LEOP Operations for a New GEO Satellite Platform

S. Breul[1]
ARSAT S.A., Benavídez, Provincia Buenos Aires, B1621BGZ, Argentina

R. Kiehling[2]
DLR, German Space Operations Center (GSOC), Oberpfaffenhofen, D-82234 Wessling, Germany

and

F. Niehaus[3]
LSE Space GmbH, D-82234 Wessling, Germany

Argentina is developing its first geostationary (GEO) satellite platform, the Arsat 3K. ARSAT as a government company shall develop the geostationary orbital slots assigned to the Argentine Republic by means of telecommunication satellites developed and built in Argentina, and operate them and provide satellite services to customers across the Americas. The project is based on the provision of 3 satellites. The first one, Arsat-1, will be launched end of 2013.

The Launch and Early Operation Phase (LEOP) of any satellite is a critical phase. Even more challenging is the LEOP of a newly designed satellite. The LEOP operations will be executed from ARSAT LEOP Control Center (LCC) and Ground Station located in Benavidez, Argentina. As Argentina, in particular ARSAT, has little experience to perform all the required tasks (Operation engineering, LEOP flight dynamics operations, LEOP planning), it was necessary to contract external support for these tasks.

ARSAT awarded the support of both operations and flight dynamics support to a partnership between DLR (Deutsches Zentrum für Luft- und Raumfahrt, the German space agency) and LSE (an SSC subsidiary). Both DLR and LSE worked closely with ARSAT (formerly NahuelSAt) in the frame of the Nahuel 1A project. As this first experience was very fruitful, ARSAT, DLR and LSE are establishing a close partnership for the LEOP of ARSAT satellites.

In the frame of this contract, DLR and LSE will provide all their experience to support ARSAT:

- **Two training packages were developed focused on LEOP flight dynamics operations and LEOP mission operations. The objective for the training was to develop a common understanding for the implementation and the performance of the Arsat-1 LEOP and to grow the team spirit between the partners,**
- **Experts are supporting the operations preparation from Oberpfaffenhofen, simulations & rehearsals and LEOP execution from Benavidez Ground Station,**
- **DLR flight dynamic team is responsible for the coarse and fine positioning of the ARSAT-1 satellite in GEO-Orbit**

This paper describes an international collaboration in order to perform a first LEOP execution from Argentina.

[1] System & Operations Engineering Resp. and Arsat-3 Project Manager, sbreul@arsat.com.ar
[2] Head of GSOC Flight Dynamic Services, reinhard.kiehling@dlr.de
[3] Principal Consultant, frank.niehaus@lsespace.com

I. Introduction

ARSAT, is a company established by the Argentine Government under a law passed in 2006. The Law of creation establishes that ARSAT shall develop the geostationary orbital slots assigned to the Argentine Republic by means of telecommunications satellites developed and built in Argentina, and operate them and provide satellite services to customers across the Americas.

The law reflects

a. The Government's strong commitment to strengthen domestic satellite development industry and
b. The high strategic value assigned to the use of orbital slots to attain a socioeconomic impact

Currently, the single shareholder is the Argentine State. The company foresees the participation of private capital in the future.

ARSAT currently holds exclusive rights to operate satellite networks at 72°W and 81°W longitude orbital slots covering the Americas

The project called SSGAT, Sistema Satelital Geo Argentino de Telecomunicaciones (in English, Argentinean Telecommunications Geo Satellite System) is based on the provision of 3 satellites based on the same platform.

a. Arsat-1 will be launched end of 2013,
b. Arsat-2 will be launched end of 2014,
c. Arsat-3 will be launched end of 2015.

The objective is to have a recurrent platform with different type of payload including different Radio Frequency (RF) Band.

ARSAT is at the same time the sponsor of the project (and even procuring most of the equipments) and the client. INVAP is the prime contractor for the satellite.

The main platform characteristics are:

a. Design lifetime: 15 years,
b. Total launch mass: circa 3 tons ,
c. Power consumption: 4.2 kW with a Payload consumption of 3.4 kW,
d. Attitude and Orbit Control System (AOCS) Sensors: ST - Star tracker, FSS - Fine Sun Sensor, IRES - InfraRed Earth Sensor, MIMU - Miniature Inertial Measurement Unit and Actuators: Reaction Wheels, 10N thrusters, 400N LAE - Liquid Apogee Engine.

