Using Synergies for Flight Procedure Development

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For every space mission flight procedures are used to guarantee save operations. These flight procedures shall be developed and tested prior to the launch and shall cover all nominal and all foreseeable contingency operations, according to the ECSS standard. Therefore the preparation of flight procedures shall ideally be accomplished by the spacecraft manufacturer, as he knows the spacecraft and its subsystems in greatest detail. But in recent small satellite missions where GSOC was involved, the preparation process of the flight procedures not always followed this standard, instead the delivery of procedures where either late or incomplete. Reasons for this may be the lack of manpower but often it is the low operational experience by these small companies. This paper describes step by step the workflow of flight procedure development in an iterative approach. This process divides the development between the control center and the satellite manufacturer specialists. As a result this approach will reduce implementation time, increase the quality of the developed flight procedures, lead to an better understanding of the satellite system by the control center specialists and will improve the quality of the delivered documentation by the manufacturer. The experience gained in recent small satellite missions of the German Space Operations Center (GSOC) during the mission preparation phase is the basis for this paper.

I. Introduction

Recent small satellite missions are a great chance for small companies, universities or scientific institutes to build satellites for the first time. The necessary engineering know-how for the various subsystems like power, thermal, electronics, structure, software, attitude determination and control etc. is present. Most satellite hardware like sensors, actuator wheels or batteries can also be purchased ready for integration if necessary.

Normally a satellite manufacturer is expected not only to deliver the satellite bus together with the onboard software, but he should also deliver a space segment user manual (SSUM) together with flight procedures to describe how the satellite should be operated.

Step	Label/Time	Activity/Remarks	Telecommand	Telemetry	Display/ Branch
		Beginning of Procedure			
		THM0300N Procedure Properties Formal Parameters STARTTIME as<abs> = 2019.360.12.30.00.000			
1		Identify Procedure			Next Step: 2
	TimeTag: ET=STARTTIME+ UT=+	Execute Telecommand CCC00000 BREAKPOINT TC Control Flags: GBM IV DSE --Y -- --- Command Parameter(s): COMMENT = THM0300N THM_HEAT_BAT_ON <str>	CCC00000		TC
2		Check status			Next Step: 3
		Verify Telemetry HEAT_BAT HEATING_BATERIES = OFF		HEAT_BAT = OFF	(None)
3		Turn on heater			Next Step: 4
	TimeTag: ET=OAG+00.00.00 UT=+00.00.00	Execute Telecommand RLYC0017 HEATER_BATTERY_ON Command Parameter(s): CC = 0 <dec> (Def) ET = 125 ms (Def)	RLYC0017		TC
4		Check successful execution			Next Step: END
		Verify Telemetry HEAT_BAT HEATING_BATERIES = ON		HEAT_BAT = ON	(None)
		Check for increase when switching on HKIBUS S/C LOAD CURR		HKIBUS	(None)
		End of Procedure			

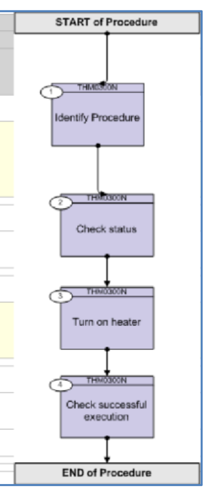

Figure 1: Example of a FCP, Steps and Flowchart

The experience at GSOC in small satellite missions over the last five years has shown that the SSUM as well as the flight procedures will not be delivered in time, they are missing important information or do not cover all operational requirements. The reason for this is often the small manpower and also the absent operational experience of such smaller companies. This also leads to a misunderstanding what a flight procedure shall be. The manufacturer often understands their telecommands like the commands of a dynamic instruction language which shall be combined dependent of the situation in which the spacecraft is. They often don't see that especially critical operations shall be done with FCPs which have as less editable parameters as possible and also shall have defined entry and termination conditions which must be checked in telemetry.

The result of this situation is that often the FCPs are developed by the GSOC subsystem engineers, as shown in Figure 1. To guarantee that all necessary procedures could be identified and developed with the same quality as if the space segment could do this a special workflow was established to combine the experience of GSOC together with the design knowledge of the space segment.

II. Flight Procedures Development

ECSS-E-ST-70 identifies procedures as the primary mechanism for conducting mission operations and defines two types of flight control procedures (FCP):

• Nominal procedures
These define the set of in-orbit operations of the space system to be used under nominal conditions. They constitute the building blocks from which the mission timelines and schedules of the flight operations plan (FOP) are constructed.

