, and the results of a bi-metallic shaped charge calculation and an exploding cylinder into a plate calculation are presented in Section 5.

1.1. Nomenclature

The nomenclature used in this paper follows the work in [3,4], and it is illustrated in Fig. 1. The stress, velocity, total energy, density and internal energy are respectively $\boldsymbol{\sigma}, \mathbf{u}, j, \rho, e$. Vectors and tensors are shown in bold type. The physical quantities at the zone center are denoted with a subscript *z*. The physical quantities projected to the node are defined as corner quantities and they are denoted with a subscript *c*. The details of a zone corner are provided below. The nodal Riemann velocity is denoted with a superscript * and a subscript *p*. The corresponding Riemann stress is defined in the zone corner so it is denoted with a superscript * and a subscript *c*. The time is discretized using the second-order Runge–Kutta method and the time levels are denoted with a superscript n, $n+\frac{1}{2}$, or $n+1$ respectively.

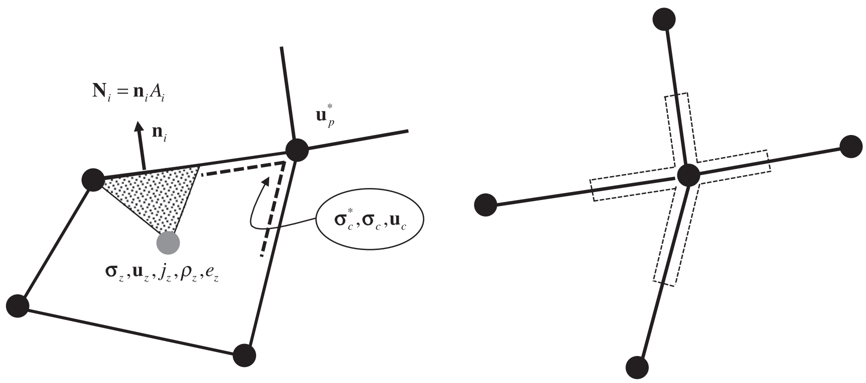

Fig. 1. The zone and the nodal control volumes are decomposed into triangles termed iotas. An iota is colored in the left image with a pebble pattern and each iota in a control volume is denoted with a subscript *i*. The control volume used with the nodal Riemann-like problem is shown in the right image with a thin dashed line. The nodal control volume is all the iota faces connected to a node. A zone corner is made from the two iota faces connected to the node, and it is illustrated with a bold dashed line in the left image. The quantities stored at the centroid of the zone use a subscript *z*. The projected quantities from the zone centroid to the node are defined as corner quantities and they are denoted with a subscript *c*. A corner quantity is constant over the zone corner, whereas, a point quantity is constant over all the corners around the node. For example, the projected quantities and the Riemann stress are defined in each zone corner because they are constant over the respective zone corner, and they may vary from corner to corner. In contrast to the corner quantities, the Riemann velocity is constant over all the zone corners around the node.