II. General overview of a critical phase

The LEOP is one of the most critical phases of a mission. These operations take place from the separation of satellite from the launcher. During this phase the first contact between satellite and ground is established, the satellite is configured and driven on its final orbital position.

Criticality of this phase is mainly due to the initial switch on of the satellite's elements after the launch phase stress. Swift reactions of the operational team are mandatory for nominal operation and furthermore in case of contingencies, to ensure a very efficient execution of the post-separation operations to account for the limited power autonomy. The success of operations is depending on both a well-trained and seasoned operations and flight dynamics team and a reliable set of ancillary means (LCC – LEOP Control Center, communications network and LEOP network).

So, this LEOP is a set of complex operations involving flight proven, heavy and particular means as well as experienced staff. In addition to operational and ground segment skills, these operations need a permanent and proactive dialog with the satellite experts.

As ARSAT and its prime contractor, INVAP, have little experience, therefore it was necessary to contract external support for these tasks and to establish an international collaboration.

III. Arsat-1 LEOP concept

In order to minimize the technical and schedule risks, ARSAT has decided to use a classical LEOP configuration and organization.

A. LEOP Configuration

The control of the satellites during LEOP will involve the ARSAT LCC and the associated Ground Station in Benavidez (close to Buenos Aires city), a world-wide Ground Station Network (GSN), communications links, computer and software facilities. The GSN (provision awarded to Telespazio) will comprise a number of TT&C stations suitably located around the Earth. The GSN will be compatible with the launch vehicle orbits and provide dual site coverage during critical activities such as initial acquisition, apogee motor firing and reorientation manoeuvres. Anyway, any station shall recover main services (TM/TC) as soon as possible in case of an antenna failure when no dual site was foreseen.

The LEOP Control Center will contain all the necessary hardware and software to support the LEOP including the following functionalities of the Flight Dynamics adapted to Arsat-1 On Orbit Control (OOC):

a. Orbit Determination and Maneuver Calibration
b. Maneuver Planning
c. Generation of Orbit-Related Information
d. Co-location Monitoring

The LEOP Control Center will include in particular, capabilities to process and display telemetry, generate and transmit commands, validate commands before transmission, verify correct execution of commands by software, retrieve telemetry and command data for anomaly analyses, perform tone ranging and angular measurements, implement the Apogee Engine Firing (AEF) manoeuvres, monitor and control the satellite orbit and attitude and communicate with the GSN stations and the launch site.

The LEOP Control Center will include an area for the satellite specialists, containing monitoring consoles, a proper voice loop system, printer devices, a time display and the necessary furniture. This configuration will be made available during validation, qualification and operations.

B. LEOP Organization

Several teams can be identified in the LEOP service, for decision authorities, mission responsibilities, satellite experts, satellite operations, flight dynamics operations, and ground segment operations as defined here below.

