"FLIGHT DYNAMICS OPERATIONS MANAGEMENT OF THE LARGE AND HETEROGENEOUS EUTELSAT FLEET OF COMMERCIAL SATELLITES"

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ABSTRACT

The EUTELSAT FDU (Flight Dynamics Unit) manages the resources to perform the typical activities of the large satellite operators and faces the usual difficulties raising from a vast and heterogeneous fleet. At present 20 satellites from 9 different platforms/sub-platforms are controlled from our Satellite Control Centre.

The FDU was created in 2002 with the aim to respond to the operational needs of a growing fleet in terms of number of satellites and activities. It is at present composed of 6 engineering staff with the objective to provide operations service covering the whole lifecycle of the satellites from the procurement phase till the decommissioning. The most demanding activity is the daily operations, which must ensure maximum safety and continuity of service with the highest efficiency.

Solutions have been applied from different areas: management, structure, operations organisation, processes, facilities, quality standards, etc. In addition to this, EUTELSAT is a growing communications operator and the FDU needs to contribute to the global objectives of the company. This paper covers our approach.

1. INTRODUCTION

EUTELSAT was created in 1978 and in the early 80's it started operating the GEO communication satellites developed by ESA. In 1985 it became an IGO and since July 2001 EUTELSAT is a French private company with the vision to "be a leading provider of S/C communications solutions, operating world-wide as an independent and publicly quoted Group".

Since 1990, EUTELSAT has successfully launched more than 22 satellites as shown in Figure 1. At present we provide capacity on 24 satellites and operate 20 from 9 different platforms/sub-platforms, which constitutes one of the largest fleets of commercial satellites in the world. It can thus be understood that the control facilities are highly complex particularly in view of the degree of integration and geographical redundancy required. Two satellites arrived to their End of Life in 2003 and were properly de-orbited.

With the change of status, EUTELSAT went through a fundamental transformation. With a profit-based objective, a larger emphasis is put in the commercial and financial aspects. Due to the increase of services and the repercussions of payload unavailability on the company business, the communication services need to be ensured with maximum reliability. The change of the status has implied the need to apply a different approach to problem solving and to become "business-oriented".

In order to respond to the large and growing amount of activities following the satellite procurement growth, the FDU was created in 2002. This has involved a large effort especially in terms of management, organisation, integration and training. The development of the Unit, including the management of the necessary resources has resulted in an efficient administration of the activities and the necessary structure to face the foreseen increase in the number of satellites.

The activities of the FDU have a direct impact in the revenue of the company. Strong emphasis is put in optimisation of propellant consumption, reliability of operations and compliance with assigned window slots. The management of the FDU has put in place different changes in the operations philosophy to ensure absolute safety, efficiency, flexibility and robustness with a business-oriented vision, which represents the contribution of the Unit to the success of the company.

2. THE SITUATION

2.1 The Fleet

At present it is composed of 20 satellites from 7 main designs covering an arc from 12.5°W to 70.5°E:

- 3 SPACEBUS 2k
- 8 SPACEBUS 3kB2, SPACEBUS 3kB3
- 5 EUROSTAR 2k, EUROSTAR 2k++
- 1 EUROSTAR 3k
- 1 ALENIA GEO (Backup centre)
- 1 MCM-272 (SESAT): Russian ionic propulsion.
- 1 HS-376: American Boeing Spinner

The average age is **4.5** years with expected lifetimes of up to **18** years in equatorial orbit, which constitutes the youngest fleet of satellites of a large operator. This lifetime expectation and the foreseen growth of the fleet imply the need for a stable FD service.

