As the use of modern high-performance composite materials becomes more widespread within the aerospace industry, sophisticated technologies are being developed to build advanced high-quality composite structures. In the traditional design of composite laminates, the fibers in each layer are straight and aligned in a particular direction. The fiber orientation angles of these conventional designs are usually restricted to 0, 90, and ± 45 degrees. The idea of using fibers in any configuration other than a straight-line format has been hampered by the inability to implement such a design. The introduction of advanced tow-placement machines has made it possible to fabricate advanced variable-stiffness (V-S) composite structures where the fiber orientation angle varies continuously within each ply and throughout the structure. This manufacturing capability now allows designers of composites to use the fiber orientation angle as design variable in their analysis, not only for each ply as with conventional composites, but at each point within a ply. Consequently, as opposed to traditional composites with straight fibers, the directional material properties of composites can be fully exploited to improve the structural laminate performance.

Pressure pillowing of the fuselage panels is a common problem in thin-walled stiffened aircraft structures. The cabin pressure in a commercial transport aircraft generates a significant pressure differential across the skin. The frames and stringers that are necessary to carry maneuver loads prevent the fuselage skin from expanding as a membrane, and the skin bulges, or "pillows", within each panel bay under the action of the internal pressure. When the skin is restrained against radial expansion at the stiffener locations, a bending boundary layer is formed causing bending stress concentrations. Such stresses can lead to failure, and hence special attention must be paid to them when designing such structures.

In this thesis, the pressure pillowing problem of fuselage skin panels is addressed using tow-placed steered fibers. The underlying goal of the research is to adopt the variable-stiffness concept based on the tow-placed steered fibers to come up with innovative tailored composite designs that are able to alleviate the pressure pillowing problem. Different models of fuselage panels with and without cutouts, with different levels of complexity are addressed. Semi-analytical and numerical solutions are developed to obtain the linear and geometrically nonlinear responses of the variable-stiffness panels. The design objective is to determine the optimal distribution of the fiber orientation angles (or the fiber paths) over the panels for different structural performance measures, minimum weight, maximum strength, and maximum buckling performance. Different fiber orientation variations are utilized to construct the variable-stiffness panels. Various design scenarios and approaches for different loading cases and boundary conditions are presented and discussed.
Optimal solutions are sought using different optimization methodologies. Optimal designs are obtained for both constant-stiffness straight fiber and variable-stiffness steered fiber laminates. It is shown that by placing the fibers in their optimal spatial orientations, the pressure pillowing problem can be alleviated, and the load carrying capacity and the buckling loads of the structures can be significantly improved compared to straight fiber design baselines. Key findings and possible mechanisms that help improve the structural performance of the variable-stiffness laminates are identified and discussed. Finally, the variable-stiffness designs obtained show smooth fiber paths with small curvatures suggesting the feasibility of manufacturing of the designs using advanced tow-placement machines.