Chapter 8 Mission Design and Mission Analysis

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8 Mission Design and Mission Analysis

8.1 General

Consistent with the dedication to provide the highest standards and a successful launch of the customer spacecraft, EUROCKOT strives to conduct a thorough, detailed and transparent mission design and analysis process for the Customer. This is evidenced by the extensive and detailed data packages provided to the customer during the review process, as described later in this chapter.

Within the framework of mission integration activities, mission design and mission analyses are conducted to ensure that the customer's mission objectives can be achieved, e. g. reliable spacecraft injection into the required orbit in the correct attitude, provision of facilities meeting the Customer's requirements,. The design and analyses are conducted on the basis of inputs from the Customer (chapter 12) and the compatibility checked versus the Interface Control Document requirements. They are undertaken in two phases:

- Preliminary mission design and analysis. This uses preliminary input data from the customer to confirm the basic design and mission scenarios to the customer. The data package is reviewed in the launch vehicle to spacecraft Preliminary Design Review (PDR). Following a successful PDR, the input data and mission aspects are studied and refined, leading to an update of the Interface Control Document and to an update in the input data from the customer.
- Final mission design and analysis. This uses final input data from the customer to finalise and freeze the actual design for the launch campaign and flight. The data package is reviewed in the launch vehicle to spacecraft Critical Design Review (CDR). Following successful conclusion of the CDR the design for flight is formally released.

The contents and tasks undertaken for the preliminary and final mission design and analyses are identical and differ only in the updated input data. The results of the design and analyses are presented in the form of books. An overview of the data package structure is provided in Table 8-1 below.

Each book contains the structure as shown in Table 8-2. The contents of the individual books are summarised in the next sections.

Book	Content
Book 1	Overall Description of *Rockot* Launch Vehicle Integration to Spacecraft
Book 2	Design Data Package Structure - for internal KSRC use only. Not provided to the customer.
Book 3	Input Data (ICD based) - for internal KSRC use only. Not provided to the customer.
Book 4	Trajectory and Mission Sequence
Book 5	Spacecraft Separation Dynamics
Book 6, part 1	Thermal Analysis: Ground Processing
Book 6, part 2	Thermal Analysis: Flight
Book 7	Coupled Loads Analysis
Book 8	Spacecraft Cleanliness Control
Book 9, part 1	Measurement System
Book 9, part 2	Launch Information Telemetry and Navigation Ballistic Support
Book 10	Spacecraft Electromagnetic Compatibility with the Launch Vehicle and Launch Site
Book 11	Onboard Electrical Interface of Spacecraft and Launch Vehicle
Book 12	Ground Electrical Cabling, Power Supply and Interfaces with Spacecraft GSE
Book 13	Intentionally left blank
Book 14, part 1	Launch Base Operations: Operations Flow
Book 14, part 2	Launch Base Operations: Facilities and GSE (except fuelling support)
Book 14, part 3	Launch Base Operations: SC Fuelling Support Activities and Facilities
Book 15, part 1	Reliability
Book 15, part 2	ILV Components Quality Assurance
Book 16	Social Services (Hotel, Intra launch site transportation etc)
Book 17	Communications Support
Book 18	Security
Book 19	Transportation of SC and Ground Support Equipment to Launch Site Facilities

Table 8-1 Data package structure.

Section Titles	Contents
Requirements Verification Matrix	• Per ICD and contract requirements
Results	• Summarized results of analyses and design work • Demonstration that ICD requirements are met
Conclusions	• Outstanding problems • Requirements remaining to be met • Actions to meet requirements
Detailed Data	• Description of techniques used for the analyses • Input data • Miscellaneous

Table 8-2 Data package book content.

