In the present work an active structural vibration control of smart composite cylindrical shell using piezoelectric sensors and actuators are studied using experimental and numerical methods. For Numerical analysis, a four noded composite facet shell element is developed based on first order shear deformation theory. In the developed element, warping is included to correct its out-of-plane deformation to capture the shell behavior. Also electro-mechanical coupling is introduced through a linear piezoelectric theory to idealize the macro characteristics of MFC actuators and PZT sensors.

The numerical results obtained using the developed element is subsequently validated with quasi-static piezoelectric coupling experiment and ANSYS11 (FEA) package. Also in this work an active shape control of laminated composite cylindrical shell is studied with integrated piezoelectric actuators. The efficiency of directionally active MFC actuators are evaluated for their application in the geometrically curved aircraft composite panels.
The structure considered for experimentation is a deep shell structure. Its elastic couplings appear to be very significant. Hence the first four modes are targeted to demonstrate the ability of in-plane actuation of MFC’s in controlling the out-of-plane elastic couplings. The PZT fibers are oriented in actuators A₁ and A₂ along the length of the shell. They are expected to induce actuation strains to counteract first two modes, which are predominantly span-wise dominated. However, they are found less effective to control the third and fourth modes, which are chord wise dominated. Accordingly, the third actuator (A₃) is located, in which the PZT fibers are oriented at 45 degree. A sufficiently large amount of disturbance is applied because the cylindrical shell is assumed to represent the panels of wing or fuselage structures.

7.1 CONCLUSIONS

The following conclusions are drawn from the results of the investigations for active vibration control on smart laminated composite cylindrical shells.

- A dynamic model of shell structure is developed based on the first order shear deformation theory. An actuating model of the surface-bonded MFC actuator is established in the system model.
• A four noded facet shell element is developed for active vibration control of composite shell with piezoelectric sensors/actuator layers.

• The numerical solution (static, dynamic and buckling) obtained from the FE program is verified with that of experimental and ANSYS11(FEA) package. From the study it is concluded that the developed shell element is performing well.

• The stiffness and mass matrices obtained from FE program are effectively used to generate system matrices (state-space) required for vibration control of composite cylindrical shell attached with piezoelectric sensors/actuators.

• The natural frequencies obtained from numerical and experimental methods are well corroborated.

• The active Vibration control of shell structures is achieved effectively with the use of LQR, LQG with Kalman filter in open/closed loop systems.

• LQG control with Kalman filter is designed and implemented in simulink to ensure stability of proposed control scheme.

• Velocity feedback and Linear Quadratic Gaussian (LQG) controller are used to determine appropriate voltage input into the MFC actuators.
- In-plane actuation strain of MFC actuator is effectively tailored to control the elastic couplings of shell structures, i.e. membrane-bending, membrane-shear, membrane-twisting etc. It is verified by the control performance of actuators A\textsubscript{1} and A\textsubscript{2} while controlling first and second modes of vibration.

- The actuators A\textsubscript{1} and A\textsubscript{2} are unable to control active vibrations of shell structures for modes 3 and 4 in IMSC technique. To achieve this control, an extra actuator A\textsubscript{3} is added with PZT fibers at 45 degrees to the elastic axis of the shell.

- When two or more modes are strongly coupled due to the influence of either aerodynamics or noise, the vibrations are controlled successfully using SMSC technique.

- To attain active vibration control for the shell structures, the voltages required for actuators in IMSC technique are high compared to SMSC technique. Especially in the case of controlling modes 2 and 4 in IMSC technique, the actuators A\textsubscript{1}, A\textsubscript{2} and A\textsubscript{3} require the voltages 96 V, 88 V and 96 V respectively. Where as in the case of SMSC technique, a voltage of 60 V is sufficient for all the actuators.

- The active vibrations of the shell structures will be able to control most efficiently with the use of SMSC technique along with proper actuators, control energy and power.
From the study it is concluded that, the vibration control is more effective pertaining to the collocated configuration in SMSC technique.

Active shape control of a cylindrical shell is achieved with negative feedback, when the shell is subjected to in-plane buckling load.

For controlling the active vibrations of the curved shell structures, Macro Fiber Composite (MFC) actuators can be effectively utilized. Because they are flexible, conformable and capable of being surface-bonded in curved structures than the traditional monolithic isotropic piezoceramic actuators.

It is envisaged that a required aerodynamic shape can be configurable using the MFC actuators for better aerodynamic performance (LIFT: L, DRAG: D, L/D Ratio).

The structure, actuator and sensor integration is well addressed in closed loop experiments, which is real time requirement to scale up any research output into real time technology.

The numerical and experimental solutions show a close agreement in predicting the closed loop system performance.

Through experiments it is demonstrated that, smart material actuators will be able to effectively reduce redundant vibrations of several systems in wide frequency domain.
7.2 SCOPE FOR FUTURE WORK

- The finite element can be developed using higher order theories with electro-mechanical coupling.
- Experimentation can be adopted for active shape control of shell structures with in-plane load.
- The developed theory can be extended for spherical shell structures.
- The study can be extended for optimal placement of actuators and sensors.
- The technique can be used for studying functionally graded materials.