QUALITY CONTROL FOR MISSION-CRITICAL FLIGHT DYNAMICS OPERATIONS

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ABSTRACT

The success of a spacecraft mission which needs e. g. a complex orbital injection procedure, involving both orbit and attitude related estimation schemes and manoeuvre optimisation is strongly dependent on the quality of the computer software prepared for such a mission phase and on the 'quality' of the flight dynamics staff and the environmental conditions. Quality in the Flight Dynamics area concerns : numerical accuracy, numerical stability, environment modelling accuracy, spacecraft subsystem compatibility, ability to cover non-nominal mission performances, ability to cope with the environmental conditions. For mission critical operations emphasis has to be put on the software system consistency, the availability of tools and the awareness of staff for the solving of unforeseen problems, the compatibility between the mission timeline and the flight dynamics operations.

1. INTRODUCTION

Quality Control is well known in industry for products such as car tires and bulbs, and in agriculture for products such as tomatoes and cotton. Flight Dynamics Operations cannot be seen as a product, but as a service performed by a team of specialists. This service is rendered with the help of software modules which are implemented on a particular computer configuration. Consequently the quality of the operations depends on the quality of the computer software, the 'quality' of the specialists and the quality of the computer hardware.

The first part of this paper is an attempt to state a general definition of quality and an outline of the purpose of quality control. Furthermore the general flight dynamics quality requirements are formulated, and the principles, methods, tools and tasks are presented. The second part of the paper emphasises those quality requirements which are predominant for mission critical operations. The last part contains the application to the specific case of the geostationary METEOSAT- project in its transfer orbit. Differences in the support for the successfully launched spacecraft in 1977 and for the planned second one in June 1981 are outlined in relation to the preparations still continuing.

2. DEFINITION OF QUALITY

Generally one may say :

> Flight Dynamics Operations has 'quality' if the mission objectives are met.

This is certainly true, but this formulation is so general, that it is not very helpful. A more detailed definition might be :

> Operations has 'quality' when the result of the operations conforms to the requirement specifications.

Requirement specifications in this context shall be all requirements of the service to be rendered. Among this set of requirements there are simple software requirements such as

> Necessity of a 'Near Real Time Attitude Determination',

and more general operational requirements such as

> Provision of a first orbit estimation within two hours after injection into transfer orbit.

Now the question arises : Are requirement specifications always available, and if so, do they represent all actual or real requirements? From experience we know that the number of actual requirements for even less complex systems is very large. Therefore, it is quite difficult to verify <u>all</u> requirements under the usually given constraints of schedule and manpower.

The proposed way out of this dilemma is to define quality requirements that are <u>most important</u> for the particular environment and case assuming that a certain level of quality already exists. 'Most important' in this context is defined by the responsible staff based on their experience and knowledge of the system. The level of quality can be pre-supposed, because experienced and qualified staff develop the software and operate the computer programs. Nevertheless, samples are taken at random on low level in order to demonstrate that the trust in the quality is justified.

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3. PURPOSE OF QUALITY CONTROL

One major reason for Quality Control in Flight Dynamics is that a satellite launch is a unique event, and if anything fails during early orbit phase (e.g. Apogee Motor Firing in wrong direction) the whole mission may be lost or the lifetime of the mission may be drastically shortened.

A general formulation may be :

> The purpose of Quality Control is to increase the confidence in the quality.

This statement though is not very helpful. A more detailed one is proposed :

> The purpose of Quality Control is to demonstrate that everything works according to the actual requirement specifications.

Here again we have the old dilemma, namely that the number of these requirement specifications is often very high. Therefore we propose the following formulation :

> The purpose of Quality Control is to ensure the highest confidence in the quality as required under the given constraints of schedule and manpower.

