This study explores the effects of turbulence and pressure gradient tailoring on the turbulent flame and vorticity transport mechanisms of premixed flames. A turbulent premixed flame stabilized by a bluff-body in a high-speed combustor is used for the investigation. The combustor pressure gradient is altered using a variable geometry test section. The turbulence within the combustor is controlled using a custom-designed, supersonic variable turbulence generator. The turbulent flame flow field is measured and characterized using simultaneous high-speed particle imaging velocimetry (PIV) and CH* chemiluminescence. The flame vortex interactions and dynamics of the turbulent flame are analyzed using a Lagrangian tracking methodology. Lagrangian fluid elements (LFEs) are tagged on the experimental data and are tracked as they propagate across the turbulent flame. The vorticity generation and transport mechanisms are decomposed along the Lagrangian trajectories to determine their relative balance under various pressure gradient and turbulence conditions. It is demonstrated that the turbulence and induced pressure gradient independently affect the relative magnitudes of dilatation, baroclinic torque, and vortex stretching mechanisms. Increasing the combustor pressure gradient augments the relative magnitudes of the vorticity mechanisms; baroclinic torque exhibits the largest gain for augmented pressure relative to attenuated. The turbulence causes a reduction of the dilatation and baroclinic torque vorticity mechanisms, meanwhile the vortex stretching increases. The results confirm that alteration of the test section pressure gradient can be used to augment the vorticity mechanisms independently from turbulence. Furthermore, a change in the relative balance of the combustion-induced vorticity mechanisms and turbulence energy transport occurs as a result of increasing turbulence.