• Contingency procedures
These define the recovery actions used to reconfigure the space system if pre-identified anomalies or failures occur.

Additional to these definitions FCPs can be divided into subsystem procedures on device level, like switching a sensor on or off and system procedures that perform a complex task, like performing a datatake, calibration or orbit maneuver. The system procedures may be an assembly of subsystem procedures or a compilation of single commands, telemetry checks and other procedures.
A FCP can be generic if the task is uncritical or if the task is critical the FCP shall be specific with as less as possible editable parameters to avoid human error. Important is that a procedure does not only contain telecommands that must be send in a specific order but also contains telemetry checks to validate if the procedure was executed successful. Ideally it also contains telemetry checks after each telecommand to be able to validate also the performance of the procedure. Some tasks also require a specific entry-condition or perquisite this check should be also included in the procedure or some subtasks require extra time before the procedure can be continued. In this case breakpoints with comments for the operator must be included. Also each step shall be commented with explanations and references.

A. Standard workflow

ECSS-E-ST-70-32C mentions that the task of procedure development is *to construct a high-level, goal-oriented activity (namely a procedure) using elementary activities consisting of telecommands and operating system calls*. It does not define exactly at which time during the integration test and validation phase of the space segment procedures shall be used but recommends the usage of procedures beginning with subsystem tests.

Ideally this is done by the space segment manufacturer to be able to reproduce subsystem, integration and assembly tests, as well as to do qualification test for the mission requirements. The test procedures will then be delivered to the ground segment together with the SSUM, the TM/TC documentation and the TM/TC database (MIB).

If the space segment uses a CCS for their tests together with the procedure development system of the ground segment, the ground segment can use the procedures without further adaptions for the ground segment qualification tests. Normally the ground segment will extend the procedures with special telemetry checks, comments or minor modifications with respect to in-orbit operations that are in contradiction to the needs of the ground tests.

B. Experiences and Problems with this approach

The ideal workflow is not always applicable. Especially in small satellite missions the manpower and operational experience of the space segment engineers is often a limiting factor especially if the usage of the CCS system is new to the space segment team the effort to learn to work with the CCS is very high. That often limits the acceptance to use additional tools like a procedure development tool. As a result tests will be performed directly with the MCS system in an interactive way. The documentation of these tests does not always contain every TC or parameter setting to reproduce the test. As a result the development of flight procedures must be done as an extra task but the testing of the satellite has a higher priority. In the worst case no procedure will be delivered at all, the SSUM and TM/TC documentation is delivered late or contains only high-level descriptions. In some cases the TM/TC documentation is missing the references between TC and TM.

In many discussions with engineers with no operational background there was often a huge misunderstanding of the purpose of FCPs. One of the most mentioned misunderstandings are that FCPs will be used by operators without knowledge about the satellite system, without monitoring the satellite state or by full automatic systems. Another common misunderstanding is the necessity to transits the satellite from one defined state to another. A common reaction during interviews with the space segment engineers about how to implement a FCP is: “You cannot simply send this command, because it depends on what you have sent before” or by discussing contingency procedures: “We cannot say what to do. We first have to analyze the root cause and then we can decide which TC we have to send.”

To be clear, both sentences are correct, but the first statement does not consider that if we define FCPs for nominal operations, the satellite will be transferred from a defined state to another. So we can state at the beginning of a procedure the entry conditions if there are any and the according telemetry checks. The second statement is also correct because of course in any contingency situation the first thing to do is to understand the situation. But after the situation is analyzed the reaction could be a predefined one. It is possible to identify potential contingency situations in advanced and to define a procedure how to check if this contingency really occurred and if so how to take countermeasures to bring the satellite back in a (defined) safe state.

Furthermore it must be mentioned that the space segment team is usually not completely aware that during routine operations the number of ground contacts are limited to a certain number, which may be even less than once a day. For LEO satellite these limited numbers of contacts are short, common contact times are between 6 to 10 minutes depending on the orbit. Within this time any activity or analyses intended by the FCP must be securely performed. Additionally there are usually other activities that are to be performed in parallel during this time. The background on the development team is more or less “we have all the time we need and concentrate on one issue” while the operations team is driven by the principle “that we need to perform as many activities possible in very short time while guaranteeing operational security for the satellite”. This requires that FCPs with editable parameters must be prepared in advance to the upcoming contact.