4. GENERAL FLIGHT DYNAMICS QUALITY REQUIREMENTS

Typical tasks of flight dynamics support are
- orbit determination including preprocessing of tracking data
- attitude determination including preprocessing of telemetry data
- optimisation of manoeuvres and manoeuvre sequences
- manoeuvre implementation (command generation) of orbit and attitude manoeuvres
- calibration of spacecraft and ground segment parameters

These tasks are performed with the help of suitably programmed mathematical methods. The specific nature of the operations necessitates the following quality requirements:

Accuracy

This plays an important role especially in the estimation area (orbit and attitude determination). Accuracy is not necessarily an intrinsic property of a program but dependent on the amount and quality of inut input data. For example, accuracy of an attitude determination for a spinning satellite equipped with infrared pencil beam earth sensors and sun-slit sensors depends on the following factors :

> Amount and Quality of the sensor measurements within the telemetry;
> Accuracy of sensor misalignment;
> Accuracy of available orbit information;
> Configuration of earth, spacecraft, and sun;
> Magnitude of nutation angle

Also important is the accuracy for the dynamics and environment modelling factor which influences the final performance.

Numerical stability

The developed software has to cope with noisy and erroneous telemetry and tracking data. The result of an estimation process must not be biased by a low percentage of bad data within the amount of good data. Stability can in addition be achieved by appropriate selection of data and data intervals.

Completeness

During the design and development phase the programmers tend to concentrate on the mission specific new items. It must, however, be ascertained that the complete support (new mission specific and already existing items) is readily available. This should include both nominal and pre-selected non-nominal mission performances. For example, a low perigee of the initial orbit is an emergency case that makes a perigee raising manoeuvre necessary.

Spacecraft subsystem compatibility

The software is developed on the basis of available spacecraft specifications. Such a specification is, for instance, a description of the telemetry format of a spacecraft with information on where specific sensor measurements can be found and which scaling factors have been used. However, it is essential that the developed and thoroughly tested software suits the relevant spacecraft subsystem rather than the documents - which could be incorrect!

5. PRINCIPLES AND METHODS, TOOLS AND TASKS

Quality Control of flight dynamics operations has developed from the fundamental ideas of ten years ago to an important management tool. It demonstrates that the required support can be given to a specific spacecraft mission. The experience gained can be divided up into different categories, viz. basic principles, useful methods, developed tools and tasks to perform.

5.1 Principles

The success of Quality Control is strongly dependent on the adherence to the following principles :

Independency or separation

This is generally accepted as one of the major principles of reference (for instance during an international seminar on 'Simulation and Space', Toulouse 1973, ref 1) and means that the specialists who perform quality control should be kept apart from the development team. They should interpret the documents and develop the test tools independently of the developing team. All important input parameters for quality control programs should be stored separately from operational parameters. The test tools should not run at the same time as the operational programs to ensure that they do not disturb the operational activities. This is in agreement with the so called open loop simulation. An open loop simulation is given if the loop : simulation of telemetry and tracking data → orbit and attitude determination → command generation for a manoeuvre → simulation of the prepared manoeuvre → simulation of telemetry and tracking data which takes the manoeuvre into account, is not performed in real time but with a time break after the generation of commands for the manoeuvre, so that the highly sophisticated time and core intensive simulation programs can be run.

High accuracy and high level of reality

With the open loop simulation it is possible to put an emphasis on high accuracy and simulate as realistic as possible at the expense of core usage and computer time consumption. Needless to say, double precision should be standard for test tools. As an example, let us choose the verification of the command generation for an attitude manoeuvre for a spinning satellite. The operational command generator uses a simplified model of the satellite dynamics in order to save computer time in the iterative calculation of the commands. The manoeuvre simulation program simulates the course of the manoeuvre by means of numerical integration using the Euler equations that describe the dynamics of the satellite during a manoeuvre. The program takes into account the sequence of clearly defined thruster pulses that are calculated by the command generator.

Independent testing on various levels

To save time and money all functions of a software system should be tested at the lowest possible level. Only thoroughly tested modules should be integrated to subsystems. Only verified subsystems should participate in system integration.

