CHAPTER 9
Discussions, Conclusions and Future Directions

In this chapter the results presented and the discussions carried out in various chapters are summarized for arriving at definite conclusions on the research work carried out in the thesis.

9.1 Discussions
The various mission characteristics are shown for three types of Low Earth Orbit (LEO) missions selected namely, Sun-synchronous orbit mission with Optical Payloads, Sun-synchronous orbit mission with RADAR Imaging Payloads and a LEO Science mission. For a sun-synchronous orbit the eclipse duration is almost fixed and the support of the main bus of the satellite during this eclipse period is a must from onboard battery. However, other functions such as maneuvering the satellite and keeping ready for next operations and also maintaining the main bus activities during eclipse are all to be carried out using battery support. When there are problems in solar panel strings or string failures happen, the power will be a premium and demand may be more for payload operations. The battery is usually strategically sized considering one or two string failures and still one can be in a position to manage the satellite and normal operations.

If only a single station is to be used for data collection, the amount of period to be used for payload operation and the resultant data to be stored onboard will be decided for a given payload or sets of payloads in the satellite and orbit configuration suitably. The data storage capacity of Solid State Recorder (SSR) will be decided based on this feature of mission. This requirement has made the battery sizing and capacity of this mission different from IRS type of missions. While this is the case for optical payloads and science missions, the RADAR missions collect enormous information as data and the storage capacity is decided by factors such as payload operational duration, mode of operation of payload and further to that the station visibility constraints. The features of LEO orbits for different missions are thus varied depending upon the type of payloads, ground stations planned, eclipse considerations and visibility of station for storage capacity of SSR and define the several satellite features onboard.
Several systems features required for Ground operations viz. TTC network, computer network and Communication systems network and different spacecraft sub-system details require constant monitoring and immediate action. In cases of failures in any of the systems, the planned and built-in redundant features have been utilized for seamless operations. Spacecraft Mission Operations comprising of receiving telemetry from the spacecraft and verifying of the state of various subsystems for a ground station through built-in features of SCHEMACS. The Ground Operations Centre and their planned redundancy are found in providing seamless operations for various types of spacecrafts. Though spacecraft sub-systems are adequately built with redundancy and reconfigurable features that avoid failures, nevertheless several autonomous functions are to be accomplished using payload sequencers.

The mathematical developments have been carried out for various onboard algorithms for LEO mission’s management on-orbit namely (i) Onboard Sun position computation model (ii) orbit computation models based on Fourier power series, Numerical Integration and GPS based solution, (iii) PAA look vector calculations (iv) necessary onboard orbital event models which allows autonomous decision making in operations model. The models were compared with the on-ground models and the accuracies of the onboard models are well established.

The management of payloads and other intimately connected sub-systems for efficient operations of the entire spacecraft for specific scientific objectives has been by Payload Sequencer. The design features of a Payload Sequencer are provided. The payloads are managed with Payload sequencer along with sub-systems and the details regarding various developments that are used for onboard implementation. However, the Payload Sequencer should also cater to failures of sub-systems as and when they occur. Therefore, spacecraft sub-system failures of the past spacecrafts are enumerated in a section so that the necessary structures for appropriate handling of these failures can be built suitably onboard. The onboard features of the payload sequencer are planned to be tuned in such a way suitable modifications can be telemetered in the structure to handle failure of sub-systems in a later stage.

The hardware / software redundancy features built-in in (i) Ground Support (ii) Power Systems and Battery and (iii) RCS sub-system developments such that failure of systems is taken care seamlessly without adhering to switching off of the systems. Other automated functions necessary for the system coordination are built through onboard stored Payload Sequencer and other control algorithms implemented with AOCS. During any attitude or
orbit control, any or both Blocks thruster can be used. No of Block to be used is decided through ground commanding. If only one block is used and any thruster from that block fails there is no hot redundancy for block change over to choose thruster from other block. If both blocks are used then AOCE can take care of failed thruster in hot redundant mode. Redundancy also exists in Latch Valve (LV) configuration. Because of this redundancy any block of thruster can use any of the propellant tanks in case of multiple tank configurations. Hence most of the RCS elements are having redundancy and they are actively participating in the operation mode in hot redundant once configured. So a hardware failure in RCS may not disturb the operation.

