

## LS-DYNA MULTIPHYSICS USER'S MANUAL

# INTRODUCTION

In this manual, there are five main solvers: two compressible flow solvers, an incompressible flow solver, an electromagnetism solver, and a battery electrochemistry solver. Each of them implements coupling with the structural solver in LS-DYNA.

The keywords covered in this manual fit into one of three categories. In the first category are the keyword cards that provide input to each of the multiphysics solvers that in turn couple with the structural solver. In the second category are keyword cards involving extensions to the basic solvers. Presently, the chemistry and stochastic particle solvers are the two solvers in this category, and they are used in conjunction with the \*CESE compressible flow solver discussed below. In the third category are keyword cards for support facilities. A volume mesher that creates volume tetrahedral element meshes from bounding surface meshes is one of these tools. Another is a data output mechanism for a limited set of variables from some of the solvers in this manual. This mechanism is accessed through \*LSO keyword cards.

The CESE solver is a compressible flow solver based upon the Conservation Element/Solution Element (CE/SE) method, originally proposed by Chang of the NASA Glenn Research Center. This method is a novel numerical framework for conservation laws. It has many non-traditional features, including a unified treatment of space and time, the introduction of separate conservation elements (CE) and solution elements (SE), and a novel shock capturing strategy without using a Riemann solver. This method has been used to solve many types of flow problems, such as detonation waves, shock/acoustic wave interaction, cavitating flows, supersonic liquid jets, and chemically reacting flows. In LS-DYNA, it has been extended to also solve fluid-structure interaction (FSI) problems. It does this with two approaches. The first approach solves the compressible flow equations on an Eulerian mesh while the structural mechanics is solved on a moving mesh that moves through the fixed CE/SE mesh. In the second approach (new with this version), the CE/SE mesh moves in a fashion such that its FSI boundary surface matches the corresponding FSI boundary surface of the moving structural mechanics mesh. This second approach is more accurate for FSI problems, especially with boundary layers flows. Another feature with the CESE moving mesh solver is conjugate heat transfer coupling with the solid thermal solver. The chemistry and stochastic particle solvers are two add-on solvers that extend the CESE solver.

The dual CESE solver is another compressible flow solver that is also based upon the Conservation Element/Solution Element (CE/SE) method, but with improvements related to accuracy and robustness. This method follows a similar novel numerical

framework for conservation laws. In LS-DYNA, the dual CESE solver also include fluid-structure interaction (FSI) capabilities. It also does this with two approaches. The first approach solves the compressible flow equations on an Eulerian mesh while the structural mechanics is solved on a moving mesh that moves through the fixed dual CE/SE mesh. In the second approach, the dual CE/SE mesh moves in a fashion such that its FSI boundary surface matches the corresponding FSI boundary surface of the moving structural mechanics mesh. This second approach is more accurate for FSI problems, especially with boundary layers flows. One of the advances in these FSI computations with the dual CESE solver as compared with the older CESE solver is that each FSI approach (or fixed mesh Eulerian solver) may be employed in different subregions of the fluid mesh in the same problem. Unlike the \*CESE solvers, the dual CESE solvers do not have conjugate heat transfer coupling with the solid thermal solver, nor coupling with the chemistry or stochastic particle solvers. It is not clear if these \*CESE capabilities will be added to dual CESE solver. On the other hand, another advance capability available only with the dual CESE solvers is the availability of equations of state for pure and pseudo-pure fluids of industrial interest in the REFPROP and COOLPROP EOS libraries. These complex EOSes are generally expensive to evaluate, so a bi-cubic table look-up mechanism has been developed that greatly accelerates their use.

The third solver is the incompressible flow solver (ICFD) that is fully coupled with the solid mechanics solver. This coupling permits robust FSI analysis via either an explicit technique when the FSI is weak, or using an implicit coupling when the FSI coupling is strong. In addition to being able to handle free surface flows, there is also a bi-phasic flow capability that involves modeling using a conservative Lagrangian interface tracking technique. Basic turbulence models are also supported. This solver is the first in LS-DYNA to make use of a new volume mesher that takes surface meshes bounding the fluid domain as input (\*MESH keywords). In addition, during the time advancement of the incompressible flow, the solution is adaptively re-meshed as an automatic feature of the solver. Another important feature of the mesher is the ability to create boundary layer meshes. These anisotropic meshes become a crucial part of the model when shear stresses are to be calculated near fluid walls. The ICFD solver is also coupled to the solid thermal solver using a monolithic approach for conjugate heat transfer problems.

The fourth solver is an electromagnetics (EM) solver. This module solves the Maxwell equations in the Eddy current (induction-diffusion) approximation. This is suitable for cases where the propagation of electromagnetic waves in air (or vacuum) can be considered as instantaneous. Therefore, the wave propagation is not solved. The main applications are Magnetic Metal Forming, bending or welding, induced heating, ring expansions and so forth. The EM module allows the introduction of a source of electrical current into solid conductors and the computation of the associated magnetic field, electric field, as well as induced currents. The EM solver is coupled with the structural mechanics solver (the Lorentz forces are added to the mechanics equations of motion), and with the structural thermal solver (the ohmic heating is added to the thermal solver as an extra source of heat). The EM fields are solved using a Finite Element Method (FEM) for

the conductors and a Boundary Element Method (BEM) for the surrounding air/insulators. Thus no air mesh is necessary.

The fifth solver is a battery electrochemistry solver. At this time, the available capability involves a one-dimensional electrochemistry solver that is coupled to the structural mechanics and structural thermal solver in each structural element identified as being part of a battery cell. It solves these one-dimensional models implicitly so as to be able to run simulations for very long physical times that are typical of battery-structure interaction problems.

As stated above, the \*CHEMISTRY and \*STOCHASTIC cards are only used in the CESE solver at this time.