Final Validation in the real environment

To make sure that the operations can successfully support a certain mission, some demonstrations have to be performed in an environment as close to reality as possible. The software, including the input files and initialised files, must be frozen. The hardware, of course, must be the final one, and the specialists operating the computer programs and taking important decisions must be those who are to support the real operations. The demonstrations must cover not only the nominal sequence of events but also emergency or contingency cases. Alterations of software such as correction of errors, extension or even conversion to other computers require repetition of the validation process.

5.2 Methods

The methods used to test a certain software piece depend on its function. In the following some successful methods are presented.

Usage of test drivers

To guarantee a speedy development of the operational software, development of software modules is started simultaneously. In principle, it is preferable to use a clearly defined modular configuration for the operational software. To test these well defined software modules before integrating them to subsystems, testdrivers are used. This is the only possibility to feed a high variety of input parameter sets into the untouched operational software pieces. For example, if one byte of 8 bits is foreseen as the only input to a particular subroutine, a testdriver can within a simple loop easily provide <u>all</u> possible input from 0 to 255.

Simulation

This method is used for various purposes. One application is the verification of commands generated for an attitude or orbit manoeuvre. Here the real dynamics are simulated with the help of numerical integration of the specific differential equations. A second application is the simulation of raw telemetry and tracking data to drive the whole system in a mode close to real operations. A third purpose is to drive a certain module with the help of realistic simulated data such as angles and range measurements. Data without errors can prove the correctness of the programmed formulas. Data with realistic errors give an estimate of the resulting accuracy. Raw data with big errors (corrupted data) can prove the stability of a certain software module.

Comparison

This method mainly closes the 'loop' of verification. A simulated orbit can be compared with a determined one by comparing the state vectors and/or the osculating elements at certain steps in time. In this case tracking data are simulated on the basis of a simulated orbit. The result of a simulated attitude manoeuvre can be compared with the target attitude for the command generation for this manoeuvre. A measure of differences in attitude is the angle between the corresponding spin axis direction vectors.

Simplified duplication

If the main function for a program is for instance to produce an aesthetic printout, simplified duplication is a good method of verification. An example of this is a coverage prediction program for a set of stations relative to a given orbit. Here the simplification can both be in the printout and by taking only one station for a run instead of several stations in parallel.

Another example is the selection of stars which lie within a certain cone around a given direction. If the star catalogue is organised in a sophisticated manner a drastic simplification would be for the duplication module to read all star coordinates in sequence from the mother tape of the star catalogue. To verify a particular selection made by the operational module, it is not enough to verify that all selected stars meet the selection criteria, but to prove in addition that all other stars lie outside the cone.

Walk-throughs

Sometimes it is hard to test out all branchings of a specific module. For instance, it may be difficult or impossible to provocate certain hardware errors. In this case one can verify by means of walk-throughs that the required action is taken. Walk-throughs should be carried out together with the developer.

Review and analysis of documents

In order to find weak points in the general concept as early as possible, quality control should start with review and analysis of the documented design. Otherwise it may happen that only at system integration and acceptance testing conceptional errors are detected. All other documents concerning the developed software should be reviewed as well. This is in particular true of user's guides for display programs. It should be possible to run such a display program successfully using only the information written in the user's guide.

5.3 Tools

Different types of software tools have been developed for testing software in different integration levels, for training specialists, for final acceptance demonstrations, for availability tests in preparation for launches and for accuracy studies.

Simulators

Two basic simulators are available :

<u>The orbit generator</u> for earth satellites which takes the following perturbations into account: air drag, solar radiation pressure, gravity of sun and moon and zonal and tesseral harmonics of the gravity of the earth. Also several impulsive ΔV-manoeuvres can be implemented.