The actual implementation of concepts and models developed are demonstrated in a small satellite “YOUTHSAT”. The main development is the Payload Operations Scheduler and the details of basic components of operating a set of payloads of YOUTHSAT have been designed to suit the mission. The onboard algorithms for orbit model, eclipse prediction and large attitude maneuvers have been implemented and successfully operated in co-ordination with payloads which require different attitude orientations when they are individually operated. Simulation cases and results have been provided which clearly brought out that the designed sequencer is meeting the requirements of the operating the payloads autonomously for a session. The simulation has even studied the effect of large attitude rates when confronted and provided necessary operational insight to keep NSC speed to a higher value. The design has been implemented, tested and operated.

9.2 Conclusions

From the results presented and discussion carried out in various chapters of the thesis the following conclusions can be drawn.

1. The operational scenario of LEO satellites in an operational centre for a multitude of satellites is presented. Imaging missions using Optical and SAR payloads have been taken as sample missions for LEO orbit missions and depending upon the mission characteristics of a particular mission and features of requirements, the onboard designs of sub systems are varied.
2. For a LEO Imaging as well as science satellite missions, the regular orbit determination activity to periodical orbit maintenance activities and the associated mathematical models are developed. The routine work in monitoring the satellites has been repetitive and boring and this has been vitiated using ground based planning software tools.

3. To minimize the continuous monitoring and commanding requirements of operational centre, several onboard features have been built in the spacecraft. The complexity of the spacecraft building increased due to these onboard software tools and testing required on ground has been found to be enormous.

4. It has been shown that the software tools developed have been very useful in making the spacecraft operations semi-autonimic and thus reducing the stress on the ground personnel due to repetitive types of work. The tools have been evaluated in comparison to the on ground models show the accuracy of the onboard models.

5. The concepts of Payload Sequencer for LEO spacecrafts have been evolved and better performance standards are achieved. Various features of building modern sequencers onboard the spacecraft have been delineated.

6. YOUTH SAT, a small satellite for science applications have been selected as a case study. The features of YOUTH SAT satellite with the payloads and their requirements of attitude orientations, showed how the onboard algorithms effectively controlled the satellite using a specially designed payload sequencer autonomously. It is found that this experiment has been a success and promises a completely autonomous satellite mission for future.

7. Though a complete autonomous space mission is in distant future, strong foundation necessary to have several autonomous features onboard mission operations centre have been laid down and sufficient progress has been made in this direction.

9.3 Future Directions of the Work

One of the most important cost factors in operating a spacecraft control centre has been the manpower and keeping them motivated doing a repetitive routine work and requirement of continuous attention in monitoring the various spacecraft system states have been a
monumental task these days. Several tools based on the operational experience need to be developed to ease out the working loads of the operational centre and make them easy in implementation of the work centre responsibilities. During the consolidation of the thesis several tasks that are yet to be fulfilled have been identified and they are listed below:

1. Future satellites planned for the Imaging missions like CARTOSAT-2C/2D aim at very high resolution imageries and therefore the orbit height planned is around 500 Km height. Due to aerodynamic forces acting on the spacecraft, the frequency of in-plane orbit raising maneuvers has increased multi-fold. In fact, the semi-major axis correction required for tight control for CARTOSAT-2C / 2D is expected to be for every week. This has created a very high demand on work load in planning and executing maneuvers on the working personnel in operating centre. For such satellites, an algorithm need to be developed for autonomous in-plane orbit correction and need to be established and implemented. If necessary, out-of-plane orbit control also can be suitably implemented onboard for complete autonomous orbit maintenance for imaging satellites.

2. Planning and scheduling software tools are all distributed and have been individually handled by various groups of the operational centre. The techniques used are varied and methods employed are not optimal. A unified software tool to plan and schedule all the space assets of a given operational centre to be developed and managed so that the payloads of each satellite are best used and orbital efficiency of the assets are increased optimally.

3. The onboard tools that have been developed and implemented in various satellites have been out of individual efforts of various engineers and the models and effects of implementation onboard are all to be studied scientifically and a unified algorithm for use to be developed.

4. Payload sequencers are developed based on the requirements of a particular satellite and its' payloads and functions. Currently every satellite runs its own specific payload sequencer, though many onboard and sub-system aspects are common in nature. Recent trend have been to develop the payload sequencers using editable MACROS which when necessary can be suitably modified for execution from ground. These new features are very useful when the operational procedures of sub-systems get modified due to sub-system failures and mitigation commands necessary to be inserted for suitable operations and an all out effort in this respect need to be planned and executed for future satellites.
5. Last but not the least, a series of small satellites can be planned and operated in order to test and verify various autonomous modes and gain experience to have a complete autonomous operating satellite.