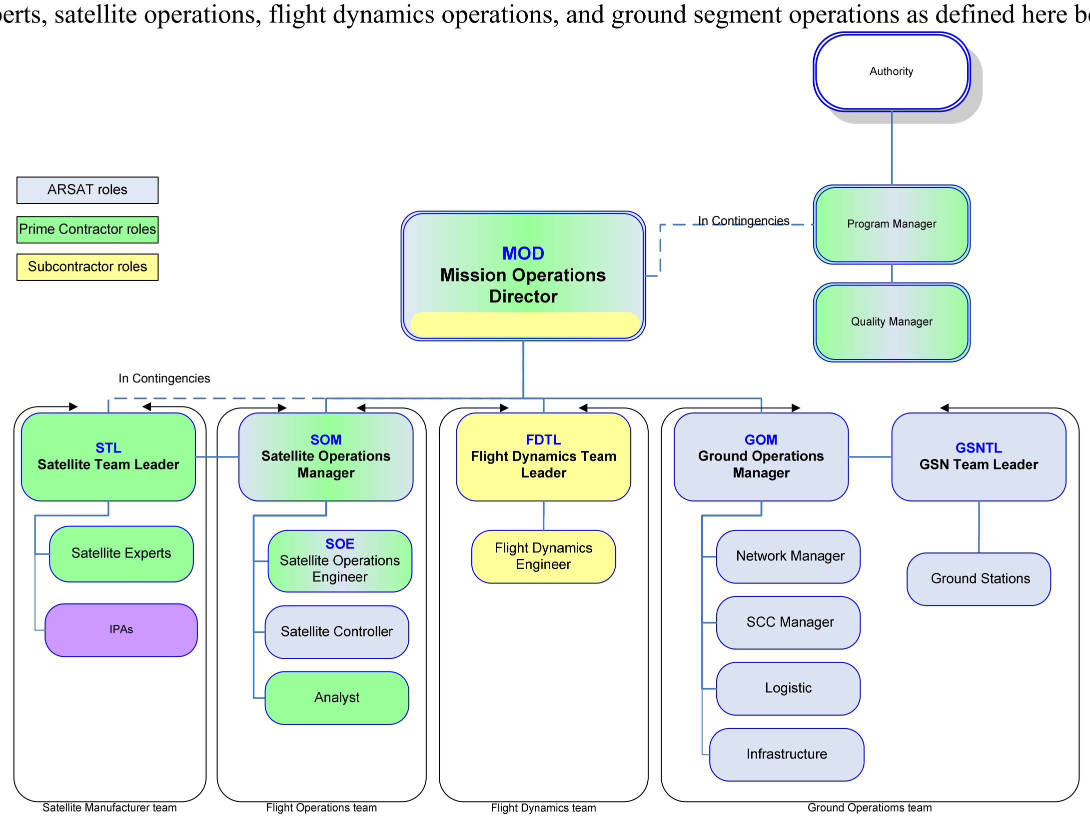

Figure 1. Arsat-1 LEOP Organization

The Decision Authorities (DA) are composed of the project manager both from ARSAT and the Prime Manufacturer.

The Mission Operations Director (MOD) formed by ARSAT, Prime Manufacturer and a subcontractor has the responsibility for the Mission Support Service during LEOP preparation and operations execution. Nonetheless, MOD is assigned to control aspects during LEOP operations (preparation, rehearsal and execution). In emergency situations, MOD receives instructions from the DA.

Their specific responsibilities include:

a. Controlling the LEOP operations progress in order to safeguards satellite health and enables mission objectives

b. Handling the operations meetings and anomaly meetings

c. Coordinating the GO/NO GO criteria for critical operation

d. Giving the authorization to begin the Flight Operations Procedures

The Satellite Team Leader (STL) heads a team of Satellite Experts coming from the Prime Manufacturer. He has the responsibility for providing a coordinated system view of the satellite health and performance.

Their specific responsibilities include:

a. Following the progress of satellite commanding in order to send the correct commands and to perform functional verification

b. Reporting anomalies behavior

c. Reporting GO/NO GO status

d. In case of anomaly, recommend a contingency procedure under the MOD responsibility in association with the SOM

The Satellite Experts monitor, in real-time, the current status of the various subsystems of the satellite and confirms to the STL, as appropriate, whether the satellite behavior is nominal or not.

The Satellite Operations Manager (SOM) is the leader of the Satellite Control Console, including the Satellite Controllers. SOM has a direct authority regarding the satellite telemetry monitoring and telecommand sending.

Their specific responsibilities include:

a. Execution of approved FOPs by assisting Satellite Controllers with command verification and related data checking

b. Verification of satellite health and status monitoring and anomaly reporting

c. Coordination with STL to ensure that they are ready to support command and the satellite health and status are as expected.

d. Keeping the Satellite Controllers informed of progress against the procedure

e. Maintenance of the Satellite operations logbook

The Satellite Controllers execute the FOPs following the SOM requirements and monitor the satellite telemetry.

The Flight Dynamics Team Leader is responsible for the generation of all required products and is the point of contact between the FD Team and the SOM and MOD.

The FDTL specific responsibilities include:

a. To develop the overall technical and operational concept to perform the assigned Flight Dynamics LEOP task

b. To coordinate all flight dynamic tasks

c. To report during mission execution the current FD activities and results to MOD

The FDT executes all flight dynamics tasks.

The Ground Operations Manager is responsible for operating the ground system including the Ground System Network

The GOM specific responsibilities include:

a. To maintain telemetry and telecommand links with the satellite

b. Management of software maintenance including operating system

c. Monitoring and operating specific hardware

d. Coordination a contingency plan in case of ground segment problems

C. LEOP Risks and Mitigations

The LEOP is the most critical of all phases of a mission and usually lasts anywhere from a few days to some weeks. Several causes may occur during this phase as:

- Technical failure on satellite (e.g. apogee motor, solar panels deployment),
- Technical failure in ground station (e.g. SCC software error, major incident e.g. power cut, failure),
- Not representative operations software: Dynamic Satellite Simulator (DSS) and Flight Dynamics Software (FDS)
- Unanticipated technical issues,
- Inexperience of the LEOP staff,
- Erroneous command instruction,
- No flight reference of the operational material such as databases, procedures, etc.

