ANGARA LAUNCH SYSTEM MISSION PLANNER'S GUIDE

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FOREWORD

The Angara Launch System Mission Planner's Guide is intended to provide information to potential Customers and spacecraft (SC) suppliers, concerning SC design criteria, Plesetsk processing facilities, Angara launch capability, available mission analysis and custom engineering support, documentation availability and requirements, and program planning. It is intended to serve as an aid to the planning of future missions, but should not be construed as a contractual commitment.

The units of measurement referred to in this document are based on the International System of Units (SI), with English units given in parentheses and all identified dimensions shown should be considered as approximate. In the event that one or more dimensions are critical to a specific payload integration or processing operation, the SC Customer should obtain accurate dimensions from International Launch Services (ILS).

This Guide will be updated periodically. Change pages to this printed document will not be provided, however, the version on the ILS website will be maintained as approved for public release by the US Government. The most current version of this document can be found on the Internet at: *http://www.ilslaunch.com/missionplanner*.

Users of this guide are encouraged to contact the offices listed below to discuss the Angara launch vehicle family and how the Angara family may meet user needs.

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REVISION HISTORY

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PREFACE

International Launch Services (ILS) is pleased to offer one of the most capable commercial launch vehicles, and the most comprehensive launch services, available today. The Angara's services are now available to worldwide Customers at a most competitive price.

ILS is the exclusive marketing agent for commercial sales of the Angara launch vehicle (LV) worldwide, and is supported in its operations by full access to the incomparable technological expertise of its parent companies; Lockheed Martin Corporation (LMC), Khrunichev State Research and Production Space Center (KhSC), and Russian Space Complex Energia (Energia). ILS provides Customers with a single point of contact for all mission analyses, custom engineering, and launch support tasks involved in using the Angara LV. Both individually and collectively, the members of the ILS team are committed to providing the most cost-effective launch services available in the world - from initial program planning to successful SC launch.

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ABBREVIATIONS AND ACRONYMS

A

A	Ampere
ac	Alternating Current
A/C	Air Conditioning
APT	Additional Propellant Tank
ATCS	Air Temperature Control System
AU	Ascent Unit

B

bpi	Bit(s) per Inch

C

^{O}C	Degree(s) Celsius
CG	Center of Gravity
CLS	Commercial Launch Services
cm	Centimeter
CRM	Common Rocket Module
CS	Control System

D

dB	Decibel(s)
dBm	Decibel(s) Relative to 1 Milliwatt
dBW	Decibel(s) Relative to 1 Watt
dc	Direct current

E

e	Eccentricity
ε	Emissivity
EMC	Electromagnetic Compatibility
EMI	Electromagnetic Interference

F

FMH	Free Molecular Heating
FOTS	Fiber-Optics Transmission System
ft	Foot; Feet
FTS	Flight Termination System

G

g	Gravity or Gram
GEO	Geosynchronous Orbit
GN_2	Gaseous Nitrogen
GSE	Ground Support Equipment
GSO	Geostationary Orbit
GTO	Geosynchronous Transfer Orbit
GTS	Ground Telemetry Station
GTV	Ground Transport Vehicle

H

HEPA	High-Efficiency Particulate Air
HPF	Hazardous Processing Facility
hr	Hour(s)
Hz	Hertz

I

ICD	Interface Control Document
I/F	Interface
ILS	International Launch Services
in.	Inch(es)
IRD	Interface Requirements Document

K

kg	Kilogram(s)
KhSC	Khrunichev State Research and Production Space Center
kHz	Kilohertz
km	Kilometer(s)
kPa	Kilopascal(s)
kV	Kilovolt(s)
KVRB	Oxygen-Hydrogen Upper Stage

L

lb	Pound(s)
lbf	Pound(s)-Force
lb_m	Pound Mass

LEO	Low-Earth Orbit
LH_2	Liquid Hydrogen
LHe	Liquid Helium
LKE	Lockheed Khrunichev Energia
LKEI	Lockheed Khrunichev Energia International
LM	Lockheed Martin
LMC	Lockheed Martin Corporation
LMCLS	Lockheed Martin Commercial Launch Services
LN_2	Liquid Nitrogen
LO_2	Liquid Oxygen
LV	Launch Vehicle
LVS	Launch Vehicle System

M

m	Meter
mA	Milliamps
MGSE	Mechanical Ground Support Equipment
MHz	Megahertz
min	Minute(s)
mm	Millimeter(s)
MMH	Monomethyl Hydrazine
MON-3	Mixed Oxides of Nitrogen
MOU	Memorandum of Understanding
mt	Metric Ton
m/s	Meters Per Second
µV	Microvolt(s)
mV	Millivolt(s)

N

N	Newton(s)
N_2H_4	Hydrazine
NM	Newton Meter
N_2O_4	Nitrogen Tetroxide
ns	Nanosecond(s)

O

O_2	Oxygen
OASPL	Overall Sound Pressure Level
Oct	Octave(s)
Ω	Ohm(s)
ω_P	Argument of Perigee

P

Pa	Pascal
PDR	Preliminary Design Review
PFJ	Payload Fairing Jettison
PLCP	Propellant Leak Contingency Plan
PLF	Payload Fairing
ppm	Parts Per Million
psi/psf	Pound(s) per Square Inch/Pound(s) per Square Foot
psig	Pound(s) per Square Inch, Gage
PSM	Payload Systems Mass

Q

q	Dynamic Pressure
qV	Free Molecular Heat Flux

R

RF	Radio Frequency
RM	Room
RP-1	Rocket Propellant 1 (Kerosene)

S

s	Second(s)
SC	Spacecraft
SCAPE	Self-Contained Atmospheric Protective Ensemble
SF	Russian Space Force
SRM	Solid Propellant Rocket Engine, Solid Rocket Motor
SSTO	Super-synchronous Transfer Orbit

T

TBD	To Be Determined
TBS	To Be Supplied

TC	Technical Complex
TIM	Technical Interchange Meeting
TLM	Telemetry

U

UDMH	Unsymmetrical Dimethylhydrazine
UPS	Uninterruptible Power Systems
U.S.	United States

V

V	Volt(s) or Velocity
Vac	Volt(s) Alternating Current
Vdc	Volt(s) Direct Current

W

W	Watt(s)
W/m^2	Watts Per Square Meter

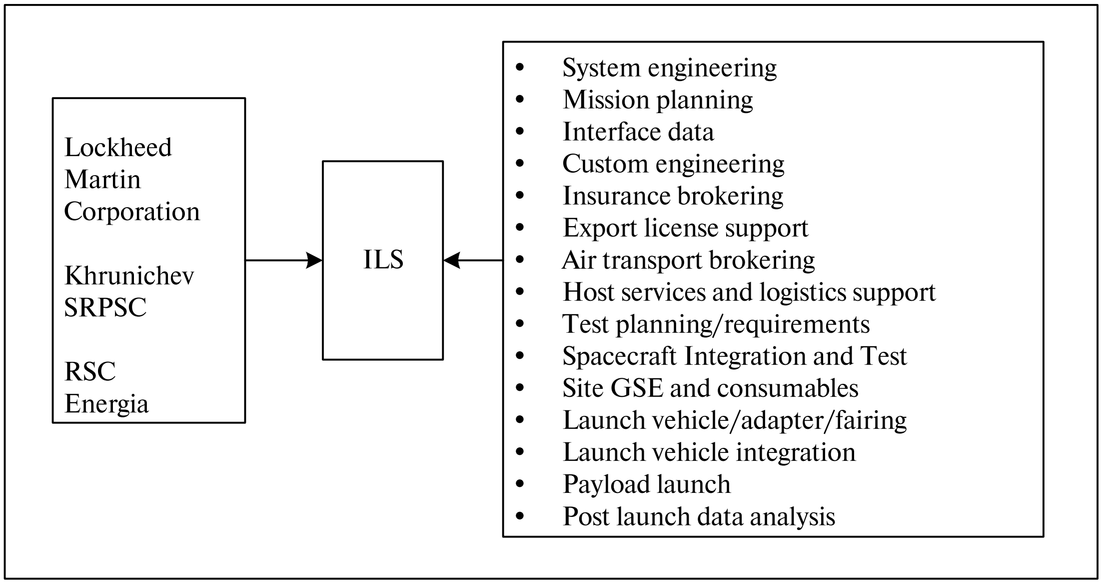
X

1. ANGARA LAUNCH SERVICES

International Launch Service's (ILS) launch support services equal or exceed in comprehensiveness and quality those services available from any other commercial launch service organization. These services include system integration, supply of the Angara LV, custom engineering services and mission analysis, insurance brokering, ground and air transport, Government export license assistance, launch site SC integration and testing, SC and LV integration, launch site support and security services, launch of the SC, and post launch mission support. These services are summarized in Figure 1-1.

The management approach to the provision of these services has been developed to ensure efficient task completion, with essential focus on Customer satisfaction. ILS functions as a prime contractor to manage all tasks associated with the supply of the LV and associated SC launch services, including all required liaison with various United States, Russian, and other government organizations and agencies, as well as accommodation of any special Customer requirements. ILS will support all SC processing activities, oversee the integration of the SC with Angara, and conduct the SC launch. The Customer need interact solely with ILS for full support in all aspects of the launch.

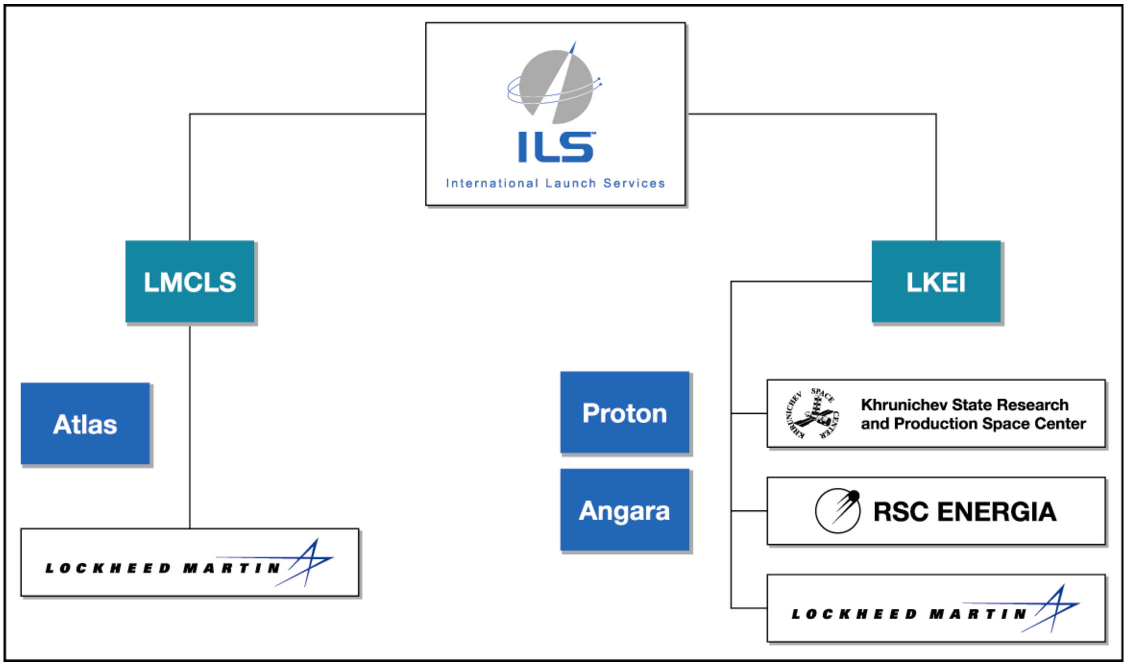
Figure 1-1: International Launch Services Charter



1.1 CONSTITUENT ILS COMPANIES

ILS is a joint venture of Lockheed Martin Corporation, Khrunichev State Research and Production Space Center and the Rocket-Space Corporation Energia. ILS is the international marketing, sales and program management organization for the Proton and Angara launch vehicles engineered, manufactured and launched by Khrunichev. The Corporate parentage of ILS is shown in Figure 1.1-1.

Figure 1.1-1: ILS Corporate Parentage



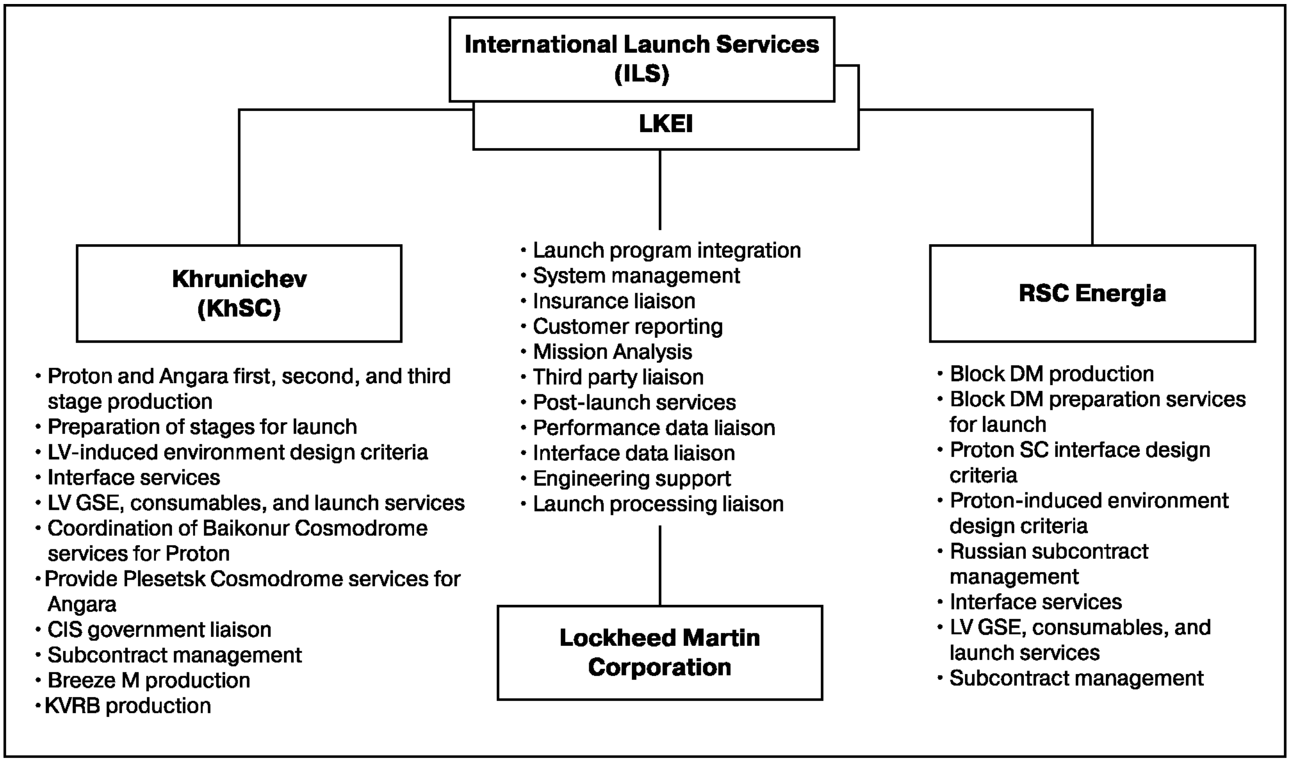
This joint venture has been approved by both the U.S. and Russian governments. Lockheed Martin is the United States leading company in all aspects of SC/LV integration, LV design, development and manufacture, and launch site operations. Khrunichev (along with its subsidiary, the Salyut Design Bureau) is the Russian designer and manufacturer of the first stage, second stage, and third stage of the Proton space LV, as well as the Breeze M and KVRB upper stages. Energia is the Russian designer and manufacturer of the Block DM fourth stage of the Proton, and is the largest producer of launch vehicles in Russia. ILS has access to all resources of the constituent companies required to fulfill SC launch campaign requirements.

Lockheed Martin, Khrunichev, and Energia all function as subcontractors, reporting to ILS, during the execution of a Customer's launch services contract. A memorandum of understanding (MOU) that delineates the responsibilities of each of the companies is in place. These organizational responsibilities are summarized in Figure 1.1-2. Constituent senior management of each of the companies have approved the overall management approach for ILS, and are each represented on the ILS Board of Directors.

The personnel, hardware resources, and facilities needed to support Customer launch programs are in place and ready for immediate activation, as needed.

ILS personnel are responsible for all Customer interface activities, and for the coordination of all activities of the constituent companies so that contract objectives are met. ILS personnel are also responsible for all program system engineering, custom engineering, mission analysis, program integration and program management, liaison with all government agencies, and liaison with the world's financial and insurance markets. Khrunichev is responsible for manufacturing the Proton and Angara first, second, and third stages, manufacturing the Breeze M and KVRB upper stages, conducting mission analysis, and providing Plesetsk services. Energia is responsible for manufacturing the Proton's Block DM fourth stage, providing the Block DM timeline, dynamics, and other data for mission analysis, and providing Baikonur services.

Figure 1.1-2: Organizational Responsibilities



1.1.1 ILS Customer Interface

To better serve our Customers, ILS has implemented a Customer-focused “Account Team” management structure overlaid above the functional organization. The Account Teams are comprised of four skill specialists, one with program management technical skills, one with contractual/financial skills, one with marketing/sales skills, and one with licensing compliance skills. Account Teams are aligned with one or more Customers, and serve as the primary official interface between the Customer and ILS.

ILS Account Team management provides a single source of comprehensive launch services knowledge—technical, licensing, program and business management.

Our business and technical experts work carefully with each Customer to clearly identify a launch solution that best supports the Customer’s business plan and meet or exceed optimal lifetime requirements for the SC. We help Customers design their business models and provide assistance in identifying financial and insurance services.

As part of the launch services contract support, administrative guidance and assistance can be provided, when needed, in meeting government regulations, including import and export licenses, permits, and clearances from government and political entities.

Mission management is a critical part of our Account Team structure. The Program Director’s primary duty is to arrange the resources necessary for the successful completion of the launch services contract and to ensure complete Customer satisfaction. The Program Director acts as the liaison with vehicle manufacturers, subcontractors and suppliers.

Each Account Team is headed by an Account Executive. The Account Executive is the one key person the Customer organization can always contact to deal with any issue. All Account Executives report to the Office of the President.

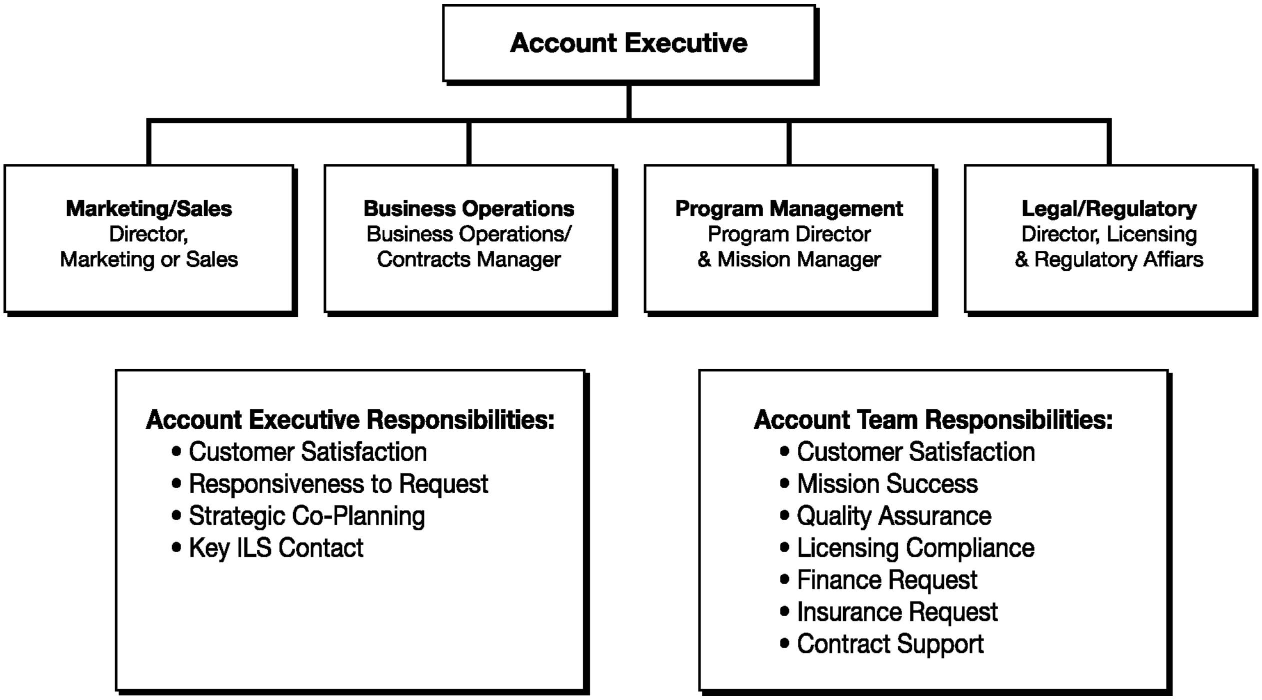
In the course of the normal business cycle, the Account Executive will depend on one or more of the Account Team members to lead the interface with the Customer. During the procurement phase, the Marketing or Sales member, supported by the other team members will work with the Procurement and Engineering groups of the Customer’s organization. During negotiations and during the formation of the contract, the Contractual/Financial member will take a lead position. And, during the program and launch phases, the Program Director will be in the lead position.

Account Executives report on a routine basis to the Executive Vice President on their interface with their Customer(s). All Account Executives also meet periodically to share lessons learned, and for formalized training in critical business, technical and administrative areas to improve their skills, and to better serve ILS' Customers.

All Account Team members are in one of four organizations: Marketing or Sales, Business Operations, Program Management and Legal/Regulatory. The Account Team organization is shown in Figure 1.1.1-1. The Account Team members rely on the support services of their functional groups to provide the in-depth resources and skills necessary to meet the requirements of the Customer.

It is ILS management's primary interest to provide to our Customers more than just being a LV provider. Our commitment is to nurture partnerships with our Customers, not just fulfilling launch contracts, and the Account Team concept was implemented to achieve that goal.

Figure 1.1.1-1: ILS Customer Support Team



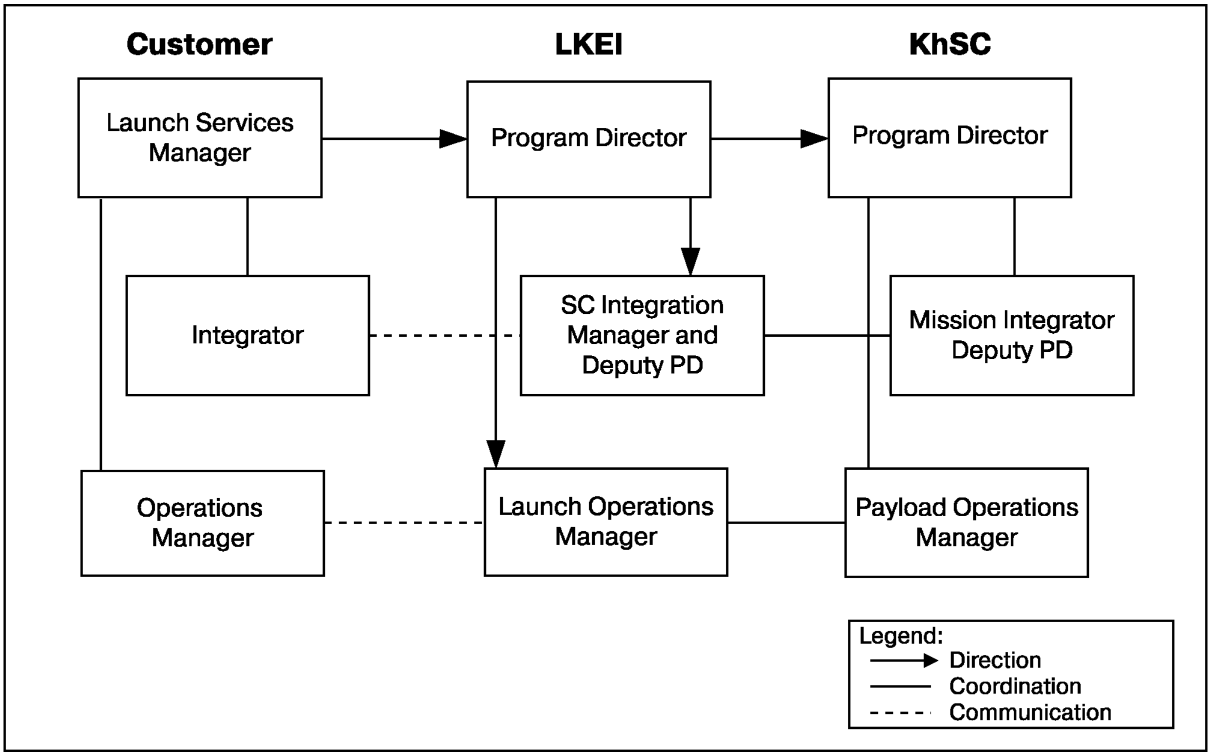
1.1.2 Mission Management

With authority to proceed on a launch services contract, the ILS Customer Support Team member from the Mission Management group becomes the Program Director responsible for program development and management. The Program Director's primary duties are to arrange resources necessary for the successful completion of the contract and to ensure complete Customer satisfaction.

Following the launch service authority to proceed, ILS will issue a subcontract to the Khrunichev Space Center to provide all LV hardware, mission integration, and other products and services required. In direct support of the ILS Program Director, a dedicated KhSC Program Director and integration team will be assigned. These dedicated members of the team will work with the ILS Program Director to ensure that all Customer needs are met, from program inception through post-launch activities and reports. The Program Director will ensure the integrity of the Angara LV. The ILS Mission Integration Manager will be the primary interface with the SC integrator to facilitate a low-risk SC-to-LV integration. The launch systems team will ensure efficient, low-risk SC processing during the launch campaign. The Mission Management Team is shown in Figure 1.1.2-1.

Additionally, KhSC will provide its considerable LV experience to the launch services program via the program office for Angara. Within the KhSC Angara program office, a Program Director and Mission Integration Manager will be selected. Their primary duties include management of both non-recurring development and the recurring integration (including ICD development and action item resolution), manufacturing, and launch operations required for the program. The KhSC Program Director will be responsible for mission success and for the achievement of all program milestones across all disciplines and functions within KhSC (i.e., engineering, manufacturing, quality, launch operations).

Figure 1.1.2-1: Mission Management for Commercial Angara Programs



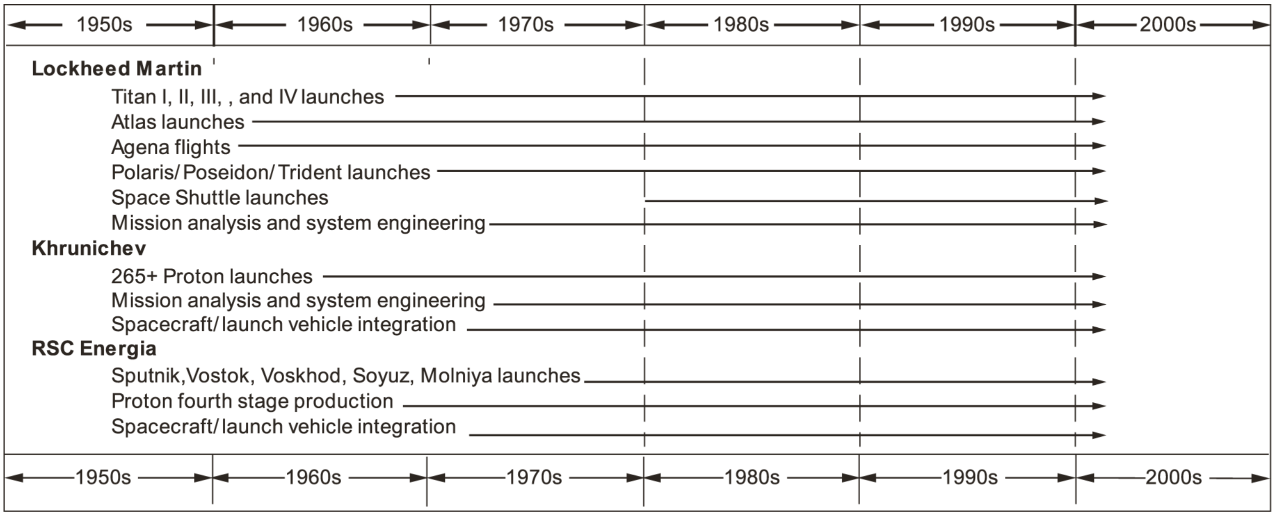
1.2 ILS CONSTITUENT COMPANY EXPERTISE

The joint venture of Lockheed Martin Corporation, Khrunichev and Energia offers the most capable, comprehensive, and cost-effective SC launch services in the world.

ILS, with access to the technological expertise and resources of Lockheed Martin Corporation, Khrunichev and Energia, can provide all necessary resources required to support a SC launch. ILS provides SC Customers with a single point of contact for all mission engineering and launch support tasks using the Angara LV.

The constituent companies of ILS have more SC and LV expertise than any other organizations providing launch services today (see Figure 1.2-1). Lockheed Martin has built more than half of all Western satellites flown, and has designed, built and launched the Atlas and Titan launch vehicles, as well as the Agena and Centaur upper stages, and the Polaris, Poseidon and the Trident strategic defense missiles. Khrunichev, in addition to designing and building the Proton and Angara LV, is responsible for subcontract management for all of the LV subsystems. Khrunichev personnel participate in all Angara integration and launch operations at the Plesetsk Cosmodrome. Khrunichev has also produced a variety of missile systems for the Russian government, as well as the Salyut, Mir, and Almaz orbital stations, and several different orbital return capsule designs. Energia has provided all of the fourth stages for the Proton from the inception of the program until 1999, and has also been responsible for significant subcontract management. Energia is the designer and builder of the R-7 series of space launch vehicles, including the Soyuz and Molniya launchers, of which more than 1300 have been launched to date. During the 1980's they developed both the Energia heavy lift LV and the Buran space shuttle, in addition to significant portions of the Mir space station hardware. The constituent companies of ILS have the necessary expertise to successfully and efficiently support any launch campaign.

Figure 1.2-1: Launch Experience



1.3 ADVANTAGES OF USING THE ANGARA LAUNCH VEHICLE

The use of the Angara LV provides several significant advantages that result in operational and revenue generating benefits for the Customer.

ILS provides full system engineering, mission analysis services and mechanical/electrical interface coordination. The Angara LV operations procedures are developed from the proven procedures used for Proton LV operations, and are backed by personnel with extensive experience in these procedures, which result in efficient and trouble-free launch campaigns.

The considerable lift capability of the Angara A5, combined with the multiple restart capability of the KVRB upper stage, provides the Customer with mission flexibility and maximized payload capacity to orbit. This results in unique mission design options, including delivery of SC directly to geostationary orbit. SC apogee fuel may be dedicated to extended mission life, because inclination reduction and orbit circularization are accomplished by the Angara upper stage.

The ability of ILS to meet Customer requirements guarantees that each launch campaign will be conducted to the Customer's satisfaction. This approach to satisfying key requirements is shown in Table 1.3-1. ILS's overriding concern in providing commercial launch services is the careful coordination of our company's resources and capabilities with the Customer's detailed requirements, so as to allow ILS to tailor each launch campaign to meet the individual Customer's unique needs. This ensures that each campaign will proceed in an efficient manner toward a successful, on-time launch to the precise orbit required.

Table 1.3-1: Benefits To The SC Designer And Owner

• Full mission analysis support by all constituent companies
• Access to proven LV manufacturing and support capability
• Use of very capable integration and launch support infrastructure
• Use of the massive lift capacity of the Angara A5 LV
• Use of the restart capability of the KVRB upper stage for final orbit insertion

1.4 INTRODUCTION TO THE ANGARA LV FAMILY

The development of the Angara launch system has been under way at KhSC for many years. The concept underlying the launch system was changed several times during the design process. As a result, a launch system based on a family of launch vehicles of the light, medium, heavy, and super-heavy classes were proposed for implementation. The Angara LV is being built at the Russian Cosmodrome in Plesetsk.

The Angara launch system and launch facilities includes the following principal components:

- LVs of the light class (Angara 1.1, Angara 1.2), medium class (Angara A3), heavy class (Angara A5), and super-heavy class (Angara A5/KVRB) in the future;
- Breeze M upper stage;
- KVRB, an oxygen-hydrogen upper stage;
- Payload fairings;
- Technical complex;
- Universal launch complex;
- Full complement of instruments and means of data acquisition and processing (used as needed);
- Ground control systems for the upper stages (used as needed);
- Set of transportation equipment for LVs, upper stages, and payload fairings; and
- Training aids and facilities.

The existing Breeze M upper stage is to be used to inject payloads into geosynchronous and highly elliptical transfer orbits.

The use of existing facilities and facilities under development in the ground space infrastructure of the Plesetsk Cosmodrome, including the filling and neutralization station, the oxygen-nitrogen plant, and others, is planned to support the operation of the Angara LV family.

All LV components that are being built draw to the greatest possible extent on existing components, scientific and technical know-how, and engineering capabilities.

The common key elements of the LVs are:

- Common rocket module;
- Common second stage booster;
- Control system; and
- Common adapters and fairings.

The use of a comparatively small number of integrated elements results in a more efficient utilization of launch complex capabilities, assuring high reliability in launch processing during the launch of all Angara LV configurations.

The development of the Angara LV is oriented toward existing Russian industrial and developmental facilities. The universal launch complex is being built on the basis of the unfinished launch complex for the Zenit LV, which is distinguished by a high degree of automation of pre-launch and launch operations. The universal launch complex makes possible the launching of all Angara LV variations with a small amount of work necessary to switch from one Angara configuration to another.