Because the experts of the satellite manufacturer know their system in greatest detail and all of their constraints and how the subsystems relate to each often it is often complicated for them to break down the complex system in their mind to an abstract high-level procedure that shall be always applicable with a minimum of human interaction as possible.

III. Using Synergies between space and ground segment

A. Division of competence

The experiences described above lead to a proactive approach by the GSOC ground segment. This approach goes far beyond simple consulting activities. Instead the development of FCPs will be done by the ground segment subsystem engineers with support of the space system engineers. This leads to a division of competence in the following way:

Space Segment engineers:

1. delivers TM/TC documentation
2. delivers the SSUM (at least as a draft)
3. delivers test reports (system and subsystem level)
4. consult/support the ground segment during developing and testing the FCPs
5. review the FCPs
6. will update the documentation with ground segment feedback

Ground Segment engineers:

1. review all delivered documentations, test reports and mission requirements
2. identify nominal and contingency procedures
3. create draft procedures
4. perform workshops or interviews with the space segment
5. test and validate the procedures

B. Iterative approach

The development can be done in an iterative process. After each step there is the chance that new FCPs will be identified or existing procedures will be adapted, changed or summarized. Of course an important prequisite is that space segment documentations are available by the ground segment engineers – at least telecommand and telemetry descriptions. Also the SSUM and design documents are needed. These documents shall cover operational requirements, FDIR descriptions and risk analysis (FMECA).

After each step of the iteration the ground segment engineers should give feedback to the space segment, either in form of questions for clarification or requests for missing information or corrections (observed behavior differs from documented behavior).

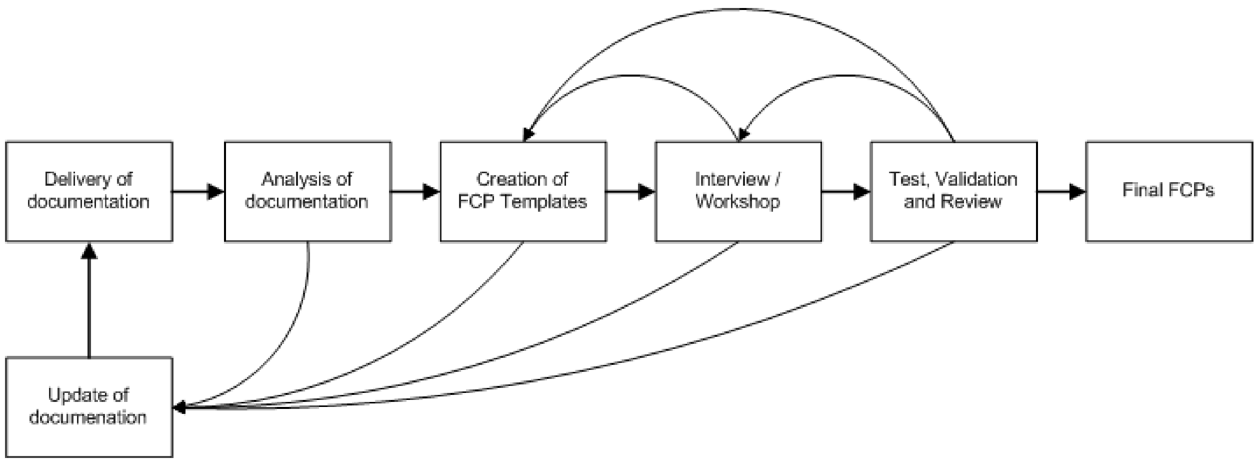

Figure 2: Iteration process

1. Creation of FCP Templates

The ground segment begins with identification of FCPs. The first input for the FCP identification process will be the mission requirements document. There the high-level tasks are described that the satellite will do during the mission, like performing a datatake. The second input is the bus and payload design document, where the subsystem elements are described. Common low-level task like switch on or off a device, etc. can be defined as a FCP. The risk analysis, FMECA or FDIR description can be used for identification of contingency procedures, like telemetry checks and counter measurements like switch to a redundancy. The TM/TC documentation shall not only be used as a reference how the FCPs could be compiled but also it shall be ensured, that all TCs are covered by FCPs and that the expected telemetry reactions which indicate success or failure are included. At a minimum a FCP shall contain one TC and a TM check that ensures that the TC was executed.