All these risks shall be minimized as possible for each mission. Knowing that Arsat-1 is a new GEO platform and the Ground segment is an updated of the one used for Nahuel 1A, all these risks may be considered.

The support from DLR and LSE on LEOP flight dynamics operations and LEOP mission operations preparations and executions allow to reduce some of these risks.

IV. Arsat-1 LEOP collaboration

A. Historic Collaboration

In 1993 NahuelSAt was founded by the European companies Aerospatiale (France), DASA (Germany) and Alenia Spazio (Italy). The telecommunication satellite Nahuel 1A was launched on January 30th, 1997 with Ariane 44L and positioned at 71.8°W. The LEOP was executed by CNES. The on station control (OOC) operations as well as the payload management and signal uplink were to be carried out from the newly built control center in Benavidez.

In this consortium Aerospatiale was responsible for the delivery of the telecommunications satellite based on the Spacebus2000 platform. Additionally they delivered training to the Argentinean Satellite Operations Engineers. Aerospatiale provided a team of own flight operations engineers for the procedure development, the training activities and the initial stage of On Station Operations.

During the final operations preparation phase 1996-1997 Aerospatiale awarded a contract to LSE Space GmbH in order to support the operations preparation and training activities and the first months of the OOC operations. The main activities consisted in the site acceptance of the Satellite Control Center (SCC) software and the customization of the flight operations procedures using this SCC. Furthermore, experience gathered in a large number of geostationary satellite projects was shared with the Argentinean colleagues who were supposed to operate the Nahuel 1A satellite for a lifetime of 12-15 years. This knowledge transfer occurred in a set of training courses both with class room as well as with hands-on lessons using the ground segment components driven by the software simulator from the satellite manufacturer.

The SCC software has been delivered by DLR/GSOC under a subcontract from Alenia Spazio. DLR subcontracted LSE Space so as to support them in this delivery to the satellite control center in Benavidez and to carry out site acceptance tests. In addition, DLR/GSOC provided the GeoControl software package for station keeping operations and has trained the personnel for its use in on-station operations. In 2008 DLR/GSOC has provided ARSAT with an upgrade of the software package.

Eventually, LSE provided their experience and their expertise through different partners and through different subcontracts, always ensuring a customer oriented service attitude without any conflicts of interest by applying a pure technical and pragmatic approach to the tasks.

In summary it can be said, that before the mid 1990s there was no activity in the scope of operating and managing telecommunication satellites on orbit at all in Argentina. A complete ground station and a complete Control Center together with the teams of engineers, operators and managers had to be built from scratch. DLR and LSE could contribute to the final success with their background and their vast experience. Now, 15 years later it is a new constellation with ARSAT as the follow-up satellite operator to NahuelSAt and with INVAP as a domestic satellite manufacturer. This also means a new challenge to which both DLR and LSE will provide their long term experience. Knowing the environment quite well and also being familiar with a number of the ARSAT staff from the previous NahuelSAt days, well established communication paths exist and problems can be tackled without a lengthy phase-in and familiarization period.

In the Nahuel 1A project, an approach had been taken by NahuelSAt to have the domestic engineers and operators trained by experienced foreign staff when finally they took over the overall operations activities. In this way, dependencies from the industries outside of Argentina were rather limited. In ARSAT this path is now consequently continued. Support is being purchased by ARSAT for various areas of consultancy requirements. The satellite is not procured turn key from one of the well known international providers, but assembled and integrated in Argentina using national experience. This is also true for the satellite control center elements such as the SCC, as well as for the operational teams.

B. Training Packages

In an early stage of the project a comprehensive training was provided by DLR/GSOC and LSE as part of the contract.

ARSAT has experienced engineers for routine and contingency operations of geostationary satellites. Therefore the characteristics and special features of geo-stationary LEOP operations and their differences to routine operations were scope of the training.

The objective of the performed training was the achievement of a common understanding for implementation of the Arsat-1 LEOP by detailed lectures and exemplary exercises. The training was also used to identify items to be clarified and possible problems.