The attitude simulator for spinning satellites, is able to cover free drift periods with and without nutation and attitude manoeuvres using various types of thrusters in pulsed and continuous mode. These basic simulators can be used singly. However, they are also integrated within the two data simulators for tracking data and telemetry data. The tracking data simulator can be used to produce different types of tracking formats : GRARR, interferometer, ranging data from Villafranca and Fucino, METEOSAT-SO ranging format, VHF tone ranging and SRE format. There are two levels of simulation possible:

a) simulation of smoothed tracking data containing the actual measurements such as range, range rate, angles and angular velocities to drive an orbit determination module;
b) simulation of raw tracking data containing realistic measurements within the specific format to drive the tracking data preprocessing program.

Bias and random errors can be simulated for both levels, transmission errors only for raw data.

The telemetry data simulator for spinning satellites has been used for the quality control of the projects GEOS, OTS and METEOSAT. Infrared pencil beam earth sensor measurements and sun slit sensor measurements are simulated. Again two levels of simulation can be selected :

a) smoothed telemetry containing angle measurements in physical dimensions as input for the attitude determination modules, and
b) raw data in the specific project dependent format containing realistic sensor measurements to drive the telemetry preprocessing modules.

Bias and random errors can be simulated for both levels, transmission errors only for raw telemetry data. The simulated telemetry is written onto a magnetic tape and can be fed in Near Real Time through the real data link to drive the Near Real Time Telemetry Preprocessing module.

Comparison programs

These are small tools to perform automatic comparison between simulation results and the results of an actual determination. An orbit comparison program which calculates the differences between simulated and determined orbit information at certain steps is a prerequisite. The same goes for an attitude comparison program which compares simulated and determined attitude information at predefined time steps for 'say' during an attitude slew manoeuvre.

List programs for operational files

'User-friendly' list programs for operational files have been found to be very useful. Therefore, for all operational files such programs should exist.

High level interface check programs

Experience has shown that a lot of problems during testing are caused by wrong information being passed through high level interface routines. Check programs to test such high level interface routines have been provided.

Stubs

For single and subsystem tests stubs are helpful to replace operational high level interface routines. It is essential that the operational subroutine and the stub replacing it have identical calling sequences. A stub is a simplified or reduced version of the actual high level routine - in drastic cases it could consist of the subroutine name and argument list and a RETURN and END statement.

5.4 Tasks

Various tasks are expected to be performed by the Quality Control Team.

Provision of a test plan

A detailed plan should be written for the different verification activities. All foreseen single tests on module level, subsystem tests for integrated subsystems and system tests for the entire integrated system have to be specified. In particular, the detailed procedure to perform a well defined test of the test plan has to be evident. Planned walk throughs should be described and the documents which are candidates for review and analysis should be named. One chapter within the test plan should contain a description of the foreseen test tools. The test plan should be reviewed by the specialists developing and operating the operational software. Testing activities should start only after agreement on the test plan.

Development of test tools

All the tools that are necessary to perform the tests described in the test plan have to be developed and tested, if they do not already exist. Naturally, the principles described above must be adhered to.

Testing

The tests should be performed following procedures which are described in detail within the test plan. The testing is finished when all tests in the testplan have been successfully performed. If during testphase operational programs have to be updated, not only the failed test cases have to be repeated, but also those tests which may be influenced by the specific changes of code.

To ensure that the quality of the operational software achieved at the end of testing is maintained until launch, a so called freezing of all operational software including initialized files is performed.

A well defined subset of tests should be repeated with the frozen software in order to demonstrate that the main functions of the operational programs are readily available.

Provision of a test report

The test report should demonstrate that the flight dynamics operations can support the specific mission successfully. Detected and resolved problems should be described in order to avoid or at least reduce the appearance of similar errors in the future. For each test, the test specific input parameters together with the obtained results should be documented. Reference should be provided to the corresponding computer program printouts.

