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Space systems — Unmanned mission operations concepts — Guidelines for defining and assessing concept products

Systèmes spatiaux — Concept d'opérations de mission non habitée — Lignes directrices pour la définition et l'évaluation des produits du concept

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Foreword

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Introduction

This International Standard defines the steps required to develop a comprehensive space system mission operations concept for the development and operations after the boost phase of a space mission is completed. Effective concept development relies on a development process that runs concurrently with the mission and flight element development efforts, balancing performance, cost, and risk issues. This International Standard is also applicable to the mission operations support to the pre-launch and launch phases of the mission using the mission operations systems.

Standard products enable industry to develop commercial off-the-shelf tools for developing a space systems mission operations concept. This International Standard is specifically tailored for unmanned space missions and may be of partial use for human flight mission operations concepts. Users of this International Standard include project managers, operations personnel, flight element engineers, and operations facility personnel who are responsible for developing and integrating the mission operations system. This International Standard lists items to be considered and defines the contents of a mission operations concept for space systems. This International Standard is applicable for the flow of data from the integration site and/or the launch pad to the operations centre and users, but does not include the items needed for a launch operations concept.

A space systems mission operations concept is prepared in parallel with the mission concept and flight element design and contains increasing levels of detail as the mission matures. During the early study phases, the operations concept is a high-level overview and contains many assumptions. As the mission operations concept evolves and advances to the approval stage, the content becomes more detailed with fewer documented assumptions. The space systems mission operations concept does not detail a mission's development or operational costs, but is the basis of cost estimation. Developing a space system mission operations concept early in the study phase helps to minimize life-cycle costs, make acceptable risk trades, and to determine the effectiveness of using existing system capabilities. The mission operations documentation and development costs are also reduced as all the documents are referenced to a specific operations concept rather than a set of high-level project documents. The earlier the space systems mission operations concept is developed, the more leverage there is for influencing the operability of the entire mission system, including the flight element. This International Standard establishes early in the project's development cycle a conceptual view of the mission data system which allows for

a) early understanding of data and command transfer between sensors and end users,

b) testing operational capabilities, and

c) training personnel as the mission operation system matures.

The development of the space system mission operations concept is most beneficial when done in parallel with the flight element design, thus creating a tight coupling between the two efforts performing trade studies in the areas of cost, performance and risks.

Space systems — Unmanned mission operations concepts — Guidelines for defining and assessing concept products

1 Scope

This International Standard gives guidelines for areas to be addressed and defines the products that are to be generated to develop a space systems mission operations concept. This International Standard enables the generation of standard space systems mission operations concept products produced either by an industry, a government agency, or by a university.

2 Terms and definitions

For the purposes of this document, the following terms and definitions apply.

2.1
mission data system
hardware and software located both on the space platform and in the ground support systems that provide the transport mechanisms for mission data together with the information system that properly configures and controls this hardware and software

2.2
mission operations concept
description, in operator and user terms, of the operational attributes of a mission's flight and ground elements

2.3
mission operations system
MOS
system consisting of mission data system and the operations organization

2.4
operations organization
people and procedures that control the flight element, including payload, and process the mission data and information

2.5
product
process, document, software tool, workstation, facility, procedure, or training aid that the operations organization develops to support their operation of the space system

2.6
trade study
report on a systematic examination of multiple factors that influence the economic and technical success of a project

3 Requirements for the operations concept

3.1 General

The space systems mission operations concept is a result of a co-operative effort of the various project systems:

— flight element,

— ground support equipment system,

— mission operations system,

— launch vehicle, etc.

Its development is closely coupled and is implemented in parallel with the development of the other project systems to produce a consistent and integrated mission operations concept. The space system's mission operations concept specifies design details and emphasises the way a mission is operated. It describes the operational characteristics of the space elements being controlled. The space system's mission operations concept consists of mission documentation, constraints, and characteristics. It also contains the specific required mission operations products, including operational scenarios, time lines, processes performed by personnel, hardware and software processes, derived requirements, contingency scenarios, and conflict resolution processes. It also may contain a technology plan. End-user data products are specified and, depending on the mission, may be in various forms such as analogue, digital, and physical (e.g. sample return) data products. Another end user data product received from the mission operations system should be a lessons-learned report to help future missions.