8.2 Overall Description of Spacecraft to Rockot Launch Vehicle Integration (Book 1)

This book provides a top level description of the measures taken to integrate the customer's satellite to the *Rockot/Breeze-KM* launch vehicle. It introduces the launch vehicle and its major systems as well as covering in particular detail the mission-specific equipment in the upper composite, such as the payload adapter and separation system. The accommodation of the payload is described accompanied by detailed clearance analyses, the fairing venting analysis, fairing jettison analysis, as well as measures for electrostatic discharge control.

8.3 Trajectory and Mission Sequence (Book 4)

This book describes the mission timeline in detail starting from the countdown sequence to separation and upper stage orbit removal/ de-orbiting.

In order to perform these analyses, the Customer is requested to submit the following detailed data in addition to the data contained within the launch services contract. This includes:

- spacecraft orbital parameters including required injection accuracy,
- constraints on the upper composite / payload orientation during the coast phase portion of the flight such as those required for thermal manoeuvres,
- orientation of the spacecraft at the moment of separation, and
- launch window constraints from the spacecraft side.

The trajectory analysis provides a description of the launch vehicle during stage 1, stage 2 and upper stage flight phases. This includes velocity, altitude, dynamic pressure, flight angle and position of the launcher, burn times and a summary of the manoeuvres of the upper stage, a detailed launch event time line and trajectory description, orbital ground-track as well mission-specific analyses, e.g. upper stage orientation angle to the sun, for the customer.

The resulting trajectory is then used as input data for various analyses such as orbit dispersion, loads, thermal, separation sequence and telemetry/ ground station coverage.

The results of the Critical Design Review provide the final flight data including:

- The flight event sequence for the on-board computer
- The guidance parameters for the on-board computer

8.4 Dynamics of Spacecraft Separation (Book 5)

This particular study provides a detailed assessment of the spacecraft dynamics after separation from the upper stage. This includes calculation of the separation velocity of the spacecraft relative to the upper stage and the angular velocities of the spacecraft after separation. A Monte-Carlo type analysis is used to provide a statistical basis for the results taking into account the uncertainties of the interface characteristics, e. g. variations in spring

pusher force and connector disconnection force characteristics. Thus, the analysis provides a confirmation of the interface design to meet the Customer's velocity and tip-off rate requirements. The results also provide a confirmation of the overall separation strategy including collision free separation for both near and long term scenarios.

The final mission analysis repeats and confirms the studies performed during the preliminary analysis for the latest configuration data taking into account the actual *Rockot/Breeze-KM* and payload parameters. Thus it enables EUROCKOT to

- define the data to be used by the onboard computer for the orbital phase (manoeuvres, sequence)
- predict the clearance between the separated elements in orbital flight to verify collision avoidance including *Breeze-KM* orbit removal.

8.5 Thermal Environment (Book 6, parts 1 and 2)

The thermal environment study is implemented to show thermal compatibility throughout the mission. Book 6 part 1 covers the ground operations phase whereas book 6 part 2 covers the launch and ascent phase up to separation. The Customer provides a thermal model of the spacecraft containing:

- Description of the thermal nodes (heat capacities, mass type, etc.)
- Internal thermal couplings of nodes (conductive, radiative and convective)·
- Heat dissipation for all applicable modes of operation during the mission phases covered
- Interface descriptions (areas of contact, conductive and/or radiative properties)
- Thermal requirements for the environment to be maintained during integration, launch and flight

The detailed requirements of the spacecraft thermal model to be provided by the Customer are summarised in the EUROCKOT specification ESPE-0009. The preliminary thermal analysis must prove compatibility of thermal requirements and environmental conditions during the following phases or identify areas of concern where modifications have to be agreed upon for those phases:

- Operations within integration facilities
- Transportation to the launch pad
- Spacecraft integration on the *Rockot* launch vehicle
- Integrated phase until launch
- Ascent
- Aerothermal heating after fairing separation
- Coast phase

The final analysis will update the thermal compatibility study for all actual launch vehicle and spacecraft parameters.