The following training modules were performed:

1. Flight Dynamics Training Module A: Mission Analysis and Mission Preparation (2 weeks)
2. Flight Dynamics Training Module B: Flight Dynamics LEOP Operations (2 weeks)
3. Ground Data Systems (2 days)
4. Mission Operations (3 days)

In the following, details of the modules are given.

1. Flight Dynamics Training Module A: Mission Analysis and Mission Preparation

In a first introductory training session the fundamentals and definitions of Astrodynamics relevant for geo-missions were addressed. The general scenario with main events of a geo-stationary LEOP was discussed.

The second part covered the planning of the Ground Station Network (GSN) for a geo-stationary positioning taking into account mission specific requirements as dual site station visibility during critical operations (e.g. first acquisition, apogee boost maneuvers, etc.). Relevant for this planning are the foreseen launcher (Ariane V in this case), the specified transfer orbit and the location of spacecraft separation from the launcher. Exercises were performed taking into account the possible GSN stations for the Arsat-1 LEOP.

In the following part the planning of positioning strategies was performed including extensive exercises based on the possible Arsat-1 LEOP GSN and targeting to the planned Arsat-1 IOT location on the GEO. In a first step 3-impulse strategies for the apogee boost maneuvers were designed including backup solutions for each maneuver. Criteria for maneuver sizing with respect tothe following Fine Station Acquisition phase were discussed. Robustness of the strategies in view of transfer orbit dispersions and maneuver execution errors were investigated. 4-impulse strategies were developed and their advantages and disadvantages with respect to a 3-impulse strategy were analyzed.

The fourth part covered the computation of a launch window for a geo-stationary mission. Different classes of launch window constraints were addressed as Earth or Moon shadows, various types of Sun- and Moon-related angles and sensor interferences. An exemplary launch window computation considering typical constraints was exercised. Possible launch window constraints for Arsat-1 were discussed.

The last part in the first Flight Dynamics Training module covered the Sequence of Events (SOE) of a geo-stationary LEOP and the products to be provided by Flight Dynamics for its generation based on LEOPs performed by DLR/GSOC in the past. Differences to the Arsat-1 LEOP were discussed.

2. Flight Dynamics Training Module B: Flight Dynamics LEOP Operations

The first part of the second Flight Dynamics Training module addressed the Flight Dynamics tasks during a geo-stationary LEOP. From these tasks the architecture of the LEOP Flight Dynamics System (FDS) is derived. Operational interfaces to Flight Operations System (FOS) and Ground Station Network (GSN) were identified, especially possible adaptations to the Arsat-1 LEOP. In addition, a WEB-based intranet in the satellite control center used for the distribution of Flight-Dynamics-related information to the operations team was presented.

The next part covered the preparation of Flight Dynamics LEOP Operations including development of Flight Dynamics Ground Procedures and delivery of nominal LEOP products to FOS and GSN.

The third section comprised launch and first Flight Dynamics operations including various practical exercises. First task was the initial orbit determination after reception of tracking data, which were simulated and provided in several portions. The implementation of an Apogee Boost Maneuver rehearsal is supported by Flight Dynamics by provision of corresponding attitude transition data. Necessary adaptations of the present DLR/GSOC-FDS for the Arsat-1 LEOP with respect to this process were discussed. The positioning strategy is updated based on the initial orbit determination. Flight Dynamics products are delivered to FOS and GSN. Different possible Transfer Orbit Contingency cases as 'No Signal from Spacecraft', 'Transfer Orbit Injection with Low/High Perigee', 'Propulsion System Leakage' were addressed. How to react on these contingencies was trained in various exercises.

The fourth part dealt with planning, execution and reconstruction of an Apogee Boost Maneuver. The process started with a pre-maneuver orbit determination. Second step was the optimization of maneuver parameters (ignition time, burn duration and thrust direction) with respect to minimize the overall fuel consumption for the positioning of the satellite at its target longitude. An important input to the maneuver optimization is the prediction of thrust level and mass flow rate for the planned maneuver, which needs support of the apogee engine experts. Flight Dynamics provides Maneuver Planning data to FOS and delivers updates of products to support FOS and GSN operations including pointing data for the tracking antennas. Flight dynamics is also prepared for possible ABM contingencies such as 'Ignition Time Delay', 'UPS Leakage after end of burn' and 'Positioning with 10 N Thruster (in case of ABM-motor failure)'. The performance of the maneuver is reconstructed by a post-maneuver orbit determination. This process in close collaboration with the engine experts provides a calibration which is used for the implementation of the following maneuver. All described processes were discussed in detail and trained in extensive exercises.