A list of elements to be considered, defined, and generated when developing a space system mission operations concept is given in 3.2. Each item of the list is described further in 3.3. This guidance specifies the broadest scope of possible mission operations, tasks, issues, and products to facilitate mission managers and engineers in assessing the full scope of their mission operations concept.

3.2 Mission operations concept guidance

3.2.1 Inputs

Define or make assumptions for the following inputs to the concept:

a) mission scope, objectives, and requirements on operations;

b) mission description and science characteristics;

c) mission environments;

d) end-user data products;

e) mission philosophies, strategies, and tactics;

f) programmatic and operational constraints;

g) data relay capabilities (space-to-space, space-to-ground);

h) ground system capabilities and characteristics;

i) customer and users identified;

j) relationships with other missions and/or programs;

k) external dependencies with other agencies or companies.

3.2.2 Mission element characteristics

Describe the following mission element characteristics:

a) space systems capabilities and characteristics;

b) payload capabilities and characteristics.

3.2.3 Mission operations processes

Identify and characterize the following mission operations processes:

a) establishment of a list of top-level operations processes that shall be performed;

b) descriptions of uplink processes:

   1) user request planning;

   2) space system resources to be managed by the ground system;

   3) space system constraints to be enforced by the ground system;

   4) space system maintenance activities to be managed by mission operation system;

   5) procedure for processing user requests;

   6) process for scheduling data acquisition services;

   7) integration of activity requests;

   8) method for validating commands (if necessary) prior to uplink;

   9) method for converting integrated requests to executable commands;

   10) method for transmitting command files to the space system and/or payload;

   11) verification process for command execution or command storage;

   12) method for receipt of command files by the spacecraft and/or payload and for storage or execution of commands;

   13) on-board execution and processing of commands or rules;

   14) method for archiving command files;

   15) flight software maintenance process;

c) descriptions of downlink processes:

   1) payload-to-user processes and interfaces;

   2) transmission of data from:

      i) payload instruments and flight element subsystems to onboard storage;

      ii) onboard storage area to the space system transmitter;

      iii) space system transmitter to the storage in the ground database (Level 0 processing);

3) processing steps required from the receipt of the space system and payload data in the project database to delivery to the end user;

4) method of data encapsulation and delivery to the user;

5) method of analysing data with regard to that analysis required to conduct the mission;

6) method to archive data;

7) effect of processed data on the mission plan or planned sequencing;

8) processes and concepts involved in anomaly detection (space and ground) and responses;

9) ground software maintenance process;

d) anomaly detection and response process;

e) end-to-end information capabilities and characteristics with data flow diagrams.

3.2.4 Process enablers

Identify ways to accomplish the process:

a) specify existing capabilities and services to be utilized and identify who provides these;

b) specify new technology development needed and plans for its verification;

c) summarize the facilities, ground support equipment, and tools needed to make the mission operations successful.

3.2.5 Perform trade studies

Perform trade studies where operating methods and operations issues have impact on cost, quality, reliability, or mission risk for the processes that may be accomplished in more than one way.

3.2.6 Mission operations organization and responsibility allocations

Describe the mission operations system organizational structure and allocate responsibilities to its individuals and teams:

a) specify operations organization;

b) define the roles and responsibilities of the operations teams and personnel;

c) describe training responsibilities and approach.