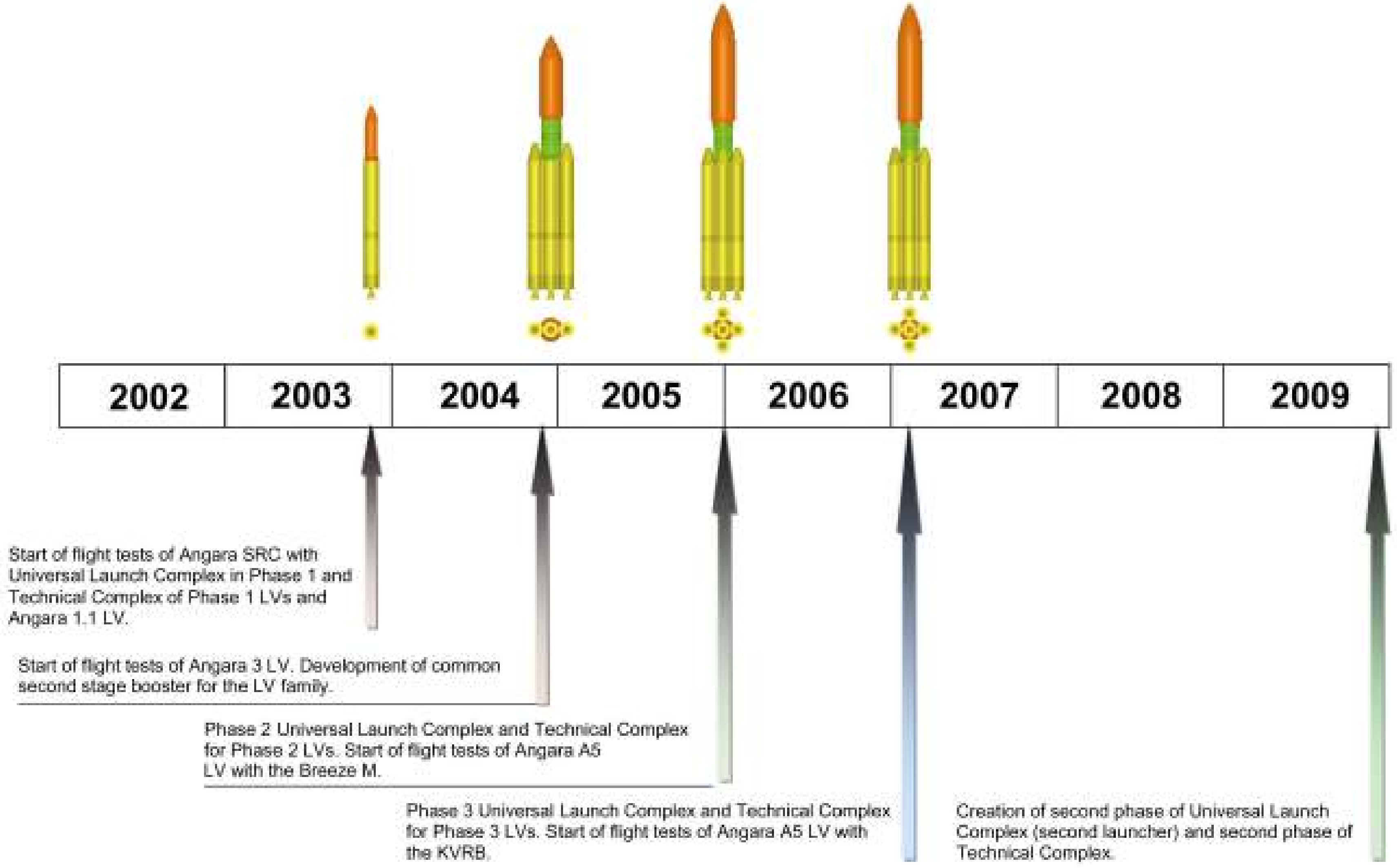
It is proposed to use the technical complex for processing of the LVs and payloads; the technical complex is made up of both existing facilities and ground handling equipment, and facilities and equipment especially built for the Angara LV family.

The infrastructure of the Plesetsk Cosmodrome supports the receiving and storage of components of integrated LVs and SC and other essential loads after they are delivered by air and rail, as well as the accommodation, work, and off-duty activities of all personnel involved, including representatives of the Customer.

The concept adopted for the development of the Angara LV family is based on a common rocket module (CRM) for the first stage, phased in at minimum cost and in the shortest possible time (see Figure 1.4-1). The costs of developing the Angara A5 heavy class launch vehicles are reduced mainly by the development of a CRM as part of the Angara 1.1 light class LV.

Once the CRM is developed in the period 2003-2005 and as part of the Angara 1.2 and A3 LVs in the period 2004-2005, and after the common second stage booster is developed as part of the Angara 1.2 and A3 LVs, flight tests of the Angara A5 heavy class LVs are to begin in 2005.

Figure 1.4-1: Phases of Development of the Angara LV System



The universal launch complex to support the Angara LV is being built in three phases:

- Phase 1 - creation of the complex to support processing and launch of Angara 1.1 and Angara 1.2.
- Phase 2 - additional modifications of the complex to support processing and launch of Angara A3 and A5 with the Breeze M.
- Phase 3 - additional modifications of the complex with equipment to support processing and launch of the Angara A5 with the KVRB upper stage.

The technical complex is also being built in three phases:

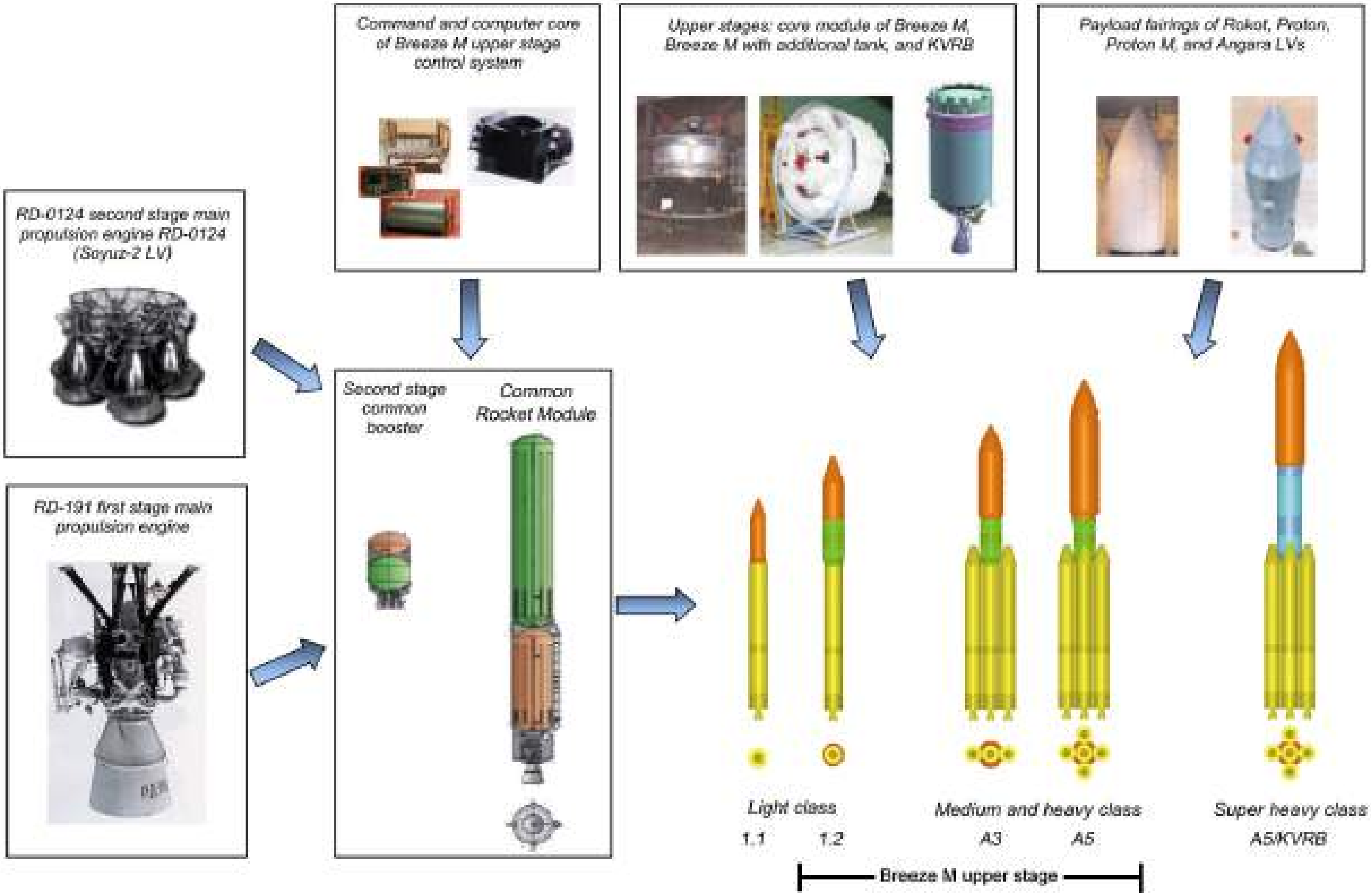
- Phase 1 - the creation of the LV technical complex to support launch processing for Angara 1.1 and Angara 1.2, with consideration for subsequent additional modifications of the complex in operation for launch processing for heavy class LVs.
- Phase 2 - additional modifications of the LV technical complex to support launch processing for heavy class LVs, as well as the building of handling equipment to support launch processing for SC, ascent units, and the Breeze M on heavy class LVs.
- Phase 3 - the development of handling equipment to support launch processing for the KVRB on heavy class LVs.

1.5 DESCRIPTION OF THE ANGARA LV FAMILY

1.5.1 Design Concept Underlying the Angara LV Family

The underlying concept for the Angara LV family is a modular construction, using a booster core with a high degree of standardization - the common rocket module (CRM). The CRM forms the first stage booster of the light class Angara 1.1 and Angara 1.2 LVs, which differ in their second stage boosters. The medium and heavy class LVs, respectively, consist of three or five CRMs. An illustration of the design concept for the Angara LV family is presented in Figure 1.5.1-1.

Figure 1.5.1-1: Design Concept of the Angara LV Family



In addition to the CRM, the basic standardized elements of the Angara LV family are:

- The standardized command and computer core of the control system, which is being built within the framework of the development programs for the Breeze M and the Angara.
- The standardized measuring complex, which is compatible with international standards for data transmission frequencies and which is being built within the framework of the development programs for the Breeze M and the Angara.
- The standardized second stage oxygen-kerosene booster of the Angara 1.2, Angara A3, and Angara A5 LVs.
- The payload fairings of the Rokot, Proton, Proton M, and Angara LVs.

The Breeze M and KVRB are to be used to inject payloads into high orbits, including geosynchronous transfer and geostationary orbits, with medium and heavy class LVs of the Angara family.

Figure 1.5.1-2 shows a general view of the Angara LV family, its composition, and the configuration naming convention used. Figure 1.5.1-3 shows a model of the LV family and Figures 1.5.1-4 and 1.5.1-5 shows Angara 1.1 in the factory and on exhibition in Le Bourget.

Figure 1.5.1-2: General View, Composition and Designations of Angara LV Family

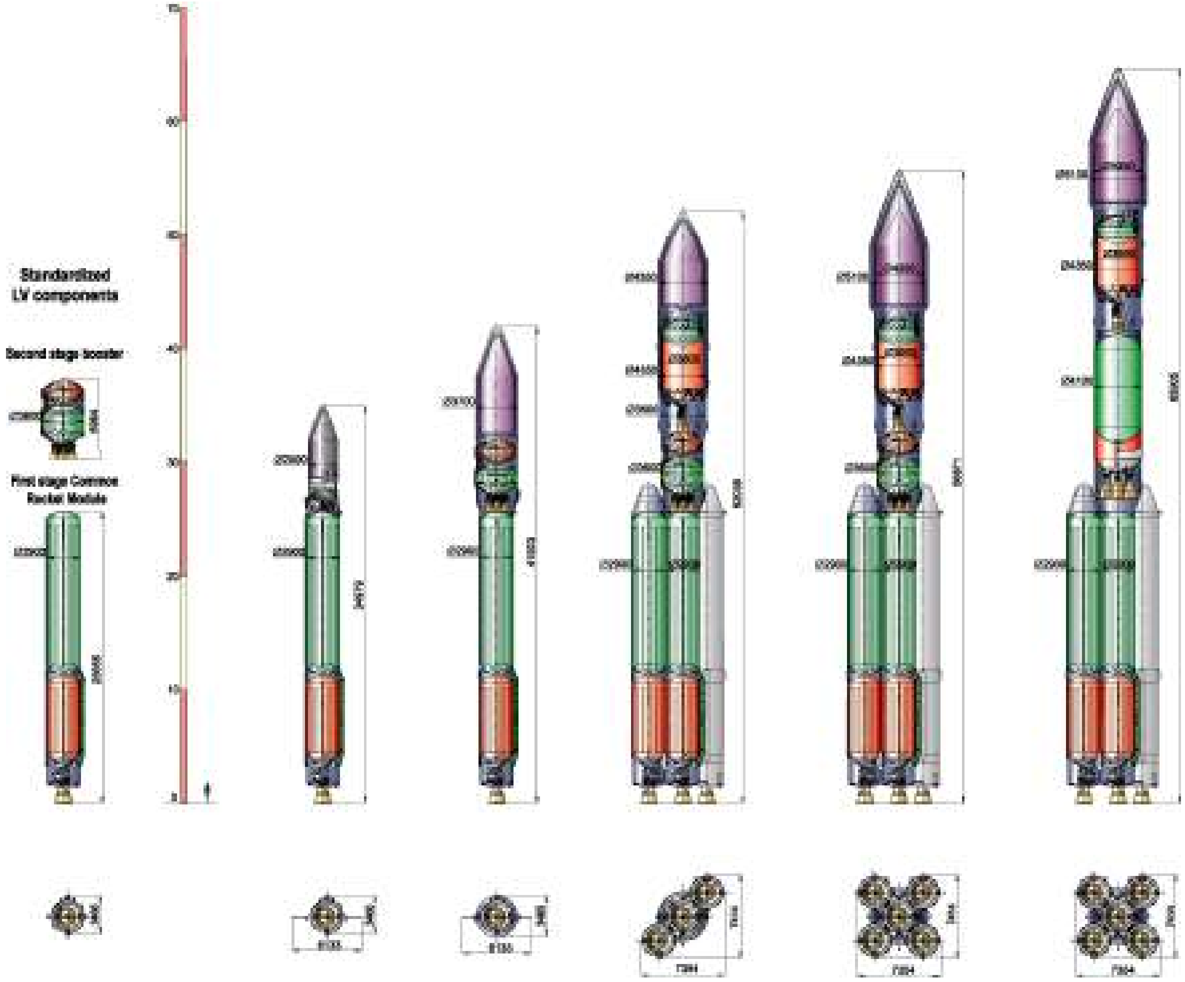


Figure 1.5.1-3: Models of the Angara LV Family

Figure 1.5.1-4: Angara 1.1 LV in Assembly Shop

Figure 1.5.1-5: Angara 1.1 LV at an Exhibition in Le Bourget

1.5.2 Basic Characteristics of the Angara LV Family

The basic characteristics of the Angara LV family are presented in Table 1.5.2-1.

Table 1.5.2-1: Angara LV Family Basic Characteristics

	Angara 1.1	**Angara 1.2**	**Angara A3**	**Angara A5**	**Angara A5/KVRB**
Launch weight (metric tons)	149.5	171.5	480	773	790
Maximum length (m)	34.9	41.5	45.8	55.4	64.0
Maximum diameter (m)	2.9	3.7	8.86	8.86	8.86
Control system	Inertial				
First Stage Booster					
Mass of loaded propellant (metric tons)	132.6	128.8	398	663	663
Propellant components	O_2 + RG-1	O_2 + RG-1	O_2 + RG-1	O_2 + RG-1	O_2 + RG-1
Propulsion system thrust (metric tons-force) - on Earth - in vacuum	 196 212.6	 196 212.6	 588 637.8	 980 1063	 980 1063
Second Stage Booster					
Mass of loaded propellant and gases (metric tons)	5.1	25.7	35.7	35.8	41.3
Propellant components	AT + UDMH	O_2 + RG-1	O_2 + RG-1	O_2 + RG-1	O_2 + H_2
Propulsion system thrust (in vacuum) (metric tons-force)	2	30	30	30	42

1.5.3 Performance Ground Rules and Characteristics of the Angara LV

1.5.3.1 Performance Ground Rules

A number of standard mission ground rules have been used to develop the referenced Angara performance capabilities identified in this document. They have been identified in this section.

1.5.3.1.1 Payload Systems Mass Definition

Performance capabilities quoted throughout this document are presented in terms of payload systems mass (PSM). PSM is defined as the total mass delivered to the target orbit, including the separated SC, the SC-to-LV adapter, and all other hardware required on the LV to support the payload (e.g., harnessing).

1.5.3.1.2 Collision and Contamination Avoidance Maneuver (CCAM)

The upper stage can perform a variety of maneuvers to minimize the possibility of recontact with or contamination of the SC. The separation event provides a typical relative velocity between the SC and the upper stage of at least 0.3 m/s.

Approximately 1.5 hours after SC separation, the upper stage performs an attitude change maneuver to re-orient the stage. A small propulsive maneuver is made to increase relative velocity between the upper stage and SC. After completion of the maneuver, the upper stage propellant tanks are depressurized and the stage is made inert.

1.5.3.1.3 Performance Confidence Levels

Angara missions are targeted to meet the requirements of each user. Historically, LV missions have been targeted based on a conservative 3-sigma confidence level (or greater) that the mission objectives would be achieved. All Angara performance information contained in this document assumes a 3-sigma confidence level unless otherwise specified.

1.5.3.2 Performance Characteristics

The performance capability for the Angara LV family in terms of PSM for low earth orbits (LEO), standard geosynchronous transfer orbits (GTO), and super-synchronous transfer orbits (SSTO) are provided in Tables 1.5.3.2-1 to 1.5.3.2-9.

Table 1.5.3.2-1: Angara 1.1 LEO Performance Capability

Altitude of Circular Orbit (km)	Payload Systems Mass (PSM) (metric tons)			
	i = 63°	i = 75°	i = 85.8°	i = 93.4°
200	2.00	1.85	1.68	1.58
400	1.87	1.73	1.54	1.47
800	1.65	1.53	1.35	1.27
1100	1.51	1.40	1.22	1.15
1300	1.42	1.32	1.14	1.07
1500	1.34	1.24	1.06	0.99

Note: Time of PLF jettison is t_j = 268 s; $q < 1135$ W/m^2.

Table 1.5.3.2-2: Angara 1.2 LEO Performance Capability

Altitude of Circular Orbit (km)	Payload System Mass (PSM) (metric tons)			
	i = 63°	i = 75°	i = 85.8°	i = 93.4°
200	3.70	3.45	3.25	3.14
400	3.35	3.10	2.91	2.80
800	2.90	2.64	2.46	2.35
1100	2.64	2.40	2.22	2.10
1500	2.34	2.09	1.93	1.81

Note: Time of PLF jettison is t_j = 217 s; $q < 1135$ W/m^2.

Table 1.5.3.2-3: Angara A3 LEO Performance Capability for Circular Orbit 200 km Altitude

Launch Vehicle	Payload System Mass (PSM) (metric tons)			
	i = 63°	i = 75°	i = 85.8°	i = 93.4°
Angara A3/Breeze M	14.1 (14.6)*	TBD	TBD	TBD

Notes: Time of PLF jettison is t_j = 220 s; $q < 1135$ W/m^2.
*The value in parentheses was determined for time of PLF jettison t_j = 217 s and $q > 1135$ W/m^2.

Table 1.5.3.2-4: Angara A3/Breeze M GTO Performance Capability

ΔV_{SC} for Transfer to GSO (m/s)	GTO Parameters: $\omega_p = 0°$, H_a = 35,786 km		Payload Systems Mass (kg)
	i (deg)	H_p (km)	
600	7	16,600	1435
700	8.2	14,400	1530
800	9.7	12,600	1630
900	11.3	11,000	1730
1000	13.1	9600	1830
1100	15.0	8300	1940
1200	17.0	7200	2050
1300	19.0	6100	2160
1400	21.1	5100	2280
1500	23.3	4200	2405
1600	25.7	3400	2530
1700	28.3	2700	2650
1800	31.0	2100	2770
1500	25.0	5500	2400

Note: PLF diameter = 4350 mm; $q < 1135$ W/m^2.

Table 1.5.3.2-5: Angara A3/Breeze M Performance Capability to Super-Synchronous Transfer Orbit

Delta-V to GSO (m/s)	Inclination (deg)	Perigee Altitude (km)	Payload Systems Mass (kg)	Injection Time (hours)
Apogee Altitude of 50000 km				
1500	25.15	3950	2420	11.6
1600	28.5	3100	2540	
1700	32.0	2300	2665	
1800	35.7	1600	2795	
Apogee Altitude of 60000 km				
1500	26.4	3700	2505	13.6
1600	30.4	2800	2630	
1700	34.6	2000	2755	
1800	39.2	1300	2890	
Apogee Altitude of 70000 km				
1500	27.6	3500	2570	15.6
1600	32.3	2500	2695	
1700	37.3	1700	2825	
1800	42.7	1000	2960	
Apogee Altitude of 80000 km				
1500	28.9	3300	2620	17.8
1600	34.2	2200	2750	
1700	40.05	1400	2880	
1800	46.3	700	3020	
Apogee Altitude of 90000 km				
1500	30.2	3100	2665	20.1
1600	36.1	1900	2795	
1700	42.8	1100	2925	
1800	50.1	500	3065	
Apogee Altitude of 100000 km				
1500	31.5	2900	2700	22.4
1600	38.1	1600	2830	
1700	45.75	830	2965	
1750	49.7	500	3035	
Perigee argument is 0°. Maximum FMH after payload fairing jettison on 3-sigma qV < 1135 W/m^2. Payload mass includes the SC mass and the mass of an adapter. Performance evaluated based on 2.33-sigma confidence level that mission objectives will be accomplished.				
The delta-V to GSO values quoted in this table include approximately 15 m/s delta-V to account for inefficiencies during SC transfer from the point of separation to GSO.				

Table 1.5.3.2-6: Angara A5 LEO Performance Capability for Circular Orbit 200 km Altitude

Launch Vehicle	Payload System Mass (PSM) (metric tons)			
	$i = 63^\circ$	$i = 76^\circ$	$i = 82.5^\circ$	$i = 93.4^\circ$
Angara A5	23.8 (24.5)*	22.9	22.3	21.4

Note: Time of PLF jettison $t_j = 340$ s; $q < 1135$ W/m^2.
* The value in parentheses was determined for time of PLF jettison $t_j = 230$ s and $q > 1135$ W/m^2.

Table 1.5.3.2-7: Angara A5/Breeze M GTO Performance Capability

ΔV_{SC} for Transfer to GSO (m/s)	GTO Parameters: $\omega_p = 0^\circ$, $H_a = 35{,}786$ km		Payload Systems Mass (PSM) (metric tons)
	i (°)	H_p (km)	
600	7.0	16,600	3.70
700	8.2	14,400	3.86
800	9.7	12,600	4.02
900	11.3	11,000	4.20
1000	13.1	9600	4.38
1100	15.0	8300	4.58
1200	17.0	7200	4.78
1300	19.0	6100	4.98
1400	21.1	5100	5.19
1500	23.3	4200	5.41
1600	25.7	3400	5.64
1700	28.3	2700	5.87
1800	31.0	2100	6.11
1500	25.0	5500	5.40

Note: PLF diameter = 4350 mm; $q < 1135$ W/m^2.

Table 1.5.3.2-8: Angara A5/KVRB GTO Performance Capability

ΔV_{SC} for Transfer to GSO (m/s)	GTO Parameters: $\omega_p = 0°$, $H_a = 35{,}786$ km		Payload Systems Mass (PSM) (metric tons)
	i (°)	H_p (km)	
600	7.0	16,600	4.75
700	8.2	14,400	4.94
800	9.7	12,600	5.13
900	11.3	11,000	5.33
1000	13.1	9600	5.53
1100	15.0	8300	5.74
1200	17.0	7200	5.95
1300	19.0	6100	6.17
1400	21.1	5100	6.39
1500	23.3	4200	6.61
1600	25.7	3400	6.84
1700	28.3	2700	7.08
1800	31.0	2100	7.31

Note: PLF diameter = 4350 mm; $q < 1135$ W/m^2.

Table 1.5.3.2-9: Angara A5/KVRB Performance Capability to Super-Synchronous Transfer Orbit

ΔV_{SC} for Transfer to GSO (m/s)	Orbital Parameters			Payload Systems Mass (PSM) (metric tons)
	i (°)	H_p (km)	H_a (km)	
1550	63	286	243,000	7.87
1600	63	285	203,000	7.94
1700	63	283	152,000	8.08
1800	63	281	121,000	8.22

Note: PLF diameter = 4350 mm; $q < 1135$ W/m^2.

1.5.4 Payload Injection Accuracy

For the light class LVs injecting a payload into an orbit up to 350 km high, the injection altitude error does not exceed 2% of the altitude or 3 angular minutes in inclination.

For the Angara A3 and Angara A5 LVs with the Breeze M, the accuracy of payload injection into standard orbits is presented in Table 1.5.4-1.

Table 1.5.4-1: Injections Accuracies for the Angara A3 and A5 with the Breeze M

Orbital Parameters	Deviations of Orbital Parameters				
	Perigee	Apogee	Inclination	Argument of Perigee	Period
Circular parking orbit 200 km high	±2.0 km	±4.0 km	±0.03°	-	±3 s
Circular orbit 10,000 km high	±20 km	±10 km	±0.1°	-	±100 s
Geosynchronous transfer orbit, 5500 × 35,786 km, with an inclination of 25.0°	±300 km	±100 km	±0.15°	±0.3	-

Orbital Parameters	Eccentricity	Longitude	Inclination	Period
Geostationary orbit	±0.0075	±0.7°	±0.25°	±550 s

For the Angara A3 and Angara A5 LVs with the KVRB, the accuracy of payload injection into standard orbits is presented in Table 1.5.4-2.

Table 1.5.4-2: Injections Accuracies for the Angara A3 and A5 with the KVRB

Orbital Parameters	Deviations of Orbital Parameters				
	Perigee	Apogee	Inclination	Argument of Perigee	Period
Circular parking orbit 200 km high	±2.0 km	±4.0 km	±0.03°	-	±3 s
Circular orbit 10,000 km high	±20 km	±10 km	±0.1°	-	±50 s
Geosynchronous transfer orbit, 5500 × 35,786 km, with an inclination of 25.0°	±200 km	±100 km	±0.15°	±0.3	-

Orbital Parameters	Eccentricity	Longitude	Inclination	Period
Geostationary orbit	±0.003	±0.7°	±0.15°	±300 s

1.5.5 Injection Schemes

For light class LVs, injection schemes are used that ensure that the jettisoned hardware will fall into specified regions. In this case two basic schemes are possible:

- Direct injection
- Injection with a second-stage coast phase

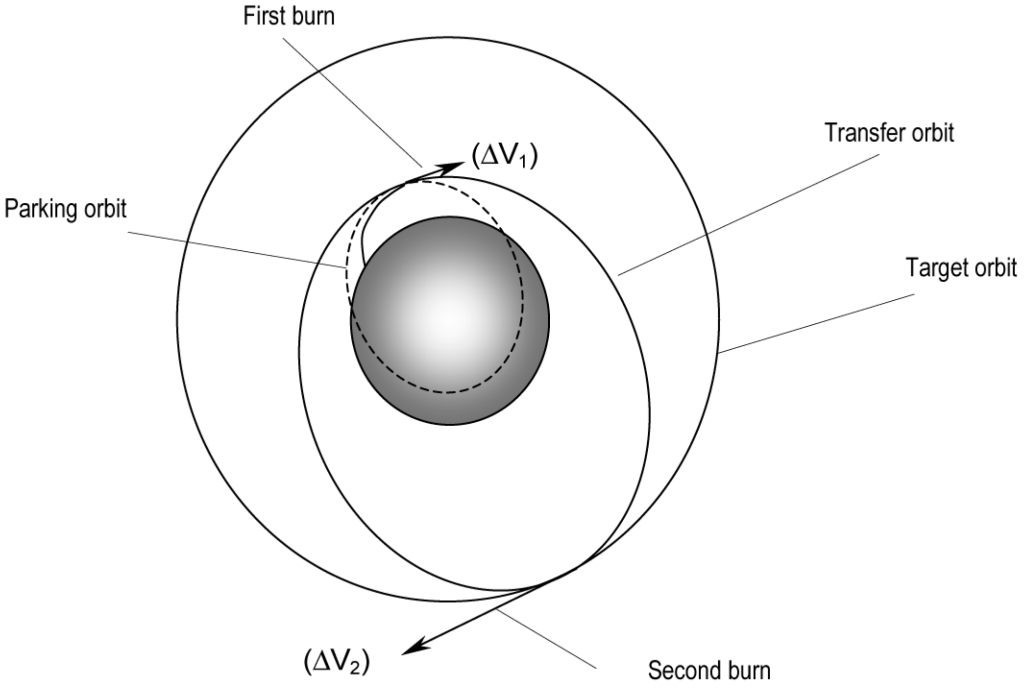
When direct injection is used, the second stage booster has one continuous engine burn, injecting the payload into the specified orbit. For the Angara 1.1, this scheme is applicable for injection to circular obits up to 300 km altitude, and for the Angara 1.2 for circular orbits up to 380 km altitude.

When SC are launched into higher orbits, injection using the second scheme is employed. This scheme presupposes that the first burn of the second stage booster injects the payload into a specified circular parking orbit. The booster, with the payload, coasts in the parking orbit until the second burn. After the second stage booster second burn in the vicinity of the transfer orbit apogee, the SC is transferred to the target orbit. All transfers with one or several coast phases are made in Hohmann ellipses.

For medium and heavy class LVs, direct injection is used to inject payloads into circular orbits up to 250 km altitude. The use of a two-burn scheme is advisable for injection into higher orbits.

The two-burn GSO injection scheme (see Figure 1.5.5-1) for medium and heavy class LVs provides for an upper stage first burn while in the parking orbit, which transfers the SC to an orbit whose altitude is close to that of the required orbit. In this case, the plane can be rotated several degrees. The second burn occurs at apogee of the transfer orbit. When this is done, not only does the velocity of the SC increase, but the orbital plane also turns until it aligns with the equatorial plane.

Figure 1.5.5-1: Two-Burn Insertion Scheme



1.6 DESCRIPTION OF MAIN DESIGN ELEMENTS

1.6.1 Common Rocket Module (CRM)

The CRM (see Figure 1.6.1-1) has a diameter of 2.9 m and is 25.1 m long.

The propellant tanks are designed to store oxidizer and fuel. Spherical helium bottles are mounted on the bottom of the oxidizer tank. The need to ensure maximum compliance with high environmental safety requirements necessitated the use of environmentally clean propellant components: kerosene and liquid oxygen. Figures 1.6.1-2 and 1.6.1-3 show the CRM in various phases of production in the factory. Figure 1.6.1-4 is a series of pictures presenting fabrication of the CRM tank structure.

The intertank compartment houses control system devices, telemetry measurement systems, and power supply units.

The RD-191 main propulsion engine, which can deflect ±8° in two planes, is mounted in the tail section on the bottom of the fuel tank.

Control components that enable communication with the full set of ground handling equipment are located on the end face of the tail section. These control components handle the filling of first stage booster tanks with propellant components, filling of the spherical bottles with helium, thermostatic control of the intertank and intermediate compartments, and power supply to on-board systems.

The lines connecting the LVs to the ground support equipment (GSE) are disconnected 4 minutes before launch by retracting the automatic arms. The connecting lines that run through these electrical connectors are disconnected when the LV rises 20 mm. The pneumatic connections are disconnected by pyrotechnics, and the disconnection is backed up by the rise-off motion of the LV.

The main propulsion system was developed based on the RD-191 rocket engine, which is a one-shot oxygen-kerosene liquid propellant rocket engine with chemical ignition and a turbo-pump system that supplies propellant components (see Figure 1.6.1-5). The engine is built with a circuit that involves afterburning of the oxidizer gas. It is equipped with sensors for telemetry measurements and elements of the monitoring, control, diagnostic, and emergency protection system. The heart of this engine (the combustion chamber, nozzle, turbo-pump unit, automatic controls, etc.) is a component of the Zenit-3SL LV, which has an extensive launch history.

Figure 1.6.1-1: Common Rocket Module

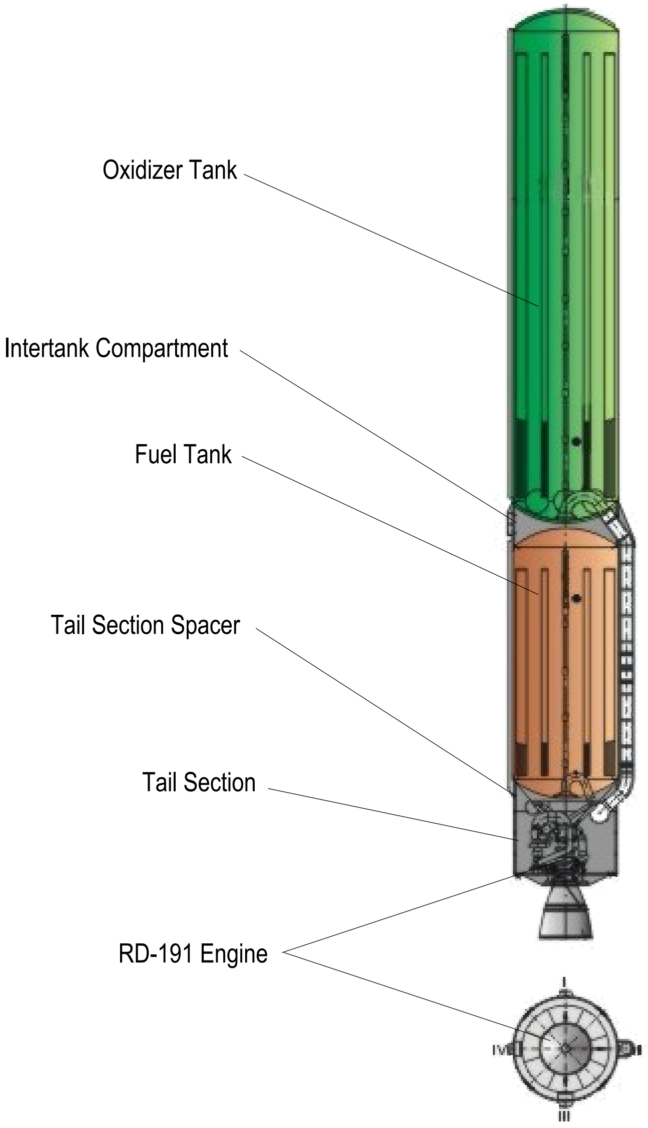


Figure 1.6.1-2: CRM in Assembly Shop

Figure 1.6.1-3: CRM Without Tail Section

Figure 1.6.1-4: Fabrication of CRM Tanks

Figure 1.6.1-5: RD-191 Liquid Propellant Rocket Engine

On the CRM, the RD-191 engine:

- Creates thrust in standard flight mode with the ability to throttle down to 30% of nominal and under conditions of the preliminary and final stages;
- Controls thrust and the propellant mixture ratio in the ranges specified by the control system and the propellant flow control system;
- Creates control moments in the pitch and yaw axes by gimbaling in two planes, and in the roll axis by utilizing the off-axis thrust nozzles;

- Supplies propulsive gasses within specified parameters (gaseous oxygen and heated helium) to pressurize the propellant tanks, and fuel to operate the hydraulic drives;
- Performs shutdown from standard flight mode and final-stage operation; and
- Outputs to the control system signals from the emergency protection system concerning the pre-accident state of the engine so that it can be shut down.