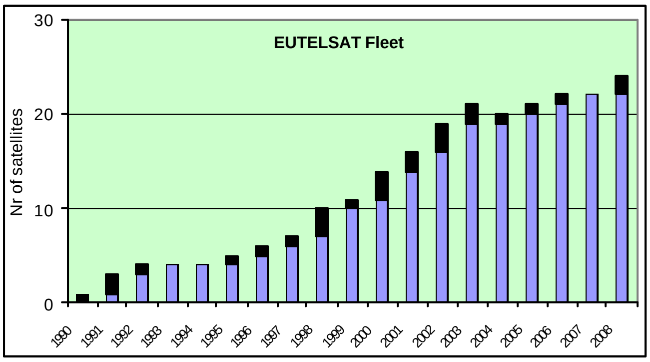

Figure 1 EUTELSAT fleet controlled from the SCC

2.2 The FDU Objectives

Among others:

- Continuity of the communications service to the customers.
- Keep the satellites inside the allocated orbital slots.
- Operate the satellites of the fleet ensuring maximum safety of operations.
- Anticipate and avoid operational problems.
- Increase the lifetime of the satellites by minimising the propellant consumption.
- Perform the operations in an efficient manner.
- Team understanding the objectives of the company.
- Responsibility and cooperative spirit.
- Robust and flexible operations team.
- Operations following highest quality standards.
- Professional excellence.
- Innovation and creativity applied to constantly improve the FD operations service.

Most of the above objectives are common to commercial operators and to GEO operations agencies though the perspective is different in the sense that a FD unit of a commercial operator needs to have the commercial vision of the objectives of the company and act proactively to achieve them.

2.3 The activities

The Unit is responsible for the flight dynamics service covering mainly following activities:

- Operations from hand-over till decommissioning.
- Daily operations are the most important aspect.
- Satellite relocations. More than 10 satellite relocations have been performed in the last two years involving up to 3 overlapping. 2000: 4, 2001: 3, 2002: 6, 2003: 7, 2004: 3 (TBC).
- Emergency operations.
- Provision of on-call support to real-time operations.
- Fuel booking and lifetime predictions.
- Development of new strategies to reduce propellant consumption and increase lifetimes.
- Studies and development of long-term strategies.
- Enhancement of procedures for operations.
- Dissemination of data.
- Liaison with external FD entities.
- Space debris follow-up and issue recommendations.
- Satellite de-orbit planning and execution.
- Preparation of operations for new missions.
- Definition, specification, monitoring of developments by contractors and validation.
- Technical monitoring of FD aspects of satellite procurements and LEOP service projects.
- Design of new systems to improve the FD service.
- Monitoring of LEOP with increasing involvement.

2.4 The challenges

- Large amount of satellites.
- Important number of different platforms.
- Half of the platforms with only a single satellite.
- Diversity of platforms operational philosophy: 3-axis from different designs, spinner, ionic.
- Complexity of certain satellite platforms.
- Increasing number of satellite constraints.
- Error prone character of the operational activity.
- Unaffordable possibility to make any errors.
- Critical consequences to EUTELSAT business of any error.
- Large amount of simultaneous operations
- Concurrent operations by different FDEs.
- Outsourcing of areas such as software development.
- Large number of different areas of activity.
- Keep a high level of know-how of the team.

2.5 The Team

To provide this service, the FDU manages the resources and the operational activities. The Head of Flight Dynamics leads a team of 5 FDEs from 4 different nationalities, consultants during activity peak periods and eventually students.

3. THE EUTELSAT APPROACH

A plan of action was established at the creation of the FDU, which included a set of actions principally in the following areas:

- Resources.
- Team Structure.
- Orbital Operations approach.
- Training.
- Emergency support.
- Satellite control strategies.
- Software Facilities.
- Quality standards.

3.1 Human Resources

Since several years the size and nature of the EUTELSAT fleet has grown at a very important rate and this progression is foreseen to continue in the following years. The Figure 2 shows the evolution of the number of manoeuvres since 2000, which is directly related to the increase in the number of satellites and especially those involving active attitude control and ionic thrusters.

