A pressure-based, Mach-uniform method is developed by combining the SLAU2 numerical scheme and the higher temporal order pressure-based algorithm. This hybrid combination compensates the limitation of the SLAU2 numerical scheme in the low-Mach number regime and deficiencies of the pressure-based method in the high-Mach number regime. A momentum interpolation method is proposed to replace the Rhie-Chow interpolation for accurate shock-capturing and to alleviate the carbuncle phenomena. The momentum interpolation method is consistent in addition to preserving pressure–velocity coupling in the incompressible limit . The postulated pressure equation allows the algorithm to compute the subsonic flows without empirical scaling of numerical dissipation at low-Mach number computation. Several test cases involving a broad range of Mach number regimes are presented. The numerical results demonstrate that the present algorithm is remarkable for the calculation of viscous fluid flows at arbitrary Mach number including shock wave/laminar boundary layer interaction and aerodynamics heating problem.