
Chapter 8 Mission Design and Mission Analysis

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8. *Mission Design and Mission Analysis*

8.1 *General*

Consistent with the wish to provide the highest standards and to provide a successful launch of the customer spacecraft, EUROCKOT strives to provide 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 and in the correct attitude, provision of facilities meeting the customer's requirements, etc.). The design and analyses are conducted on the basis of inputs from the customer (see chapter 12) and the compatibility checked versus the Interface Control Document requirements. They are undertaken in two phases, namely:

- 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 of the data package structure is provided in Table 8-1 below.

Books	Contents
Book 1	Overall Description of <i>Rocket</i> 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	Reliability

Books	Contents
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

Each book contains the following structure as shown in table 8-2 below:

Section Titles	Contents
Requirements Verification Matrix	<ul style="list-style-type: none"> Per ICD and contract requirements
Results	<ul style="list-style-type: none"> Summarized results of analyses and design work Demonstration that ICD requirements are met
Conclusions	<ul style="list-style-type: none"> Outstanding problems Requirements remaining to be met Actions to meet requirements
Detailed Data	<ul style="list-style-type: none"> Description of techniques used for the analyses Input data Miscellaneous

Table 8-2: Data Package Book Content

The contents of the individual books are summarised in the next sections.

8.2 Overall Description of Spacecraft to Rockot Launch Vehicle Integration (Book1)

This book provides a top level description of the measures taken to integrate the customer's satellite to the *Rockot* launch vehicle. It introduces the *Rockot* 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 and accompanied by detailed clearance analyses. Also covered is the fairing venting analysis, fairing jetti-

son analysis as well measures for electrostatic discharge control.

8.3 Trajectory and Mission Sequence (Book4)

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:

- Payload 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 payload at the moment of separation
- Launch window constraints from the payload side.

The trajectory analysis provides a description of the launch vehicle during powered flight for the 1st stage, 2nd stage and *Breeze* 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 *Rocket* upper stage. This includes calculation of the separation velocity of the spacecraft relative to the *Breeze* upper stage. Furthermore it also provides the tip-off rates (angular velocities) of the spacecraft after separation (angular velocities). A 'Monte-Carlo' type analysis is used to provide a statistical basis for the results to take into account the uncertainties of the interface characteristics, e.g. variations in spring pusher force and connector disconnect force characteristics etc.

The analysis thus 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 both for both near and long term scenarios.

The final mission analysis repeats and confirms the studies performed during the preliminary analysis for the latest configura-

tion data, taking into account the actual *Rocket* and payload parameters. Thus it enables EUROCKOT to:

- Define the data to be used by the on-board computer for the orbital phase (manoeuvres, sequence)
- Predict the clearance between the separated elements in orbital flight and verify collision avoidance including *Breeze* 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 thermal compatibility of 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 *Rocket* 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 dynamic coupled loads analysis (CLA) includes several steps.

The preliminary dynamic coupled loads analysis (CLA) allows the first estimation of the in-flight loads applicable to the Customer's payload for the major *Rocket* launch vehicle load cases which include lift-off, maximum wind/gust cases and first stage MECO (main engine cut-off).

This study is based on the preliminary payload dynamic model submitted by the Customer according to the standard specified by EUROCKOT in section 8.6.3. The preliminary CLA includes the following items:

- Modal analysis for the composite launch vehicle / payload
- Description of the payload dynamic responses to the most severe longitudinal and lateral load cases induced by the launch vehicle
- Presentation of min./max. tables and time histories for forces, accelerations and relative deflections, as well as launch vehicle / payload interface, acceleration and force time histories at the nodes selected by the Customer
- Verification of the payload accommodation concept regarding interface loads as well as dynamic clearance between one or more spacecraft and the payload fairing during ascent

The dynamic coupled loads analysis allows the Customer to verify the validity of payload dimensioning and to adjust, if necessary, its qualification test plan after discussion with EUROCKOT.

The coupled loads analysis cycles and logic are provided below:

- Input data: preliminary spacecraft model
- Preliminary CLA providing preliminary loads on spacecraft.
- Spacecraft vibration tests using notching strategy developed and agreed from preliminary CLA results.
- Spacecraft model correlation with vibration test results resulting in an updated verified model.
- Final coupled loads analysis to define the final prediction for in-flight loads

8.6.1 *Coupled Loads Analysis Scope*

The coupled loads analysis is performed for the basic design cases of the orbit injection representing the most severe spacecraft load environment, namely:

- First stage ignition
- Wind + gust in the XOY plane of the LV
- Wind + gust in the XOZ plane of the LV
- First stage MECO (main engine cut-off)

Additional cases may be included in the CLA as agreed with a Customer.