Every commercial engine undergoes checkout and pre-delivery firing tests without subsequent overhaul, but with a cycle of preventive maintenance including thermal vacuum processing of the fuel circuits, soot removal from outside surfaces, and replacement of the starting fuel ampoules and the cables of the telemetry measurement system.

The modifications and operating conditions of the engines for different classes of Angara LVs have some specific features. For the first stage of the Angara 1.1 and Angara 1.2 LVs and the second stage of the Angara A3 and Angara A5 LVs, the engine is equipped with roll control units. The side modules do not have such units. Furthermore, the second stage of the Angara A3 and Angara A5 LVs has a throttle mode (30% of nominal thrust) that lasts up to 160 s.

The basic characteristics of the RD-191 engine are presented in Table 1.6.1-1.

Table 1.6.1-1: RD-191 Basic Characteristics

1	Engine nominal thrust in standard flight mode (metric tons-force)	
	at the ground	196
	in a vacuum	212.6
2	Maximum deflection angle from neutral position, no more than . . . deg	±8
3	Engine dimensions (m)	
	length	3.8
	diameter of nozzle exit section	1.45
4	Probability of accident-free operation during launch processing and in flight, no lower than	0.999

1.6.2 Second Stage Booster

The second stage booster (see Figure 1.6.2-1) has a diameter of 3.6 m and a length of up to 6.9 m. Kerosene and liquid oxygen are used as the propellant components. The propellant tanks are interconnected by the intertank compartment, which houses the instruments and equipment of the control and telemetry system, and carries on its frame the equipment that handles communications between the LV and GSE.

The four-chamber RD-0124A main propulsion engine is mounted on the lower section of the tank and fires after the nozzles extend from the compartment that connects the first and second stage boosters. The stages are separated by the operation of the solid propellant retro-rockets on the first stage booster.

The RD-0124A engine uses a scheme that involves afterburning of the oxidizer generator gas. This engine is a single unit that includes four combustion chambers, the primary turbo-pump unit, booster fuel and oxidizer turbo-pump, a set of starting fuel ampoules for gas generator and chambers, control actuators, automatic control units, and the primary structure (see Figure 1.6.2-2).

As part of the second stage, the engine:

- Generates thrust;
- Controls the propellant mixture ratio in the specified range;
- Creates control moments in the pitch, roll, and yaw axes by turning any of the combustion chambers in one plane;
- Makes possible the final thrust stage;
- Supplies propulsive gasses (heated helium) within specified parameters to pressurize the propellant tanks, as well as fuel for operation of the hydraulic drives;
- Performs shutdown from standard flight mode and from final stage operation; and
- Outputs to the control system signals from the emergency protection system on a pre-accident state in the engine so that it can be shut down.

Every commercial engine undergoes checkout and pre-delivery firing tests without subsequent overhaul.

The basic characteristics of the RD-0124A engine are presented in Table 1.6.2-1.

Figure 1.6.2-1: Second Stage Propulsion System

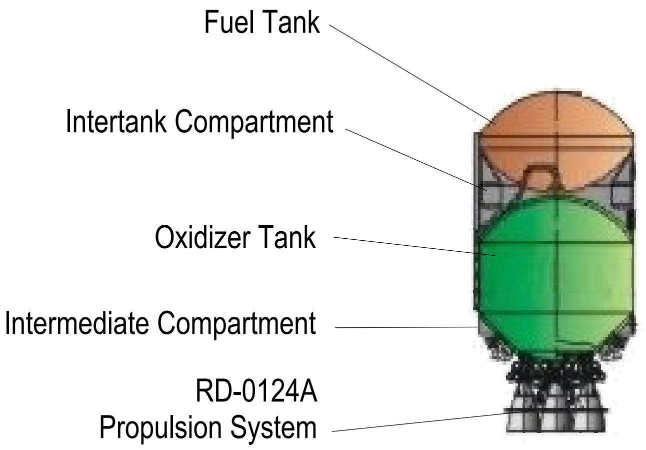


Figure 1.6.2-2: RD-0124A Liquid Propellant Rocket Engine

Table 1.6.2-1: RD-0124A Basic Characteristics

1	Engine nominal thrust in vacuum (metric tons-force) in standard flight mode in final stage operation	 30 18
2	Maximum deflection angle of chambers, no more than . . . deg	±4
3	Engine dimensions (m) length diameter at thermal protective screen	 1.575 2.4
4	Probability of accident-free operation during launch processing and in flight, no lower than	0.995

1.6.3 Control System

The control system of the Angara LV family is being built based on the well-refined design solutions used in the control system of the Proton M LV and the Breeze M. The control system equipment and units in the CRM are common to the entire LV family. In the second stage of the LV, the control system is common with the control system of the Proton M LV.

The on-board control system is self-contained and inertial, and is based on the on-board digital computer system. The structure of the control system uses the modular method for communications between devices; this method allows both system growth and updating of individual control system subsystems while preserving the minimum number of connections between them.

1.6.4 Upper Stages

To satisfy as fully as possible the Customer's requirements for payload delivery to high orbits, including geosynchronous transfer and geostationary orbits, the Angara LV family is compatible with three upper stage options, whose characteristics are presented in Table 1.6.4-1.

Table 1.6.4-1: Upper Stage General Characteristics

	Breeze M Core	Breeze M With Additional Propellant Tank	KVRB (Oxygen-Hydrogen) Upper Stage
Mass of filled stage (metric tons)	6.3	22.47	22.6
Mass of propellant loaded (metric tons)	5.2	19.8	19
Propulsion system thrust (metric tons-force)	2	2	10.5
Dimensions (diameter × length) (m)	2.5 × 2.65	4.0 × 2.65	3.8 × 10.1

The Breeze M (see Figures 1.6.4-1 through 1.6.4-4) is used together with the Angara LVs in two versions: with or without the additional propellant tank (APT). The Breeze M upper stage without the APT is used as the second stage of the Angara 1.1 LV, and as the upper stage of the Angara A3 and Angara A5. The Breeze M with the APT is used with the Angara A3 and Angara A5.

The Breeze M is intended to inject payloads into high-energy orbits (geosynchronous transfer and geostationary orbits). A general view is shown in Figure 1.6.4-1.

The key elements of the Breeze M are:

- The core module;
- The propulsion system;
- Control system devices and equipment; and
- The additional propellant tank.

In addition to these elements, the upper stage includes a propulsion system for stabilization, orientation, and ignition of the main propulsion system.

Figure 1.6.4-5 presents the layout diagram of the KVRB upper stage, which uses liquid oxygen and liquid hydrogen as propellant components. The KVRB is used with the Angara A5 LV. The KVD1M3 liquid propellant rocket engine is used as part of the KVRB.

The fuel and oxidizer tanks are the heart of the fuel compartment. The tanks are separated by spherical bottoms. The cylindrical tank frame has a diameter of 3.6 m. The main propulsion engine and two thruster modules are mounted on the lower, conical section of the fuel tank. The tank compartment and the piping are covered with thermal insulation on the outside.

Figure 1.6.4-1: General View of Breeze M Upper Stage

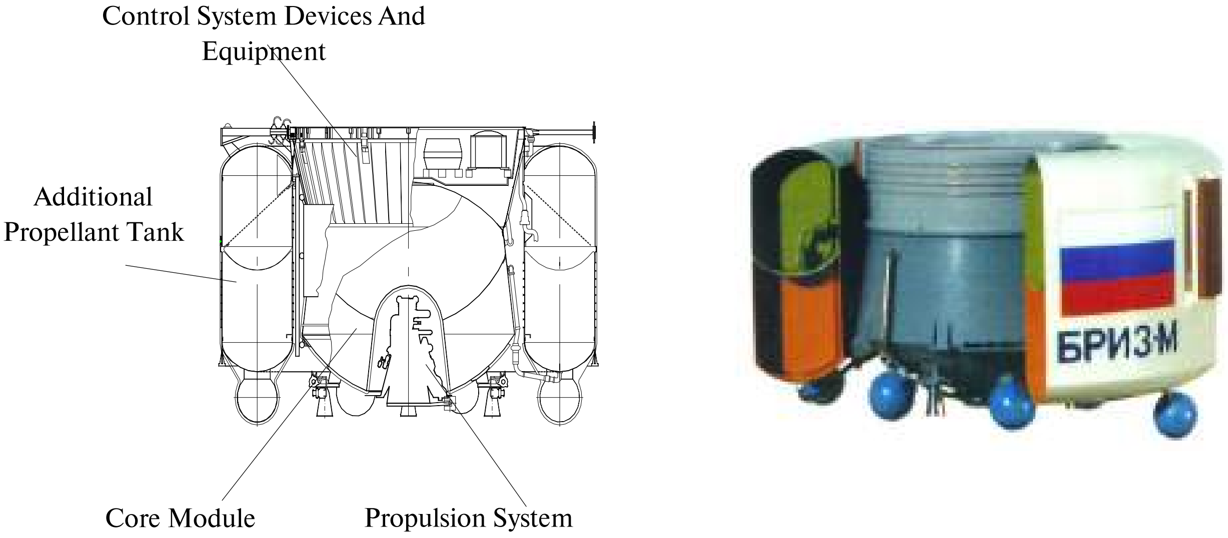
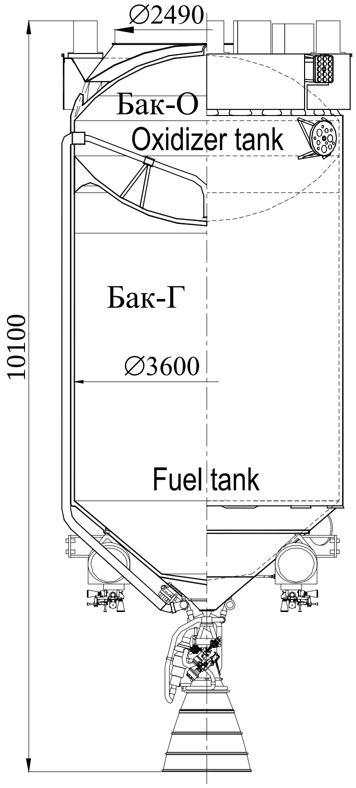


Figure 1.6.4-2: Breeze M Upper Stages in Assembly Shop

Figure 1.6.4-3: Breeze M Upper Stage Without Additional Propellant Tank

Figure 1.6.4-4: Breeze M Upper Stage at Technical Complex

Figure 1.6.4-5: Layout Diagram of KVRB Upper Stage


∅2490
Бак-О
Oxidizer tank
Бак-Г
10100
∅3600
Fuel tank

1.6.5 Payload Fairings

The wide energy capabilities of the Angara LV family allowed the wide range of the PLFs used. They are equipped with devices that maintain the specified temperature conditions inside the PLF, both during transportation and during LV processing at the launch complex.

The dimensional characteristics of the PLFs of the Angara LV family are presented in Table 1.6.5-1.

1.6.5.1 PLF for the Light Class LVs

The Angara 1.1 LV uses the same PLF used on the Rokot LV. At the time of jettison, the PLF separates into two halves on stabilization plane II-IV. The mass of the PLF is 710 kg. A general view of the fairing is presented in Figures 1.6.5.1-1 and 1.6.5.1-2. This PLF is oval in sections perpendicular to the longitudinal axis.

In addition to the PLF shared in common with the Rokot LV, a different fairing may be used on Angara 1.2 (see Figure 1.6.5.1-3).

This fairing includes the basic structure, the thermal control system, the separation system, in-flight ventilation system, telemetry monitoring sensors, and the on-board cable network.

The structure of the PLF has a composite form and a composite design. It is divided along longitudinal plane II-IV into two halves that are interconnected by the mechanical locks of the longitudinal joint. The PLF mates to the adapter spacer by means of the locks of the transverse joint. The LV control system outputs a command to jettison the PLF. Measurement system sensors are installed to monitor environmental parameters.

With consideration for all tolerances, deviations, and deformations that occur during launch processing of the LV and during injection of the SC, the payload must not protrude beyond the permissible zone, except certain points, with respect to which special agreement may be reached between the Customer and KhSC. With consideration for all production deviations of the SC and PLF and their maximum dynamic motions, the gaps between the SC structure and the PLF structure must be at least 50 mm (this value is subject to revision on the basis of the results of a joint analysis).

Table 1.6.5-1: Angara PLFs Dimensional Characteristics

	Angara 1.1	Angara 1.2		Angara A3	Angara A5			
Upper stage used	-	-	Breeze M without additional propellant tank	Br and version witho t upper stage	Breeze M	Oxygen-hydrogen upper stage	Oxygen-hydrogen upper stage	-
Version of PLF	Rokot LV PLF	New development	Rokot LV PLF	Prot LV PLF	Proton M LV PLF	New development	New development	New development
Dimensions of PLF (mm): - diameter - length	 2500 × 2620 6735	 3700 9830	 2500 × 2620 6735	 43 15	 4350 15,255	 4350 16,570	 5100 19,650	 4350 17,175
Mechanical interface with SC (mm)	∅2390	∅2800	∅2390	∅	∅2490	∅2490	∅2490	∅4130

Figure 1.6.5.1-1: General View of Angara 1.1 PLF

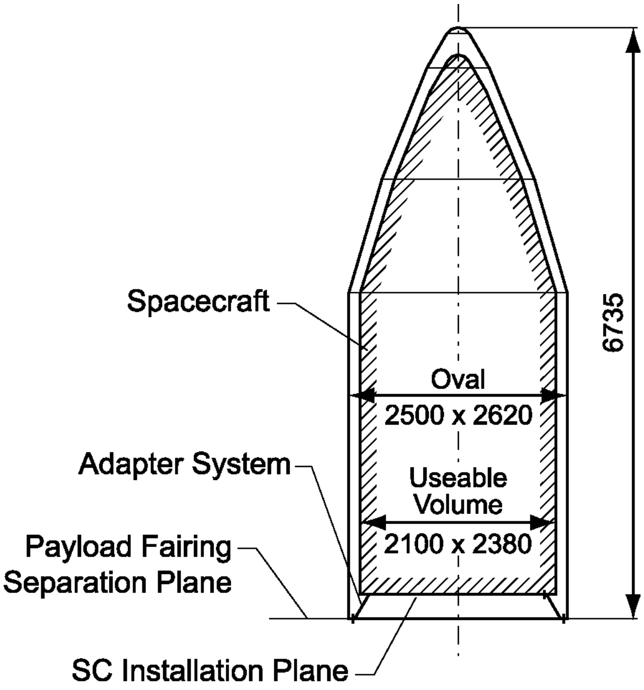
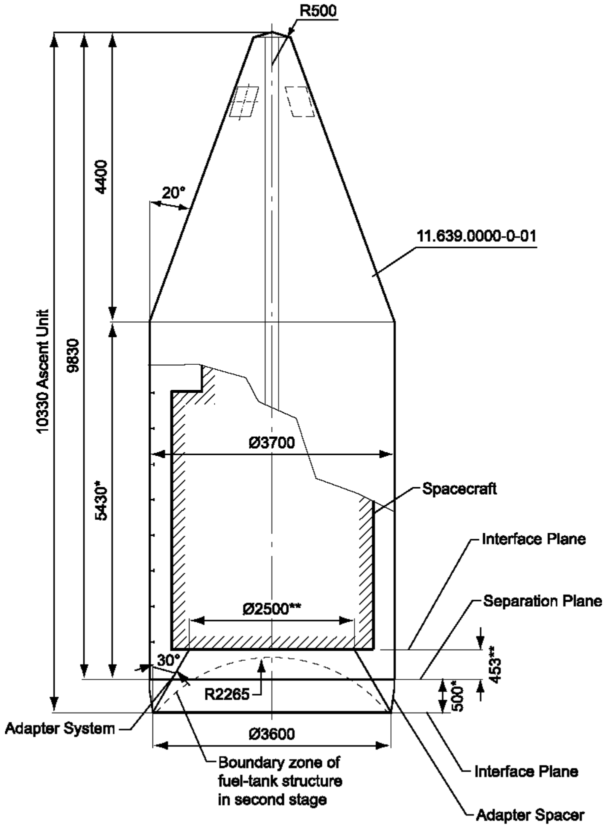


Figure 1.6.5.1-2: PLF on the Ascent Unit of the Rokot LV at the Technical Complex

Figure 1.6.5.1-3: PLF Options for Angara 1.2



* Dimensions for reference.
** Minimum overall dimensions of adapter system.
Note: The dimensions of the SC's adapter system are determined by the specific type of SC.

1.6.5.2 PLF for the Medium Class LV

The PLF for Angara A3 (see Figure 1.6.5.2-1) consists of a structure on which are mounted the separation system, thermal control system, ventilation system, sensors, and the on-board cable network. This fairing is the extended long payload fairing being used on the Proton M/Breeze M LV configuration.

The dimensions of the SC useable volume for the Angara A3 PLF are shown in Figure 1.6.5.2-2.

Geometrically, the structure is a cylindrical frame with a bi-conical nose section that terminates in a spherical curve.

Structurally, the fairing body is a composite tri-layer structure consisting of multi-layer skins of carbon-fiber-reinforced plastic and a honeycomb aluminum filler. A thermal protective coating is applied to the outside surface of the nose and top cylindrical parts of the PLF. If necessary, access doors for servicing the SC may be cut into the shell of the fairing, and radio-transparent windows also can be installed.

Figure 1.6.5.2-1: PLF General View for Angara A3

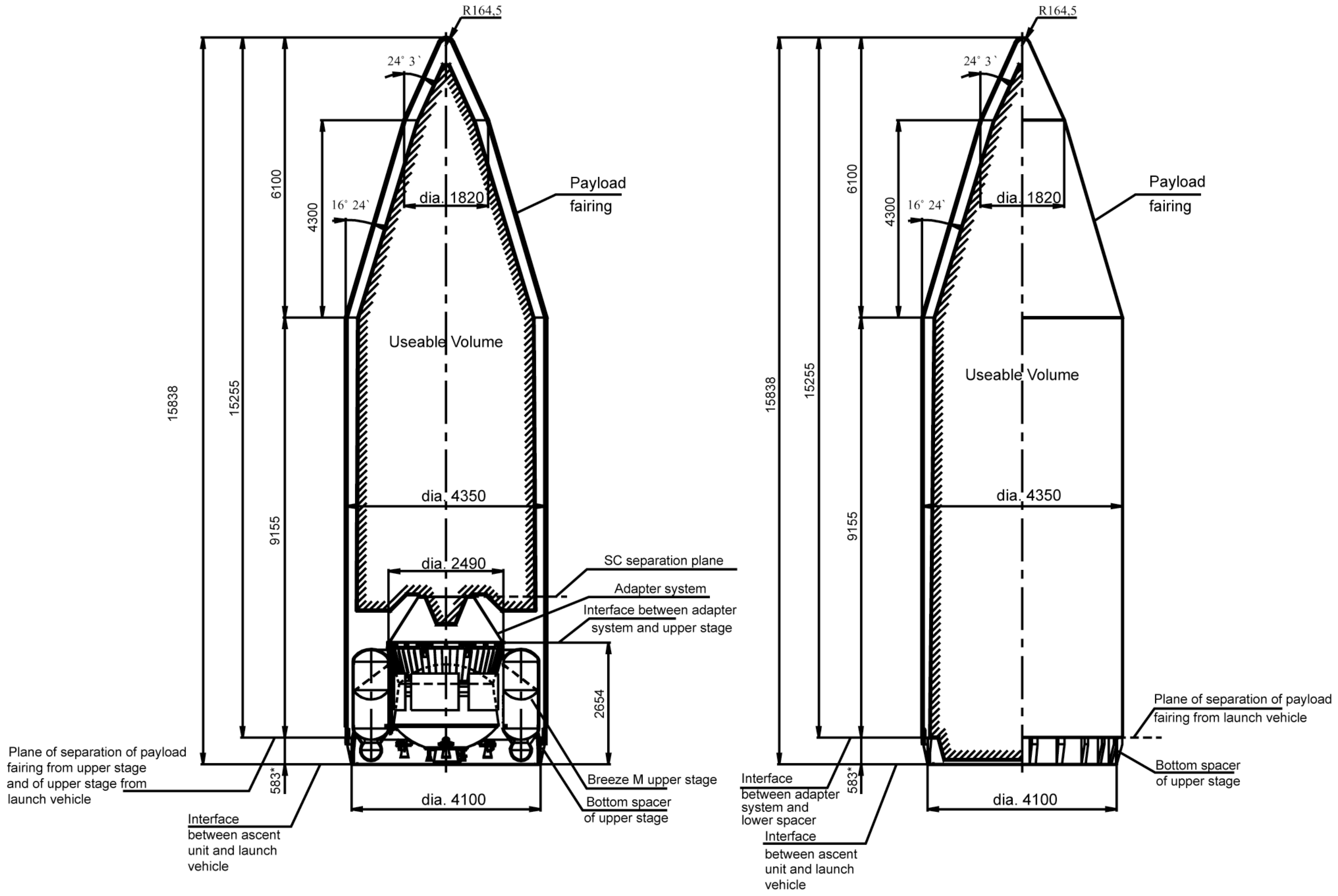
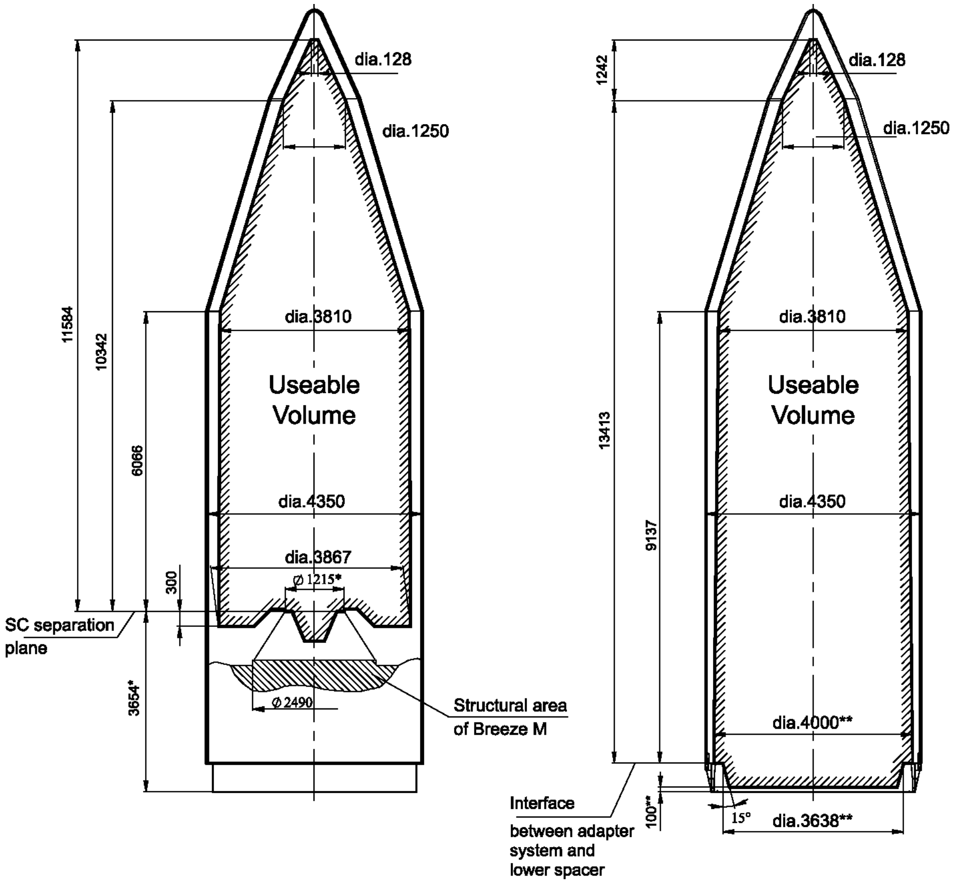


Figure 1.6.5.2-2: SC Useable Volume for Angara A3 PLF



* Dimensions for reference.
** The dimensions will be revised on the basis of the results of design analysis.

The necessary temperature conditions at the launch complex are provided by using the air thermal control system.

The necessary pressure level inside the PLF is provided by using the vent ports.

The PLF is separated along longitudinal plane II-IV into two halves that are connected by the mechanical locks of the longitudinal joint. The mechanical locks of the transverse joint are on the lower frame of the PLF and secure the PLF to the adapter spacer.

The PLF is jettisoned with preliminary separation into two halves, which, when acted upon by the pushers, begin to turn relative to the axes in the opening assemblies. When the design angle is reached, the fairing halves lose their kinematic coupling to the spacer.

If necessary, a shortened PLF, 11,600 mm in height (Breeze M standard PLF), can be used on the ascent unit for Angara A3.

The mass of the PLF does not exceed 2600 kg (or 2200 kg for the shortened PLF).

1.6.5.3 PLF for the Heavy Class LVs

The heavy class LV with the Breeze M uses the same PLFs as the Angara A3.

If the KVRB upper stage is used on the heavy class LV, a special fairing is employed (see Figure 1.6.5.3-1). This fairing, which is fabricated by attaching the KVRB fairing to the payload fairing, is mounted on the lower spacer of the KVRB upper stage.

The PLF is available in two versions: cylindrical diameters of 4350 mm and 5100 mm. The dimensions of the payload useable volumes are shown in Figure 1.6.5.3-2. These dimensions were determined based on the use of an adapter system with a height of 1000 mm.

At the Customer's request, radio-transparent windows and SC maintenance access doors may be placed on the fairing. The fairing has two quick-release connectors that allow nitrogen and air purging of the KVRB area and thermostatic control of the SC zone by using air.

The required pressure level under the PLF while at the launch complex is maintained by using the windows of the fire and explosion prevention system, and in-flight by using the drain ports.

The PLF is jettisoned at the transverse joint with the lower spacer, with preliminary separation into two halves along plane II-IV.

If the upper stage is not present in the ascent unit of a heavy class LV (as when oversized SC are injected into low near-circular orbits), the PLF shown in Figure 1.6.5.3-3 can be used.

1.6.6 Adapters and Adapter Systems for Payload Mounting

The adapter systems are intended to maintain mechanical and electrical connection between the SC and the LV (or upper stage).

The SC adapter system for light class LVs is used when the design of the SC does not allow it to be mounted directly on the 2390-mm diameter, on which the openings are positioned on the LV mating ring. In this case, the SC adapter system, whose lower ring mated to the LV on a 2390-mm diameter, is used. The shape and height of the adapter system are chosen in relation to the design features and connectors for the specific SC.

Figure 1.6.5.3-1: PLF Options for Use With the Angara A5/KVRB

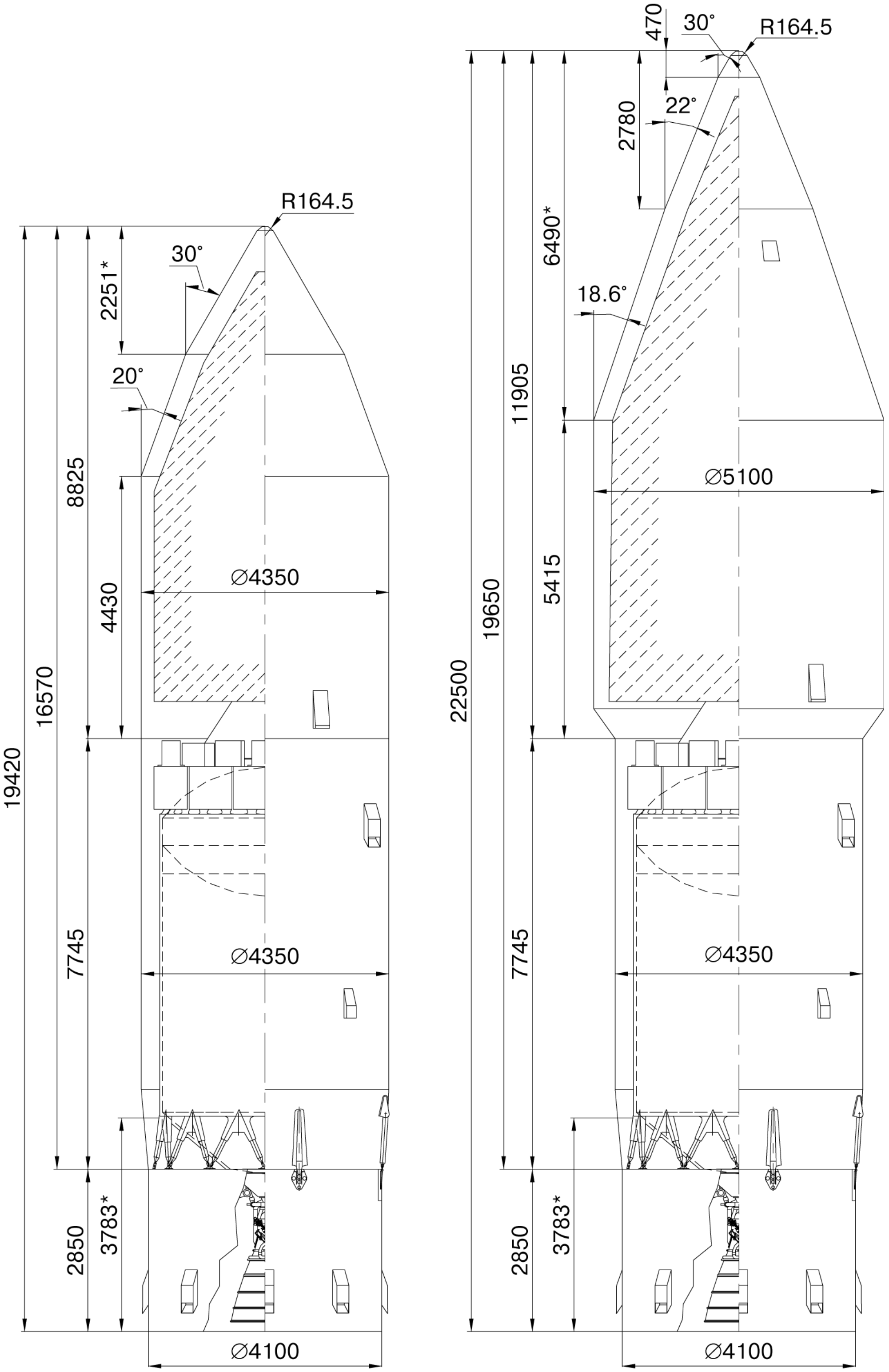


Figure 1.6.5.3-2: Angara A5 PLF - SC Useable Volumes With 4350-mm and 5100-mm Diameters

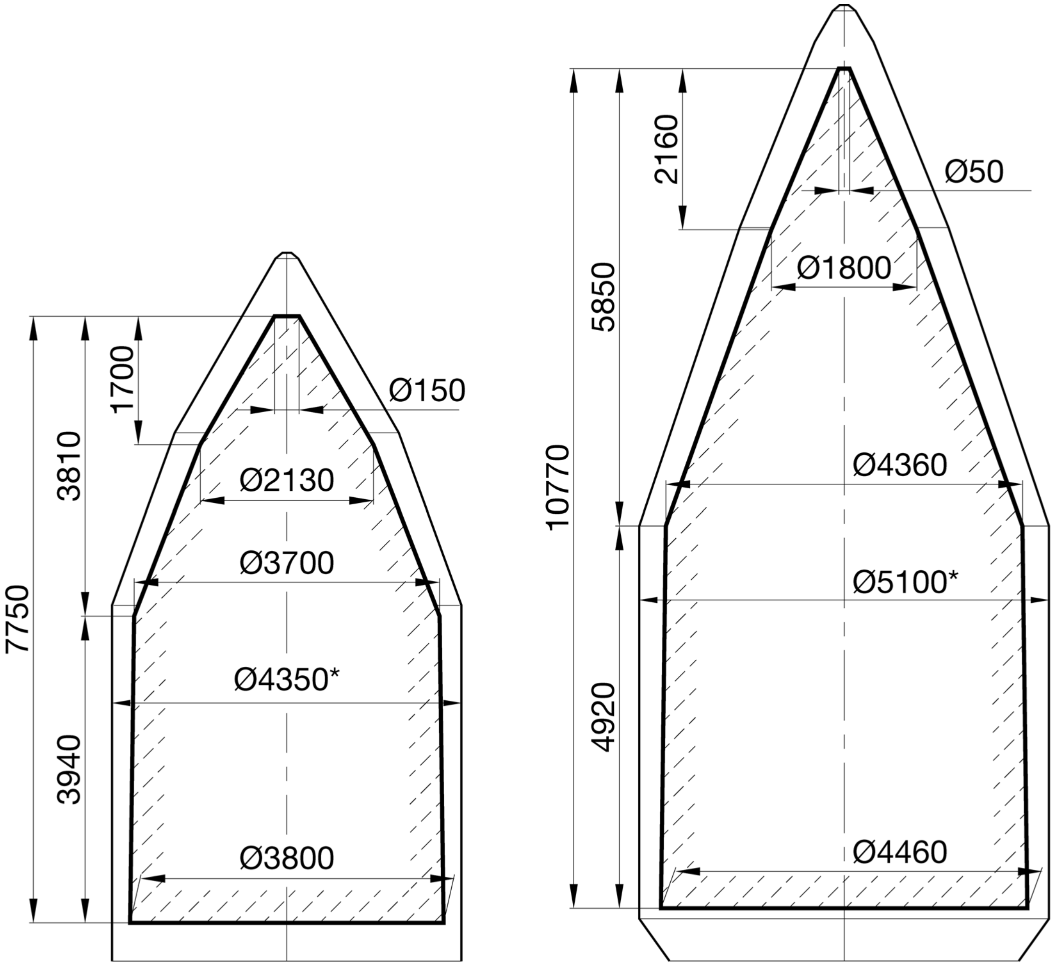
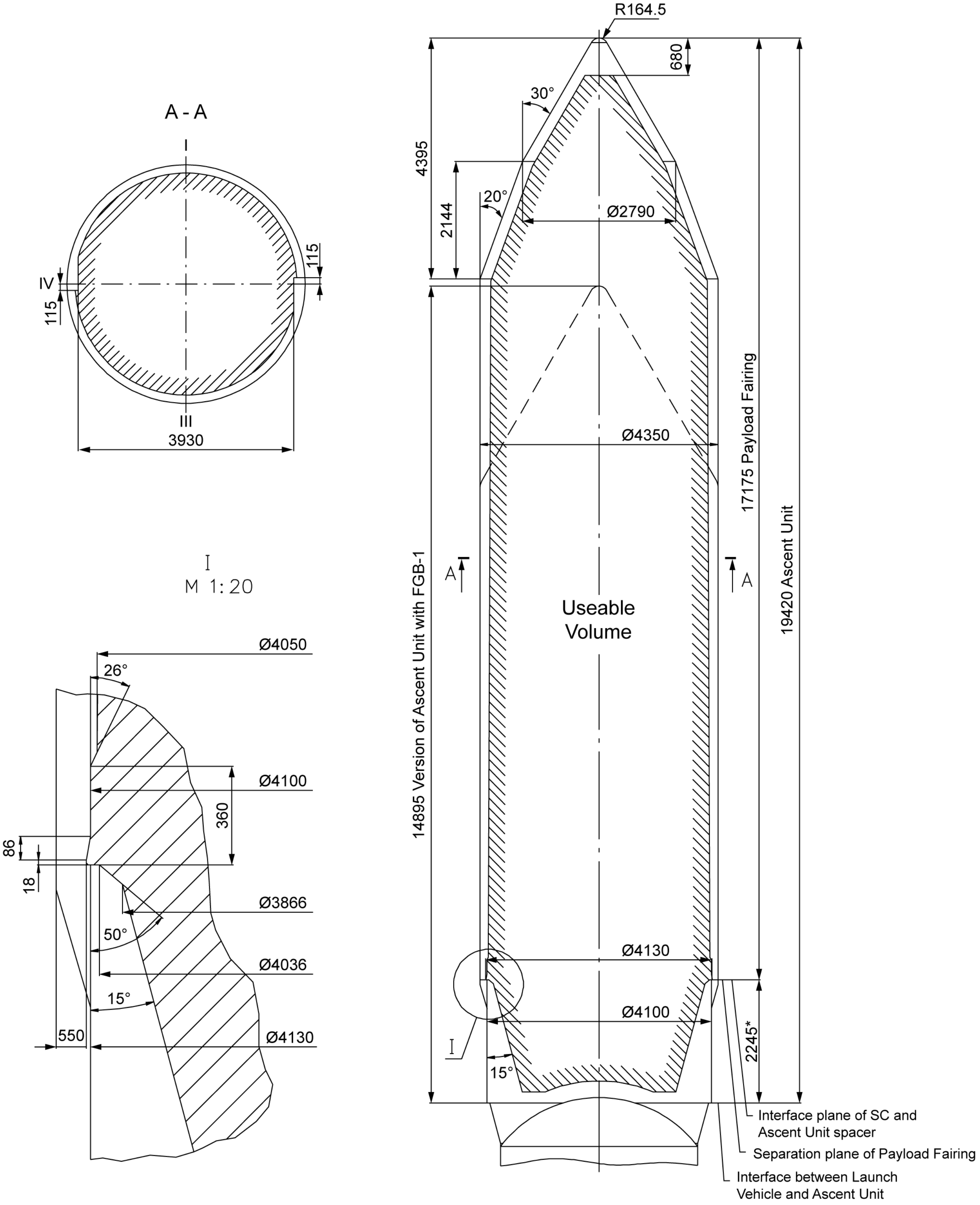


Figure 1.6.5.3-3: Angara A5/No Upper Stage PLF - SC Useable Volume



The design of the adapter system is determined for each specific case of LV use. An example of an adapter system and the design of the mechanical joint between it and the LV second stage booster are shown in Figure 1.6.6-1.