8.6 Dynamic Coupled Loads Analysis (Book 7)

The goal of the coupled loads analysis (CLA) is to evaluate the limit levels and the frequency response of low-frequency dynamic loading of the payload below 100 Hz as part of the Integrated Launch Vehicle (ILV) in the key ascent events.

The CLA includes as many simulation runs as are required for each specific launch vehicle to spacecraft integration project phase:

In the launch vehicle to spacecraft compatibility study phase, it shall be established whether the ILV mechanical environment is compatible with the payload requirements.

In the PDR phase,

- preliminary levels of payload dynamic loads shall be evaluated,
- requirements for the adapter system shall be finalised and
- acceptable notching levels shall be determined, if required.

In the CDR phase,

- the system-level test conditions for the adapter system and the separation system shall be finalised,
- payload dynamic loads during ascent shall be predicted and
- dynamic displacements and sufficient clearance to payload fairing shall be verified.

More then one CLA simulation run may be required in any single project phase. This is particularly true for the launch vehicle to spacecraft compatibility analysis. A new updated payload model will usually be used in each successive CLA simulation run.

This analysis is based on a spacecraft dynamic model submitted by the customer as specified in detail in EUROCKOT specification ESPE-0008.

The payload experiences the worst-case dynamic loads during stage 1 flight including the worst-case dynamic pressure environment that results from aerodynamic disturbances and lasts about 60 s. Loads experienced during powered flight of either stage 2 or upper stage are much lower and are therefore of no interest in terms of payload load capability.

Thus, three major events are considered in the CLA:

- Lift-off
- Worst-case dynamic pressure q_{max}
- Stage 1 shutdown

Axial dynamic loading of the structure results from transient processes in the propulsion unit and can be predicted with a fairly high accuracy. This is evidenced by telemetry obtained in earlier missions. As for radial loads, these are caused by random phenomena such as thrust differences between cluster engines at lift-off or shutdown, the ground wind direction and speed at the time the ILV leaves the transportation and launch container, and the wind direction and speed at the time the dynamic pressure attains its peak level. Therefore, the CLA is carried out for two mutually orthogonal directions of radial

disturbance when studying the above key events. These directions are usually selected to run in payload orientation planes.

The CLA time interval for each simulated event shall be long enough to ensure a reliable prediction of load levels under study.

After a description of the calculation method and the covered load cases for each event and each radial disturbance direction, the CLA Report includes

- a table of maximum CoG accelerations for each spacecraft,
- a table of maximum interface loads fo each spacecraft,
- tables of maximum values of the quantities generated by recovery matrices, and
- acceleration time histories and CoG shock spectra for each spacecraft.

The summary results in this report include summary tables of maximum CoG accelerations and interface loads for the events investigated. For a payload having a clampband interface, the maximum interface line loads and the clampband tensioning specifications are provided.

Attached to the CLA Report are ASCII files containing

- tables included in the CLA Report and specifying the maximum CoG accelerations, the maximum interface loads and the maximum values of the quantities generated by recovery matrices, and
- time variations of Craig—Bampton accelerations and displacements for each payload spacecraft.

The appendices to the CLA Report may also include supplementary data such as

- time histories of the quantities specified by the Customer,
- shock spectra of the pre-specified quantities, and
- any other data as agreed upon with EUROCKOT.

8.7 Spacecraft Cleanliness Control (Book 8)

This study provides an assessment of how the cleanliness requirements for the customer's spacecraft are implemented including methods, standards and measurement methods. The following items are covered:

- Particle cleanliness referring to the concentration of the particles in the air within the clean rooms and the payload fairing. Also the particle concentration for surfaces located close to spacecraft such as the payload fairing.
- Organic contamination (optional) considering the concentration of the organic compounds in the air within the clean rooms and the payload fairing. Also the organic compound concentration for surfaces located close to spacecraft such as the payload fairing.
- Consideration and mitigation of the outgassing and offgassing by spacecraft dispenser and payload fairing

- Consideration and mitigation of potential pyrotechnic contamination from the fairing and separation system
- Consideration and mitigation of plume contamination by retro-rockets during second stage separation as well as *Breeze-KM* thrusters during orbit or attitude manoeuvres especially during collision avoidance manoeuvres after separation.