8.6.2 *Coupled Loads Analysis Report*

The coupled loads analysis is performed in the Preliminary Design and Critical Design phases as well as in the event of any payload design modification (or design model updates) associated with changes in the payload dynamic properties. A CLA report is an integral part of the Preliminary/Critical Design activity.

A final CLA report is issued according to the agreement with the Customer. The report incorporates:

- Calculation method description
- Description of load cases and models used
- Tables of maximum and minimum values presented in different matrices
- Loading time domain data agreed upon with customers

- ASCII files of generalised accelerations and generalised displacements relative to the Craig-Bampton payload model for all the design cases

8.6.3 *Requirements for Spacecraft Mathematical Model*

The spacecraft mathematical model is to be provided by the Customer for a non-fixed structure mathematically reduced to a Craig-Bampton model format. In the case of a multiple satellite payload, the mathematical model will be provided to simulate the entire payload right-handed coordinate system coupled with the payload base geometric centre in the payload/adaptor interface plane.

The model should incorporate:

- Coordinate system definition
- Interface node coordinates
- Numbers of the model's degrees of freedom (DOFs) and associated directions of displacements (rotations) in the LV coordinate system for each interface node; sequence of node DOFs; three displacements relative to the OX, OY and OZ axes and three rotations relative to the OX, OY and, OZ axes
- Stiffness, mass and damping matrices in a Craig-Bampton format
- Stiffness matrix verification results related to solid body displacements
- Transformation matrices and their line description if necessary. The standard for this is described in more detail in the EUROCKOT specification ESPE-0008.

Other formats of the mathematical model (for example a spring-mass model) are to be agreed with EUROCKOT. As far as physical displacement is concerned, the number of the model's dimensions must be equal to the total DOFs of the payload interface nodes.

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: 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): 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* 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 *Rocket* launch system.

The ground measurement facilities, which make up part of the overall measurement system, support acquisition of data required during ground operations. The flight measurement system has two main functions, namely 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 *Rocket* 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 temperatures,



humidities and loads during ground operations. For the flight phase the parameters monitored include pressure, temperatures, loads as well as separation confirmation signals. This thorough characterisation of such parameters during ground operations and launch allows EUROCKOT to provide an extensive and thorough post launch evaluation which allows 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 GHz frequencies) 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 *Rocket* transmission and reception systems during ground preparation, in flight and immediately after spacecraft deployment (before the *Rocket* transmission and reception systems are switched off). The Customer also has to 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 payload.

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 hooking 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 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 parts 1, 2 and 3)*

Book 14 provides a summary of the agreed services necessary to support the customer launch site operations as provided from the EUROCKOT/ Khrunichev 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 cherry pickers, access platforms, fork lift trucks etc, safety aspects including definition of hazardous operations, crane operations, as well spacecraft fuelling support services and equipment. A successful conclusion of these aspects in the critical design review leads to the establishment and release of a Joint Operations Plan which then becomes the working document at the launch site.

8.13 *Reliability (Book 15)*

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 Khrunichev including

the procedures, practices and testing methods used to verify this. Furthermore theoretical reliability figures for various *Rocket* subsystems are established to provide an overall reliability figure for the complete *Rocket* launch system. Lastly, a summary of the complete licensing process including the customer inputs and responsibilities is covered.

8.14 *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. The customer therefore has the possibility at the Preliminary and Critical design reviews to express their agreement with these arrangements or to discuss other arrangements and services, e.g. special dietary requests like Asian food etc.

8.15 *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 the provision of a



multitude of satellite television channels in the hotel. Last but not least a thorough description of the communications channels and back-up services available at the *Rocket* mission control centre at the launch site is given.

8.16 *Security (Book 18)*

This book provides a description of the jointly agreed security plan between the customer and EUROCKOT / Khrunichev 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 Khrunichev have gained extensive experience in this area especially in meeting the strict standards imposed for the launching of US payloads, wherein round the clock guarding and restricted access must be ensured around the satellite and equipment.

8.17 *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. 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 timings, interfaces to transport equipment, such as trucks and 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 wanting 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.