The composition and design of the elements installed on the adapter system are determined with the consent of the Customer for each specific case in which a LV is used.

The SC adapter system is used on the light class Angara 1.2 when the design of the SC does not allow it to be mounted directly on the 3400-mm diameter on which the openings are positioned on the upper stage ring. In this case, a SC adapter system is used in the form of a truncated cone, whose lower ring is mated to the ring of the upper stage at the 3400-mm diameter. The height and cone angle of the adapter system are selected in relation to the design features of the specific SC.

Furthermore, the SC may be mounted on the LV adapter spacer, which mates the LV to the PLF and which has internal beams with openings on a 3400-mm diameter, which are used to mount the SC or the SC adapter system.

In the Angara A3 LV, use also is made of an adapter system when the SC design does not allow the SC to be mounted directly on the 4006-mm diameter (the inside diameter of the adapter spacer). In this case, a SC adapter system is used in the form of a truncated cone whose lower ring is mated to the adapter spacer at a 4006-mm diameter. The height and cone angle of the adapter system are selected in relation to the design features of the specific SC.

If the Breeze M is used, an adapter system is installed whose dimensions and characteristics depend on which SC (Russian or foreign) is mounted on the upper stage.

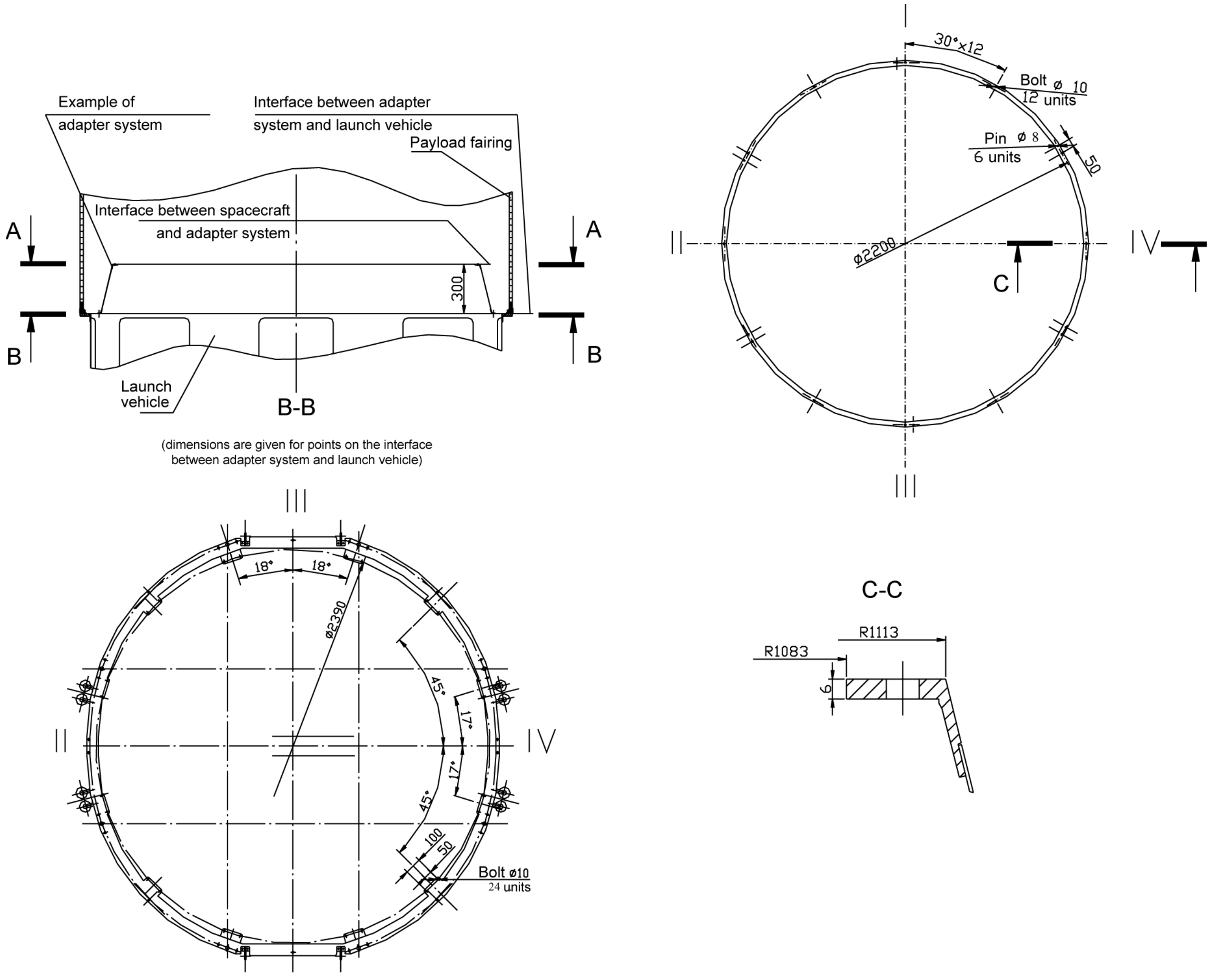
An adapter system 465 mm high generally is used for Russian SC; its lower mating ring has openings at the 2490-mm diameter, and its top mating ring (the joint with the SC) at the 2000-mm diameter.

Either a composite adapter system or a mono-adapter may be used for commercial SC. The dimensions of the adapter system are determined in relation to which standard diameter will be used to mount the SC. The height of the adapter system does not exceed 1000 mm.

The standard adapter system for the Angara A5 consists of the basic structure with the following mounted hardware: the separation system, the passive thermostatic-control system, detachable electrical connectors, and telemetry monitoring system sensors.

The body is a conical spacer made of aluminum alloy with two end rings. The lower ring is mated, by means of bolts and pins, to the upper stage. The SC is secured to the top ring by means of the clampband separation system.

Figure 1.6.6-1: Example of an Adapter System for a Light Class LV



Depending on the requirements of the launch Customer, a separation system with a standard size of 1194 or 1666 mm or with some other standard size specified by the Customer may be used.

To provide the initial impulse upon separation of the SC from the LV, spring pushers are mounted on the top end ring. The number of spring pushers and their forces are determined by the SC separation requirements and consented to by the Customer. A total of up to 12 spring pushers may be installed on the adapter system.

Two brackets with umbilical electrical connectors that provide electrical connection between the SC and the LV are installed on the adapter system structure. The type of umbilical electrical connectors, and the coordinates at which they are installed, are determined with the consent of the Customer.

1.6.6.1 Separation System for a SC With an Adapter System

The following separation system components are used to separate a SC with a LV adapter system:

- Separation assembly;
- Spring pushers;
- Umbilical electrical connectors;
- Bonding elements (two units); and
- Umbilical pneumatic connector.

The circular separation assembly provides a structural mechanical link to the parts being separated up until the time of separation. The assembly comprises a clampband that encompasses the outer conical surfaces of the SC and adapter system rings that are being separated. Separation of the structural mechanical link is performed upon an electrical command received from the KVRB control system. On this command, two diametrically opposed pyro mechanical assemblies (pyro bolt cutters) separate the clampband into two arcs. The arcs are moved back to the periphery and secured in their assigned positions. The umbilical electrical connectors of the bonding elements and pneumatic connector are separated by the movement of the parts being separated.

Separation of the indicated connections is accompanied by the imparting of a relative longitudinal velocity of ~0.6 m/s to the parts being separated by the spring pushers. The conveyance of linear velocity also may be accompanied by transverse stabilization of the SC's spinning (by the same spring pushers) with an angular velocity of no more than ~3 deg/s. Longitudinal stabilization spinning of the SC is possible by using the thrusters of the upper stage.

Depending on the SC design, it is possible to use SC separation aids developed by KhSC, off-the-shelf aids, or aids furnished by the SC developer.

Up until separation, the separation aids for the structural loads can transfer both distributed and concentrated forces between the SC and the adapter system.

The functioning of the separation means of a SC with an adapter system is monitored with circuitry. The use of contact sensors (two units) also is possible.

1.7 BASIC DESIGN PRINCIPLES OF THE ANGARA LV SYSTEM

The main feature of the Angara LV system (LVS) is the modular principle of construction of the LV family. The degree of commonality of key elements of the system is presented in Table 1.7-1.

Table 1.7-1: Angara Modular Design - Key Common Elements

No.	Units, Design Elements and Systems Used to Equip the CRM	Launch Vehicle			
		A1.1	A1.2	A5 (A3)	
				Center Module	Side Module
1	CRM including:	1 each	1 each	1 each	4 (2) each
1.1	Oxidizer tank	+	+	+	+
1.2	Fuel tank	+	+	+	+
1.3	Intertank compartment	+	+	+	+
1.4	Propulsion spacer	+	+	+	+
1.5	RD-191 main propulsion engine	+	+	+	+
1.6	Upper tail section	+	+	+	+
1.7	Lower tail section	+	+	+	+
1.8	Board of oxidizer automatic connection	+	+	+	+
1.9	Board of quick-release connector G-KP	+	+	+	+
1.10	Middle fuselage fairing	+	+	+	+
1.11	Pneumatic and hydraulic delivery system	+	+	+	+
1.12	Air thermal control system	+*	+	+	+
1.13	SPP [*expansion unknown*]	+	+	+	+
1.14	Seats for launch supports	+	+	+	+
1.15	Seats for roll nozzle modules	+	+	+	+
1.16	Fittings for brackets of the lower structural inter-module links (on the tail section) and seats for assemblies of the middle structural inter-module links (on the intermediate module)	+	+	+	+
1.17	Seats for aerodynamic control surfaces	+	+	+	+
2.	Launch supports**	4 units (type 1)	4 units (type 1)	4 units (type 1)	2 units (type 2)

Table 1.7-1: Angara Modular Design - Key Common Elements (Continued)

No.	Units, Design Elements and Systems Used to Equip the CRM	Launch Vehicle			
		A1.1	A1.2	A5 (A3)	
				Center Module	Side Module
3.	Electrical connectors of lift-off switches	2 units	2 units	0	1 unit (for A5 only on side modules I and III)
4.	Roll nozzle modules	+	+	+	0
5.	Aerodynamic control surfaces	+	+	0	0
6.	Structural inter-module connections	0	0	+	+
7.	Boards of umbilical connectors (inter-stage)	Identical for A1.1 and A1.2		Original	Original
8.	Board of umbilical connectors (inter-module)	0	0	+***	+
9.	Seats for assemblies of upper (on front) structural inter-module links (accepted transverse forces)	+	+	+***	+
10.	Brackets for upper structural links (accepted longitudinal forces)	0	0	+***	Original
11.	Seats for boards of umbilical inter-stage connectors	Identical for A1.1 and A1.2		Original	Original
12.	Seats for boards of umbilical inter-module connectors	0	0	+***	+
13.	Solid propellant retrorocket motors	4 each	4 each	4 each	0
14.	Brackets for securing solid propellant retrorocket motors and their fairings	*** Original	*** Original	*** Identical for center modules of A3 and A5	0

Notes:

+ Indicates the presence (and "0" the absence) of the unit or element on the booster made according to unified design documents for the entire LV family.

* Indicates that the air supply line on the A1.1 is throttled above the intertank compartment of the first stage booster.

** Indicates that the "type 1" launch supports are equipped with aligning side stops. "Type 2" launch supports are not equipped with stops.

*** Indicates that the assemblies in question are mounted on the intermediate compartment of the second stage booster.

1.8 ADVANTAGES OF IMPLEMENTING COMMON LV ELEMENTS

The principle for common elements on the LVs and ground complex are the main concept of the Angara LV family, which results in a number of advantages, chief among which are the following:

- Good energy-to-mass characteristics, achieved through the use of highly efficient engines and propellants and modern design principles for the LV control system and components, and through the use of modern technologies for the development and fabrication of key LV elements.

- Adaptability to a wide range of payloads through the extensive use of common elements: LVs, upper stages, adapter systems, and PLFs.

- Reduction of the cost of fabricating LV hardware through an enlargement of the production series for standardized elements (the CRM, second stage booster, control system, PLFs) and the use of thoroughly mastered design and engineering solutions.

- Reduction of the cost of LV launch processing through the use of standard practices in LV launch processing and a high level of as-made completeness of the LV when it leaves for the Cosmodrome.

- An increase in LV reliability due to the use of standard design and engineering solutions that have won broad approval in rocket and space technology already in operation.

- An increase in the environmental safety of LV operation due to the use of environmentally clean propellant components.

- Shortening of the time and reduction of the technical risk of adapting a SC to a LV, due to the use of standard design solutions with a high level of reliability and the use of "standard" solutions to provide mechanical, electrical, and telemetry interfaces and to ensure electromagnetic, electrostatic, and other kinds of compatibility between the SC and the LV.

1.9 RELIABILITY AND QUALITY GUARANTEES

1.9.1 Reliability

Reliability of the Angara LV is the aggregate of the technical properties that assure:

- Readiness for use as intended at the time of arrival of the launch command from corresponding readiness state - the parameter K_r;
- Processing for and execution of LV launch from the corresponding readiness state in the mandated time - the parameter $P(t_{LV})$; and
- Preservation of the operable state of the LV during injection - the parameter P_{af}.

The values of the reliability indices obtained in the conceptual (preliminary) design phase are presented in Table 1.9.1-1.

Table 1.9.1-1: Value of Reliability Indices

Index Name	Index		
	Symbol	A3 Value	A5 Value
1.	K_r	0.98	0.99
2. Probability of processing for and execution of launch in mandated time	$P(t_{LV})$	0.95	0.96
3. Probability of accident-free flight	P_{af}	0.96	0.97

1.9.2 Quality Guarantees

Faults and anomalies in the operation of the LV are prevented by:

- Design of the operating logic of the LV control systems with two-out-of-three redundancy;
- Adequacy of the guaranteed propellant reserves;
- Check of the functioning of electrical, pneumatic, and hydraulic systems in the assembly and test building;
- Joint functional checkout of the readiness state of the LV mounted on the launcher and of the launch complex equipment for filling of the LV with propellants;
- Integrated tests of the control system of the LV mounted on the launcher together with launch complex launch equipment according to the launch and flight timeline, followed by pre-launch analysis of telemetry data;
- Continuous automatic and visual monitoring of the parameters that characterize the technical state of LV systems, throughout the entire processing period; and
- Granting of permission to accept for launch only LV with all monitored systems in good working order.

The quality and reliability of the LV are assured by:

- Incoming inspection of materials, intermediate products, and assembly components;
- Monitoring of the quality of manufacture of units, assemblies, and devices before they are installed on the LV;
- Monitoring of the stability of the parameters of units, assemblies, and devices, as well as monitoring of the stability of production processes;
- Spot checks of every batch of units and periodic tests (after a preset time period) according to an expanded program;
- Pre-delivery firing tests of LV engines;
- Monitoring of the strength and leak tightness of propellant tanks and other tanks and lines operating under gage pressure;
- Integrated electrical checks and monitoring of the leak tightness of the propulsion system with a helium leak detector;
- Designer's oversight of the production and operation of the LV;
- Keeping a record of especially critical operations;
- Recording in the technical certificates (logbooks) of units, assemblies, and the LV whether they meet the requirements of technical documents, with placement of the personal seals of the builder and inspector;
- Use of product marking during production and inspection operations; and
- Statistical assessment of the indices of failure-free operation of design elements and the LV as a whole.

The quality and reliability of design elements of the LV are regulated and are assured by observance, under the oversight of an independent state agency, of the requirements of state and industry standards for quality control, and by the reliability of rocket and space technology, including:

1. The inter-industry Regulation on the Procedure for Creation and Series Production of Rocket and Space Complexes

2. The State Standard for Rocket and Space Complexes, Reliability Assurance and Control

3. The industry standard Launch Vehicles, Reliability Assurance and Control

These standards stipulate the organization and work sequence for creating, carrying out series production, and operating rocket and space technology, and present the qualitative and quantitative attributes that determine the completeness and adequacy of quality and reliability assurance measures.

1.10 GROUND COMPLEX

The ground complex for operation of the Angara LV family includes the technical complexes for assembly of LVs, upper stages, payloads, and ascent units, as well as the universal launch complex.

The ground complex is located at the Plesetsk Cosmodrome in Arkhangel'sk Oblast (see Figures 1.10-1 and 1.10-2), about 800 km (500 miles) north-northeast of Moscow (the geographic coordinates of the Cosmodrome are 62.7° north, 40.3° east).

The climatic conditions of the Cosmodrome are characterized by the following data:

- Mean air temperature: -28°C in winter, +23°C in summer
- Maximum precipitation rate: 0.04 mm/min
- Mean annual precipitation: 398 mm

The Angara LVS is designed for reliable operation in this range of climatic conditions.

All basic infrastructure of the Plesetsk Cosmodrome, including facilities of the ground complex, which is designed to provide the launch support for the Angara LV family, is maintained in accordance with instructions in force within the Russian Federation for the efficient operation and safety of space systems.

The locations of the main facilities of the Plesetsk Cosmodrome that are used to prepare and launch SC with the Angara LV family are shown in Figure 1.10-3.

1.10.1 Technical Complex

The technical complex for the Angara LVS includes:

- LV technical complex
- Unified technical complex
- Technical complex used on an as-needed basis from the Rokot launch support facility

The LV technical complex, located at Area 142 (see Figure 1.10.1-1), is used to prepare Angara. The LV technical complex includes buildings (the assembly and test building, LV storage facility, and auxiliary structures), engineering systems, test and checkout equipment, local handling equipment controls, and test controls.

Figure 1.10-1: Geographic Location and General Site Map of the Plesetsk Cosmodrome

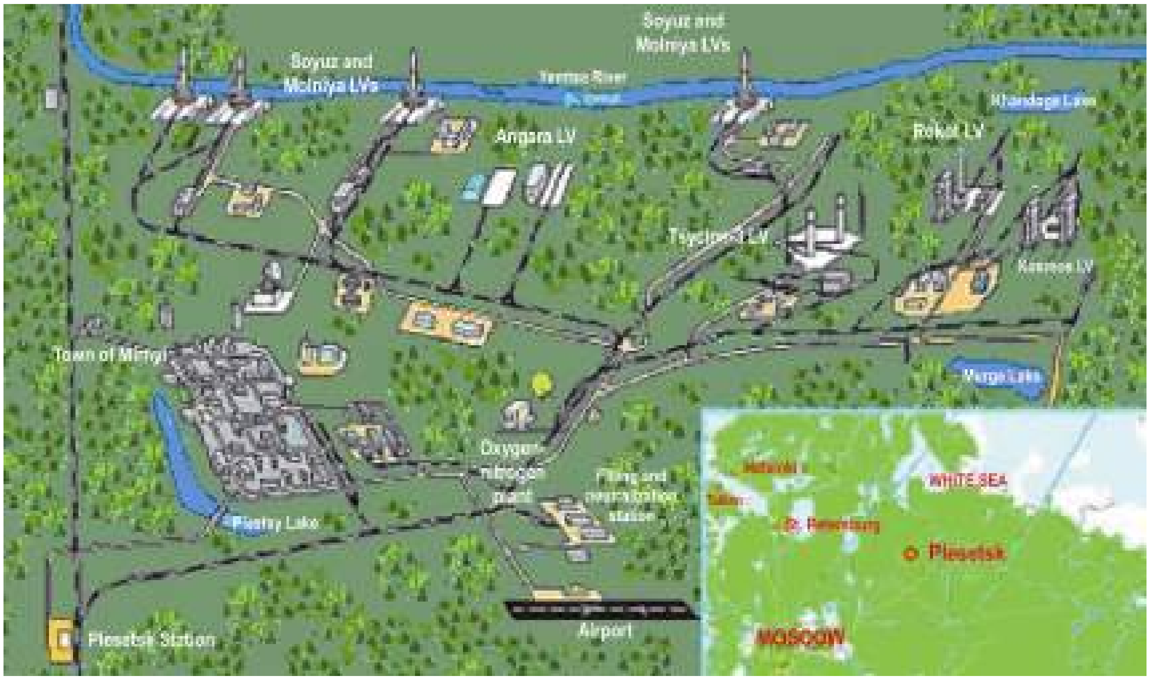


Figure 1.10-2: The Vast Expanses of Arkhangel'sk Oblast

Figure 1.10-3: Plesetsk Cosmodrome - Locations of Main Facilities For Angara Launch Support

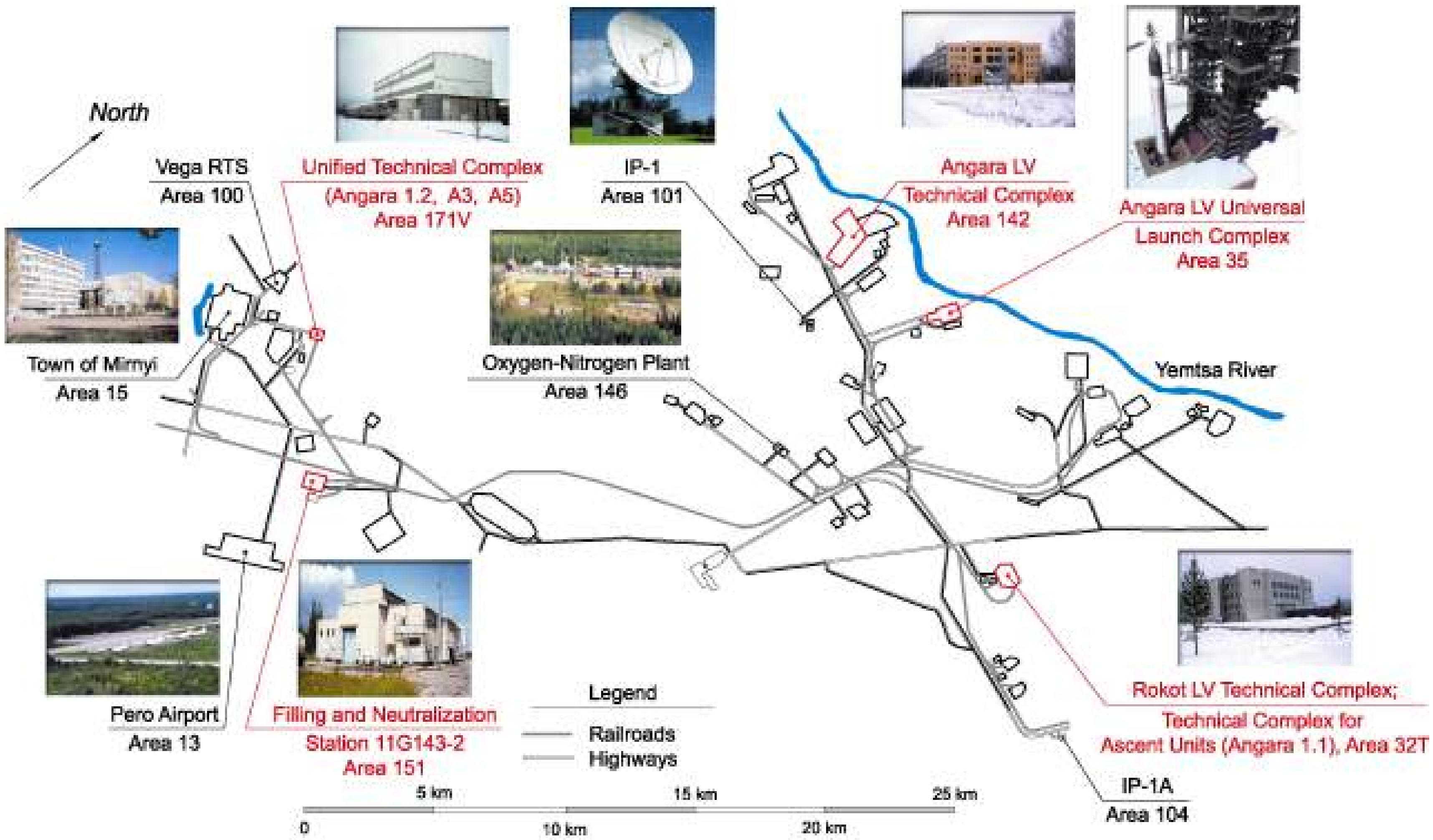


Figure 1.10.1-1: Assembly and Test Building at Area 142

The LV technical complex handles the receiving and unloading of LV stages, LV assembly, checks and tests, mating of the LVs to the ascent units, checking and final operations involving LVs, transfer of these LVs to the transporter/erector, acceptance of LVs from the launch complex, and performance of any work needed in the event of a launch abort.

Processing of SC intended for launch with the Angara 1.1 and Angara 1.2 and of ascent units for these LVs are carried out at the Rokot LV technical complex, which is at Area 32T (see Figure 1.10.1-2).

The unified technical complex is to be built at Area 171V to handle processing of SC and ascent units for the Angara 1.2, Angara A3, and Angara A5 (see Figure 1.10.1-3). The unified technical complex will include complete sets of ground handling equipment and checkout equipment for the Breeze M, the KVRB, and SC; these equipment sets will be built and supplied by the developers of the facilities listed.

Figure 1.10.1-2: Assembly and Test Building at Area 32T - (top) General View, (Lower Left) Main Hall, (Lower Right) Cleanroom (Ascent Unit Assembly Area)

Figure 1.10.1-3: Unified Technical Complex Assembly and Test Building at Area 171V

The assembly and test building at Area 32T and the assembly and test building in the unified technical complex receive and unload the upper stage, SC, and fairing, perform functional electrical and pneumatic tests of ascent unit components and prepare them for assembly, perform ascent unit assembly, conduct joint electrical and pneumatic checks, and receive ascent units in the event of a launch abort.

Ascent units to be assembled with LVs are transported in observance of the required conditions of thermostatic control.

The support complexes for processing and fueling of the SC make it possible to work on the SC utilizing manpower and resources of the SC manufacturer according to SC procedures. Area 32T has all the facilities needed to prepare a SC from the time of its arrival until it is mated to the upper stage (if one is used) and encapsulation. The containers carrying the SC and GSE are delivered to the receiving hall, where they are cleaned, before moving them to the unloading hall. There the containers are opened and the SC unloaded in compliance with cleanness procedures. The unloading and fueling hall has controlled environmental conditions (a temperature of 15 - 25°C, a relative humidity of 35 - 60%, and dust content in the air no worse than class 100,000 per FedStd 209E).

During SC fueling operations, the hall is isolated from other enclosed areas of the assembly and test building by pressurizing special airlocks. There are special rooms for thermal conditioning of fuel and oxidizer prior to fueling.

Additionally, the Area 32T assembly and test building also has a control room, utility rooms, administrative office areas, and a conference hall.

1.10.2 Universal Launch Complex

The universal launch complex is the aggregate of the launch facilities, engineering systems, and handling and support equipment and is designed to receive the Angara LVs, perform pre-launch processing, and carry out the launch. A diagram of the universal launch complex is presented in Figure1.10.2-1 and construction of the universal launch complex is shown in Figure 1.10.2-2.

The delivery of the LV to the launch pad, transfer of the LV to the vertical position, and mounting of the LV on the launch pad are carried out by the transporter/erector. In the erected position, the first stage of the LV are connected to ground handling equipment through the automatic umbilical mating units, which are housed in the launch pad structure, and connect to the receptacles on the bottom of the LV.

The second stage of the LV and upper stage (when used) are connected to the ground handling equipment through quick-release connectors of the cable and fueling tower.

The universal launch complex equipment handles the receiving and mounting of the LV on the launch pad, with mating of lines and connections, thermostatic control of compartments of the LV, SC and ascent unit, checks and safety operations, filling of tanks of the LV and KVRB (if used) and on-board high-pressure tanks. The checkout of the integrated LV control system, launch readiness verification, and launch occur at the pad.

Wind restraint is provided by the restraint devices of the cable and fueling tower. During launch, the cable and filling tower restraints restrain and accompany the integrated LV to a height of 250 mm, after which they are retracted to a safe distance.

In case of a launch abort, universal launch complex equipment handles drainage of propellant from the LV, placement of the LV in the transporter/erector, and evacuation of the LV from the launch complex. When this is completed, thermostatic control of the ascent unit is provided (if necessary).

1.10.3 Processing of the LV Stages at the Ground Complex Facilities

The LV processing at the ground complex is based on the principle of parallel processing of its components (LV stages, upper stage, and SC). During processing phases, preliminary operations, tests, checks, and filling of LV tanks with propellants and compressed gases are carried out at the appropriate technical complex facility. The final operations and testing of the LV and filling of LV propellant tanks are carried out at the universal launch complex.

Figure 1.10.2-1: Universal Launch Complex

Note: 1 = Launcher with launch structure
2 = Command center
3 = Diverters

Figure 1.10.2-2: Construction of Universal Launch Complex

The assembly of the stack comprising the first and second stages (for Angara A3 and Angara A5) and functional checks of the stack or of the first stage for the Angara 1.1 and Angara 1.2 are carried out at the LV technical complex in parallel with the independent processing and functional tests of the upper stage (the second stage for the Angara 1.1 and Angara 1.2, or the third stage for the Angara A3 and Angara A5). Independent processing of the SC and upper stage (if used) is also carried out in parallel.

After the completion of independent processing of the upper stage, the propulsion systems are filled with propellant and compressed gases at the fueling and neutralization station (in the case of processing of the Angara 1.1, the entire second stage is filled). Then the upper stage is returned to the LV technical complex, where the LV is assembled, followed by a check of the mating of the stages, mounting of auxiliary solid propellant rocket engines and pyrotechnic devices, and final operations.

After independent processing, the SC and upper stage also are filled with propellant and compressed gases (if the KVRB is used, only the propulsion system tanks are filled); then the SC and upper stage are mated. After joint checks and mounting of the fairing, the ascent unit (including the SC, upper stage, and PLF) is delivered to the LV technical complex, where it is mated to the LV. After joint checks, the integrated LV (including the LV and ascent unit) is transferred to the transporter/erector and transported to the launch pad. In the cases where Angara 1.1 and Angara 1.2 are prepared, and for some cases in which Angara A3 and Angara A5 are used, the upper stage may not be present.

After the integrated LV is delivered to the launch pad, it is erected on the launch pad, the restraint devices of the cable and filling tower are guided to the LV, and the lines and connections are mated (the break in thermal control of the ascent unit as part of the LV while at the launch pad is no more than 15 minutes). Gyro-compassing of the upper stage (or LV, if there is no upper stage) and input of mission data are carried out in parallel. (see Figure 1.10.3-1)

Figures 1.10.3-2 through 1.10.3-5 show diagrams of the processing of Angara family integrated LVs at the technical complex and universal launch complex.