6. QUALITY REQUIREMENTS FOR MISSION CRITICAL OPERATIONS

A variety of requirements are set up by the project group in order to guarantee a successful mission (e.g. apogee motor firing of a geostationary satellite nominally at a well defined apogee). From these mission requirements and other conditions and constraints such as station coverage, operations requirements are derived. These are entered into the sequence of events of the Flight Operations Plan.

To guarantee the quality of Flight Dynamics Operations during a critical phase, a particular concept is established. This concerns mainly :

- Staff redundancy (every operational activity can be done by more than one specialist);
- Reduction of manual intervention - system integration (to avoid human mistakes as much as possible);
- Parallel execution of computer programs - efficient usage of computer resources (in order to meet the time line);
- Centralised storage of the common mission and spacecraft parameters.

It is the task of Quality Control to verify this concept during system testng . For this, the following additional quality requirements for mission critical operations are important :

Compatibility with flight operations plan
It is essential to ensure that the required service is provided according to schedule. This means that there must also be sufficient time to interpret and assess the computational results. This test can only be conducted in an environment as close to reality as possible.

Availability of tools for emergency cases
For certain spacecraft and ground segment failures tools have to be available to cope with non-nominal conditions. For instance a back-up attitude determination method must be available in the case sun slit sensor measurements are missing.

Availability of a plan for non-nominal performances
A plan containing the necessary actions in the case of non-nominal events must be provided. This plan should also contain organisation procedures to be performed before the launch to allow a quick reaction. For instance, if there are no tracking data available at ESOC, NASA could provide orbit information during the first hours of the transer orbit.

Availability of trained staff
During system tests the specialists must be made cognisant of the total support to be provided and of the tools available. This should include as well the handling of unexpected and non-nominal events. For example it could be assumed that an attitude slew manoeuvre moves the spin axis into the wrong direction. The specialists operating the attitude determination would have to recognize this early and a decision would have to be taken whether the manoeuvre should be interrupted.

'Redundancy' of staff
Enough well trained specialists must be available for all operations during the entire critical phase. The schedule for the specialists during such a phase has to cover not only the nominal duration but also an extended one in case of emergency.

Availability of documents
Essential documents must be available in the flight dynamics control room. Examples are : flight operations plan, user manuals, program listings and file descriptions, and a manning schedule.

7. QUALITY CONTROL FOR FLIGHT DYNAMICS OPERATIONS OF METEOSAT TRANSFER ORBITS

The transfer orbit of a geostationary satellite is a typical mission phase that is called critical. The resources of the electric energy provided by onboard batteries are limited, e.g. , or the apogee motor firing has to take place within a time limit after launch. In case of METEOSAT there is in addition an unstable rotation which makes active nutation damping necessary before apogee boost motor firing and ejection. It is therefore desireable to perform the apogee motor firing as early as possible. Because of these characteristics we have chosen the METEOSAT transfer orbit as an example of quality control for mission critical operations.

7.1 Sequence of events and operational activities during transfer orbit of METEOSAT 1

Meteosat 1 was launched successfully in November 1977 by a Thor Delta launcher. Key events during transfer orbit are attitude slew manoeuvres and apogee motor firing at first apogee. To support these events, a well defined sequence of activities is required. This sequence of events and operational activities is shown in figure 1.

The attitude slew manoeuvres (the large one with the size of apparently 160°) are foreseen to bring the thrust direction of the solid fuel apogee motor into the desired optimal direction for firing. The optimal direction is dependent on the actual transfer orbit reached. Optimal in this context means that the fuel necessary to bring the spacecraft into the desired geostationary orbit is a minimum under given constraints. During the entire phase monitoring of the performance of the on board active nutation damping (AND) is required. With the firing of the apogee motor the end of the transfer orbit is reached.

7.2 Required operations and tools used

In accordance with the Flight Operations Plan, well defined services have to be given at fixed terms and for determined time periods. These services are provided with the help of computer programs running on the MSSS computer configuration. In addition to these tasks the flight dynamics specialists under the guidance of their coordinator have to react on emergency cases and/or changes in planning. The tools to perform all these operations are software and documents.

