An algorithm is described to efficiently compute aerothermodynamic design sensitivities using a decoupled variable set. In a conventional approach to computing design sensitivities for reacting flows, the species continuity equations are fully coupled to the conservation laws for momentum and energy. In this algorithm, the species continuity equations are solved separately from the mixture continuity, momentum, and total energy equations. This decoupling simplifies the implicit system, so that the flow solver can be made significantly more efficient, with very little penalty on overall scheme robustness. Most importantly, the computational cost of the point implicit relaxation is shown to scale linearly with the number of species for the decoupled system, whereas the fully coupled approach scales quadratically. Also, the decoupled method significantly reduces the cost in wall time and memory in comparison to the fully coupled approach.

This decoupled approach for computing design sensitivities with the adjoint system is demonstrated for inviscid flow in chemical non-equilibrium around a re-entry vehicle with a retro-firing annular nozzle. The sensitivities of the surface temperature and mass flow rate through the nozzle plenum are computed with respect to plenum conditions and verified against sensitivities computed using a complex-variable finite-difference approach. The decoupled scheme significantly reduces the computational time and memory required to complete the optimization, making this an attractive method for high-fidelity design of hypersonic vehicles.