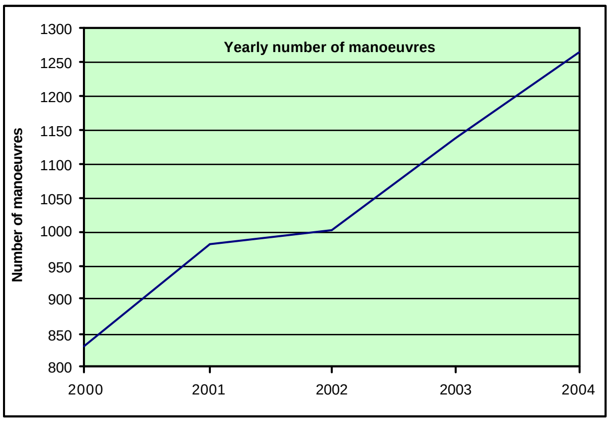

Figure 2: Yearly number of manoeuvres

The monitoring and evaluation of the foreseen workload of the Unit, has provided a tool to correctly size the team to support the different tasks. From 2002, the size of the FDU has been progressively increased from 2 FDEs in 2000, to 6+ at present.

The size of the team has proven to be adequate to respond to the workload requirements, providing a high level of operations flexibility and stability.

3.2 Team structure

Together with the resize of the FDU a structure has been put in place in order to respond to the different areas:

- The 5 FDEs follow a predefined rotation to perform the routine manoeuvre planning, with an average distribution of 4 satellites per FDE.
- The distribution of satellites maximises the number of different platforms per FDE.
- The platforms are rotated among the FDEs.
- In addition, each FDEs carries out the tasks of "FD Platform Coordinator" for a different platform.
- A "FD Software Validation Officer" was nominated in order to centralise and better control the process of facilities procurement.
- External support is provided at foreseeable periods of activity peaks, except for operational activities.
- Positions are available for students.
- The above positions report to the "Head of Flight Dynamics", who carries the overall responsibility.

The above has resulted in a better control of the different processes and activities.

3.3 Orbital Operations Approach

It is foreseen that during 2004 a total of **1260** manoeuvres will be executed, which implies an average of **105** monthly manoeuvres and **252** yearly manoeuvres per FDE. The Figure 3 shows the shows the evolution of the number of manoeuvres per FDE.

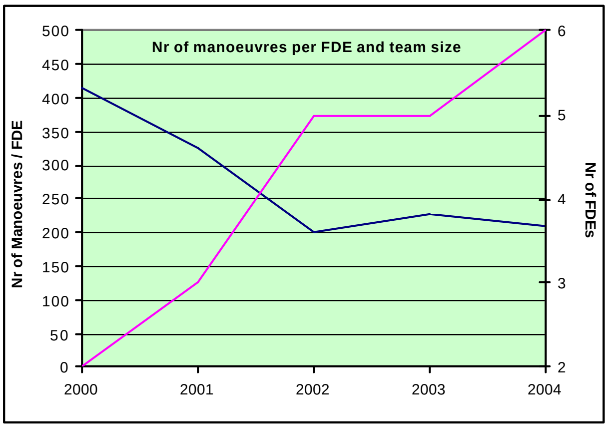

Figure 3: Nr of manoeuvres per FDE and team size

To cover this in a reliable manner, a number of measures were put in place:

- Selection of fixed manoeuvre cycles. At beginning of each year the nominal days of all manoeuvres for all satellites are fixed. All manoeuvres of the fleet and the assignments are precisely co-ordinated in order to ensure the correct daily workload of the FDEs, coverage in case of absences and coordination of the operational activities in the SCC. Nevertheless there is some margin to cover changes due to manoeuvre performance reasons, satellite relocations and to apply propellant optimisation strategies.
- Operational process follows quality procedures.
- Highest priority given to the daily operations.
- Operational data follows two independent checks by FDEs and a technological check by an SCOE before a manoeuvre is executed in the SCC.
- A centralised tool updated in real-time provides the team with the capability to identify the daily operational activities and to monitor the state of the operations performed by the team.
- Software is in line with the EUTELSAT operational needs and operations philosophy.
- On-call is provided by the most senior FDEs to the full fleet, which implies that this sub-group is well aware of all the operational aspects of all platforms. This avoids the need of simultaneous teams of FDEs providing on-call for different platforms.