Figure 1.10.3-1: Transporting Angara A5 LV to the Universal Launch Complex and Erecting on Launch Pad

Figure 1.10.3-2: Processing Diagram of Angara 1.1 at the Technical Complex and Launch Complex

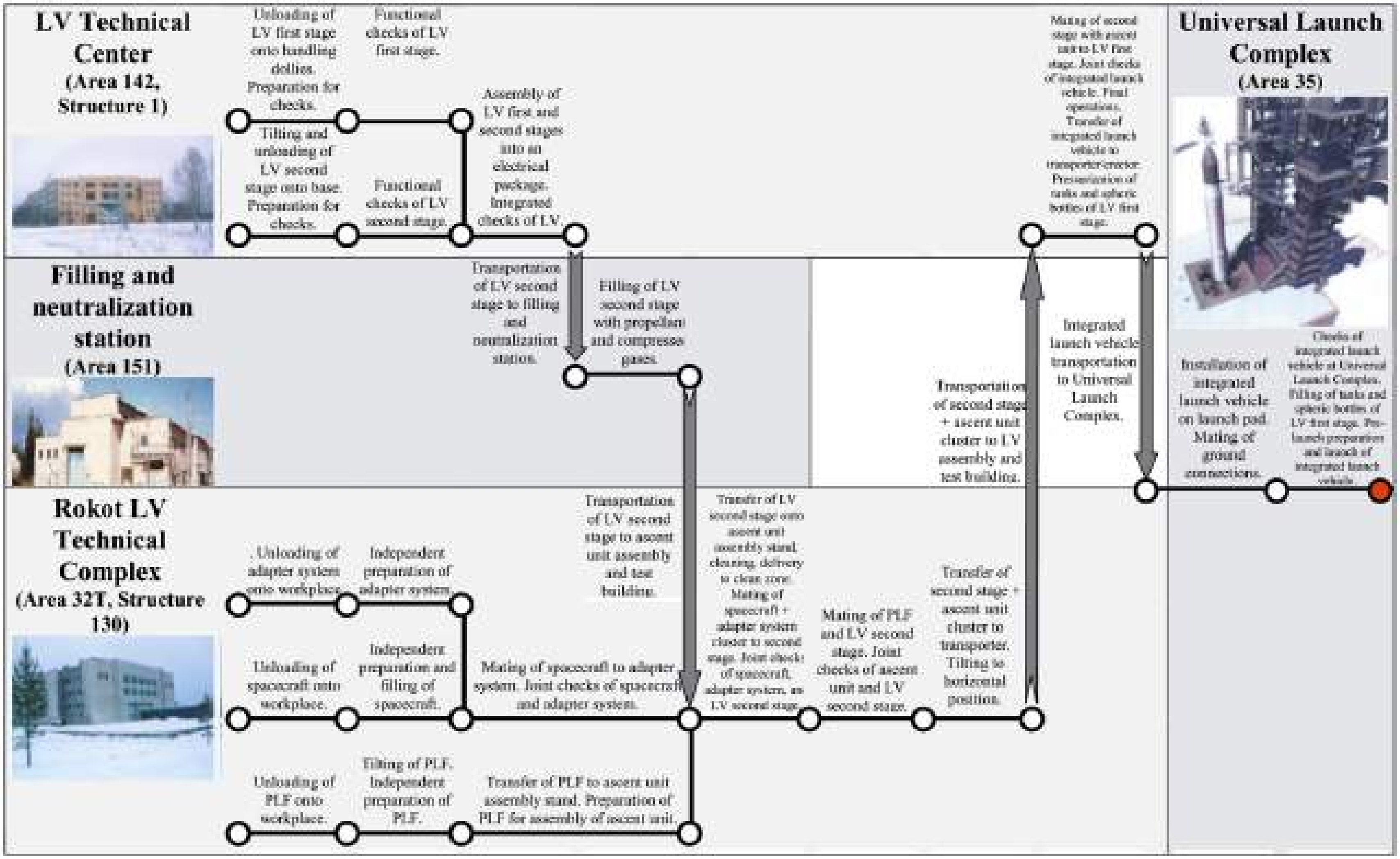


Figure 1.10.3-3: Processing Diagram of Angara 1.2 at the Technical Complex and Launch Complex

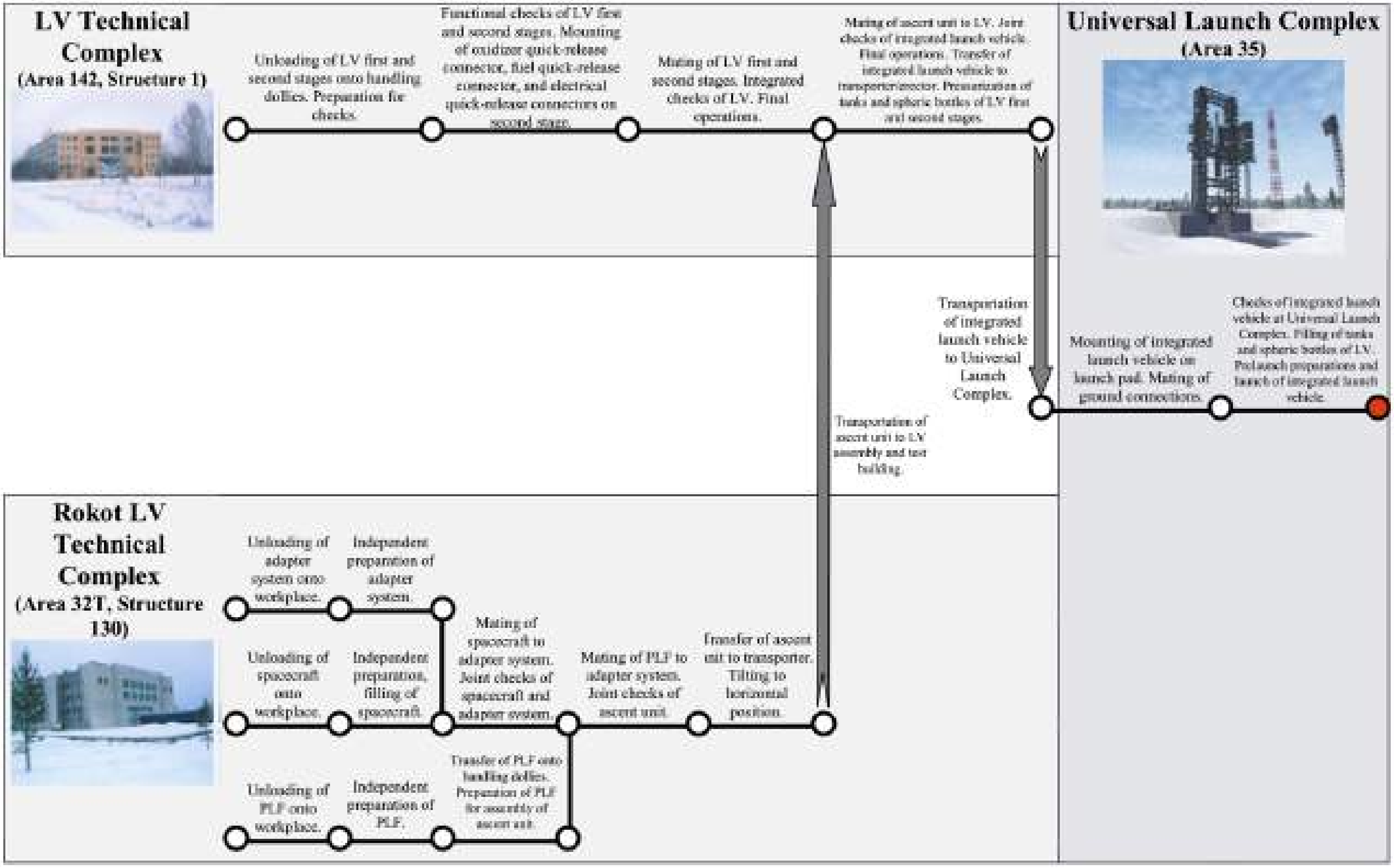


Figure 1.10.3-4: Processing Diagram of Angara 3 with Breeze M at the Technical Complex and Universal Launch Complex

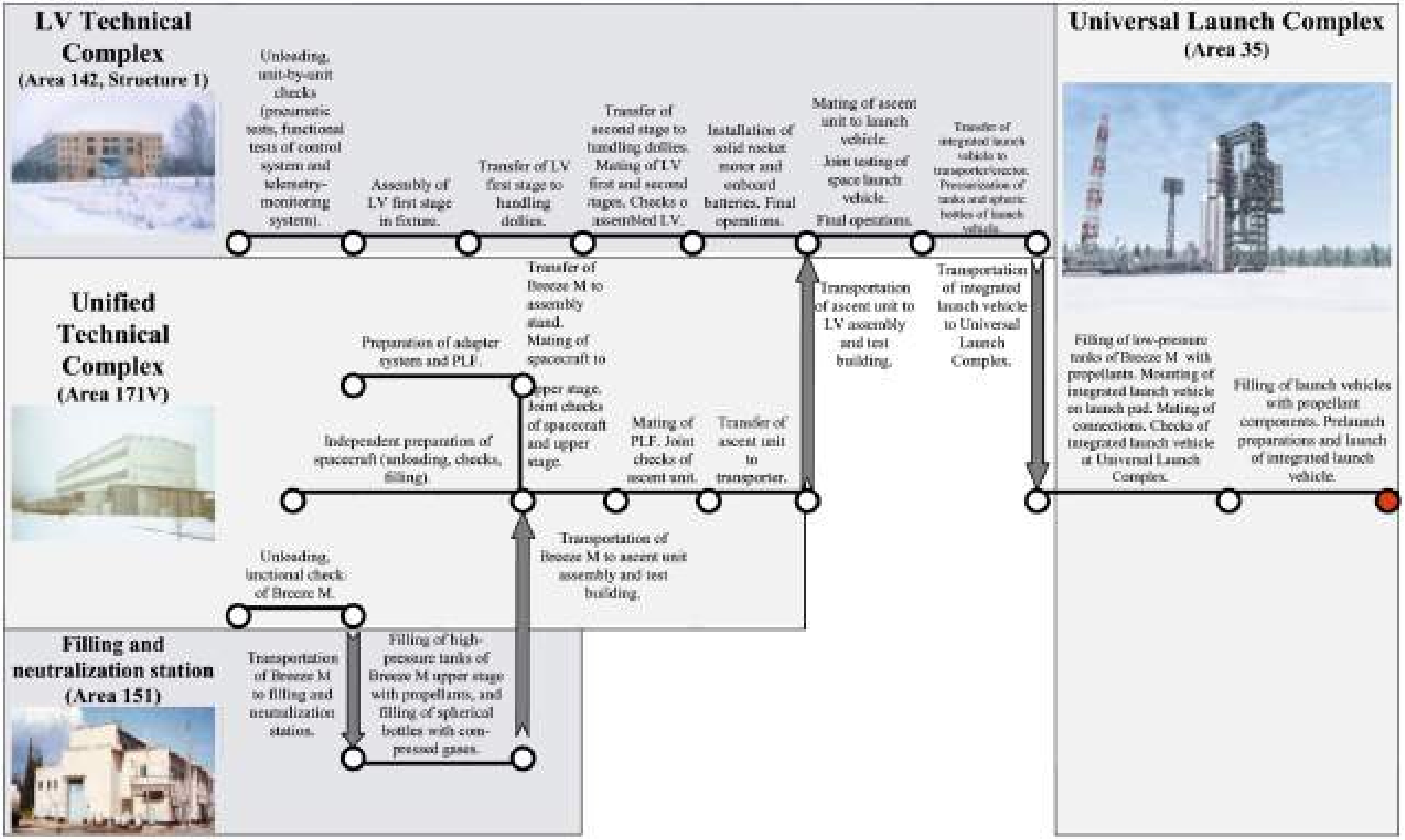
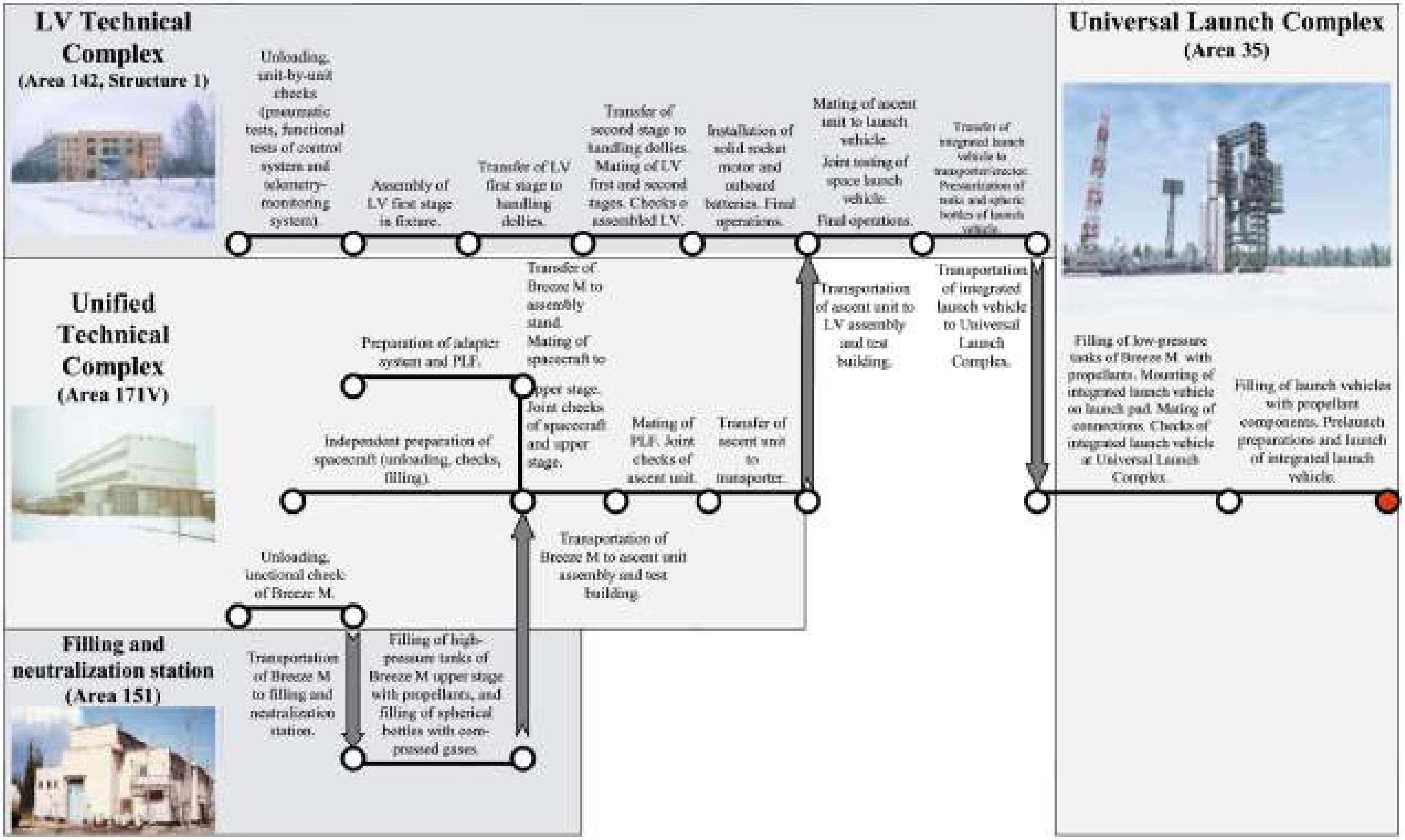


Figure 1.10.3-5: Processing Diagram of Angara 3 with KVRB at the Technical Complex and Universal Launch Complex



1.11 INTEGRATION OF LV WITH SC

The following work is performed during payload integration:

- Delivery of the tested and the fueled SC to the ascent unit processing hall.
- Transportation of the upper stage to the ascent unit assembly hall.
- Mounting of the upper stage in vertical position and performance of upper stage handling operations.
- Mounting of the SC on the adapter system and performance of integrated checks.
- Mating of the SC with the adapter system onto the upper stage.
- Mating of the PLF.
- Transfer of the ascent unit to the transporter.
- Transportation of the ascent unit to the assembly hall for mating to the LV.
- Joint checks on the integrated LV.
- Transfer of the integrated LV to the transporter/erector and transportation of the LV to the launch complex.

Figures 1.11-1 through 1.11-5 show photographs of some of the activities at the technical complex.

A typical work cycle with a Customer takes 24 months for a SC that is being launched on the Angara LV for the first time and 12 months for SC previously launched on the Angara. The cycle begins on a date determined from the launch date specified in the launch contract. Work begins with the preparation of the Integration Control Document (ICD), based on the standard operator document and the Integration Requirements Document (IRD*)*, detailing technical requirements for the launch of a specific SC and characteristics and limitations of the LV.

Launch operations draws up an integrated processing schedule, which the Customer and the operator jointly approve. During project implementation, the necessary hardware (e.g., the adapter, PLF, etc.) is fabricated and tested. Final approval of the integration plan comes 6 months before the planned launch date.

Before the payload and LV are delivered to the Cosmodrome, reviews of the readiness of the payload and LV for these operations are carried out (separately). The readiness of the Cosmodrome's ground complex is reviewed 2 months before the planned launch date.

Figure 1.11-1: Transfer of Upper Stage at the Technical Complex

Figure 1.11-2: Assembly of Ascent Unit in Technical Complex Cleanroom

Figure 1.11-3: Transfer of Assembled Ascent Unit From Technical Complex Cleanroom

Figure 1.11-4: Upper Stage and SC Joint Vibration and Strength Tests

Figure 1.11-5: SC Separation System Tests (If Required)

A specially appointed board of representatives of the operator and the Customer grants permission for transportation of the assembled integrated LV to the universal launch complex (6 days before launch date) for filling of the LV (24 hours ahead of time), and for launch of the integrated LV.

Two months after launch, the operator provides the Customer with a complete report on the launch campaign, the launch, and analysis of the results.

The primary documents on the integration of the payload and LV are the IRD (on the payload side), the ICD, the integration process plan, test reports, records of reviews of phases of the integration process, and reports on test result analysis and launch result analysis.

During preparation and implementation of the payload and LV integration process, meetings are held between representatives and management of the operator and the Customer. During these meetings, the primary documents are examined and approved, the course of phases of the integration process are checked, and decisions to move to subsequent phases are made.

1.12 PLESETSK COSMODROME GROUND SUPPORT INFRASTRUCTURE

The Pero Airport, which is part of the ground support infrastructure of the Plesetsk Cosmodrome, is used to receive aircraft delivering SC and other cargo necessary to carry out launch, and to receive flights carrying personnel involved in the launch campaign (see Figure 1.12-1).

The airport is supported with a complete set of facilities with engineering structures, systems, and equipment that supports the receiving, landing, servicing, parking, taxiing, and takeoff of An-12, Yak-40, An-24, and other airplanes of similar classes with a landing weight of up to 51 metric tons. The approaches to the landing strip are open in both directions. The air situation for the airport's operation meets the requirements of flight operations manuals. Communications with aircraft crews are maintained until on-board systems are shut off after the airplane comes to a stop. The landing strip is 2000 m long with stopways of up to 200 m, and is 40 m wide with safety shoulders 20 m wide. The airport is to be renovated to accommodate the landing of larger airplanes.

The airfield has hoisting and transport equipment, including forklifts and utility cranes. After an airplane is unloaded, the cargo can be placed on vehicles for delivery to other Cosmodrome facilities or for subsequent transfer to rail transport at the station on the branch line 10 km from the airport.

It also is possible for cargo, including SC, to be delivered by air transport to the modern airport in Arkhangel'sk, from which it can be delivered by Mi-26T helicopter to the helipad near the SC technical complex (the SC technical complex is about 45 km from the Pero Airport).

The residential area for personnel involved in the launch campaign is in the town of Mirnyi, which is approximately 15 km from the Pero Airport and about 45 km from the SC technical complex (see Figures 1.12-2 and 1.12-3).

Personnel can live in hotels in the town or at specially assigned multiplexes. The town has a modern infrastructure with a well-developed network of dining facilities and recreation sites. Customer personnel can be delivered to their workplaces by specially assigned vehicles, including passenger cars, minivans, and buses.

All Cosmodrome structures and facilities used in the processing of the Angara LV and their payloads are connected to each other by paved roads and by railways (the track gage is 1524 mm).

Figure 1.12-1: Pero Airport

Figure 1.12-2: Town of Mirnyi - (Left) Entry to the Town and General View, (Right) Center of Town (Zarya Hotel in Foreground)

Figure 1.12-3: Town of Mirnyi

Central Square Of Town

Cultural Center

Orbita Cafe

Lukomor'ye Cafe

KhSC Hotel

Headquarters and Computer Center Buildings

Lake Plestsy

Memorial to Deceased Cosmodrome Testers

1.13 LIST OF CUSTOMER DATA REQUIREMENTS TO BE FURNISHED TO KHSC

Initial data on the SC are needed to perform SC-to-LV compatibility analyses to carry out calculations to determine loads, ballistics, stability and controllability, and to develop a mission integration and launch processing schedule.

1.13.1 Requirements for Orientation of LV Second Stage or Upper Stage

- Accuracy of angular orientation of longitudinal and transverse axes during solar orientation, programmed turns, and so forth.
- Allowable for reorientation to new attitude.

1.13.2 SC Orientation Requirements

- Maximum values of angular velocities and angular accelerations in all flight phases.
- Rate of programmed turns with respect to the three-body axes.

1.13.3 Characteristics of Isolated SC as a Dynamic System

- Mass and inertia characteristics of “dry” and filled SC, and their tolerances.
- Geometry, placement, and fill level of tanks.
- Model of fluid hydrodynamics in tanks for active injection phases.
- Model of fluid dynamics in coast phases.
- Parameters of propellant components (density, viscosity, temperature).
- Model of the dynamics of the SC as an elastic body.
- Model of fluid dynamics in the SC on SC separation.

1.13.4 Materials on Injection Dynamics

- Parameters of the pendulum model of propellant sloshing in SC tanks on active flight phases, including the amount of damping and the maximum amplitude of sloshing when the linear model is used (for calculations of injection dynamics).
- Mathematical model of SC motion with consideration for the liquid in its tanks on flight phases with a low or transient load.

1.13.5 Requirements for SC Separation Process

- Relative position of coordinate systems of SC and LV.
- Injection orbit parameters and their accuracy.
- Accuracy of angular orientation of orbital module at time of separation with respect to angles and angular velocities.
- Accuracy of angular orientation with respect to angular rotational velocities of the SC after separation from the upper stage; the timeline for separation of the SC from the orbital module.
- Restrictions on angular accelerations or loads in the separation process.
- Accuracy of orientation of SC antennas [during] passive motion (uncontrolled) after separation of the SC, with an indication of the radiation pattern of the SC antennas, the position of the SC antennas, and the allowable deviation of the longitudinal axis of the SC from the specified direction for which ground control stations can enter into communications with the SC.

1.13.6 Materials on Separation Hardware

- Disposition and parameters of SC separation system: spring pushers and electrical connectors, with tolerances.
- Coordinates of critical points at SC separation.

1.13.7 Materials on Aerodynamics and Heat

- Allowable value of rate of decrease of pressure under PLF.
- Maximum value of aerodynamic heat flux to SC after jettisoning of PLF.
- Requirements for allowable level of mass flow of contaminant fractions onto SC.
- "Archimedean" volume of SC.

Notes:

When ascent units that differ in their external lines from the standard ones used in LV development are mounted on the LV, additional work is needed on aerodynamics, ballistics, and assurance of the stability, controllability, and strength of the LV as a whole, the stages, and separable elements. Similarly, when the PLF is jettisoned at altitudes below 80 km and the SC separates at altitudes below 200 km, additional work must be done on aerodynamics, ballistics, and the stability and controllability of the corresponding stages of the LV, SC, and separable elements.

The geometry of the ascent unit with all external superstructures and the detailed geometry of the SC and separable elements, as required for the purposes stated, are submitted to KhSC by the manufacturer of the ascent unit and SC; the necessary aerodynamic characteristics of the ascent unit, SC, and separable elements also are supplied by the manufacturer of the ascent unit and SC (obtained by calculation and confirmed experimentally to the extent agreed to by KhSC) or may be obtained directly by KhSC within the framework of additional work on the theoretical and experimental development of the LV.

In aerodynamic heat flux calculations, KhSC uses the upper atmosphere model according to the Russian standard. If necessary, the calculations can be performed by using an upper atmosphere model provided by the SC manufacturer.

1.13.8 Materials on SC Thermal Conditions

- Requirements for thermal conditions of the interface in flight.
- Simplified thermal model of the SC reflecting the thermal load of the SC on the interface between the SC and the adapter system.

The document titled Requirements for Spacecraft Thermal Model During Integrated Thermal Analysis Including the Proton LV, LKET-9704-0206, created with the joint participation of KhSC and ILS, can serve as the format template for the thermal model.

1.13.9 Requirements for Environmental Parameters Around SC

- According to the ICD with regard to the requirements for environmental parameters around the SC — temperature, relative humidity, and allowable air flow velocity near SC elements in all stages of ground processing of the SC for launch — must be presented in the format provided in Table 1.13.9-1.
- Thermal model of the SC in the format specified in LKET-9704-0206 and consented to by ILS.

Table 1.13.9-1: SC Environmental Parameters

Phase of Processing	Temperature (°C)		Humidity (%)		Means of Assurance
	Min.	Max.	Min.	Max.	
Air transport to Cosmodrome					Container
Vehicular transport to technical complex					Container
In SC processing and filling area					Technical systems of structures
In booster module and LV integration area					Technical systems of structures
Transportation of SC as part of LV to launch complex					Thermal control unit
Mounting at launch complex					There is no active thermal control for ≈0.5 hr until ground air thermal control system is connected.
Processing at launch complex before tra					Air thermal control system
Pro transporter/erector is removed					Air supply through cable and filling tower
Launch abort					There is no active thermal control for ≈0.5 hr until ground air thermal control system is connected.

1.13.10 Materials on Procedures for Independent and Joint (With LV) Processing of SC at Technical Complex and Launch Complex

- Composition and amount of equipment to be delivered, and requirements thereof.
- Overall cycle of SC processing at technical complex and launch complex.
- Scope and duration of operations related to unloading and installation of SC and equipment onto workplace.
- Scope and duration of functional testing of SC.
- Scope and duration of SC filling.
- Scope and duration of work during joint operations on ascent unit assembly.
- Scope and duration of work during joint operations on mating of ascent unit to LV.
- Scope and duration of work involving SC at launch complex.
- Timeline (cyclogram) for charging of SC batteries at technical complex and launch complex.
- Timeline (cyclogram) for operation of SC RF link.
- Basic work requirements.

1.13.11 Environmental Safety Requirements

- Environmental safety in all phases of SC operation, including cases of non-standard and emergency situations, must be assured by the design of the SC, the selection of environmentally clean structural and consumable materials and propellant components, operating procedures, and technical and organizational measures.
- The concentrations of vapors and gases of toxic substances released in all phases of ground processing and operation of the SC must not exceed the mandated values (GOST V 29.06.011-89, GOST V 29.06.007-85, GOST 12.1.005-88, GOST V 21116-75, GOST V 21118-75, GOST V 23185-78, GOST V 21186-78, GOST V 29.06.004-84, GOST, SN-245-71, OTT 2.1.86).
- Tanks intended to collect liquid waste from fuel and oxidizer used to fill the SC must undergo neutralization prior to reclamation or reuse.
- In all phases of SC processing and operation, electromagnetic radiation must not exceed mandated values (GOST 12.1.002-84, GOST 12.1.006-84, GOST 12.1.045-84, GOST V 21953-76).
- The SC must ensure the timely submission to KhSC of the initial data for assuring that the LV passes State Environmental Expert Review.

1.13.12 Electromagnetic Compatibility Requirements

An analysis of the electromagnetic compatibility of the LV and SC (payload) is performed for every launch.

The Customer (SC contractor) must submit data on the SC radiation during processing of the SC at the technical complex, during ground operations at launch, and in flight up until separation from the LV. Data also must be provided on the maximum allowable irradiation of the SC by radio frequency radiation (on the SC susceptibility to electromagnetic radiation).

The LV contractor must provide the characteristics of electronic aids mounted on the LV and the electrical field strengths generated by the LV and launch equipment.

The characteristics of the SC electronic aids must be furnished in tabular form (per Table 1.13.12-1).

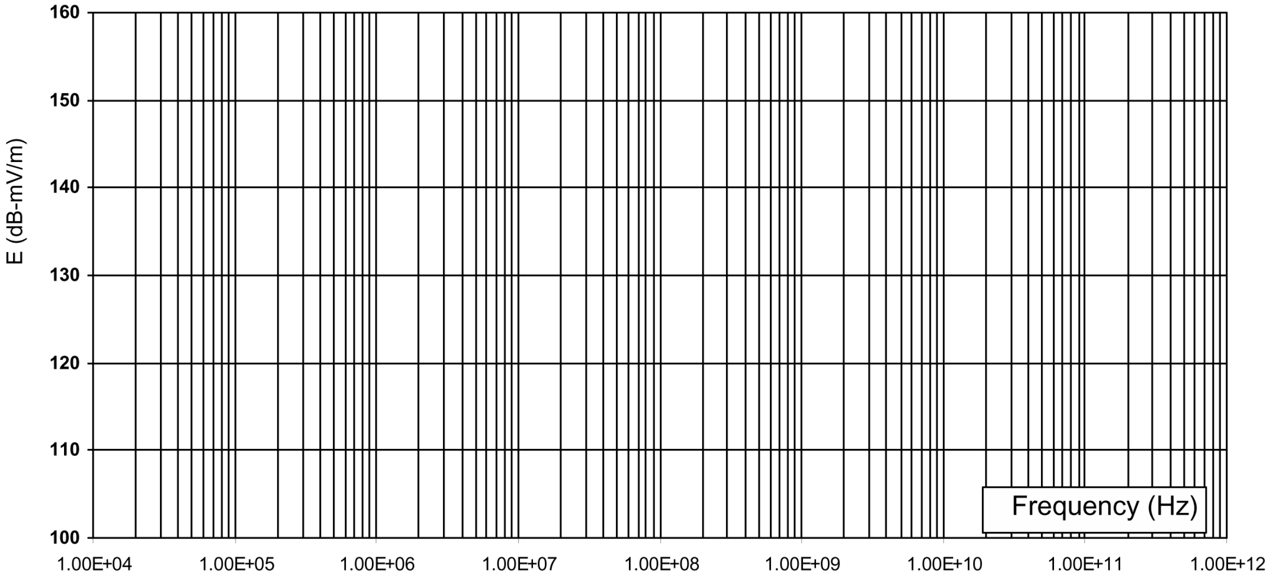
The following must be submitted in graphical form:

- SC radiation spectrum (see Figure 1.13.12-1)
- sceptibi y to radio frequenc radiation (see Figure 1.13.12-)

Table 1.13.12-1: Characteristics of Radio Frequency Equipment of SC and GSE

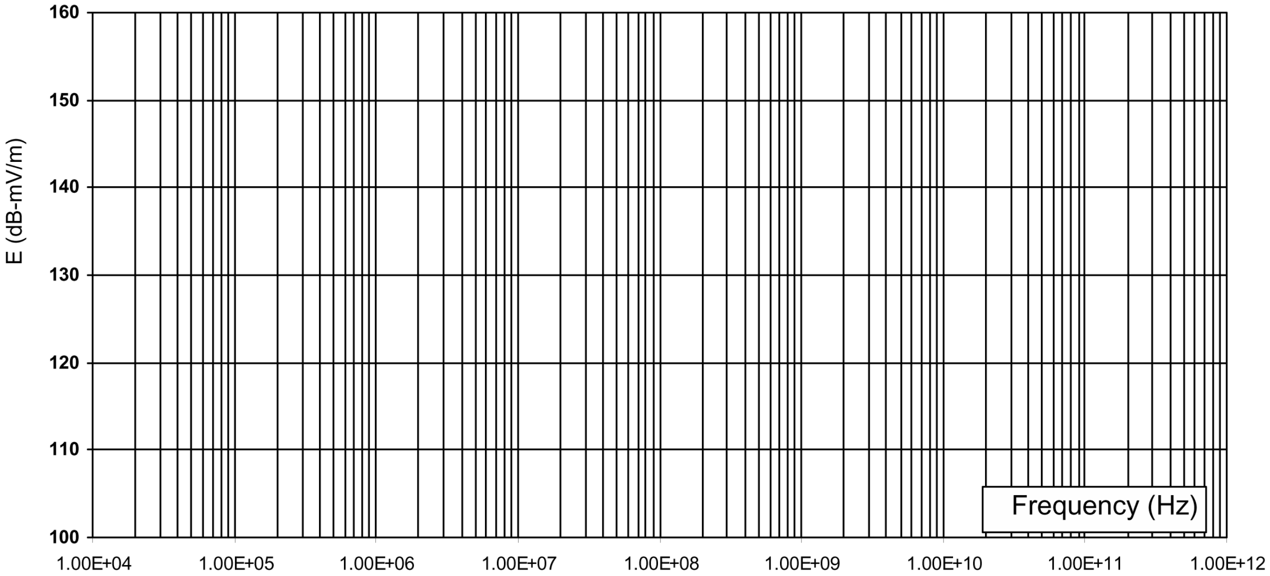
Item	Transmitter T_{x1}	. . .	Transmitter T_{xn}	Receiver R_{x1}	. . .	Receiver R_{xk}
Carrier frequency (MHz)						
Bandwidth at 3 dB (MHz)						
Bandwidth at 20 dB (MHz)						
Bandwidth at 60 dB (MHz)						
Modulation type and characteristics						
Output power of transmitting antenna (effective isotropic radiated power, dB-W) Maximum Nominal Minimum						
Flux density needed by receiving antenna (dB-W/m^2) Maximum Nominal Minimum						
Description of antenna, polarization						
Output power of ground equipment (dBm) Maximum Nominal Minimum						
Received power of ground equipment (dBm) at input Maximum Nominal Minimum						
Does it work at launch pad?						
Does it work in flight during jettisoning of PLF and up until separation of SC?						

Figure 1.13.12-1: SC Radiation Spectrum



Frequency (MHz)	**Value of Field Strength**	
	dB-μV/m	**V/m**

Figure 1.13.12-2: Spectrum of SC Susceptibility To Radio Frequency Radiation



Frequency (MHz)	Value of Field Strength	
	dB-μV/m	V/m

2. ANGARA 1.1 LAUNCH VEHICLE

2.1 DESCRIPTION OF DESIGN AND BASIC TECHNICAL CHARACTERISTICS

The two-stage Angara 1.1 LV is built on a "tandem" scheme made up of one CRM and a second stage. A general view of the LV with its PLF is presented in Figure 2.1-1.