The scope of the last part was the Fine Station Acquisition phase which brings the satellite from a drift orbit achieved by the main engine firings to the final location on the geo-stationary orbit using the small thrusters of the satellite. The fine station acquisition planning was exercised under the aspect that close conjunctions with other satellite control boxes are to be avoided. The current situation of satellites around the planned Arsat-1 IOT position was assumed and part of the training. To be prepared for non-nominal execution of the fine station acquisition, coordination with other satellite control centers by exchange of orbit data was discussed. Simulated orbit data of the other satellites close to the Arsat-1 IOT position were used to train co-location and conjunction monitoring. After selection of the most favorable fine station acquisition strategy the implementation and calibration of the maneuvers were exercised.

3. Ground Data Systems

In the Ground Data System module, the training started off with an introduction on the various components of a Ground Station Network as required during a LEOP, in particular the interfaces to other entities such as Flight Dynamics and Flight Operations were introduced.

Design drivers of a Ground Station Network such as the availability, redundancy aspects, link margins and security issues have been discussed prior to the definition of the Arsat-1 specific GSN requirements.

The training continued with the definition of the products for exchange within the GSN, in particular the required protocols and the specific exchange interfaces. The mapping of the Space-to-Ground Interface Control Document (S/G ICD) to the different configurations of the ground stations, namely the RF interface considerations, formed an important module within the training block.

Cost structure and cost drivers have been discussed and a number of exercises completed the sessions before the design part of the GDS training was terminated.

In the GDS operations part of the training, the different phases and the associated activities during the GSN preparation and the mission execution were trained, exercised and discussed.

The development of test plans and the execution of the relevant tests including the proper reporting of system and staff performances have been exercised, too.

A core element for the improvement of coordination between different GSN partners in GDS operations, the GDS-relevant Sequence of Events and its generation and use were shown, before aspects of Operational Readiness have been discussed.

The GDS training was concluded with a detailed demonstration of the organization of the Network Operations Center (NOC) console, the required documentation and the typical voice traffic during pre-launch and LEOP activities, particularly on first acquisition issues.

Exercises on TM&TC service performance metrics, link budget and detailed ranging performance analysis, as well as on troubleshooting methods completed this part of the training.

4. Mission Operations

In this training module, the main elements in mission operations such as the FOS-relevant Sequence of Events, the Flight Operations Plan and a selection of auxiliary operations tools have been introduced to the teams of trainees. One session on the reporting of anomalies and recommendations and how to handle non-nominal situations and one session to refresh the participants' voice operations skills were held in this context.

Mainly the aspects of satellite operations during the positioning phase have been addressed. This culminated in the execution of a small LEOP simulation which was scheduled more or less ad-hoc. Due to the fact that the trainees were extremely busy every day of the training courses, they had little preparation time and very little familiarization with the specific operational systems and elements used at DLR/GSOC, e.g. the control room layout, the MCS, the procedure format and many others.

The trainees were taking over dedicated roles/positions within the operations team, such as Operations Director, Satellite Team Lead, Subsystem Engineers, Satellite Operator and GDS NOC etc. All positions were double manned in order to reduce the work load. Additionally the trainees were supported by experienced mission operations staff from DLR/GSOC including the Flight Dynamics position.

During this simulation, the operations and associated procedures following the satellite's separation from the launcher up to the partial deployment of the solar arrays were performed, such as: Health Check of the different satellite subsystems by the responsible and dedicated subsystem engineers, Propulsion subsystem Venting and Pressurization, 1st Sun Acquisition, Solar Array Partial Deployment.

This exercise was well appreciated as all the aspects of the preceding trainings were addressed and required, in order to successfully manage the tasks during the simulated LEOP. It became very evident how much expertise, exercise and proficiency will still be necessary in order to successfully carry out the Arsat-1 LEOP.

C. Operations Support

The role of LSE in the framework of the support contract between DLR and ARSAT consists in the provision of consultancy services during the Operations Preparation phase as a sub-contractor of DLR. During the simulation and rehearsal phase as well as during the LEOP phase LSE will provide the staffing of the Deputy Operations Director (DOD) position. With the end of the LEOP a final LEOP Post Mission Report will be provided, describing in detail the results of the positioning phase and the performance of the satellite, the ground station network, the ground operations segment and of the associated teams.