This approach has achieved error-free operations since the beginning including no violations of the assigned control windows.

3.4 Training

The size and heterogeneity of the fleet requires a thorough and continuous process of training that involves an important investment in resources.
A minimum number of expert FDEs has been defined for each platform depending on its foreseen growth and specific workload, being an important issue the single-

satellite platforms. For any new platform the needs in terms of support are defined and the process of training is initiated.

The process follows different phases of familiarisation and acquisition of the knowledge, involvement in operations with support from another expert FDE, direct involvement without supervision finished by a presentation to the FDU of the platform specificity covering all operational aspects. After this point the authorisation to perform operations for a certain platform is provided.

When a training period is completed, the distribution of satellites and platforms is changed to maximise the distribution of satellites form different platforms. For platforms with a low number of satellites a rotation method is applied to ensure refreshment training.

Weekly reporting is implemented to ensure correct information flow of all the operational aspects. In addition, a yearly reporting provides long-term analysis and help to improve the satellite control. Also for each manoeuvre there is a specific report including all the execution elements.

The robustness of the team and reliable and efficient operations activities to support routine and emergency situations has been achieved by acting on the training area. Nevertheless this is a continuous effort and as such a constant investment is being done.

3.5 Emergency support.

EUTELSAT can cover the 90% of the world population. Several strategic locations are operated, such as 13º EAST with 5 collocated satellites, and increasing capacity at other longitudes. With such a large communications service, a satellite anomaly leading to an emergency situation involving the loose of communications services can have far reaching consequences.

The FDEs need to have the capabilities to perform the activities leading to the recovery of the nominal attitude and orbit to re-establish the service in the shortest possible delay. This has been ensured by several means:

- The infrequent nature of such situations is an issue to take into account in maintaining a high level of training in crisis situations. A program of emergency simulations is being introduced, which involves the analysis of the situation, the use of software and different tracking mechanisms.
- As part of the quality standard, a recovery procedure has been introduced, which defines steps to be followed to ensure a fast recovery. The procedure is of a very high-level, which implies that the engineering capabilities and know-how are fundamental to successfully recover the service.
- Offline tools have been procured for first step analysis. With the use of very few tracking measurements a rough estimation of the orbit can be obtained shortly after a perturbation.
- No automation capabilities are used to support emergency recovery due to the difficulties to put boundaries to the problem because of to the large amount of initial conditions
- All efforts have been put to reduce human potential risks that can lead to a satellite anomaly.
- Any potential situation that might potentially lead to risk is covered by observations that are analysed at the FD Anomaly Review Board to put solutions.
- In addition, the recovery strategies take into account as one of the parameters the propellant use in order not to penalise the satellite lifetime.

3.6 Satellite control strategies

The usage of propellant to enlarge the lifetime of the satellites and therefore increasing the life of communications service is basic for a commercial operator. The activities of the FDEs in this area have an important impact on the company business. An important effort is being put in the development of control strategies to increase the lifetime and to better calculate the satellites lifetime.

- The use of the sun-pointing-perigee strategy allows avoiding double-pulse manoeuvres to control the eccentricity. It is to be noted that during the whole 2003 a total of 2 double-pulses were executed and it is foreseen that 1 will be executed in 2004.
- Close monitoring of manoeuvre performances to avoid any correction manoeuvres.
- Re-distribution of inclination manoeuvres using the favourable periods of the year.
- Analysis of the geometrical characteristics to use the more suitable periods of the year.
- Long-term analysis.
- Lifetime predictions and close monitoring of the mass consumption with software mainly based on dead-reckoning methods.
- Avoid de-optimisation of manoeuvres.

The strategies are being put in place and analysed. The first estimations provide an increase of the lifetime of certain satellites by **3%.**

3.7 The software facilities

EUTELSAT philosophy is to adapt the existing facilities to any new mission rather than different control systems for each new mission. The experience has demonstrated that his method has larger advantages. Our FD facilities need to have a strong emphasis on multi-mission, long-term analysis, powerful graphical applications, collocation evaluation, and automation support and concurrent operations among others. In addition, the facilities need to ensure reliability, flexibility and effectiveness.