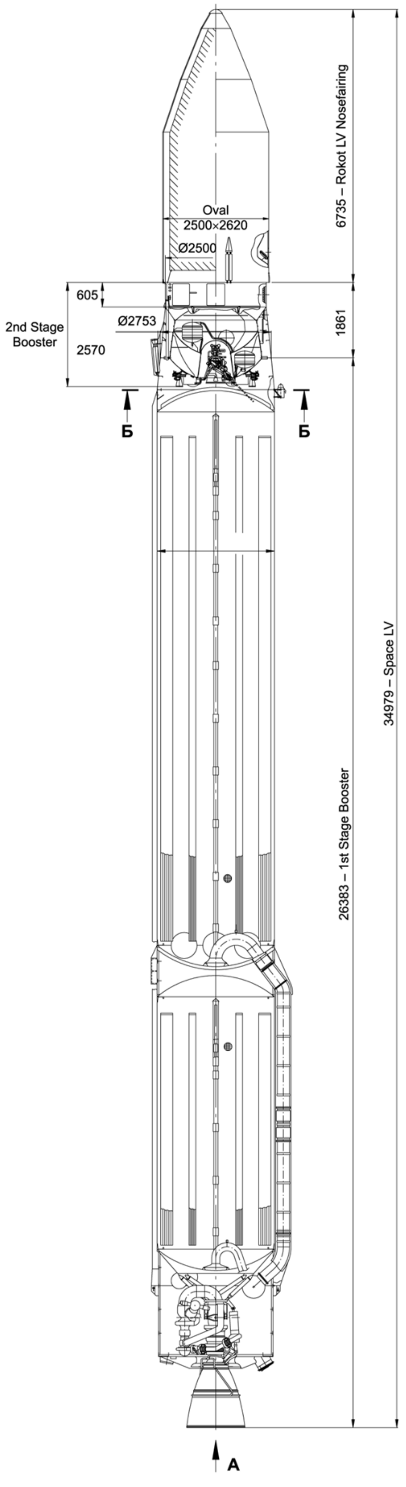
The CRM first stage booster uses kerosene and liquid oxygen propellants. The booster has a diameter of 2.9 m and consists of an oxidizer tank, an intertank compartment, a fuel tank, and a tail section. The tail section houses the RD-191 main propulsion engine. To allow control of the LV with respect to pitch and yaw, the engine thrust chamber and nozzle is gimbal-mounted. Engine thrust is conveyed through the gimbal, truss, and conical spacer to the shell of the fuel tank. To control the LV with respect to roll, two aerodynamic control surfaces and four nozzles that run on gas drawn from the main propulsion engine are mounted on the outside of the tail section. Control components with connectors for pneumatic and hydraulic lines for connection to the ground support equipment are mounted at the end of the tail section.

The second stage booster is built based on the Breeze M upper stage. The maximum diameter of this module is 2.5 m, and it uses nitrogen tetroxide and unsymmetrical dimethyl hydrazine (UDMH) propellants. The booster consists of a propellant compartment, a propulsion system, and an instrument compartment. The main propulsion engine is gimbal-mounted in a niche in the tank module. Four thruster units are mounted on the bottom of the tank module. The design of the second stage booster propulsion system allows repeated engine firing in flight and allows the booster attitude to be controlled during coast phases of flight. The instrument compartment is mounted on top of the tank module. The tank module, with the main propulsion engine, is housed inside the intermediate compartment, and four solid rocket motors for separation of the first stage booster are mounted on the outside. There is a control component in the instrument compartment that handles electrical connections between on-board equipment and the cable and filling tower of the GSE.

When the first stage booster separates by means of the four solid propellant retro-rockets, the intermediate module separates together with the first stage booster. For a shock-free separation of the tank module from the intermediate compartment, the latter has guides and the tank module has clips that slide along the guides.

The PLF is mounted on the instrument compartment. The SC is also secured through the adapter system to the structure of the instrument compartment.

Figure 2.1-1: General View of the Angara 1.1 LV



Basic Characteristics:

Launch mass of integrated LV: 149 metric tons

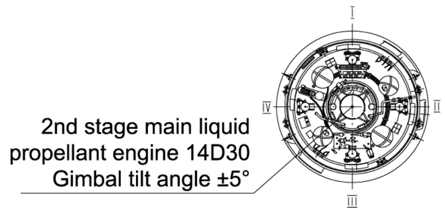
Mass of payload on parking orbit (H_{cir} = 200 km, i = 63°): 2 metric tons

Main propulsion engine thrust:

— first stage booster (at ground): 196 metric tons-force

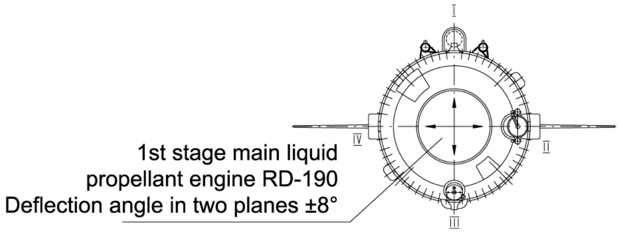
— second stage booster (in vacuum): 2 metric tons-force

Б-Б



2nd stage main liquid propellant engine 14D30
Gimbal tilt angle ±5°

A



1st stage main liquid propellant engine RD-190
Deflection angle in two planes ±8°

2.2 ASCENT UNIT

The ascent unit (AU) is an independent assembly put together at the technical complex. The AU includes:

- Payload fairing
- SC and the SC adapter system (if necessary)

The version of the PLF for the Angara 1.1 is shown in Figure 2.2-1. Once assembled, the AU is secured at the interface of the second stage.

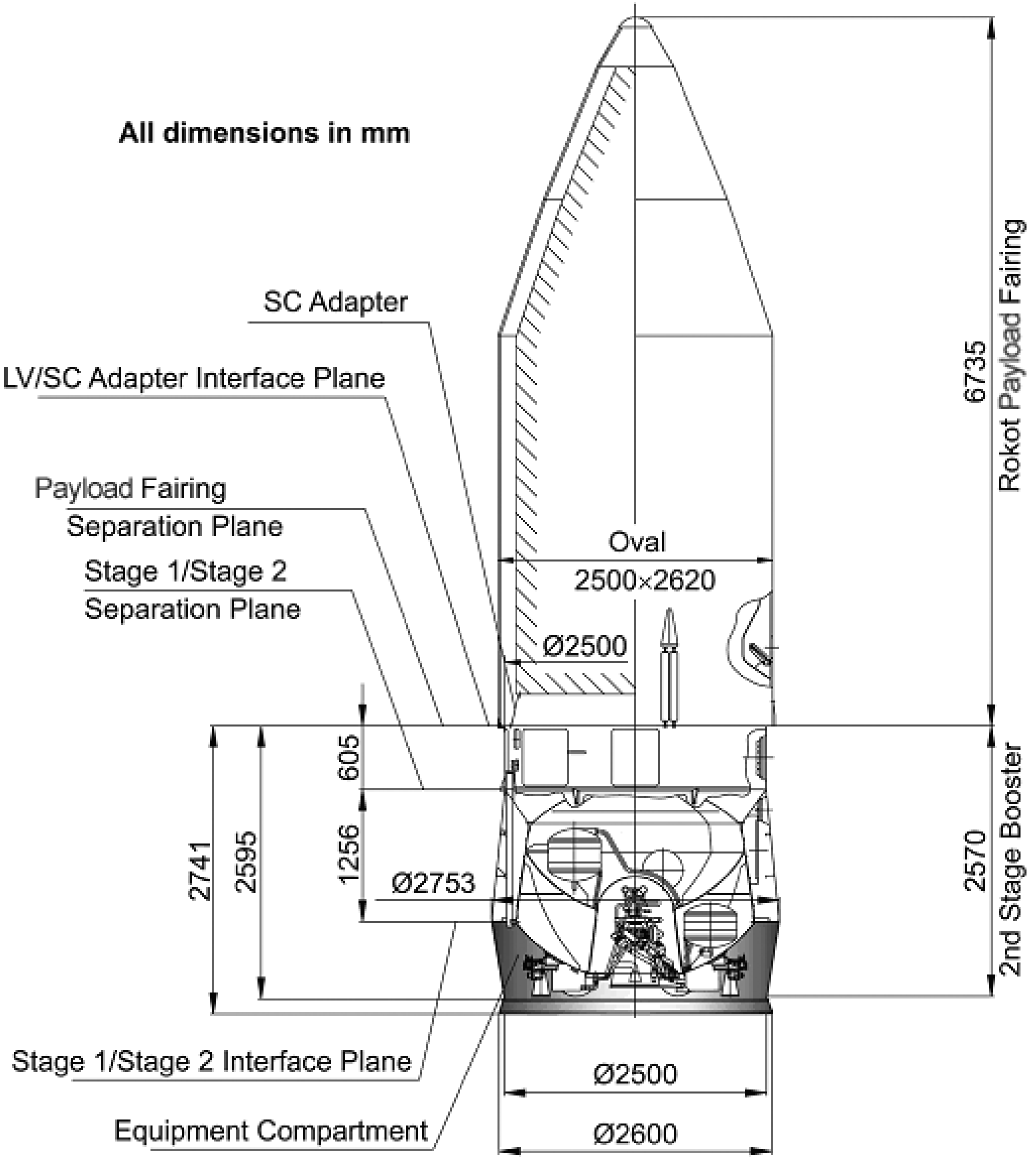
2.2.1 Payload Fairing

The PLF from the Rokot LV is used. If necessary, SC access doors and radio-transparent windows may be installed in the PLF for maintenance of the SC. Thermal insulation is installed under the PLF on its inside surface to provide the necessary thermal conditions for the SC. The necessary pressure level under the PLF is provided by using the drain ports. When jettisoned, the PLF separates into two halves along stabilization plane II-IV; acted upon by the spring pushers, these half sections turn ~45° and are cast aside. The PLF carries (at an angle of 52° from stabilization plane I in the direction of stabilization plane IV) the supply lines of the air thermal control system, through which thermal control of the interior volumes of the ascent unit is performed by using low-pressure air on stages of LV transportation from the assembly and test building, during erection of the LV at the launch pad, and through launch. Thermal control issues are examined in greater detail in Section 2.5.1.2. The SC useable volume is shown in Figure 2.7.1.1-1.

2.2.2 Payload

The SC adapter system is used in the ascent unit when the design of the SC does not allow it to be mounted directly at the 2390-mm diameter, where the openings are located on the mating ring of the LV. The SC adapter system, whose lower ring mates with the LV at the 2390-mm diameter, is used in this case. The shape and height of the adapter system are selected in relation to the structural features and seats of the specific SC. An example of the SC adapter system is examined in Section 2.7.1.2.

Figure 2.2-1: Layout of Angara 1.1 LV Ascent Unit



2.3 LV BASIC TRAJECTORY DESIGN AND PERFORMANCE PARAMETERS

2.3.1 Flight Design and Injection Trajectory Parameters

Two payload injection schemes may be used in launches from the Plesetsk Cosmodrome, depending on the altitude of the targeted orbit.

- Direct Injection Scheme - After separation of the first stage booster, the LV second stage booster, with a single burn, inserts the payload into the specified orbit. This scheme is implemented for circular orbits with altitudes up to 300 km.

- Scheme Using the Coast Phase of the LV Second Stage - After the first stage booster separates, the first burn of the main propulsion engine of the second stage of a light class LV injects the payload into an elliptical transfer orbit with an apogee altitude equal to the altitude of the specified circular orbit. Until apogee of the transfer orbit is reached, the second stage booster is in a coast phase. At orbital apogee, a second burn of the second stage main propulsion engine transfers the payload into the targeted orbit. When the payload is inserted into orbits with an altitude of from 300 to 1500 km, the coast phase time of the second stage changes from 45 to 51 minutes.

When optimizing a trajectory design, the program for the pitch angle of the LV first and second stages is selected so that the jettisoned hardware (the first stage booster and PLF) will fall into specified regions. The time of jettisoning of the PLF is determined so that the fairing pieces fall into the same region as the first stage booster. The maximum value of the free molecular heat flux acting on the SC after PLF jettison does not exceed 1135 W/m^2.

Figures 2.3.1-1 and 2.3.1-2 show a typical flight scheme, possible inclinations of injection orbits, and impact regions of jettisoned hardware. The LV ascent characteristics for a payload directly injected into a circular orbit, 200 km altitude with an inclination of 63°, is presented in Figure 2.3.1-3. Figure 2.3.1-4 presents a typical flight path for payload injection into a circular orbit with an altitude of 1100 km and an inclination of 63°.

2.3.2 Injection Accuracy

For injection into an orbit up to 350 km high, the error in injection altitude does not exceed 2% of the altitude, and the error in orbital injection does not exceed 2 angular minutes.

2.3.3 Dynamic Parameters of Second Stage Flight

During orbital flight and during coast phases, the second stage booster can perform programmed turns relative to any of the body axes of the upper stage. The angular velocities of turns relative to any axis do not exceed 1-2°/s.

Figure 2.3.1-1: Angara 1.1 Typical Flight Design and Orbit Parameters

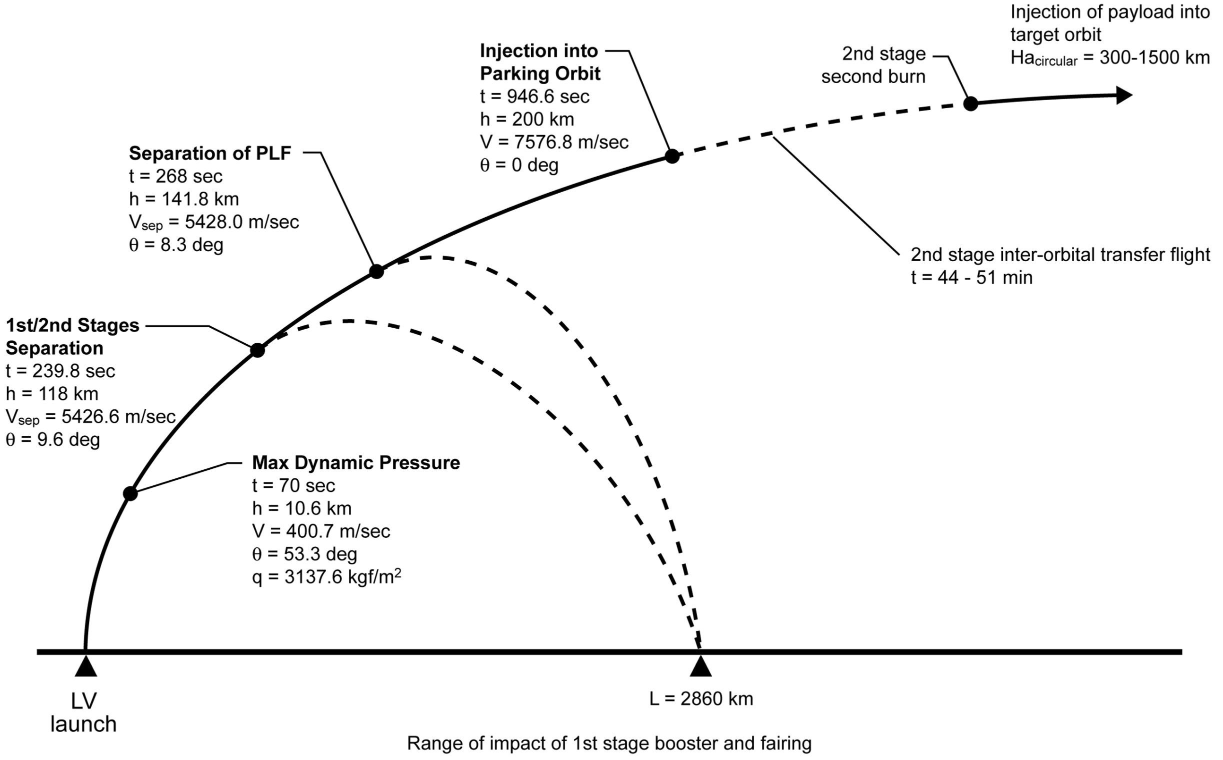


Figure 2.3.1-2: Angara 1.1 Possible Orbit Inclinations and Jettisoned Hardware Impact Zones

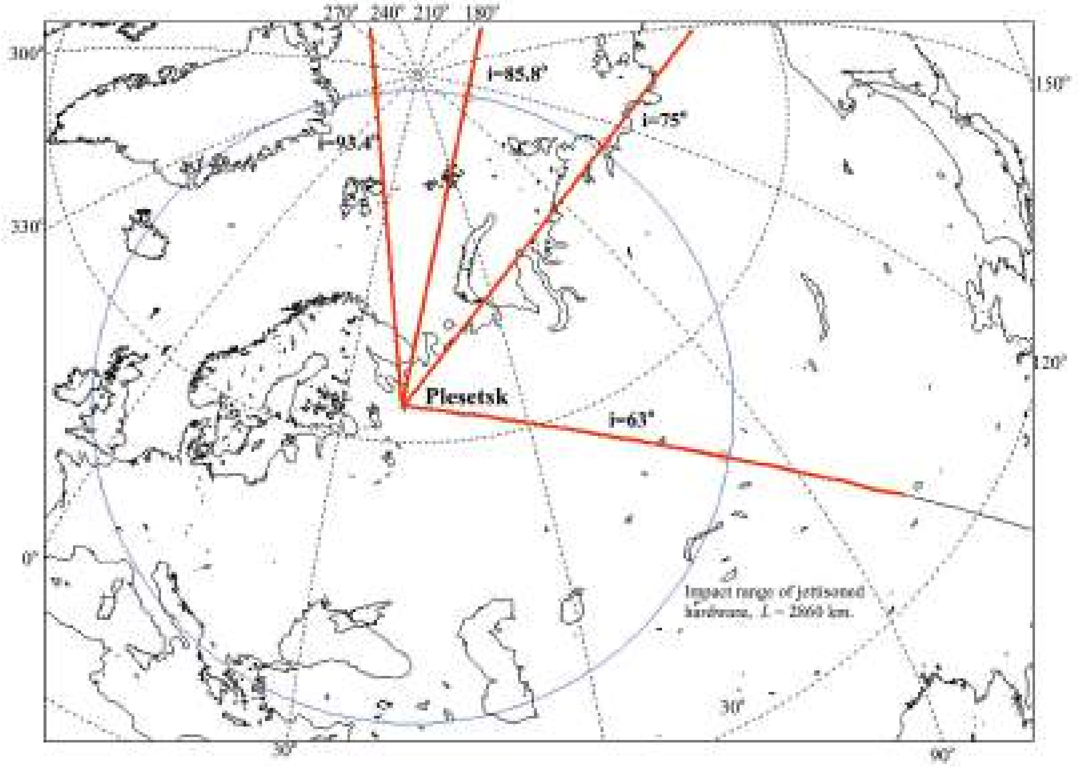


Figure 2.3.1-3: Angara 1.1 LV Ascent Characteristics

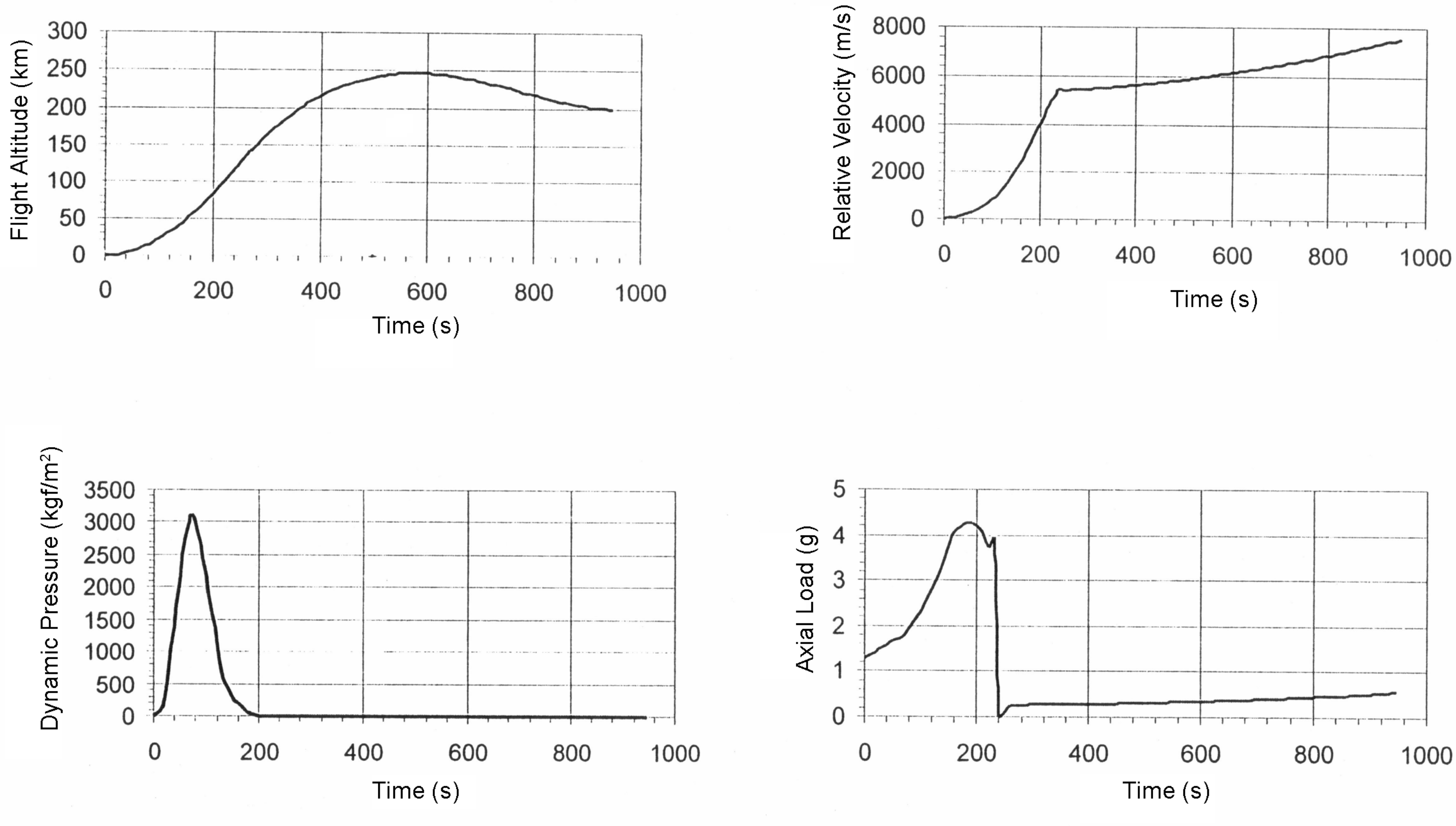
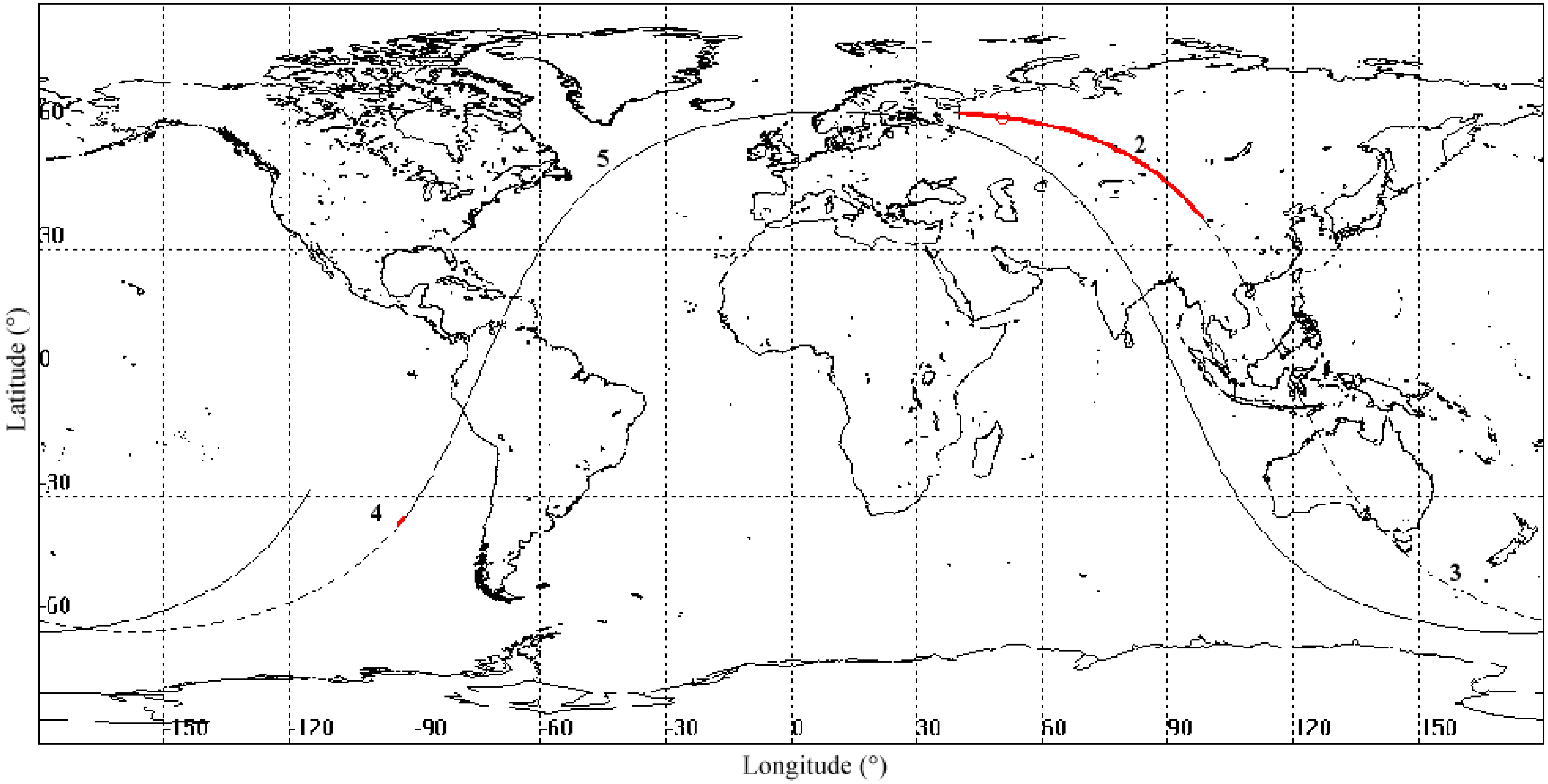


Figure 2.3.1-4: Typical Flight Path For Payload Injection Into a Circular Orbit With an Altitude of 1100 km and an Inclination of 63°



1) First stage ascent
2) Second stage 1st burn - injection into intermediate elliptical orbit with an apogee altitude H_a = 1100 km
3) Coast phase of second stage
4) Second stage 2nd burn - transfer to circular orbit H_{cir} = 1100 km
5) Path of first revolution of SC after LV separation.

While the main propulsion engine is in operation, control of booster attitude is determined by the pitch, yaw, and roll programs selected for each specific flight program. Any orientation of the booster can be effected prior to separation of the SC.

At the time of SC separation, the booster may be either in stabilization mode or, if necessary, in spinning mode.

In stabilization mode, angular velocities relative to the body axes can be attained:

- $\omega_X \leq \pm 1°/s$ and
- $\omega_{Y(Z)} \leq \pm 0.5°/s$.

The error in the spatial orientation of the booster axes relative to the base inertial coordinate system does not exceed ±0.5°.

In spinning mode, an angular velocity relative to the *OX* longitudinal axis of the booster of up to 12°/s can be provided.

The possibility of raising the angular velocity to 30°/s is being analyzed.

> **Note:** The maximum deviation of the longitudinal axis of the booster from the program position in spinning mode depends mainly on the mass and inertia characteristics of the specific SC, the required value of the angular velocity of SC spin, and the aggregate of the perturbing factors at work during spinning, and will be determined in the stage of pre-contract analysis of the feasibility that a specific SC will meet the requirements for the separation process.

2.4 PERFORMANCE CAPABILITY OF THE ANGARA 1.1 LV

Table 2.4-1 provides the performance capability of the LV in terms of payload systems mass (PSM) for low circular orbits as a function of various orbital inclinations.

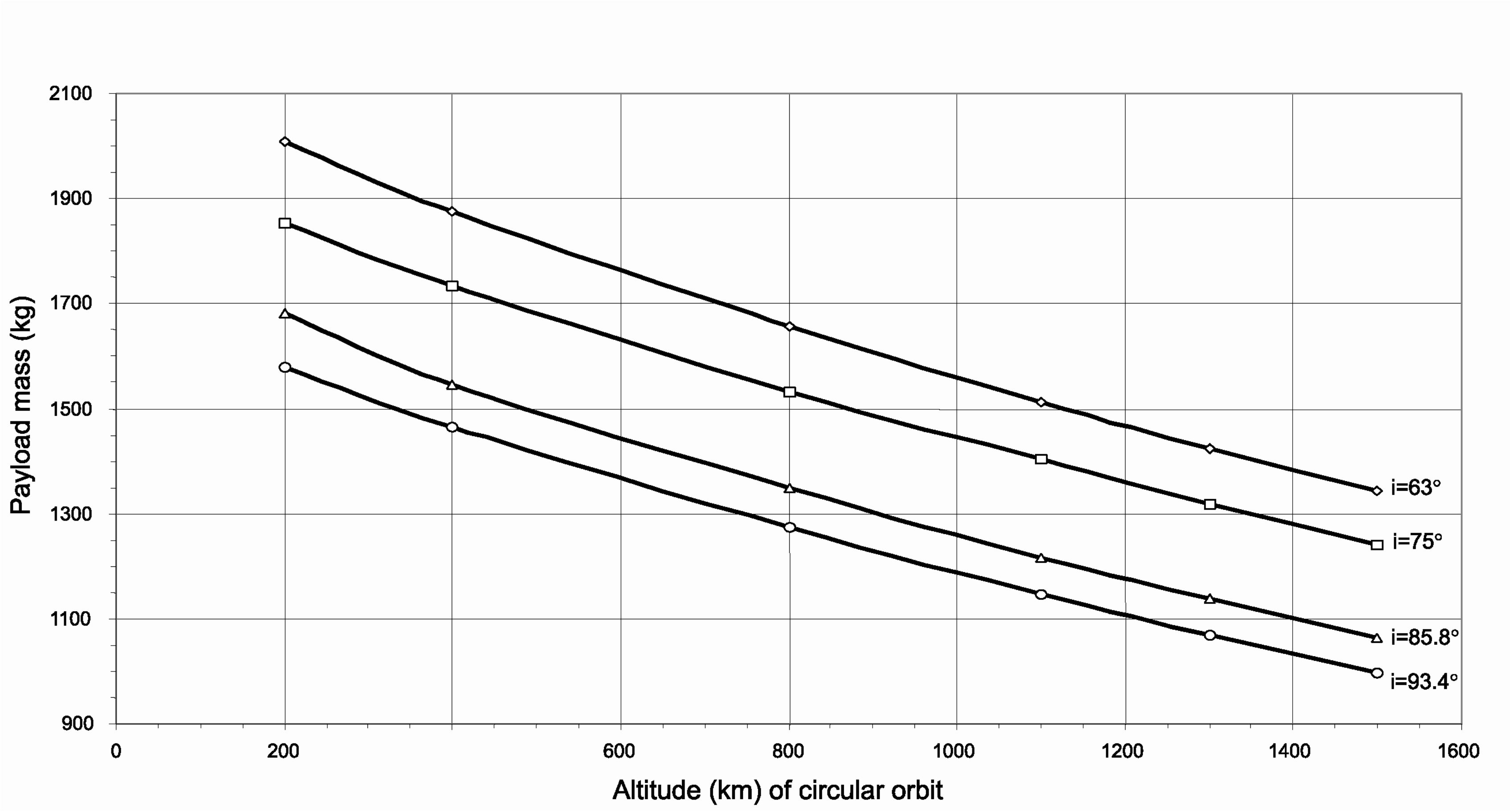
The dependence of the injected payload mass on target orbit parameters (inclination, altitude) is presented in Figure 2.4-1.

The range of orbits with altitudes from 200 to 1500 km is not a LV limit for lighter payload masses. If the Customer desires, a light class LV can insert payloads into higher orbits if the payload mass is reduced.

Table 2.4-1: Angara 1.1 LEO Performance Capability

Altitude of Circular Orbit (km)	PSM (metric tons)			
	i = 63°	i = 75°	i = 85.8°	i = 93.4°
200	2.00	1.85	1.68	1.58
400	1.87	1.73	1.54	1.47
800	1.65	1.53	1.35	1.27
1100	1.51	1.40	1.22	1.15
1300	1.42	1.32	1.14	1.07
1500	1.34	1.24	1.06	0.99

Figure 2.4-1: Angara 1.1 LEO Performance Curves in Terms of PSM and Apogee Altitude



2.5 SC ENVIRONMENTAL PARAMETERS

2.5.1 Pre-Launch Processing

2.5.1.1 Mechanical Loading During Transportation and Handling Operations

The following types of transportation of the SC are provided from the Plesetsk Cosmodrome during the processing activities for launch of Angara 1.1.

- Transportation of the SC over a distance of ≈15 km from the Pero Airport to Building 171V, independently by rail, at speeds ≤15 km/hr.
- Rail transportation of the SC with the ascent unit over a distance of ≈40 km from Building 171V to Building 142-1 at speeds of up to 5 km/hr.
- Rail transportation of the SC as part of the LV over a distance of ≈7 km at speeds of up to 5 km/hr.

The vibration regimes during transportation are specially generalized mechanical forces equivalent to the forces acting on the SC in the stage of transportation over the roadways of the Plesetsk Cosmodrome.

The actual conditions that apply to structural hardware, that serve as attachment points for the SC, are given for all transporting phases.

- For independent transportation: the attachment point of the container with SC to the transporter.
- For transportation as part of the ascent unit: the location of the joint between the SC and the adapter.
- For transportation as part of the LV: the location of the joint between the SC and the adapter.

The following orientation of axes has been adopted for load specification:

- X-X axis runs in the direction of motion.
- Y-Y axis runs vertically (up-down).
- Z-Z axis is the side axis in the right-handed coordinate system.

Vibration loads for three axes, in the form of the values of the spectral densities of vibration accelerations for each mode of transport and as transient loads for independent transportation, are presented in Figures 2.5.1.1-1 through 2.5.1.1-4 and in Tables 2.5.1.1-1 through 2.5.1.1-6.

The spectral densities are probabilistic in character and are specified with a probability of 0.997 that the specified levels will not be exceeded.