Over the past 23 years LSE has accumulated experience in the operations of geostationary telecommunication satellites based upon various generations of European built satellite platforms (Spacebus and Eurostar). LSE staff involved in the Arsat-1 mission have participated in approximately 30 missions in various functions to customers such as Eutelsat, SES, DLR/GSOC, Arabsat, Yahsat, German Telecom, German Army and of course, NahuelSAt either through a direct contract or through a subcontract by another party.

LSE took various roles in the technical area but also in the mission management area. They provided a highly needed cost efficient and quality driven service in very close relationship to their customers.

In the scope of the Arsat-1 mission, the focus of the support from LSE will be the support and the backing of the Mission Operations Director. On the management side, LSE will play an active role in the preparation and execution of the classical Milestone Reviews. Furthermore, special emphasis will be given during the operations preparation phase on activities such as the definition, the validation and the realization of operational processes and procedures. These will be enacted and overlooked in particular during the simulation and rehearsal campaigns. Contributions will be made in the generation of the Flight Operations Sequence of Events and in the staff planning for the mission itself.

Having the role of the Deputy Operations Director, LSE will oversee during the simulation and rehearsal phase the interactions of the various individuals and teams, the quality of the used operational products and tools and finally deliver a Qualification and Performance Report.

Finally during the LEOP mission of Arsat-1 the DOD will be on site in the Benavidez SCC on a 24/7 basis in order to interchange with the MOD in order to monitor the flow of flight and ground operations, to consult and follow up anomaly operations where needed and to report to the MOD.

With the satellite finally being positioned at its desired longitude, a special Post mission Analysis and Performance Report will be compiled and submitted to ARSAT as "Lessons Learnt". It will form an important input for the upcoming Arsat LEOPs.

D. Flight Dynamics

1. DLR/GSOC Experience in Field of Geo-Stationary Missions

DLR/GSOC has successfully positioned 20 geo-stationary communication satellites on station since 1974 beginning with involvement in the German-French SYMPHONIE program. Between 1987 and 2002 GSOC was responsible for the LEOPs of various geostationary satellites for EUTELSAT (European Telecommunications Satellite Organization) and for German Telecom. For some of the national missions GSOC also has performed routine operations including station keeping. At last DLR/GSOC has positioned COMSATBw-1 & 2 for the German Military Services and is currently the control center for routine operations and station keeping of these two geo-stationary satellites. GSOC also supported various external agencies in the field of geo-stationary missions, and provided NahuelSAt with its Flight Dynamics software.

2. Operational Concept of the Flight Dynamics Service for Arsat-1

Flight Dynamics LEOP Operations for the Arsat-1 satellite will be executed by a DLR team at the ARSAT Satellite Control Center (SCC) in Benavidez. The presence of Flight Dynamics experts performing their operations on site within the LEOP SCC ensures a close interaction with mission operations and satellite manufacturer which is essential especially in the following cases and tasks:

a. Strategy fine-tuning or re-planning;
b. Implementation of maneuver-related contingencies (e.g. ignition time delay etc.);
c. Fine station acquisition planning satisfying all operational and technical constraints;
d. Implementation of thruster performance forecasts for maneuver preparation;
e. Calibration of executed maneuvers and the consequences for upcoming maneuvers;
f. Occurrence of special events (e.g. interferences etc.);
g. Flight dynamics analyses in case of non-nominal situations.

All these situations would be more difficult to handle in case of a remote Flight Dynamics Support located at DLR/GSOC premises.

3. LEOP Preparation

a) The LEOP Flight Dynamics System

The GSOC Flight Dynamics System (FDS) for geo-stationary missions is a widely platform-independent generic system which is flight proven in numerous missions. Usually adaptations of the system are needed due to specific platform characteristics such as launch window constraints, gyro calibration, generation of parameters for attitude transition into maneuver attitude, maneuver attitude profiles, maneuver execution parameters to be commanded to the s/c, sensor interference predictions, wheel unloading, etc.

DLR/GSOC will perform a requirement analysis for the FDS S/W and H/W and will design the architecture of the FDS including all data interfaces to FOS and GSN to be implemented to support the Arsat-1 LEOP. Data provided by FDS are parameters for maneuver execution commands, event files for FOS and GSN operations planning (SOE), information and WEB Files to ARSAT intranet to support the Flight Operations Team with orbit-related information, current orbit data for antenna pointing purposes. Input to FDS are tracking data files containing range and angle data used for orbit determination.