This will result in a first list of FCPs. For each FCP the following shall be defined by the ground segment engineer:

- Procedure Identifier (ID)
- Title
- Objectives
- Draft definition of end condition

2. Interview/Workshop with manufacturer

After the first set of draft FCPs is ready the ground segment engineers shall do an interview or a workshop whatever is more applicable with the space segment experts. The outcome of this work must be the extension of the draft FCPs with the following information:

- Pre- or entry conditions:
  It shall be documented if the FCP depends on a specific entry condition or spacecraft state, or if the FCP could be performed in any situation. If an entry condition must be met, the TM checks for this state shall be added to the beginning of the FCP.

- Defined end condition:
  According to the objectives of the FCP an end condition must be defined. This definition could be the one the ground segment engineer did in the step above, but should be discussed with the space segment experts, if this condition is feasible. Also the TM checks to verify the correct execution of the FCP must be defined in this step and shall be added to the end of the FCP.
- FCP body:
  In the FCP body all TCs must be inserted that are necessary to perform the objectives of the procedure. If possible after each TC a TM check shall be added for beeing able to do progress checks during the FCP execution. This will also be important during the validation of the FCP.

During this step often new FCPs are identified because in some cases it makes more sense to divide one FCP in a subset of other more elementary FCPs and only to call these from some high-level FCPs. Or the discussion of the telemetry checks lead to the identification of a new contingency procedure or special checkout procedure for the LEOP and Commissioning phase. The usability may also be the cause of the necessity for new FCPs e.g. that it is decided to rework a generic FCP with editable parameters to many special FCPs with fixed parameters, each for one parameter set. Also the other case can occur that some small FCPs can be summarized in one FCP.

3. Test and validation of FCP

Finally the FCP is ready for testing. The test and validation of the procedure shall be done under conditions as realistic as possible, as the FCP will later be used during the mission. Every unexpected observation should be reported to the space segment experts and should result in an updated documentation or an updated FCP (added comment, correction of parameters etc.). This step is also very important because during the test and validation of the FCPs the ground segment engineers are trained in the satellite operations. They will learn how the spacecraft reacts to telecommands and where special attention is needed.

4. Approval by space segment provider

The last step is a formal approval of the prepared procedures by the space segment provider. This step aims at a detailed review of the set of FCPs and often minor corrections are the result. If these procedures are used during the subsequent simulation activities chances are good to identify if the FCP set is complete or if still some procedures are missing or need corrections.

C. Benefits of this approach

This approach was successfully used in recent small satellite missions performed by GSOC. As mentioned above the delivery of the SSUM happens often very late in Phase C, sometimes after the agreed deadline and no or not enough procedures to cover every nominal or contingency case were delivered. But if the ground segment offered the FCP development as a support to the space segment early enough and followed the described approach no delay was experienced in mission preparation due to this. In addition the FCPs reached a very high level of quality and a wide coverage of nominal and contingency cases due to the combined knowledge of the space segment engineers and operational experiences of the ground segment and the due to iterative process. During each step of this process there is a good chance that a missing procedure will be identified. The quality of the space segment documentation was constantly increased due to the feedback of the ground segment specialists during the development process. As a result a very good system insight of the ground segment experts and a good partnership between space and ground segment could be achieved. Also the training of the ground segment specialist will increase, because the preparation of the flight control procedures requires an intensive study of the documentation and due to the involvement during the whole life-cycle of the FCPs.

IV. Conclusion

It must be pointed out that the described approach shall only be followed if the standard approach is not applicable. If the space segment provider has gained operational experience and knows the benefit of the CCS system. The ideal approach is still recommended, because it will reduce double work. If the space segment will test their system already with procedures the effort to transfer these test procedures in ready to use FCPs is low.

But in reality the ideal approach is often not feasible due to several reasons, e.g. manpower, knowledge etc. In that case it is recommended to follow the described iteration. Finally the ground segment should always be involved in the development process of the FCPs, at least during the identification of nominal and contingency procedures.

This will increase quality and the chance be prepared for all operational situations.

Appendix A
Acronym List

CCS	Central Checkout System
FCP	Flight Control Procedure
FDIR	Failure detection, identification and repair
FMECA	Failure mode, effects and criticality analysis
FOP	Flight Operations Plan
GSOC	German Space Operations Center
LEO	Low Earth Orbit
LEOP	Launch and early orbit phase
MIB	Mission Information Base (TM/TC Database)
SSUM	Space Segment User Manual
TC	Telecommand
TM	Telemetry

References

Standards

[1]*ECSS-E-ST-70-32C, "Test and operations procedure language", 31 Jul. 2008, p. 15*