3.2.7 Operational scenarios

Develop the following operational scenarios for the processes:

a) total mission scenario based on the trajectory and the mission goals;

b) specify scenarios which reflect activity periods and mission phases and are defined in terms of trajectories, tracking approaches, data flow, timelines, and mission goals, that may include:

1) space system electrical integration and checkout;

2) mission data system checkout;

3) pre-launch testing and checkout;

4) launch;

5) space system bus checkout;

6) payload checkout;

7) key payload periods;

8) manoeuvres;

9) space vehicle-to-space vehicle relay;

10) orbiter insertion;

11) entry, descent, and landing;

12) *in situ* exploration (rovers, samplers, balloons, etc.);

13) sample return to Earth;

14) extended mission possibilities and considerations;

15) end of mission;

16) contingency scenarios;

c) allocation of steps of the scenarios to hardware and software or to people;

d) derived requirements from the operational scenarios.

3.2.8 Products

Based on the developed operational scenarios, generate the following products:

a) input assumptions;

b) end-user data product definition;

c) flight element characteristics including key operability features;

d) process descriptions:

1) process named and described;

2) interfaces and process output products specified;

3) hardware and software functional allocations for the processes;

4) tools and facilities utilized;

e) ground element characteristics including key operability features;

f) data flow diagrams;

g) new technology development and verification plan;

h) mission operations organization and team responsibilities;

i) scenario descriptions and time lines;

j) requirements and derived requirements on mission operations.

3.3 Guideline descriptions

3.3.1 General

The elements in this International Standard provide guidelines for areas to be included in the development of a space system mission operations concept. The following subclauses contain more detailed descriptions of the items in the guideline, the information to include, and requirements to be considered.

3.3.2 Guideline inputs

A space system mission operations concept should include in some depth a description of each of the items contained in these guidelines. These items shall either be defined prior to the generation of the space systems mission operations concept or as assumptions by those generating the space systems mission operations concept.

3.3.3 Flight element characteristics

To determine what operations processes shall be performed, the end user needs to understand the flight element's characteristics and the products required from the mission. The flight element's capabilities determine the detailed operations processes that shall be carried out. A completely autonomous space system requires few operators, whereas one that cannot compute or store onboard data requires continuous ground control or ground automation. The payload and spacecraft capabilities and characteristics and the end-user data products should be described. It is critical to balance the capabilities and requirements of the flight element and of the user with the existing and to-be-developed operational processes, ground support equipment, and operations personnel to obtain the optimum mission design relative to cost, risk and performance.

3.3.4 Mission operations processes

3.3.4.1 Processes

Operations processes may be defined based on an understanding of guideline inputs, end user product requirements and flight element characteristics. The operations processes should give strong consideration to existing standard operational services and capabilities to reduce costs and risks. The top-level list of operations processes shall be identified and described based on ground or flight vehicle characteristics that affect operations costs, operations development costs, or risks. Along with the processes, a clear understanding of the end-to-end information system capabilities and characteristics should be developed.

3.3.4.2 List of top-level processes

An operations concept should identify a number of top-level processes for managing and implementing space mission operations. Three critical, top-level processes are the uplink process, the downlink process, and the process for detection and response to anomalies during operations. These critical processes are described in 3.3.4.3 to 3.3.4.6, but other processes do exist such as configuration management, problem reporting, and long-range planning processes.

3.3.4.3 Uplink process

The uplink process shall be defined in terms of the activities necessary to convert a scientific or engineering thought into a command sequence that has been transmitted and verified for correct receipt. The suggested uplink process activities to consider are listed in 3.2.3 where the design parameters of command capacity, command rates, and the ground-to-space links are characterized. It is important to remember that the uplink process may be used for transmitting information (telemetry including video) from the ground to a spacecraft. Finally, the uplink process includes event- and rule-driven on-board processing, which results in command activities that are generated and executed on-board.

3.3.4.4 Downlink process

The downlink process shall be defined in terms of the activities necessary to process the data from the output of the payload or engineering sensor to the receipt of the processed data by the scientist or engineer. The processing may take place onboard or on the ground. Downlink rates, data storage requirements, and the characteristics of the space-to-ground links are included in this process. The processing includes conversion and calibration as well as data distribution and archival. Key steps in the mission scenario or command sequences, where the planned flight activities may change based on data received from the flight or ground elements, shall be identified with the uplink process.

