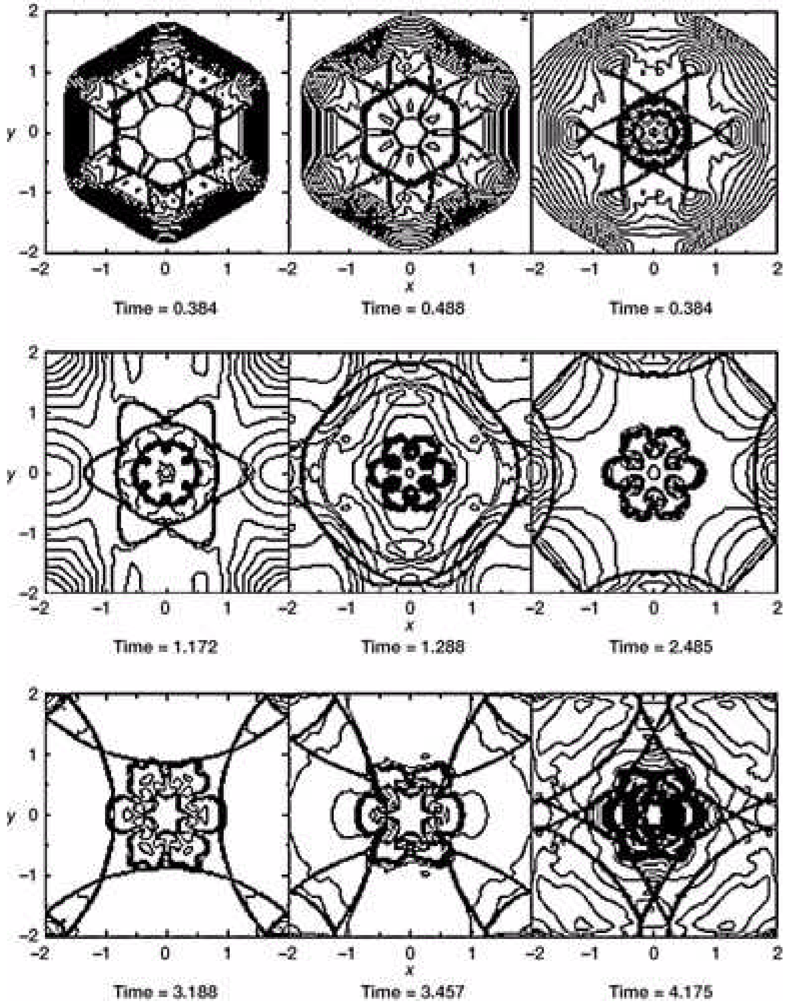
Space-Time Conservation Element and Solution Element Method Being Developed

The engineering research and design requirements of today pose great computer-simulation challenges to engineers and scientists who are called on to analyze phenomena in continuum mechanics. The future will bring even more daunting challenges, when increasingly complex phenomena must be analyzed with increased accuracy. Traditionally used numerical simulation methods have evolved to their present state by repeated incremental extensions to broaden their scope. They are reaching the limits of their applicability and will need to be radically revised, at the very least, to meet future simulation challenges.

At the NASA Lewis Research Center, researchers have been developing a new numerical framework for solving conservation laws in continuum mechanics, namely, the Space-Time Conservation Element and Solution Element Method, or the CE/SE method. This method has been built from fundamentals and is not a modification of any previously existing method. It has been designed with generality, simplicity, robustness, and accuracy as cornerstones.

The CE/SE method has thus far been applied in the fields of computational fluid dynamics, computational aeroacoustics, and computational electromagnetics. Computer programs based on the CE/SE method have been developed for calculating flows in one, two, and three spatial dimensions. Results have been obtained for numerous problems and phenomena, including various shock-tube problems, ZND detonation waves, an implosion and explosion problem, shocks over a forward-facing step, a blast wave discharging from a nozzle, various acoustic waves, and shock/acoustic-wave interactions. The method can clearly resolve shock/acoustic-wave interactions, wherein the difference of the magnitude between the acoustic wave and shock could be up to six orders. In two-dimensional flows, the reflected shock is as crisp as the leading shock. CE/SE schemes are currently being used for advanced applications to jet and fan noise prediction and to chemically reacting flows.



Snapshots in time (nondimensionalized) of the implosion/explosion of a hexagonal shock in a square box. Pressure ratio, 10.

Key features and advantages of the CE/SE method follow.

- Space and time are treated in a unified fashion. The space-time domain is discretized into Solution Elements (SE's), within which the numerical approximation is a simple (linear, for example) function of space and time. Conservation Elements (CE's) that fill the space-time domain without overlap are also defined.

- The main emphasis is on solving the integral form of the conservation law in the space-time domain, although the differential form is also considered. Conservation of space-time flux is enforced for each CE. Because the CE's fill space-time without overlap, and because the flux through any face of a CE is uniquely defined, this local conservation of flux ensures that space-time flux is conserved globally in the space-time domain.

- The method is very simple. It uses only the simplest of approximation techniques.

In addition, no knowledge of the properties of the solution, such as the characteristics or the shock-wave profile, is used.

- The flux-based nature of the method leads to the use of flux-based boundary conditions. The nonreflecting boundary conditions needed for practical computations on unbounded spatial domains are remarkable for their simplicity, needing only a few lines in the computer program. These conditions allow even shock waves to pass out of the domain with no noticeable reflection at the boundary.
- The CE/SE method is genuinely multidimensional; that is, no directional splitting is employed in modeling multidimensional problems.
- The two- and three-dimensional spatial meshes employed by the present method are built from triangles and tetrahedrons, respectively. Triangles and tetrahedrons, respectively, are also the simplest building blocks for two- and three-dimensional unstructured meshes. Thus, the multidimensional schemes can be directly applied on unstructured meshes, which are the only efficient way to deal with complex geometries.
- The simplicity of the CE/SE schemes makes the computer programs easy to vectorize and parallelize.

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Bibliography

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