7.2.1 Software subsystems. The Flight Dynamics Software is built up by different subsystems and implemented in the Multi Satellite Support System (MSSS) computer set-up.

Orbit determination
This package comprises tracking data preprocessing orbit determination, orbit prediction including station coverage prediction and antenna pointing prediction and various small programs for file initialisation, file updating and file listing.

Attitude determination
While all programs of the orbit determination package are batch programs, for the attitude determination area also near real time programs play an important role. A program is called near real time program if it provides results synchronously with the periodically incoming driving data, however with a certain constant time delay.

EVENTS AND ACTIVITIES DURING TRANSFER ORBIT OF METEOSAT 1

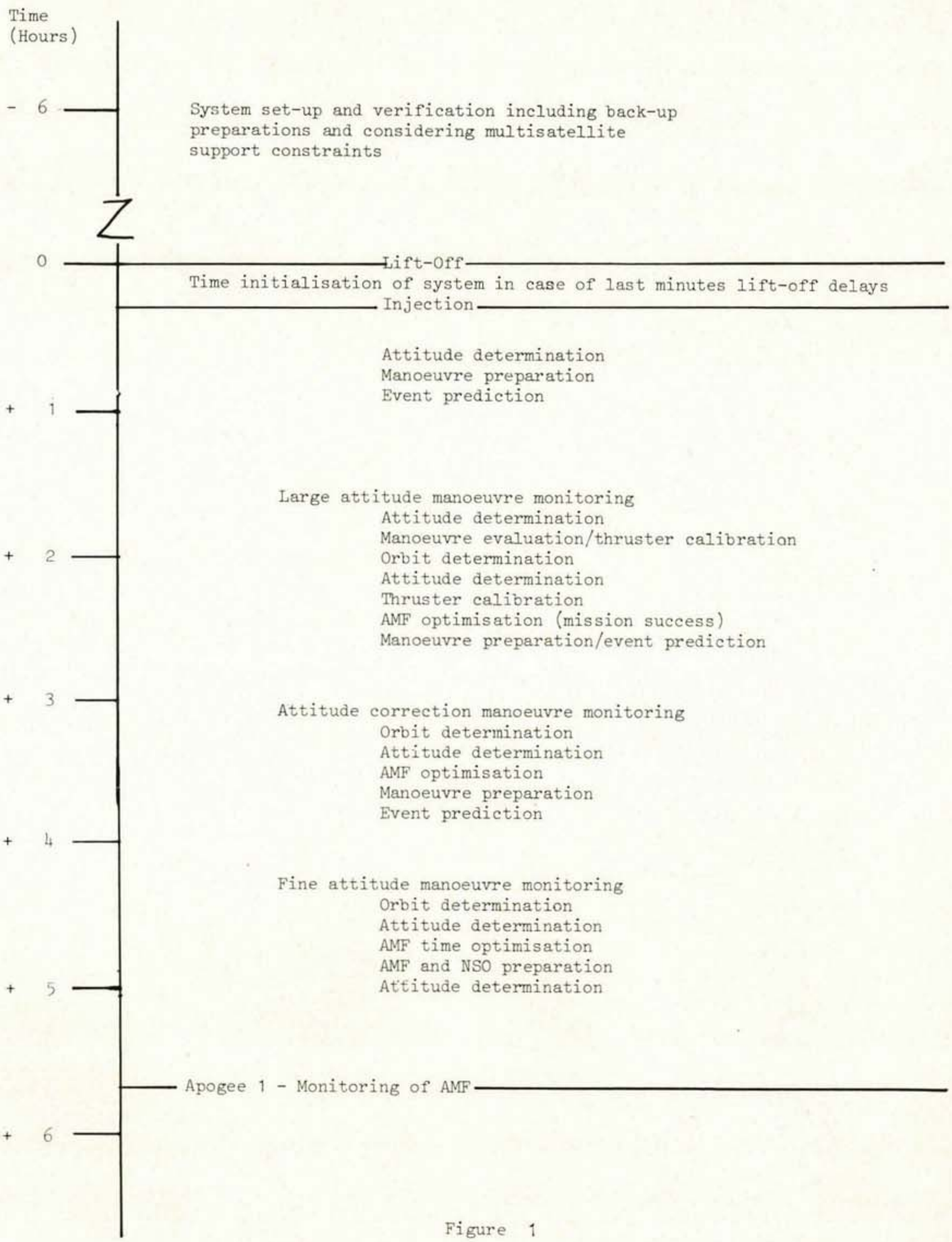

Figure 1

Several spin axis attitude determination programs including telemetry preprocessing in near real time and batch mode belong to this subsystem as well as an infrared pencil beam earth sensor coverage prediction program and other small programs for initialisation updating and listing of files.

Orbit/attitude manoeuvre support
This package contains apogee motor firing optimisation, command generation, calibration of thruster parameters, a program for the formatting of telecommands and other programs for initialisation updating and listing of files. For emergency cases programs for preparing perigee raising and apogee raising manoeuvres are included.

Task, data and display handling
This subsystem comprises more general facilities supporting the application programs mentioned before:
Foreground User Task for the supervision of all software activities in the task, data and display handling area (e.g. automatic sequences of jobs, suppression of jobs in conflict, near real time mechanism for roll-in/roll-out).
Interactive Display Program for the operation of the software on job level including facilities for : start, stop, monitoring, data check points and archiving and near real time data processing.

7.2.2 Documents. To avoid delays during operations a set of documents has to be available for the specialists in the flight dynamics control room.
Flight Operations Plan. This document comprises all spacecraft and stationspecific events and in particular the time line for the required flight dynamics support including contingency recovery procedures.