For the FDU the facilities are considered as a tool to do the work, therefore the development of the facilities is done by external providers and the management of the software and facilities is supported by other areas. The

FDU invests an important amount of time to design enhancements, monitor the implementation and to validate the software.

The main flight dynamics tool, FocusSuite®, has been developed by GMV with a design substantially influenced by EUTELSAT, which implied an important investment in time and effort on both companies. The computational layer is based on the PEPSOC software developed by ESA and since 1990 deeply modified by EUTELSAT to adapt to new platforms, to new operational environments and to increase its capabilities. FocusSuite® has different components:

- FocusGEO, which contains the modules to support all missions. User interface, powerful graphical applications together with potential possibilities for further developments are important characteristics.
- Autofocus allows running the manoeuvre planning procedures in an automated manner. The software executes the so called "job sequences", which perform two types of actions: run software modules and data checks. The sequences are in permanent process of enhancement by the FDEs to increase their capabilities.
- FocusART, which is used to validate the RT (regression-test) phases of new software builds has the target to perform this phase in a fast and safe manner with little involvement from FDEs. The system runs the selected software in an automated way and provides results through a visual interface. The validation activity is now reduced to evaluate the summary of results.
- Future investments being considered at present would cover the LEOP FD activities. Further investments focus on the graphical enhancements and the safety and efficiency of operations.

The investments in new facilities had an important positive impact on safety and efficiency of the operations. The investment in software validation tools have achieved much faster and efficient processes: the RT of a standard build takes now 3 days instead of the 3 weeks, is reliable and the amount of time for evaluation of results has also been dramatically reduced.

3.8 Quality standards.

EUTELSAT is working to put in place a quality system aligned with that of ISO9001, which promotes the adoption of a "process" approach when implementing and improving the efficiency of a Quality system and it is hence very well adapted to operations. Moreover it provides confidence to EUTELSAT customers on the quality of the services provided.

In this framework it was decided to cover the FD routine operations and other FD related activities by a "Management plan for Flight Dynamics Operations". This document establishes the basic processes and instructions to perform the operational activities of the FDEs. Although the engineers are expected to use the necessary judgement, common sense, skills and experience, these rules must be applied during the performance of the tasks. They do not intend to limit the engineering capabilities but to establish a minimum set of instructions that are to be followed during the routine activities to ensure maximum safety by avoiding potential risk situations. The system is flexible enough to use the individual capabilities at the same time that is hard on safety issues, where no potential error is allowed. It was important to find a trade-off between the level of detail of the process definition and the freedom to allow the engineers to use their skills on the routine and emergency situations.

The Management plan for FD provides for reviews of non-compliances (ARBs) and for review of the processes with the view of continuous improvement of the system. As part of it, a common operational system to control satellite restrictions has been put in place and constitutes a common understanding of the different operations areas of the applicable operational constraints.

The document is being applied since Feb-2004. The complete lack of anomalies in the satellite control cannot be only attributed to the application of the quality standards but it is clear that it has demonstrated a contribution to eliminate risks.

4. CONCLUSIONS

Since the creation of the FDU, in 2002, only 2.5 years have passed. In such a short time the unit has reached the necessary maturity.

Since then more than **3000** manoeuvres for **20** different satellites have been planned without errors. Additionally, the Unit has taken the control of **5** new missions from **4** different designs. The amount of satellites and manoeuvres compared to the size of the team makes the efficiency of the EUTESLAT FDU outstanding.

The measures applied during this time in the fields, among others, of facilities, management, training, quality and strategies have contributed to highly reliable, efficient and flexible operations. In addition to this, the control strategies under development are having an impact in increasing the lifetime of satellites.

The FDU has been able to adapt itself in a very flexible manner to the new environment providing innovation in satellite control and contributing to the overall success of operations during the latest years. It is this vision together with our proactive approach that has contributed to the success of the FDU and the image of excellence of EUTELSAT.