The standard cleanliness analysis is performed in two phases. The preliminary contamination analysis must prove that accumulated contamination can be kept within the specified limits or identify areas of concern where improvements have to be agreed. The final analysis will confirm contamination compatibility for all actual launch vehicle and spacecraft parameters.

8.8 Measurement System (Book 9)

This book provides a detailed overview of the measurement system which covers both the ground and the flight operations of the *Rockot* launch system.

The ground measurement facilities, which make up part of the overall measurement system, support the acquisition of data required during ground operations. The flight measurement system has two main functions, to provide tracking of the launch vehicle during ascent within visibility of the ground stations and to downlink important telemetry information from the vehicle during the whole flight.

The tracking system of the *Rockot* launcher which uses ground radar stations and an on-board transponder is described in some detail.

The measurement system description is mainly concerned with the capabilities of this system and measurements undertaken on ground and in flight. Among other things, a list of the parameters measured by the ground measurement facilities is provided. This list includes temperature, humidity and loads during the ground operations. For the flight phase, the parameters monitored include pressure, temperatures, loads as well as separation confirmation signals. This thorough characterisation of parameters during ground operations and launch allows EUROCKOT to provide an extensive and thorough post launch evaluation giving the Customer full visibility as to whether the ICD requirements have been met and to provide lessons learned for future missions.

8.9 Electromagnetic Compatibility Study (Book 10)

The preliminary electromagnetic compatibility (EMC) study allows EUROCKOT to check the compatibility between frequencies and their harmonics used by the launch vehicle, the ground stations and the spacecraft during launch operations and flight. This study is based upon the spacecraft frequency plan including intermediate frequencies from 14 kHz to at least 20 GHz which has to be provided by the Customer. It also considers the impact of radiated emission caused by spacecraft or launch vehicle on RF communication capabilities.

The Customer is also requested to submit parameters of radio-telemetric equipment operating simultaneously with the *Rockot*

transmission and reception systems during ground preparation, in flight and immediately after spacecraft deployment before the *Rockot/Breeze-KM* transmission and reception systems are switched off. The Customer also shall provide limits for emissions and susceptibility regarding radiated disturbances. In case of conflict, the study will include an analysis of possible solutions related either to the launch vehicle or to the spacecraft.

The final EMC study considers the actual configuration of the launch vehicle and spacecraft. The study involves the examination of possible spurious emission frequencies and the susceptible frequencies of the receivers.

8.10 Onboard Electrical Interface of Spacecraft and Launch Vehicle (Book 11)

This book covers in detail the configuration of the ground electrical cabling designed to provide interfaces between the Customer's electrical ground support equipment (EGSE) on the one hand, and the spacecraft at the integration facility and the launch site on the other. The extent of and procedures for electrical check-outs of the ground cabling are specified. The available power supply systems are described together with the types, quantities and the locations of outlets for connecting the Customer's EGSE at the integration facility or the launch site.

8.11 Ground Electrical Cabling, Power Supply and Interfaces with Spacecraft GSE (Book 12)

This book covers in detail the design solutions for the ground electrical cabling and interfaces of the Customer's ground support equipment (GSE) as well as a summary of the available power supplies for customer equipment. Specifically, this describes cables and harnessing in the Undertable Room 7, where the Customer's GSE is located, as well as the test steps and check-out procedures used to verify the correct installation and functioning of these circuits. Furthermore, a detailed description of the available power supplies including uninterruptible power supplies is given.