The downlink process is not limited to sending telemetry. The downlink process may direct commands to be transmitted from something other than from an Earth-based operations facility, such as from a space system to the ground or from an *in situ* element (lander, rover, penetrator, etc.) to an orbiter or intermediate space relay vehicle. Thus, the processing steps on the ground may well be responding to a command sent by the spacecraft.

3.3.4.5 Anomaly detection and response process

The anomaly detection and response process defines a methodology for identifying and accommodating unplanned events and conditions that come along during the life of the mission. These unplanned events may affect services and capabilities of the ground system or problems within the flight element that impact performance and/or space system resources. Response to these anomalies may follow a prescribed activity that uses predefined commands and contingency procedures or follow a general, systematic approach in its identification and characterization of the unplanned event while working to re-establish nominal operations.

3.3.4.6 End-to-end information capabilities and characteristics

A mission operations system should contain a clear understanding of how information flows throughout its mission elements and within its processes. An end-to-end understanding of a mission's information flow from the flight and ground elements is illustrated through the use of data flow diagrams. Data flow diagrams depict the mission elements and the flow of functional information throughout the systems. As the operations concept matures, the level of detail contained in the data flow diagrams should be increased accordingly.

These diagrams and software output become the linkage between the operations concept and requirements to the development phase of a project. A discussion of computer security approaches should be included with the data-flow diagrams.

Object-oriented descriptions of the processes are also a way to describe the processing and data relationships. Other tools such as workflow tools may be used in this area to electronically describe the flows for each scenario. Whatever the method chosen, the important point is to use a structured approach to the early definition of the processing, data relationships and storage requirements.

3.3.5 Process enablers: services, technology, tools and facilities

3.3.5.1 Processes

Ways to accomplish the processes shall be identified. Whether the capability, service, or enabling technology exists or is to be developed shall also be determined. To achieve the most cost-efficient distribution of processes for the mission, process development shall consider both the space system and the ground system. To understand the process options, a table containing the operations processes that apply to the mission’s database and avionics should be prepared.

Next, whether the process functions are accommodated within the avionics or the ground system or a combination of both shall be decided. If the decision is the ground, it shall be further determined whether the hardware, software, or operators shall perform the process. The process functions to be performed in each place and whether options exist shall be specified. For the ground hardware and software, the question “Could the avionics partially or completely perform this process and thus lower the mission’s life-cycle costs?” should be asked. For processes where operators are identified, the following question shall be answered, “What automation options are available and can the development cost of the automation be lower than the life-cycle cost of the operators performing the process?" A trade study of the amount of onboard data storage versus the number of ground station contacts and downlink capacity shall be made.

3.3.5.2 Existing operations capabilities and services

For the operation processes identified in 3.3.5.1, specify the capabilities and services which may be provided from existing operational organizations and facilities and who should provide them. Making use of existing and standard services is generally a big cost savings to a mission and reduces the risks by avoiding untried capabilities.

3.3.5.3 New technology development

Processes requiring new technologies for operational capabilities and services should have a corresponding technology development plan that specifies early development and verification. The technology to support a mission concept may not exist or may not yet be focused and prototyped to a level that is appropriate for mission approval. In case the technology does not become available in time for the mission to make use of it, alternate plans should be identified and a decision date to switch over to the alternate plan should be specified. Identifying the technology that is needed to support a space systems mission operations concept, along with the schedule and an indication of the needed funding, is an important output of the generation of the space systems mission operations concept.

3.3.5.4 Facility, ground support equipment and tools summary

Early identification of operation facilities, ground support equipment and tools needed to implement the processes is needed to establish a complete operations concept, to allow for complementary development of the flight element and to begin initial design of the mission data system.

3.3.6 Perform trade studies

Trade studies shall be provided for the items identified in 3.3.4 and 3.3.5. When a process has options, a life cycle cost analysis and risk assessment shall be performed to determine the most cost-effective place to perform the task with acceptable risk. Trade studies may be conducted by hardware, software, or operations personnel for functions on the ground or within the flight element. Trade studies should factor in cost, performance and risk parameters to obtain the optimum mission operations system design.