Figure 2.5.1.1-1: Acceleration Spectral Density - SC Rail Transport

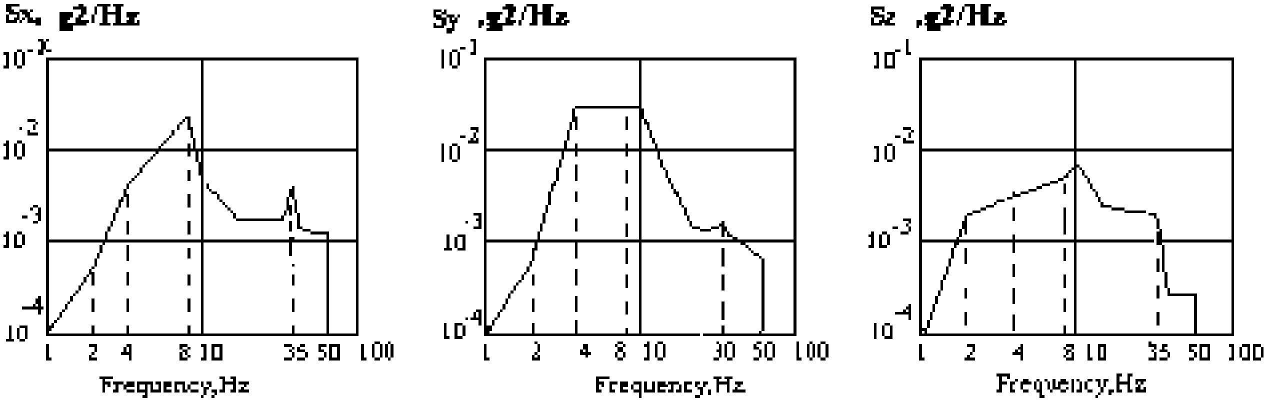


Figure 2.5.1.1-2: Acceleration Spectral Density - SC Motor Vehicle Transport

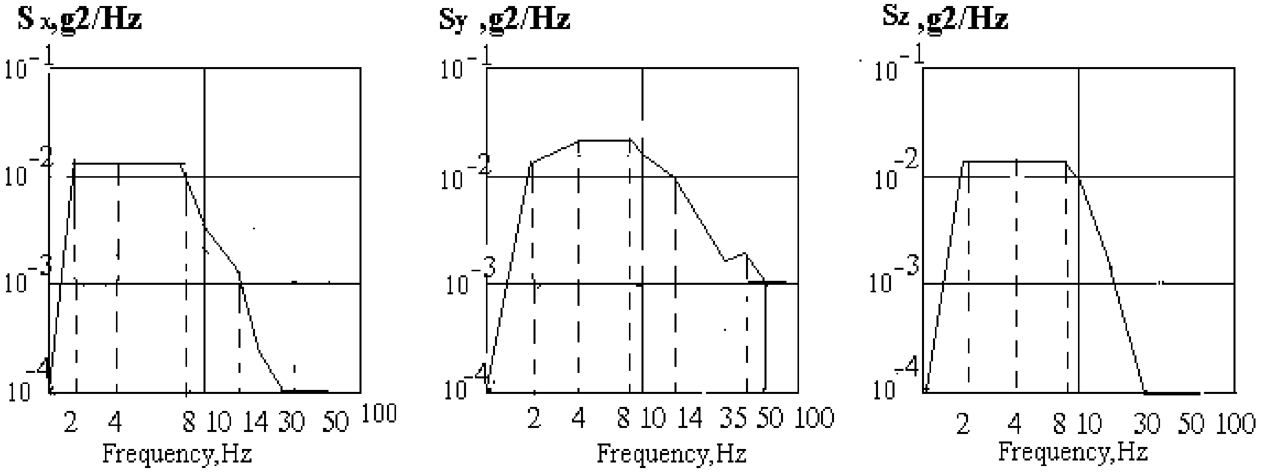


Figure 2.5.1.1-3: Acceleration Spectral Density - AU Rail Transport

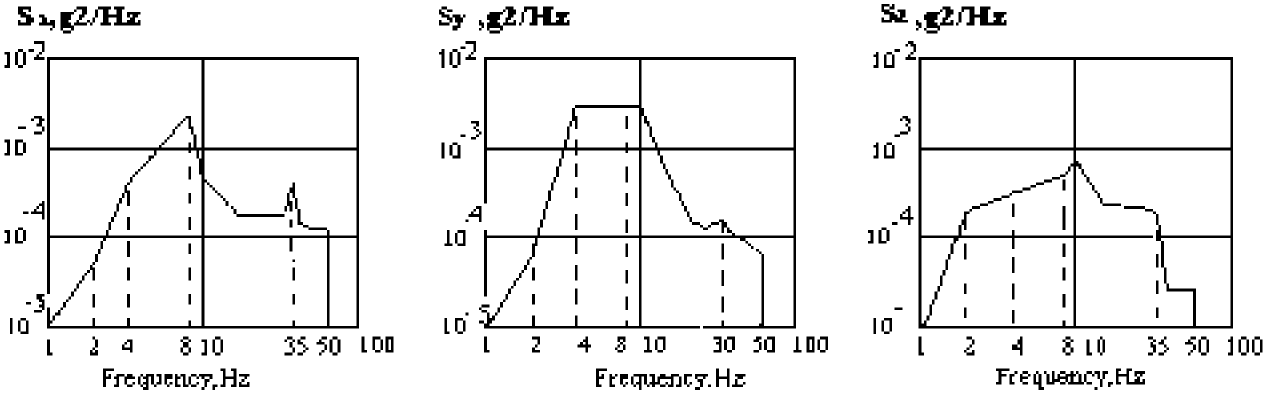


Figure 2.5.1.1-4. Power Spectral, S (g^2/Hz) – LV Rail Transport

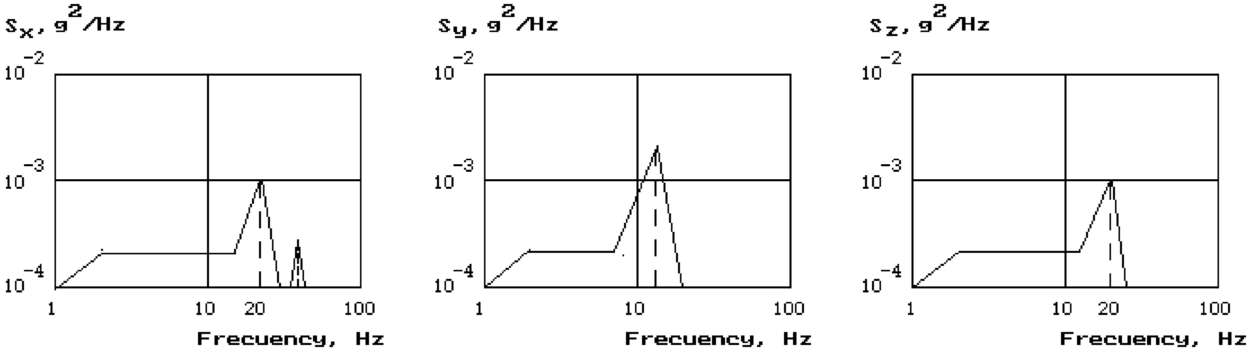


Table 2.5.1.1-1: Allowable Shock Loads on Container With SC

Mode of Transport	Direction of Axis	Amplitude (g)	Duration (ms)	Pulse Shape
Motor vehicle	±X	3.0	30	Sine half-wave
	±Y	2.0	30	Sine half-wave
	±Z	0.5	30	Sine half-wave
Rail	±X	2.5	30	Sine half-wave
	±Y	2.0	30	Sine half-wave
	±Z	0.5	30	Sine half-wave
Airplane	±X	3.0	100	Sine half-wave
	±Y	2.0	100	Sine half-wave
	±Z	1.7	100	Sine half-wave

Table 2.5.1.1-2. Maximum Random Vibration Loads on SC Container During Independent Rail Transport

Frequency (Hz)	Direction of Axis		
	X-X	Y-Y	Z-Z
	Spectral Density (10^4 g^2/Hz)		
2	7.5	7.5	15.0
4	57.5	330.0	33.0
8	200.0	320.0	66.0
10	60.0	320.0	80.0
14	28.0	83.3	33.0
20	27.5	15.0	32.0
25	27.5	12.0	31.0
30	2.75	15.0	30.0
35	50.0	11.0	18.5
40	18.0	10.0	3.7
45	12.5	8.3	3.7
50	12.5	7.5	3.7
Time (min)	420	420	420

Table 2.5.1.1-3: Transient Dynamic Loads – SC Rail Transport

Direction of axis	Maximum Amplitude of Vibration Acceleration (g)	Pulse Length (ms)	Number of Loadings
X-X	1.5	0.16-0.035	100
Y-Y	1.1		
Z-Z	0.6		

Note: The pulse shape is triangular or a sinusoidal half-wave.

Table 2.5.1.1-4: Maximum Random Vibration Loads on SC Container During Independent Transportation by Motor Vehicle

Frequency (Hz)	Direction of Axis		
	X-X	Y-Y	Z-Z
	Spectral Density (10^{-3} g^2/Hz)		
2	15	15	15
4	15	30	15
8	15	30	15
10	6.0	20	10.0
14	1.4	10	1.5
20	0.42	5	0.5
25	0.18	3.2	0.18
30	0.1	2.5	0.1
35	0.1	2.8	0.1
40	0.1	1.4	0.1
45	0.1	1.2	0.1
50	0.1	1.0	0.1
Time (min)	10	10	10

Note: The values of the spectral densities are specified with a probability of 0.997 that they will not be exceeded.

Table 2.5.1.1-5: Maximum Random Vibration Loads on SC Container During Ascent Unit Rail Transport

Frequency (Hz)	Direction of Axis		
	X-X	Y-Y	Z-Z
	Spectral Density (10^{-5} g^2/Hz)		
2	7.5	7.5	15.0
4	57.5	330.0	33.0
8	200.0	320.0	66.0
10	60.0	320.0	80.0
14	28.0	83.3	33.0
20	27.5	15.0	32.0
25	27.5	12.0	31.0
30	2.75	15.0	30.0
35	50.0	11.0	18.5
40	18.0	10.0	3.7
45	12.5	8.3	3.7
50	12.5	7.5	3.7
Time (min)	120	120	120

Table 2.5.1.1-6: Loads on SC During LV Rail Transport

Frequency (Hz)	Direction of Axis		
	X-X	Y-Y	Z-Z
	Spectral Density (10^{-4} g^2/Hz)		
2	2.0	2.0	2.0
4	2.0	2.0	2.0
8	2.0	2.0	2.0
10	2.0	2.0	2.0
14	2.0	20.0	2.0
20	10.0	1.0	10.0
25	1.0	1.0	1.0
30	1.0	1.0	1.0
35	3.0	1.0	1.0
40	1.0	1.0	1.0
45	1.0	1.0	1.0
50	1.0	1.0	1.0
Time (min)	10	10	10

2.5.1.2 Linear Loads During Transportation at Technical Area and During Handling Operations

The quasi-linear loads during transportation and handling operations are presented in Table 2.5.1.2-1.

2.5.1.3 Thermal Conditions of SC During Ground Operation

Ground thermal loads on the SC arise during transportation of the SC and during launch processing of the SC at the technical and launch areas.

Information on the environmental parameters around the SC during various phases of ground processing of the SC for launch, and on the means used to maintain them, are presented in Table 2.5.1.3-1.

Two air temperature sensors in the area of the SC and two temperature sensors for the adapter system (adapter) structure are installed to monitor the thermal state under the PLF. A sensor to measure relative humidity is provided to monitor air humidity in the area of the SC.

A diagram of the thermal control of the ascent unit at the launch complex is presented in Figure 2.5.1.3-1.

The technical data of the launch air thermal control system are presented in Table 2.5.1.3-2.

Table 2.5.1.2-1: Quasi-Linear Loads During Transport

Phase of Operation	Level of Vibration Acceleration (m/s^2 (g))			Safety Factor
	X	Y	Z	
Independent transportation at technical area	±9.8 (±1.0)	9.81 ± 4.9 (1 ± 0.5)	±3.9 (±0.4)	1.5
Transportation as part of ascent unit	±9.8 (±1.0)	9.81 ± 4.9 (1 ± 0.5)	±3.9 (±0.4)	1.5
Transportation as part of LV	±4.9 (±0.5)	9.81 ± 1.18 (1 ± 0.2)	±0.98 (±0.1)	1.5
Handling operations	±1.8 (±0.2)	9.81 ± 2.94 (1 ± 0.3)	±1.8 (±0.2)	1.5

Notes:

1. For the transportation case, the axes are given in the coordinate system of the LV:

   X axis - in the direction of motion
   Y axis - directed vertically (up-down)
   Z axis - lateral in right-handed coordinate system

2. For the handling operations case:

   Y axis - on vertical line of hoisting or lowering
   X axis - in any lateral direction

3. Accelerations act simultaneously in the directions of the X, Y, and Z axes.

4. Accelerations are specified for a wind speed $V \leq 20$ m/s.

Table 2.5.1.3-1: Environmental Parameters Around SC

Processing Phase	Temperature (°C)	Humidity (%)	Means Used to Maintain
Air transportation to Cosmodrome	Meets the conditions for transportation in an unsealed cabin		Container
Motor vehicle transportation to technical complex	10-30		Container
Transportation of SC as part of LV to launch complex	10-30	30-60	Thermal control unit
In SC processing and filling area	15-25	30-60	Technical systems of structures
In area of integration with upper stage and LV	15-25	30-60	Technical systems of structures
Erection at launch complex	10-30	30-60	Air thermal control system (thermal control through transporter/erector). Flow up to 6000 kg/hr.
Processing at launch complex	13-27	≤60	Air thermal control system (air supply through cable and filling tower). Flow up to 6000 kg/hr.
Launch abort	5-30	≤60	Air thermal control system (air supply through cable and filling tower until transporter/erector is connected; flow is up to 6000 kg/hr) until mobile thermal control unit is brought up. An interruption in active thermal control for ≈0.5 hr is possible.

Figure 2.5.1.3-1: Diagram of Thermal Control of Ascent Unit on Launch Pad

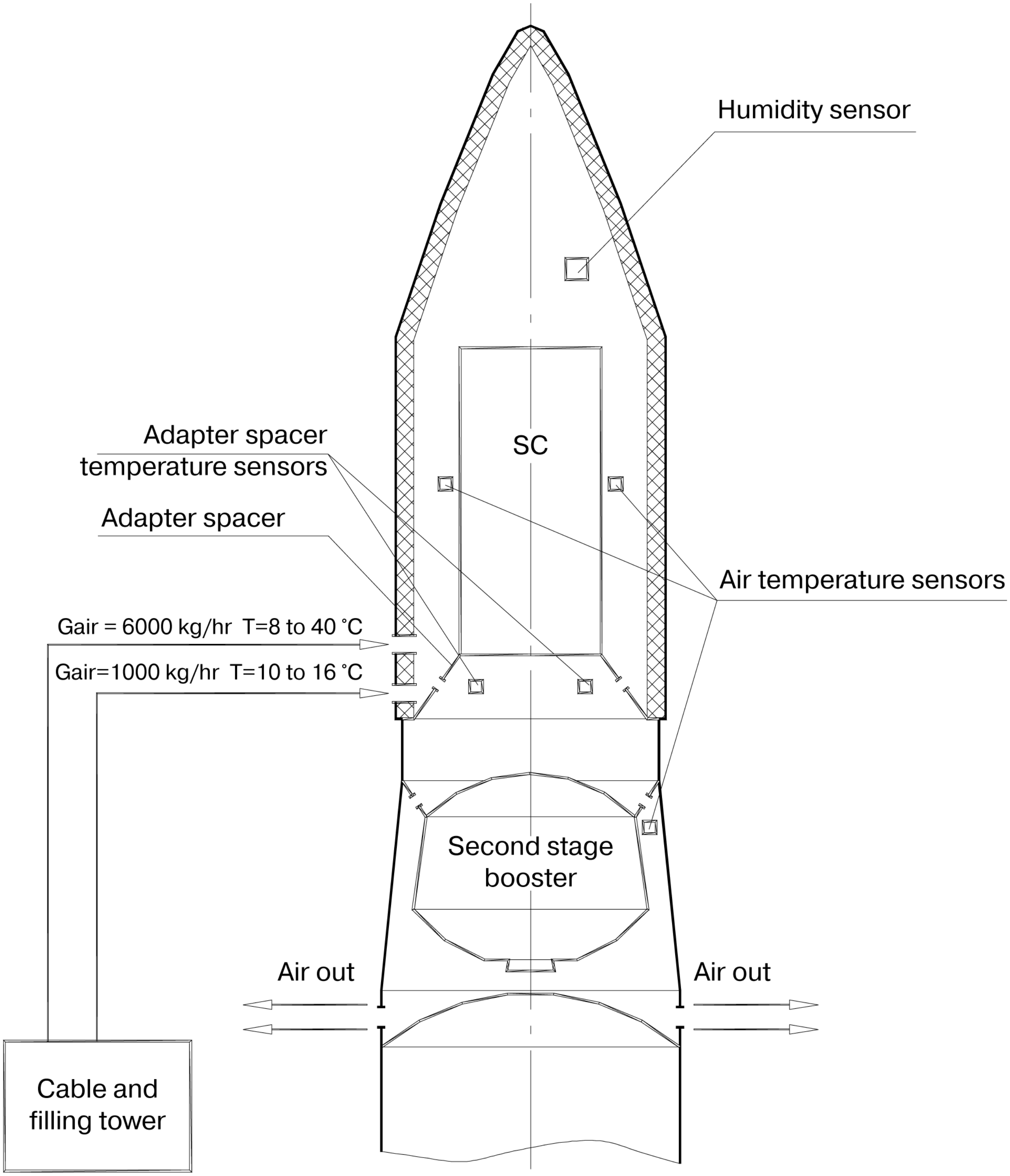


Table 2.5.1.3-2: Technical Data on Launch Air Thermal Control System

Technical Data	Value
Temperature of supplied air	8-40°C
Accuracy of temperature maintenance at system outlet	±2°C
Relative air humidity	≤ 60%
Air flow	6000 kg/hr
Purity of supplied air, class per Standard FS 209	100,000

Thermal control of the interior space of the ascent unit is performed through the air thermal control system duct by using low pressure air during the phases of LV transport from the assembly and test building, during erection of the LV at the launch pad, and while on the pad through launch. The separation of connections between the SC air thermal control system and the GSE is backed up by the rise-off motion of the LV during launch.

Thermal control of the ascent unit by supplying air at a rate of up to 6000 kg/hr from the air thermal control system is performed during erection through the transporter/erector, and later to the lift-off switch command with the same flow through a line laid on the cable and filling tower.

The air temperature under the PLF is regulated by changing its temperature.

In case of launch abort, while propellants are being drained and the LV is removed from the launcher, thermal control of the ascent unit is performed from the cable and filling tower (up until the time of de-mating of the cable and filling tower and the transporter/erector is subsequently mated before the process of lowering the LV to the horizontal position). During the process of transfer of the LV to the horizontal position, up until the mobile thermal control unit is mated, the ascent unit receives thermal control from the transporter/erector. An interruption of ≈0.5 hr in active thermal control is possible.

Furthermore, additional air supply is provided from the air thermal control system via a separate line laid on the cable and filling tower directly to the SC area, with the following parameters:

- Temperature of supplied air: 10-16°C
- Relative humidity: ≤60%
- Air flow: up to 1000 kg/hr
- Air pressure: 0.25 kgf/cm^2

The basic characteristics of the thermal control unit are presented in Table 2.5.1.3-3.

Table 2.5.1.3-3: Characteristics of Thermal Control Unit

Parameter	Value
Temperature of supplied air	10-30°C
Minimum increment of temperature setting	2°C
Accuracy of temperature maintenance	± 2°C
Relative humidity	30-60%
Air flow	≤ 8000 m^3/hr
Air pressure	350 mm H_2O

2.5.1.4 Cleanliness

The cleanliness of the SC is assured in ground processing phases by keeping the SC in a controlled air environment, maintaining the cleanliness of the surfaces of ascent unit elements that come into direct contact with the SC environment, and using in the ascent unit design materials with minimal dust release and out-gassing.

2.5.1.4.1 Cleanliness on the Second Stage Booster, PLF and Adapter System During Processing at the Manufacturer

Before being placed in the handling container, all outside surfaces of the booster are cleaned to level 600 per Mil-Std-1246B.

Before being placed in the transport crate, the inside surfaces of the PLF and the adapter system are cleaned to level 600 per Mil-Std-1246B.

2.5.1.4.2 Cleanliness During Transportation From the Manufacturer to the Technical Complex

Ascent unit components are transported from the manufacturer to the technical complex in a packed, shrouded foam that prevents dust, dirt and moisture from reaching their surface. The SC arrives at the technical complex in a sealed container.

2.5.1.4.3 SC Cleanliness at the Technical Complex

The processing and assembly of elements of the ascent unit and second stage booster are carried out in clean rooms of class R8 per GOST R50766-95 (100,000 per U.S. Standard Fed-Std-209E).

When thermal control is performed at the technical complex and while in enclosed areas with cleanliness worse than R8 (100,000), the components of the ascent unit and LV second stage undergo thermal control with air of cleanliness R8 per GOST 50766-95 (100,000 per U.S. Standard Fed-Std-209E). This is assured by a supply of purified air under the PLF or into the container from the mobile thermal control unit.

Prior to assembly of the ascent unit and LV second stage, all surfaces of elements that come into direct contact with the SC environment are cleaned to level 600 per Mil-Std-1246B.

2.5.1.4.4 SC Cleanliness at the Launch Complex

While at the launch complex, the SC is in an air environment with R8 (100,000) cleanliness. This is assured by supplying purified air under the PLF from the launch thermal control system.

> Note: In the absence of thermal control (e.g., while the LV is being erected on the launch pad), the volume in which the SC is located is not connected to the external environment, thereby preserving a clean environment inside.

2.5.2 Flight Environments

2.5.2.1 Flight Loads on the SC

The maximum (static and dynamic) loads on the SC at launch and during flight of the Angara 1.1 are presented in Table 2.5.2.1-1. Transverse loads may act in any direction perpendicular to the longitudinal axis of the LV.

The quasi-static load n_x^{op} is the sum of the static load n_{x-st}^{op} and the dynamic load n_{x-dy}^{op}: $n_x^{op} = n_{x-st}^{op} \pm n_{x-dy}^{op}$.

Table 2.5.2.1-1: Maximum Quasi-Static Loads on the SC

Loading Case	Safety Factor f	Longitudinal Loads (n_x^{op})		Transverse Loads ($n_{y(z)}^{op}$)
		Static	Dynamic	Quasi-Static
Launch	1.3	1.35	+0.7 -1.2	±1
Flight at $q_{\max}$	1.3	1.8	-	±0.4
Flight at $P_{\max}$	1.3	4	±0.4	±0.9
Flight at $n_{xx\max}$	1.3	4.6	±0.46	±0.6
Separation of first and second stages	1.3	0.1	±4.6	±0.15
Second stage flight	1.3	0.7	-	±0.2

2.5.2.2 Mechanical Loading

Mechanical loading regimes apply to the location of the interface between the second stage and the SC and contain the recommended loading conditions for the LV structure and devices and units mounted on the LV near the location of the interface.

The regimes include the values of linear loads and the parameters of vibration and shock, and transient dynamic loads and acoustic pressure during second stage operation through SC separation.

The vibration load regimes are given in two forms:

1. Harmonic vibration
2. Random vibration

The following orientation of axes is assumed in the regimes:

- X - longitudinal axis of LV
- Y - lateral axis of LV (plane I-II)
- Z - lateral axis of LV (plane II-IV)

These regimes may be revised on the basis of additional calculations, laboratory and bench development, flight tests, and full-scale operation.

2.5.2.2.1 Vibration Loads

Vibration loads that act under steady-state conditions in flight, in the direction of three axes, are presented in Table 2.5.2.2.1-1 in the form of harmonic vibration, and in Table 2.5.2.2.1-2 in the form of the spectral density distribution of a random vibration.

The transient non-stationary dynamic loads in flight under transient operating conditions of the propulsion system are presented in Table 2.5.2.2.1-3. These conditions are specified for functional tests of any equipment attached.

2.5.2.2.2 Vibration and Shock Loads

The vibration and shock loads, in the direction of three axes at stage separation, are presented as the values of the shock spectrum in Table 2.5.2.2.2-1.

Table 2.5.2.2.1-1: Mechanical Loads - Harmonic Vibration

Structural Zone	Frequency Range (Hz)	Vibration Acceleration ($m\text{-}s^{-2}$ (g))		Action Time (s)
Interface between LV and SC during first stage operation	1.5-50	9.81-29.43	(1-3)	240
	50-600	29.43-98.1	(3-10)	
	600-2000	98.1	(10)	
Interface between LV and SC during second stage operation	1.5-50	0.98-14.1	(0.1-1.44)	706
	50-600	14.1-58.9	(1.44-6)	
	600-2000	58.9	(6)	

Note: The vibration loads vary linearly between the indicated frequencies.

Table 2.5.2.2.1-2: Mechanical Loads - Random Vibration

Equipment Installation Point	Frequency (Hz)							Action Time (s)
	20	50	100	200	500	1000	2000	
	Spectral Density of Vibration Acceleration ($m^2\text{-}s^{-4}$/Hz (g^2/Hz))							
Interface between LV and SC during first stage operation	6.549 (0.068)	7.7 (0.08)	5.54 (0.058)	5.13 (0.053)	6.47 (0.067)	4.28 (0.044)	2.14 (0.022)	240
Interface between LV and SC during second stage operation	2.13 (0.022)	1.76 (0.018)	1.92 (0.02)	5.55 (0.058)	2.57 (0.027)	1.53 (0.016)	0.768 (0.008)	706

Notes:

1. The change in spectral densities between the indicated frequencies is linear.
2. In the frequency range up to 20 Hz, the conditions of vibration loading are represented as harmonic vibration (see Table 2.5.2.2.1-1).

Table 2.5.2.2.1-3: Transient Non-Stationary Dynamic Loads In Flight

Frequency Range (Hz)	Maximum Amplitude Of Vibration Acceleration n_{max} (m-s $^{-2}$ (g))	Duration of Process (s)	Number of Loadings
10-30	$n_x^{max} = 58.86$ (6)	2.5-0.8	4
1.5-10	$n_{y,z}^{max} = 14.7$ (1.5)	6.0-2.0	2

Notes:

1. The qualification coefficient is 1.5.
2. The maximum load lasts no more than 2-3 periods.
3. By the duration of the process is meant the time over which the load rises and falls from n_{max} to $0.1n_{max}$.
4. The duration of the process is linearly dependent on the frequency (in inverse proportion).

Table 2.5.2.2.2-1: Vibration and Shock Loads at Stage Separation

Frequency Sub-Range (Hz)					
35-50	50-100	100-200	200-500	500-1000	1000-2000
Value of shock spectrum (m-s^{-2} (g))					
245-490 (25-50)	490-1470 (50-150)	1470-3930 (150-400)	3930-17,200 (400-1750)	17,200-49,000 (1750-5000)	49,000 (5000)

Development of flight hardware and units for the conditions in Table 2.5.2.2.2-1 may be replaced with tests for the impulsive forces presented in Table 2.5.2.2.2-2.

The vibration and shock at PLF jettison, in the direction of all three axes, are presented in the form of the shock spectrum values in Table 2.5.2.2.2-3.

Development of flight hardware and units for the conditions in Table 2.5.2.2.2-3 may be replaced with tests for the impulsive forces presented in Table 2.5.2.2.2-4.

The vibration and shock loads at SC separation (preliminary values), in the direction of three axes, are presented in the form of the shock spectrum values in Table 2.5.2.2.2-5.

Development of flight hardware and units for the conditions in Table 2.5.2.2.2-5 may be replaced with tests for the impulsive forces presented in Table 2.5.2.2.2-6.

Table 2.5.2.2.2-2: Impulsive Forces at Stage Separation

Mounting Point of Devices and Units (Distance Along Structure From Pyrotechnics)	Load ($m\text{-}s^{-2}$ (g))	Impulse Length (ms)	Total Number of Shocks on Each Axis
up to 0.7 m, inclusively	±9810 (±1000)	0.3-0.5	1

Note: The pulse shape is a sine half-wave or triangular.

Table 2.5.2.2.2-3: Vibration and Shock at PLF Jettison – Shock Spectrum

Frequency Sub-Range (Hz)					
35-50	50-100	100-200	200-500	500-1000	1000-2000
Value of Shock Spectrum ($m\text{-}s^{-2}$ (g))					
370-740 (37.5-75)	740-2200 (75-225)	2200-5890 (225-600)	5890-25,750 (600-2625)	25,750-73,575 (2625-7500)	73,575 (7500)

Table 2.5.2.2.2-4: Impulsive Forces at PLF Jettison

Mounting Point of Devices and Units (Distance Along Structure From Pyrotechnics)	Load ($m\text{-}s^{-2}$ (g))	Impulse Length (ms)	Total Number of Shocks on Each Axis
up to 0.5 m, inclusively	±14,715 (±1500)	0.2-0.3	2

Note: The pulse shape is a sine half-wave or triangular.

Table 2.5.2.2.2-5: Loads at SC Separation – Shock Spectrum

Frequency Sub-Range (Hz)					
35-50	50-100	100-200	200-500	500-1000	1000-2000
Value of Shock Spectrum ($m\text{-}s^{-2}$ (g))					
245-490 (25-50)	490-1470 (150-400)	1470-3930 (150-400)	3930-17,200 (400-1750)	17,200-49,000 (1750-5000)	49,000 (5000)

Table 2.5.2.2.2-6: Impulsive Forces at Stage Separation

Mounting Point of Devices and Units (Distance Along Structure From Pyrotechnics)	Load (m-s^{-2} (g))	Impulse Length (ms)	Total Number of Shocks on Each Axis
up to 0.7 m, inclusively	±9810 (±1000)	0.3-0.5	To be determined during design of the adapter system and separation hardware of the SC

Note: The pulse shape is a sine half-wave or triangular.

2.5.2.2.3 Acoustic Loads

The acoustic loads under the payload fairing do not exceed the values presented in Figure 2.5.2.2.3-1 and Table 2.5.2.2.3-1.

Figure 2.5.2.2.3-1: Acoustic Loads in SC Area

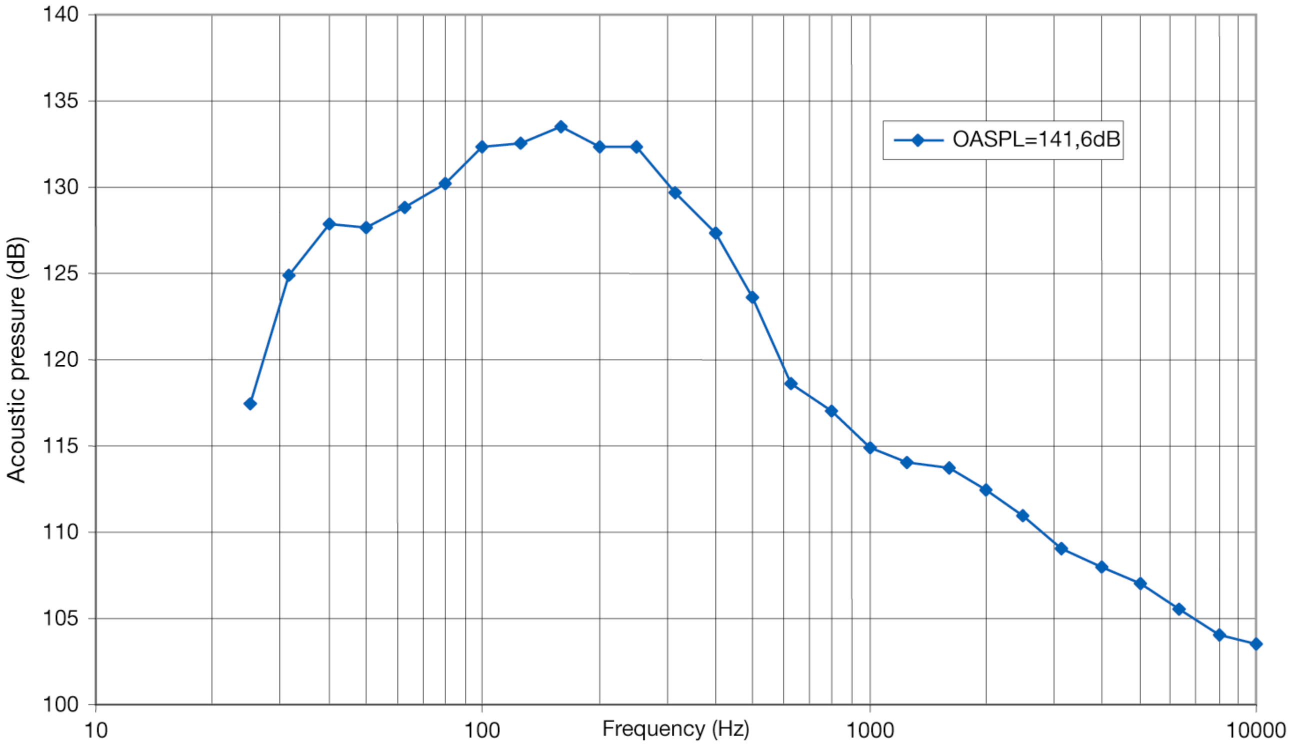


Table 2.5.2.2.3-1: Angara LV Acoustic Loads in SC Area

Structural Zone	Center Frequency of 1/3-Octave Frequency Band (Hz)	SPL (dB)	ActionTime (s)
Under PLF in SC mounting area	25	117.4	60
	31.5	124.9	
	40	127.9	
	50	127.7	
	63	128.8	
	80	130.2	
	100	132.3	
	125	132.6	
	160	133.5	
	200	132.3	
	250	132.3	
	315	129.7	
	400	127.3	
	500	123.6	
	630	118.6	
	800	117.0	
	1000	114.9	
	1250	114.0	
	1600	113.7	
	2000	112.5	
	2500	111.0	
	3150	109.0	
	4000	108.0	
	5000	107.0	
	6300	105.5	
	8000	104.0	
	10,000	103.5	
	OASPL (dB)	141.6	

2.5.2.3 Thermal Conditions In Flight

During the ascent phase of flight, the SC is in radiative heat transfer with the inside surface of the PLF. The allowable temperature level of the PLF structure is maintained by application of a thermal protective material. A thermal insulation material lined with a film with low radiant emissivity ($\varepsilon < 0.1$) is mounted on the inside surface of the PLF. The value of the maximum radiant heat flux from the inside surface of the PLF to the SC will not exceed 250 W/m^2 from the time of launch until the PLF separates. Based on a separate requirement by the SC manufacturer, the level of radiant heat flux to the SC can be lowered to 160-180 W/m^2.