8.12 Launch Base Operations Support (Book 14 part 1, 2, 3)

Book 14 provides a summary of the agreed services necessary to support the Customer launch site operations as provided from the EUROCKOT / KSRC side. This covers the responsibilities and support as well as the agreed processing schedule in such areas as spacecraft transportation within the launch site, off-loading operations of the Customer spacecraft container and equipment at the facility, support for standalone spacecraft processing, ground operations support including support equipment such as boom lift, access platforms, fork lift etc. as well as safety aspects including definition of hazardous operations, crane operations, spacecraft fuelling support services and equipment. A successful conclusion of these aspects in the critical design review leads to the es-

tablishment and release of the Joint Operations Plan which then becomes the working document at the launch site.

8.13 Reliability (Book 15, part 1)

This book provides an overview of the measures to ensure quality and reliability of the launch process according to Russian Federation standards. Specifically this provides a description of the qualify assurance process used at KSRC including the procedures, practices and testing methods used to verify this. Furthermore theoretical reliability figures for various *Rockot/Breeze-KM* subsystems are established to provide an overall reliability figure for the complete *Rockot/Breeze-KM* launch system. Finally, a summary of the complete licensing process including the Customer inputs and responsibilities is given.

8.14 ILV Components Quality Assurance (Book 15, part 2)

This book describes the quality management system, namely, responsibilities, the system's documentation, personnel training and continuous improvement. The plan of measures to implement the ILV quality requirements is presented.

The existing KSRC quality assurance procedures are described in detail including the respective manuals, operation guidelines and quality inspection procedures.

It is emphasised that the Customer will be enabled to track all life cycle phases of each procedure envisaged by the Quality Management System.

8.15 Social services (Book 16)

This book provides a summary of an important but often overlooked part of the launch campaign, i. e. the comfort and welfare of customer and contractor personnel during their stay at the launch site. This book describes the city infrastructure, personnel transportation services available within the launch site, the hotel and amenities such as laundry services, satellite television, medical services, dining facilities etc. Therefore, the customer has the possibility to express their agreement with these arrangements or to discuss other arrangements and services, e. g. special dietary requests like Asian food, at the preliminary and critical design reviews.

8.16 Communications support (Book 17)

This book reflects the services and infrastructure available to support the Customer's communications requirements. This includes a description of the available telephone and facsimile services, internet access via LAN or direct dial-up, mobile communications through walkie-talkies, intra-launch site high data rate communications such as fibre optic and microwave transmission as well as the provision of a multitude of satellite television channels in the hotel. Furthermore, a thorough description of the communications channels and back-up services available at the *Rockot* Mission Control Centre is given.

8.17 Security (Book 18)

This book provides a description of the jointly agreed security plan between the customer and EUROCKOT/KSRC and the

launch site authorities. This aspect can be particularly important when dealing with customers with technology sensitive payloads wherein their national governments impose high security requirements on spacecraft and equipment. EUROCKOT and KSRC have gained extensive experience in this area especially in meeting the strict standards imposed for the launching of payloads from the USA, wherein round the clock surveillance and restricted access must be ensured around the satellite and equipment.

8.18 Transportation from Port-of-Entry to the Launch Site Facilities (Book 19)

This book provides a thorough description of the agreed transportation plan for the customer spacecraft and equipment from its arrival at the Russian port-of-entry Archangel Talagi airport to EUROCKOT's facilities in Plesetsk Cosmodrome. This includes definition of the transportation timeline, definition of cargo and containers to be transported, customs clearance, paperwork requirements and specific responsibilities, the transportation route and timing, interfaces to transport equipment, such as lorries, rail wagons and lifting devices, contingency planning for off nominal situations, e.g. delays as well as shipping returnable equipment after conclusion of the launch etc. It also provides an overview of the available transportation methods for personnel intending to travel to the launch site. The review of this book during the preliminary and critical design review allows the customer sufficient time to fine tune this important aspect of the launch campaign such that a smooth and successful transportation of the spacecraft and its equipment is assured.