The FDS will run in DLR/GSOC furnished workstations, which will exchange data (tracking and ranging files, FDS products and intranet updates) according to an ICD. The work will be easier as parts of the LEOP FDS are shared with the current ARSAT OOC FDS.

b) Mission Analysis

One of the main tasks of Flight Dynamics Support during the preparation of the Arsat-1 LEOP is the performance of a mission analysis comprising

a. Assessment of Ground Station Network (GSN);
b. Analysis of first acquisition conditions at separation from the launcher;
c. Design of positioning strategies including backup maneuver tree;
d. Estimation of ΔV-budget for the positioning;
e. Launch window computation;
f. Computation of relevant events (ground station visibility, shadows, sensor interference etc.);
g. Fine Station Acquisition Analysis.

c) Operational Preparation

The planning of Flight Dynamics Operations during the LEOP comprises the generation of nominal and contingency Flight Dynamics Ground Procedures. These procedures specify all flight dynamics activities to be carried out during the service in order to bring the satellite to its geostationary In-Orbit Test (IOT) position covering also non-nominal situations.

The Flight Dynamics Sequence of Events and Shift and Manpower plan will be generated in close coordination with Flight- and Ground Station Network operations.

For support of the generation of FOS and GSN sequence of events Flight Dynamics will provide orbit-related information comprising ground station visibility, shadow events, specific angles and sensor interference, maneuvers, and others, as applicable.

Flight Dynamics will implement with assistance of ARSAT data exchange processes with other satellite control centers which operate satellites close to the Arsat-1 IOT target position to be prepared for orbit coordination during Fine Station Acquisition in order to minimize collision risks in case of non-nominal situations.

The GSOC Flight Dynamics Team is experienced from numerous geo-stationary LEOPs performed in the past. Peculiarities of the LEOP of the new Arsat-1 platform will be addressed first in classroom sessions and simulations at DLR/GSOC premises well before the LEOP. The GSOC Flight Dynamics Team will then participate in Mission Rehearsals performed at the LEOP SCC in Benavidez in order to get familiarized with the Operations at the SCC, to validate finally the Flight Dynamics Procedures and to harmonize the interactions between all involved parties.

4. Flight Dynamics LEOP Operations

The GSOC Flight Dynamics Team will conduct the following main tasks for support of the Arsat-1 LEOP:

a. Orbit determination and prediction;
b. Generation and delivery of flight dynamics related information required by FOS and GSN;
c. Generation and delivery of current orbit or pointing data for ground stations;
d. Re-planning of positioning strategy, if necessary;
e. Planning, optimization and calibration of Apogee Motor Firings;
f. Calculation of the required attitude transient for achieving the maneuver attitude;
g. Prediction of interference (sensor blinding or radio frequency);
h. Fine Station Acquisition strategy planning (including avoiding of other satellite control boxes);
i. Planning, realization and calibration of fine station acquisition maneuvers;
j. Orbit coordination with other satellite operators (as necessary);
k. Performance of Flight Dynamics analysis support (on request by FOS or GSN);
l. Execution of Flight Dynamics contingency procedures in case of non-nominal situations.

It is currently planned to hand-over the flight dynamics operations to the customer's routine operations control center two weeks after having achieved the target orbit position.

V. Conclusion

The LEOP trainings based on theoretical and practical support provide all the experience to support ARSAT and INVAP in the Arsat-1 LEOP execution. The objective for the training was to develop a common understanding for the implementation and the performance of the Arsat-1 LEOP and to grow the team spirit between all entities.

In addition, the old collaboration between ARSAT and DLR and LSE help to establish an efficient process to reach the final objective to launch successfully a new GEO satellite platform from an updated control center.

Risk mitigations measures are put in place such as Flight Dynamic responsibilities on DLR, Ground Segment Network responsibilities on Telespazio, LEOP operations support on LSE and operations preparation phase based on trainings, simulations and rehearsals.

While the Arsat-1 system is expected to represent a key milestone for future technology developments in Argentina, it will set also an effective benchmark for all the space industry in South America.

Acknowledgments

All authors thank the whole teams of DLR, LSE, ARSAT and INVAP involved in this LEOP Operations collaboration.

As ARSAT (formerly NahuelSAt) and DLR are working together in a fruitful and pragmatic way since mid of 90s, this international collaboration has to be brought to the fore.