Launch support document. All flight dynamics activities starting two days before lift off and covering the critical phases are contained in this document.
Software documentation. Listings of the source code and the corresponding job control language of all operational METEOSAT programs together with all relevant manuals must be available.

7.3 Quality control for METEOSAT 1 operations

METEOSAT 1 was the third satellite which was supported by the MSSS-Flight Dynamics Software System. Therefore there was a certain level of confidence available in the general mission-independent software elements. As a consequence, concentration had to be put mainly on METEOSAT-specific software, operations, and parameters. Because software was a launch holding item for METEOSAT 1, special procedures were set up to guarantee the availability of the tested and frozen software and the data (parameters and initialised files).

7.3.1 Single and subsystem tests. Before taking part in system tests, the METEOSAT specific software modules were tested extensively, both separately and in subsystem environment.

Test of telemetry preprocessing
Meaningful data of METEOSAT telemetry were simulated with the telemetry simulator for spinning satellites using realistic METEOSAT spacecraft parameters. In additon , spacecraft subsystem compatibility tests and data flow tests were performed successfully with the hardware prototype which was installed at the Odenwald station.

Test of accelerometer data preprocessing and nutation monitoring.
Telemetry containing meaningful accelerometer measurements has been provided by the telemetry simulator. In addition, data flow tests for accelerometer data from NASA were successfully performed.

7.3.2 System tests. Subsequently a series of system test sessions took place. These system tests had the following objectives :

Verification of the integrated software system
Only in the fully integrated software system could the correct data flow and transmission of information between programs and subsystems through high level interface routines and disc files be proved. The realistic sequencing of operations showed that the concept was able to give the required mission support. Furthermore it was demonstrated that, with realistic starting conditions in orbit and attitude, METEOSAT could be brought into an acceptable near synchronous orbit. This demonstration was carried out using realistic telemetry and tracking data provided by the simulation programs on the one hand, and using the operational software to perform the flight dynamics operation on the other.