3.3.7 Mission operations organization and responsibility allocations

Once the processes have been defined, the “people” steps of the process may be gathered together into logical units, and an organization may be formed around these groups. The number of interfaces between teams is an indication of the organization’s complexity. Single interfaces between teams usually indicate a good operations organization. To an extent, the organization structure should also reflect the personalities of the key personnel. This should not, however, be allowed to the extent that the operations processes become inefficient. A description of probable contingency scenarios and the team interactions and responsibilities helps to validate the organization approach. The way the teams work together to resolve conflicts is also a good check on the viability of the organization. The training approach and process should also be addressed.

3.3.8 Operational scenarios

3.3.8.1 Description

Operational scenarios are key to an operations concept. A scenario is a list of steps required to complete an activity and, generally, involves both flight and ground elements. A scenario may have a duration of several minutes to a few days until the process is completed and/or starts to become repetitive.

A clear way to describe the time-related activities of a mission scenario is to show the steps of the activities in time order. Time may be added to each set of steps and the decision may then be made about which steps shall run in parallel and which shall run in serial. This information becomes the source of derived requirements for the mission operations system's performance.

Data-flow diagrams, discussed in 3.3.4.6, are an integral part of defining a scenario. System engineering tools are able to assist engineering in converting the machine steps into data-flow diagrams showing processes, points for data storage and interrelationships. These tools also prepare a data dictionary that ensures a unique name for each process or storage point in the data flow.

3.3.8.2 Total mission scenario

A space operations concept can be described in approximately 20 top-level scenarios which invoke both the uplink and the downlink processes for any given mission phase. Typically, planners generate the following three types of scenarios during study and design, with the level of detail increasing with the maturity of the mission:

a) user/science scenarios;

b) system scenarios;

c) subsystem scenarios.

During the early study phases of a mission, a scenario is developed by users to define how to acquire data and receive products from the payload. A system scenario is developed during the operations system design and emphasises the steps within a process needed to conduct the mission. Finally, during the subsystem design, the system scenarios are expanded to include more detailed events and subsystem activities. Each of these scenarios has a corresponding time line and data-flow diagram as described in 3.3.8.1.

Another method of describing the scenarios is to specify services that are required with a description of the input to the service, the product to be delivered by the service and the quality requirements on that service. Space agencies are starting to define standard services that are available, along with associated costs for these services.

3.3.8.3 Mission scenario based on activity periods and mission phases

The mission should be defined in terms of activity periods and mission phases. These activity periods and mission phases correspond to the mission trajectories and define tracking approaches and mission goals to be accomplished during each period or phase. Suggested activity periods are listed in 3.2.7 b).

3.3.8.4 Allocation of steps of the scenario to hardware and software or people

Each of the steps of the scenario may be assigned to machines and/or people. Those assigned to machines may be shown as data-flow diagrams, and those assigned to people may be shown in the context of an operations organization with the responsibilities for the steps mapped to the organization. For each step assigned to an operator, again ask the questions "Can this process be automated to eliminate the operator? How? What is the optimal functional allocation between automation and human operators for this process?" A person should be assigned to do something only when life-cycle costs demand human involvement.

3.3.8.5 Derived requirements concerning mission operations

Many times the steps within the scenarios that support the top-level requirements are a source of lower-level, derived requirements on elements of the mission operations system. Collecting them at this point and preserving the relationship to the top-level requirements are excellent bridges into the development phase.

3.3.9 Products

The products in a space system mission operations concept are outlined in 3.3.2 to 3.3.8. Space systems mission operations concepts that are consistent with this International Standard contain most of the products above. The final operations concept constitutes an agreement between the users, the builders, and the operators of a space system. The first concept should be developed early using the products that specify known processes, designs and assumptions. As the concept and mission system mature, the concept contents and products should be updated with approved processes and designs. The products should be updated even during the flight for missions lasting longer than one year. The operations concept is a key document for introducing new operators to the program.

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