As supercritical carbon dioxide (sCO2) Brayton cycles have shown potential to be the next generation power cycle, an immense amount of research has gone into developing this system. One of the setbacks facing development and optimization of this cycle is the unknown in current design and analysis methods ability to accurately model sCO2 turbomachinery. Due to the desired inlet conditions to the compressor close proximity to the critical point, accurate design and analysis of this power cycle component is a concern. The present study provides aerodynamic analysis of a centrifugal compressor impeller blade with sCO2 as the working fluid through a comparative study between three-dimensional (3D) computational fluid dynamics (CFD) and one-dimensional (1D) analyses. Through the use of conventional loss correlations for centrifugal compressors found in literature and defined geometrical parameters, losses are calculated for the specified compressor impeller and the aerodynamic performance is predicted. Furthermore, the boundary conditions for the CFD analysis are derived through the 1D analysis of the centrifugal compressor to carry out the 3D study of the sCO2 impeller blade. As the Span and Wagner equation of state has been proven to be the most accurate when working in the vicinity of the critical point, this real gas equation of state is implemented in both analyses. Consequently, a better understanding is developed on best practices for modeling sCO2 centrifugal compressors along with the limitations that currently exist when utilizing commercial CFD solvers. Furthermore, the resulting performance and aerodynamic behavior from the two analyses were compared. Additional procedures to gain further accuracy and modeling ease when analyzing turbomachinery with this unconventional fluid are noted.

The lack of commercial CFD codes able to model phase change within sCO2 turbomachinery and the possibility of condensation at the leading edge of the impeller blade creates a limit to the operating conditions that can be simulated. Further, the rapid expansion rate within this region has been predicted to cause non-equilibrium condensation leading the fluid to a metastable vapor state. Due to the complexity of two-phase models, a proposed methodology to model sCO2 compressors as a single phase is to represent metastable properties through the extrapolation of equilibrium properties onto the liquid domain up until the spinodal limit. This equation of state definition with metastable properties will be used to model a 3D converging-diverging nozzle due to the similar flow dynamics occurring when compared to a compressor blade channel. The equation of state will be implemented through a temperature and pressure dependent property table amended with metastable properties. Modeling was performed for inlet conditions with varied proximity to the fluid's critical point. Investigation on the accuracy of utilizing this table to define sCO2 properties with respect to its resolution was executed. Through this, it was determined that the resulting interpolation error was highly influenced on the closeness to the critical point. Additionally, the effect on the capable modeling operating region when utilizing the metastable real gas property table through single phase modeling was examined.