Demonstration of compatibility with the flight operations plan
Tests for the transfer orbit have been conducted following the schedule for Flight Operations Plan in real time. This demonstrated finally that all activities necessary for the injection into the Near Synchronous Orbit could be performed. AND monitoring had to be performed simultaneously with all other activities.

Training of staff
During test sessions, care was taken that all specialists of the launch team learnt to operate the software for a nominal performance and for certain non-nominal cases, such as :
hardware errors, which make a switch over to the other redundant computer necessary;
program errors requiring recompilation of a subroutine followed by relinking of the relevant modules;
loss of infra-red pencil beam earth sensor coverage during attitude manoeuvre;
failures of sensors and thrusters

Demonstration of launch readiness
Readiness test.
The readiness of the flight dynamics software before launch was demonstrated by the successful performance of availability tests. The purpose of these tests were
- to check the availability of the software and the related items such as data files
- to operate all software modules in their main modes to gain last confidence in the correct choices of load modules

Additionally several simulations (essential for staff training) have been attended utilizing a real time spacecraft simulator residing on a remote computer.

7.4 Preparation for the METEOSAT 2 transfer orbit

After having supported METEOSAT 1 successfully one may assume a high confidence in the facilities available. Nevertheless, it still has to be ensured that all required operations can be performed and that the necessary software tools are available.

7.4.1 Differences between METEOSAT 1 and METEOSAT 2
METEOSAT 2 differs from METEOSAT 1 in the following items :

Sequence of events

Because of low spinrate of about 10 revolutions per minute after separation from ARIANE's third stage, a spin-up manoeuvre to reach 100 revolutions per minute will have to be performed. On the other hand, an advantage of the ARIANE launch is the faet that the third stage brings METEOSAT 2 close to apogee motor firing attitude. Consequently, instead of the large attitude slew manoeuvre of almost 180 degrees, which was needed for METEOSAT 1, only a relatively small manoeuvre in the order of ten degrees is expected. The apogee motor firing is foreseen to take place in the second apogee instead of in the first apogee as for METEOSAT 1.

Support requirements

New tasks are the command generation and monitoring of the spin up manoeuvre. Because on board nutation damping is assumed to be more reliable and a new simplified procedure of flat spin recovery has been established ground support is reduced to pure monitoring.

Software

Some modifications for the software in order to simplify the data handling have been made.

Parameters

Some spacecraft parameters are different from those for METEOSAT 1. It has tobe verified that the set of parameters for METEOSAT 2 is complete and that the complete set is consistent with the spacecraft.

Staff

Although specialists of the METEOSAT 1 launch team are still available new staff have to be integrated into the team in some positions. Training of the new staff is one of the most important objectives of the launch preparations.

Environment

Since launch of METEOSAT 1 a separate flight dynamics control room has been established. Although the general working conditions have improved, the longer distance to the printer is a disadvantage.

7.4.2 Single and subsystem tests. Because the software changes have been carefully tested by the programmers, single and subsystem tests are not planned, but whenever problems during a system test arise, they have to be resolved by lower level tests before the relevant system test can be repeated or continued. Also the training of staff is partly done in subsystem environment.

7.4.3 System tests. In order to keep the flight dynamics software of METEOSAT alive, METEOSAT system tests have been performed occasionally since the launch of METEOSAT 1. Generally, for the METEOSAT 2 system tests the same objectives have to be fulfilled as for METEOSAT 1. During the verification of the integrated software system emphasis has to be laid on the correctness of the changed parameters and software pieces. Compatibility with the flight operations plan is not such a predominant feature anymore because there is one orbit more time to prepare the apogee motor firing.

8. SUMMARY

Quality Control of Flight Dynamics Operation has developed to an important management tool for controlling the progress and quality of development. Furthermore, it enables statement of readiness for the support of critical mission phases.

9. REFERENCES

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