For the LV injection trajectory at the time of PLF jettisoning, the maximum value of the free molecular heat flux to the area perpendicular to the velocity vector of the LV will not exceed 1135 W/m^2.

2.5.2.4 Pressure in Payload Compartment

In absolute value, the maximum rate of decrease of the pressure under the PLF does not exceed the value $|dp/dt| \leq 5$ kPa/s.

2.6 ELECTROMAGNETIC COMPATIBILITY

2.6.1 Characteristics of Telemetry System

The characteristics of the LV telemetry system are presented in Table 2.6.1-1.

Table 2.6.1-1: LV Telemetry Frequencies

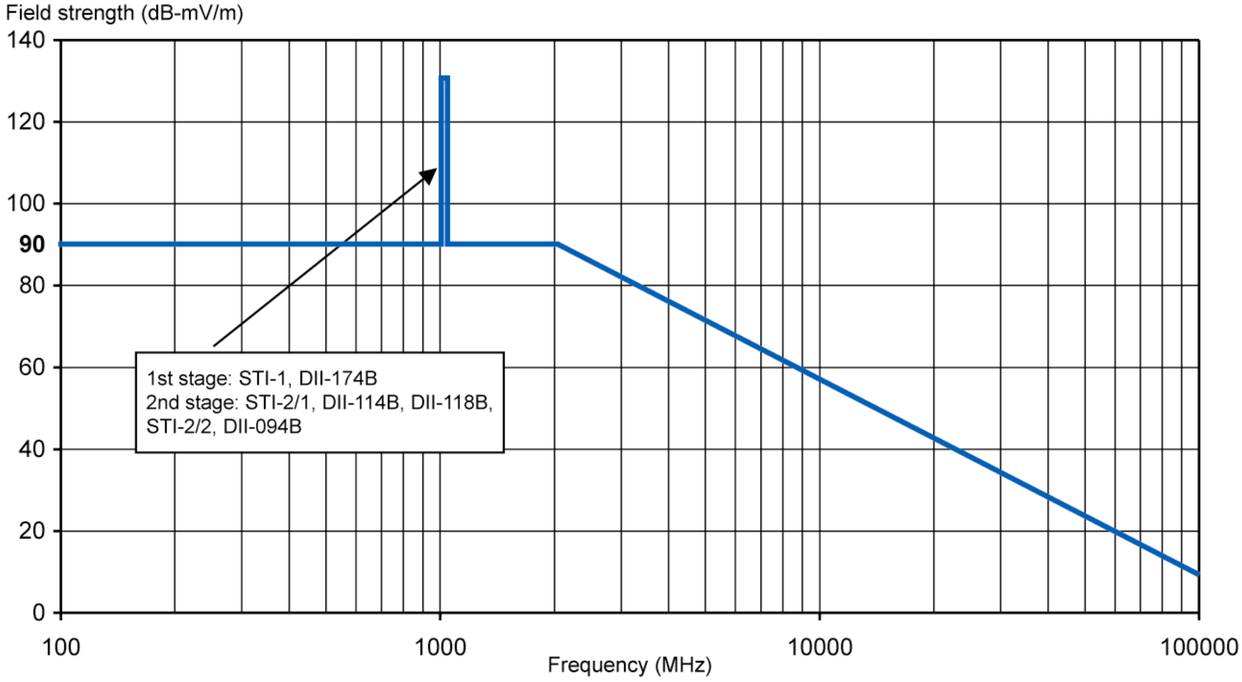
Item	Frequency (MHz)	Symbol
First stage telemetry	1042.5	STI-1
Second stage telemetry	1018.5	STI-2/1
	1020.5	STI-2/1
Second stage telemetry	1010.5	STI-2/2

2.6.2 Electromagnetic Levels at the Plesetsk Cosmodrome

The design radiation levels of the LV and Cosmodrome equipment do not exceed the levels shown in Figure 2.6.2-1.

The values of the radiation levels are given for the plane of the LV/SC interface at a distance of 1 m from the outside surface of the LV.

Figure 2.6.2-1: Electric Field Strength Levels Generated By the LV GSE



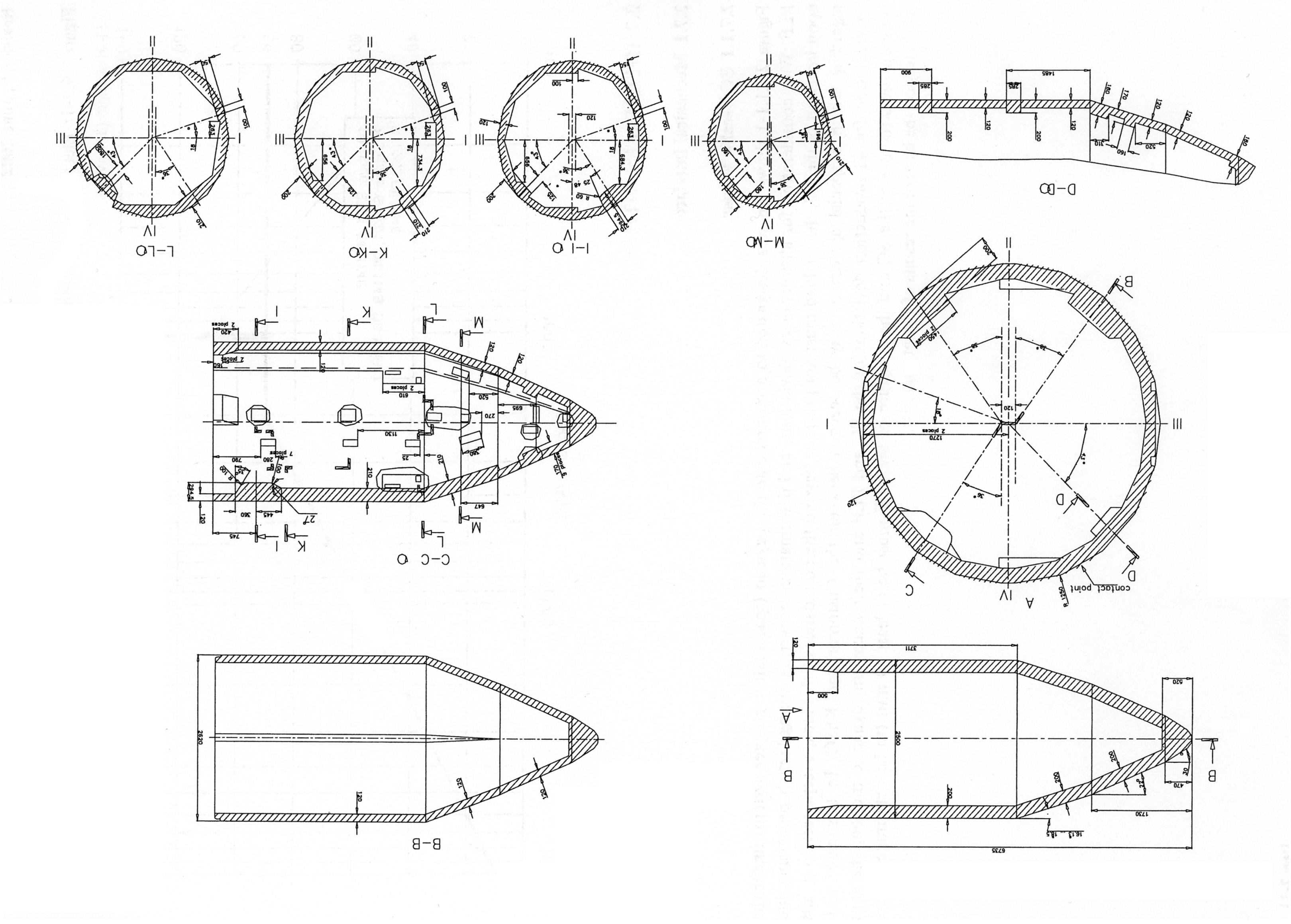
2.7 INTERFACES WITH SC

2.7.1 Mechanical Interface

2.7.1.1 PLF Useable Volume

Figure 2.7.1.1-1 shows the area designated to accommodate the payload (spacecraft + adapter system) under the PLF. With consideration for all tolerances, deviations, and deformations occurring during launch processing and upon injection of the SC, the payload must not protrude beyond the boundaries of this area, except certain points regarding which a special agreement may be reached between the Customer and KhSC. In this case, with consideration for all production deviations of the SC and PLF and their maximum dynamic motion, the gaps between the structure of the SC and the structure of the PLF must be at least 50 mm (to be determined more accurately on the basis of the results of a joint analysis).

Figure 2.7.1.1-1: Payload Fairing Useable Volume



2.7.1.2 Adapter System

The adapter system design is determined for each specific case in which the LV is used. An example of the adapter system and the design of its mechanical joint with the booster of the LV second stage are shown in Figure 2.7.1.2-1. The following are mounted on the adapter system:

- SC separation system
- Brackets for mounting the umbilical connectors intended for electrical connection to the SC
- Sensors used to monitor separation, and others

The composition and design of elements mounted on the adapter system are determined with the consent of the Customer for each specific case in which the LV is used.

2.7.1.3 Possible Areas to Accommodate Access Doors for the SC on the PLF

A diagram of possible areas to accommodate access doors for the SC on the PLF is presented in Figure 2.7.1.3-1.

2.7.1.4 Allowable Payload Center of Mass

Allowable SC mass and CG offset values relative to the second stage load carrying capability are shown in Figure 2.7.1.4-1. The position of the center of mass is determined by the interface between the adapter system and the second stage.

To ensure the second stage controls operate effectively, the SC CG displacement from the LV longitudinal X-axis along the lateral Y and Z axes (pitch and yaw) must not exceed ±25 mm.

Actual SC design allowable CG offset values may vary depending on mission specific coupled loads analysis. The second stage mechanical interface flexibility makes it possible to consider cases that exceed the typical CG locations.

2.7.2 Electrical Interface

2.7.2.1 Layout of Umbilical Cables of the LV for Interface Between the GSE and SC

Umbilical cables are used for servicing the SC at the technical complex and launch complex.

A diagram showing the layout of the umbilical cables on the LV is presented in Figure 2.7.2.1-1.

Figure 2.7.1.2-1: SC Adapter System

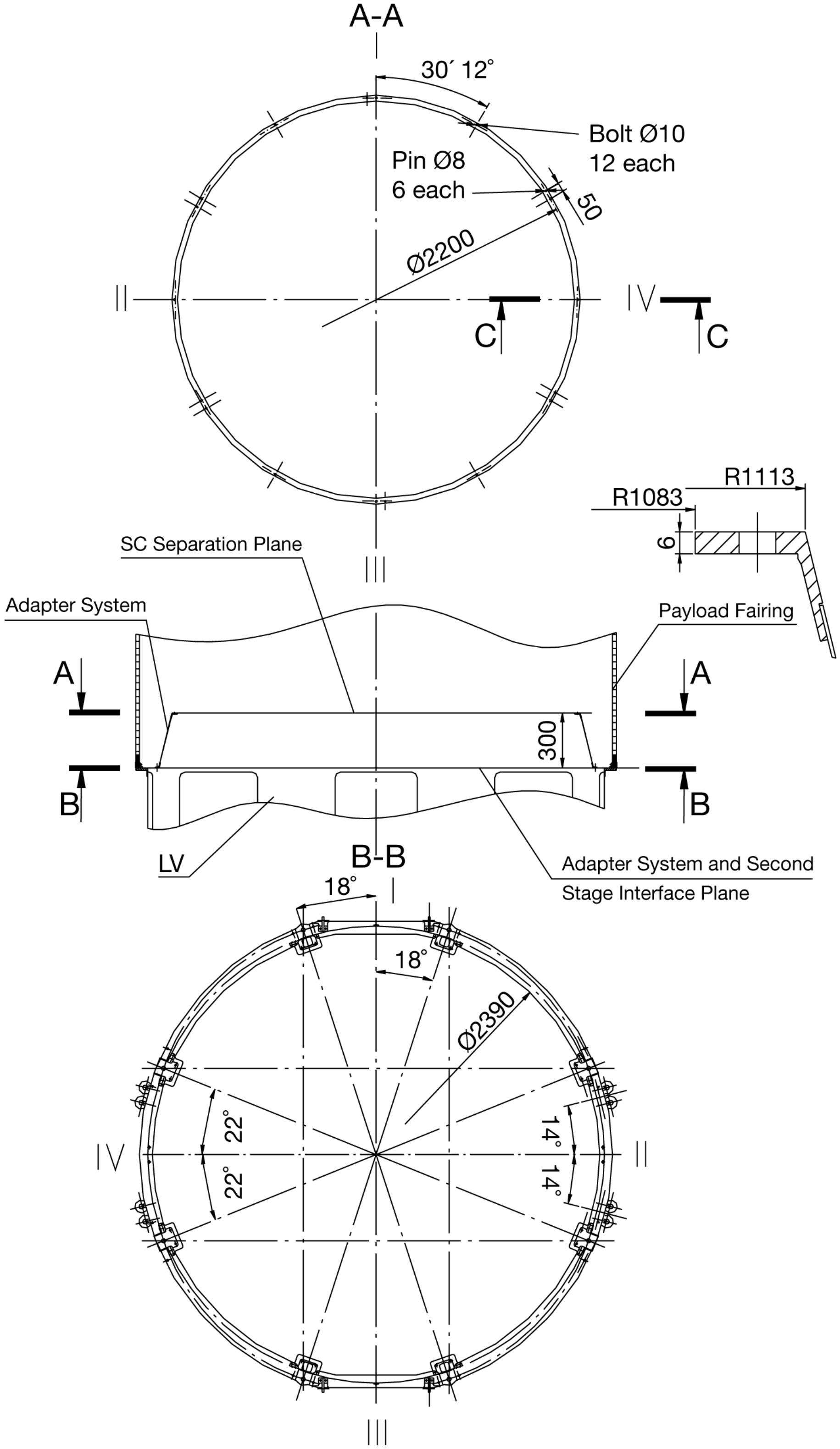


Figure 2.7.1.3-1: Diagram of Areas for Possible Placement of SC Access Doors

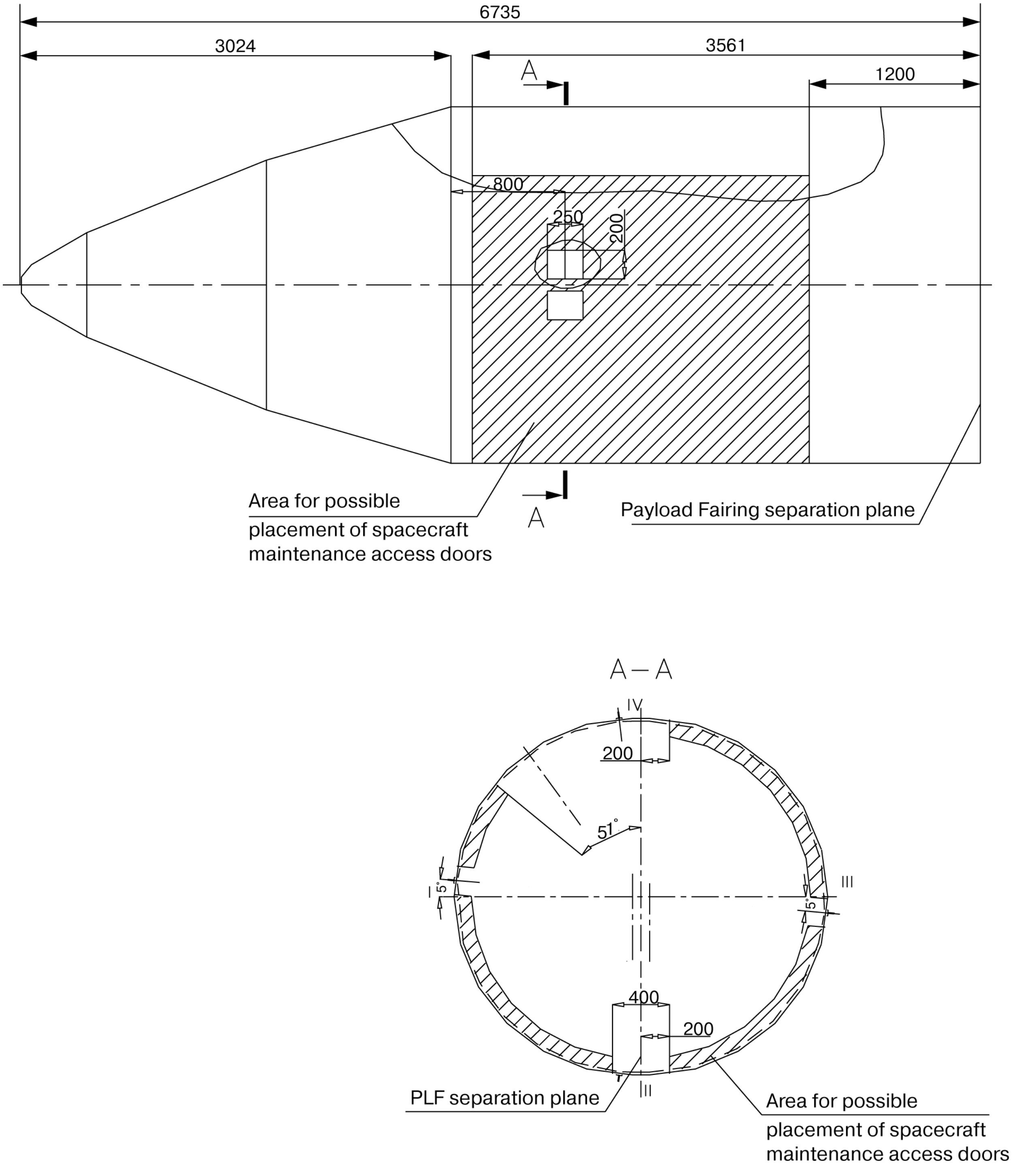
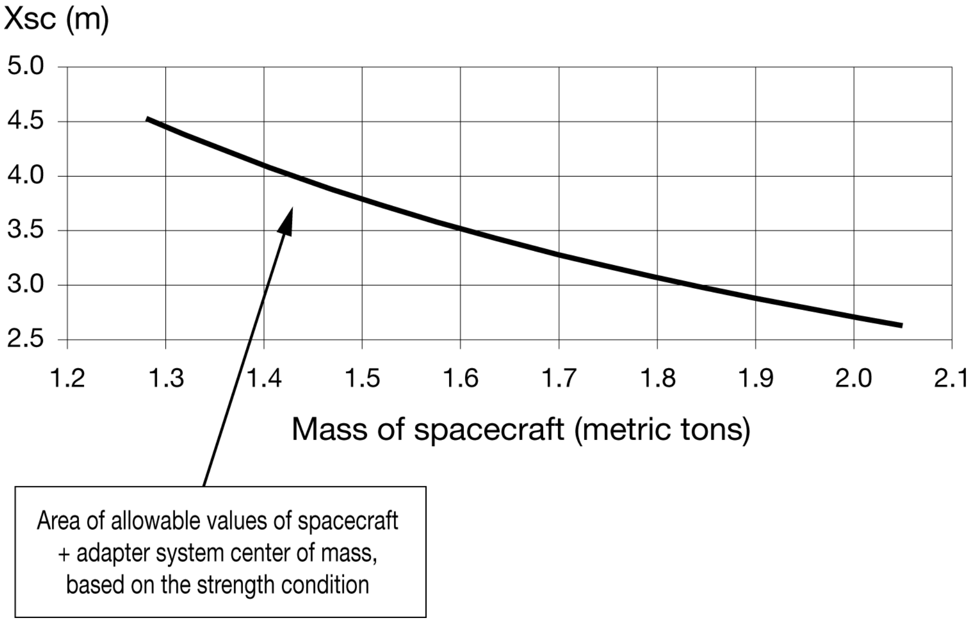
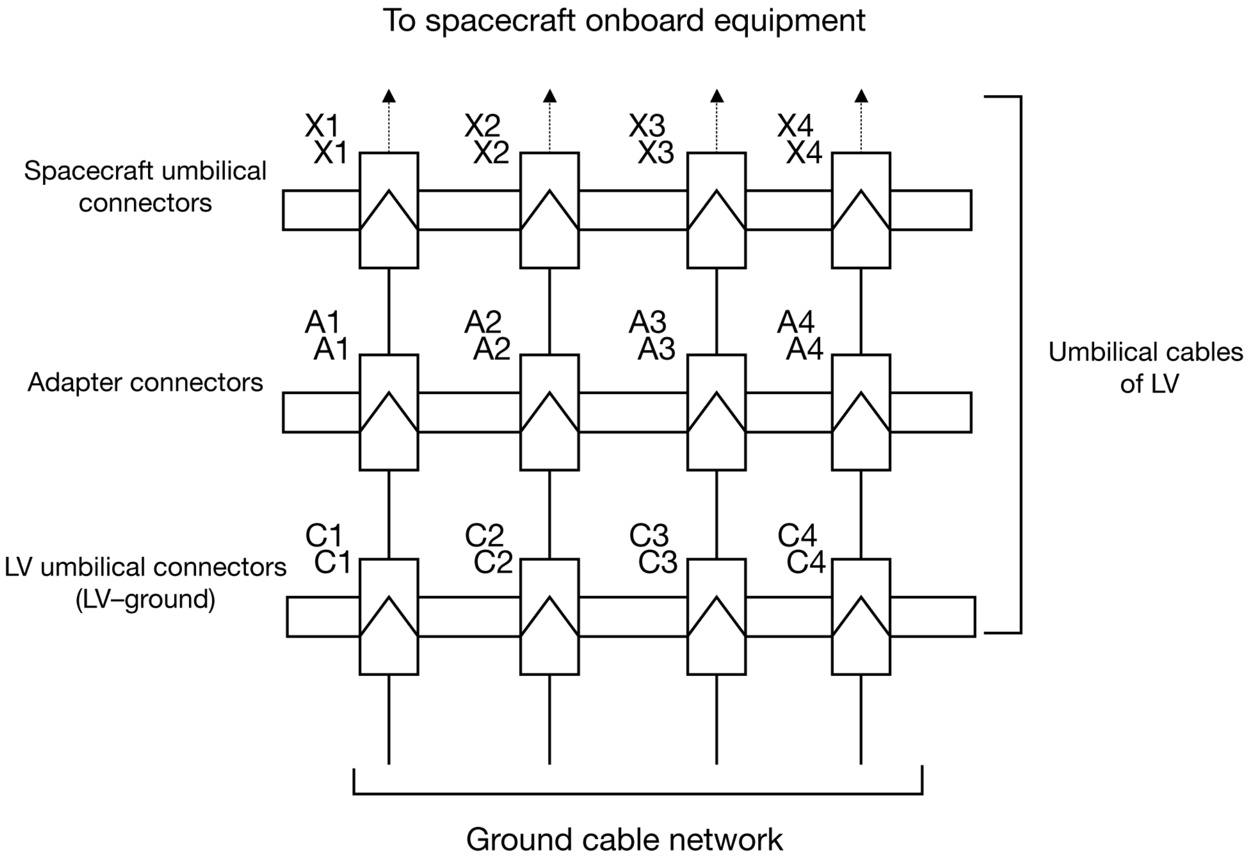


Figure 2.7.1.4-1: Allowable SC Mass and CG Location



Area of allowable values of spacecraft + adapter system center of mass, based on the strength condition

Figure 2.7.2.1-1: Layout of LV Umbilical Cables



Electrical connectors A1-A4, X1-X4, and C1-C4 have 50 contacts each.

The total number of electrical communications lines for maintenance of the SC on the LV is 200, including:

- 100 to provide power and mating monitoring circuits;
- 26 pairs (52 wires) to handle digital interchange;
- 44 to pass relay commands (28 V); and
- 4 for bonding.

The cross-section of all communications lines is $S = 0.35$ mm^2.

The maximum allowable current density in the lines is 3 A/mm^2.

The length of the on-board lines is ≤ 6 m.

All communications lines are galvanically isolated from the body of the LV.

Electrical connectors A1, A3, C1, C3, X1, and X3 are of type 2RMD45-50.

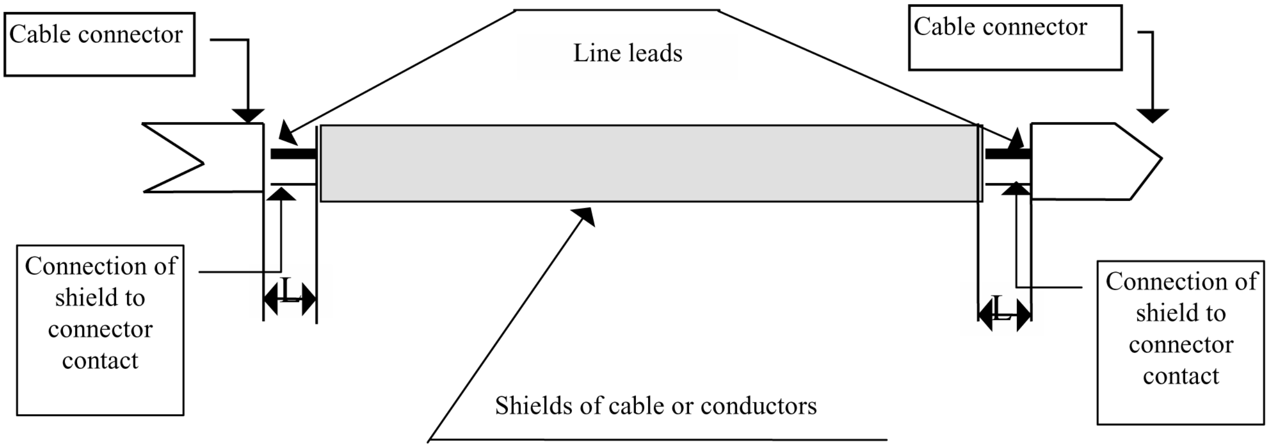
Electrical connectors A2, A4, C2, C4, X2, and X4 are of type 2RM42-50.

For protection from interference and static electricity, the cables are continuously shielded and electrically grounded to the LV structure. The inner shielding and braiding is electrically connected to the sleeve terminals of the electrical connectors. The wires, before the connectors, may have ends no longer than 150 mm that are unprotected by the inner shielding and braiding. The shielding design is shown in Figure 2.7.2.1-2.

2.7.2.2 Electrical Communications Interface Between SC and LV Control System

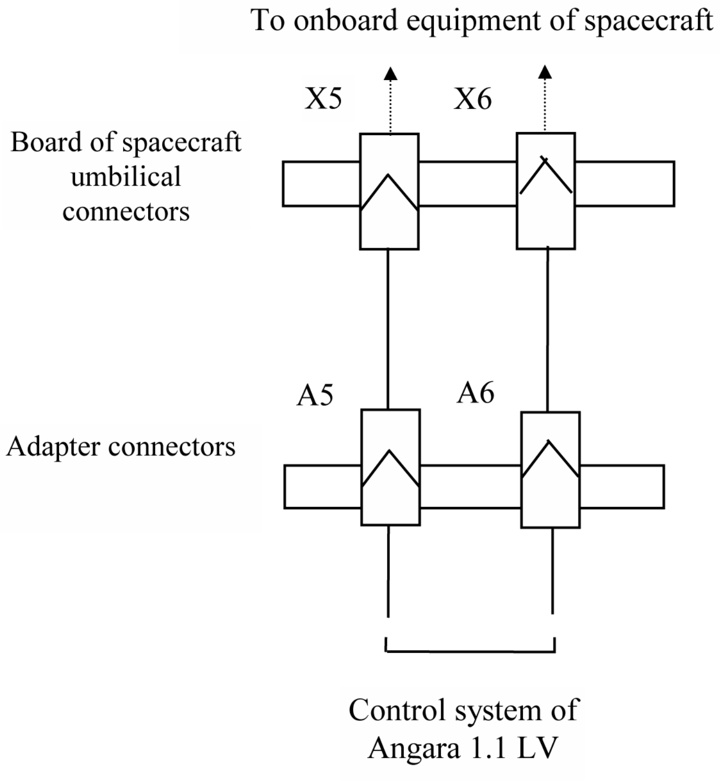
The electrical communications interface between the SC and the LV control system is intended to transmit (receive) commands during launch processing phases and during flight of the LV. A connection diagram of the communications lines is shown in Figure 2.7.2.2-1. The electrical connectors X5, X6, A5, and A6 are of type 2RM42-50.

Figure 2.7.2.1-2: Electrical Connectors Shielding Design



L = 150 mm.- Length of non-shielded cable portion or wires within cable.

Figure 2.7.2.2-1: Communication Lines Connector Diagram



Up to 15 commands can be transmitted from the on-board equipment of the LV control system to the SC, and up to three commands can be sent from the SC to the on-board equipment of the LV control system. Commands are output by closing relay contacts (of the "dry contact" type). The polling voltage is 27 V (+5/-3 V), and the polling current is no more than 1 A. Three commands from the SC to the on-board autonomous control system and ten commands from the on-board autonomous control system to the SC have a length of 0.2-0.5 s, and the five commands from the on-board autonomous control system to the SC has prolonged action (the maximum time from the start of the processing timeline ("cyclogram") to separation of the SC from the LV).

The cross-section of all communications lines is $S = 0.35$ mm^2.

The length of the on-board lines is ≤6 m.

All communications lines are galvanically isolated from the LV body.

For protection from interference and static electricity, the cables are continuously shielded and electrically connected to the LV structure. The inner shielding and braiding is electrically connected to the sleeve terminals of the electrical connectors. The wires, before the connectors, may have ends no longer than 150 mm that are unprotected by the inner shielding and braiding.

2.7.2.3 Ground Electrical Interface

Electrical connections between the on-board equipment of the SC and ground checkout equipment are effected through the ground cable network.

This section shows the organization of the ground cable network for transmitting information and power to SC equipment from the ground checkout equipment in the indoor areas of the launch complex and technical complex.

A diagram of how the ground cable network of SC checkout equipment is laid at the technical complex is presented in Figure 2.7.2.3-1.

The ground cable network laid at the technical complex is used for communications between the umbilical cables of the LV and ground checkout equipment of the SC that is installed in indoor areas of the technical complex.

The ground cable network is used only if some electrical checks are being done or if work involving the spacecraft and requiring the use of ground checkout equipment of the spacecraft is being carried out at the technical complex while the ascent unit is being assembled and then mated to the LV.

A diagram of how the ground cable network of checkout equipment of the SC is laid at the launch complex is presented in Figure 2.7.2.3-2.

Figure 2.7.2.3-1: Ground Cable Network at Technical Complex

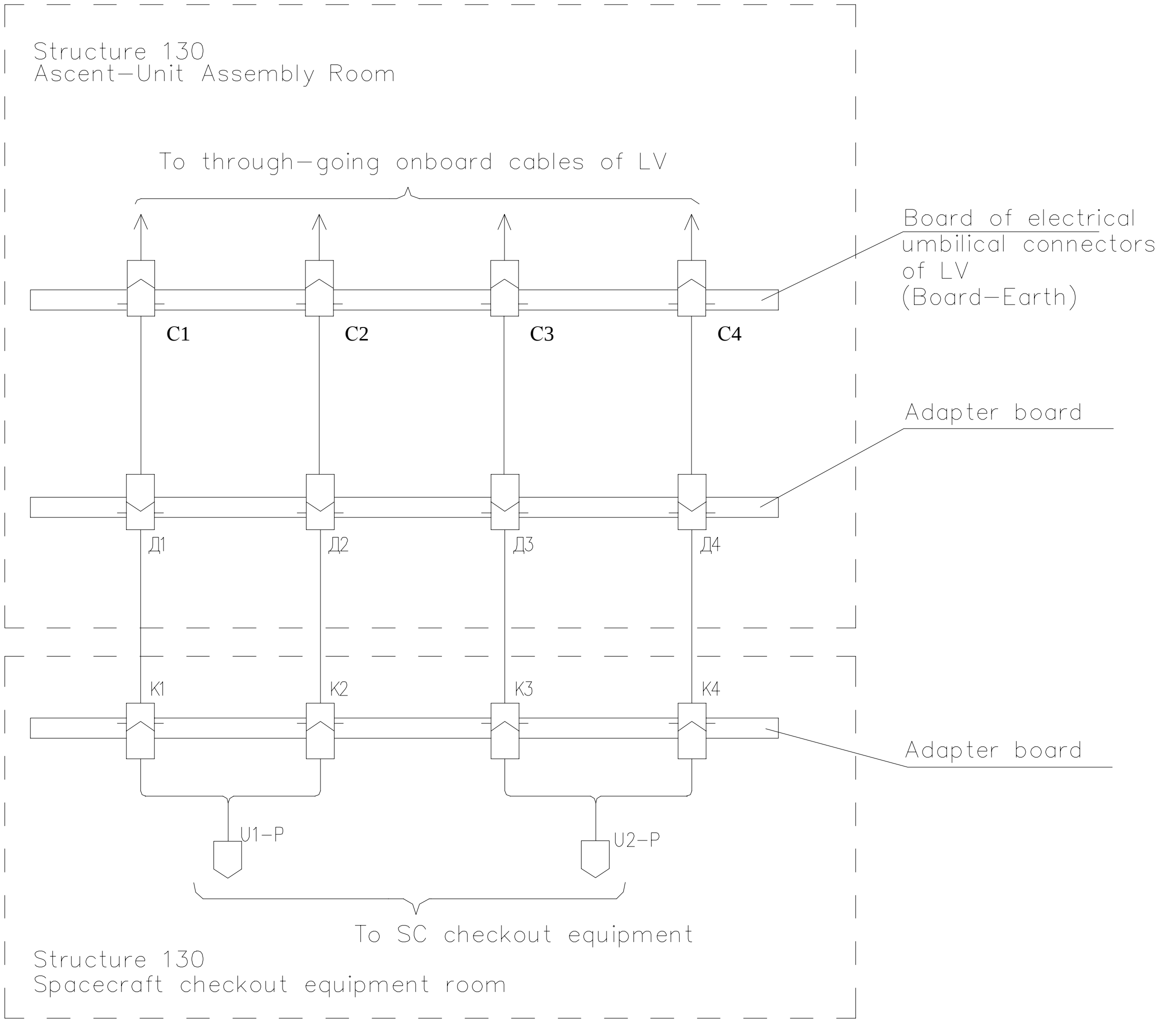
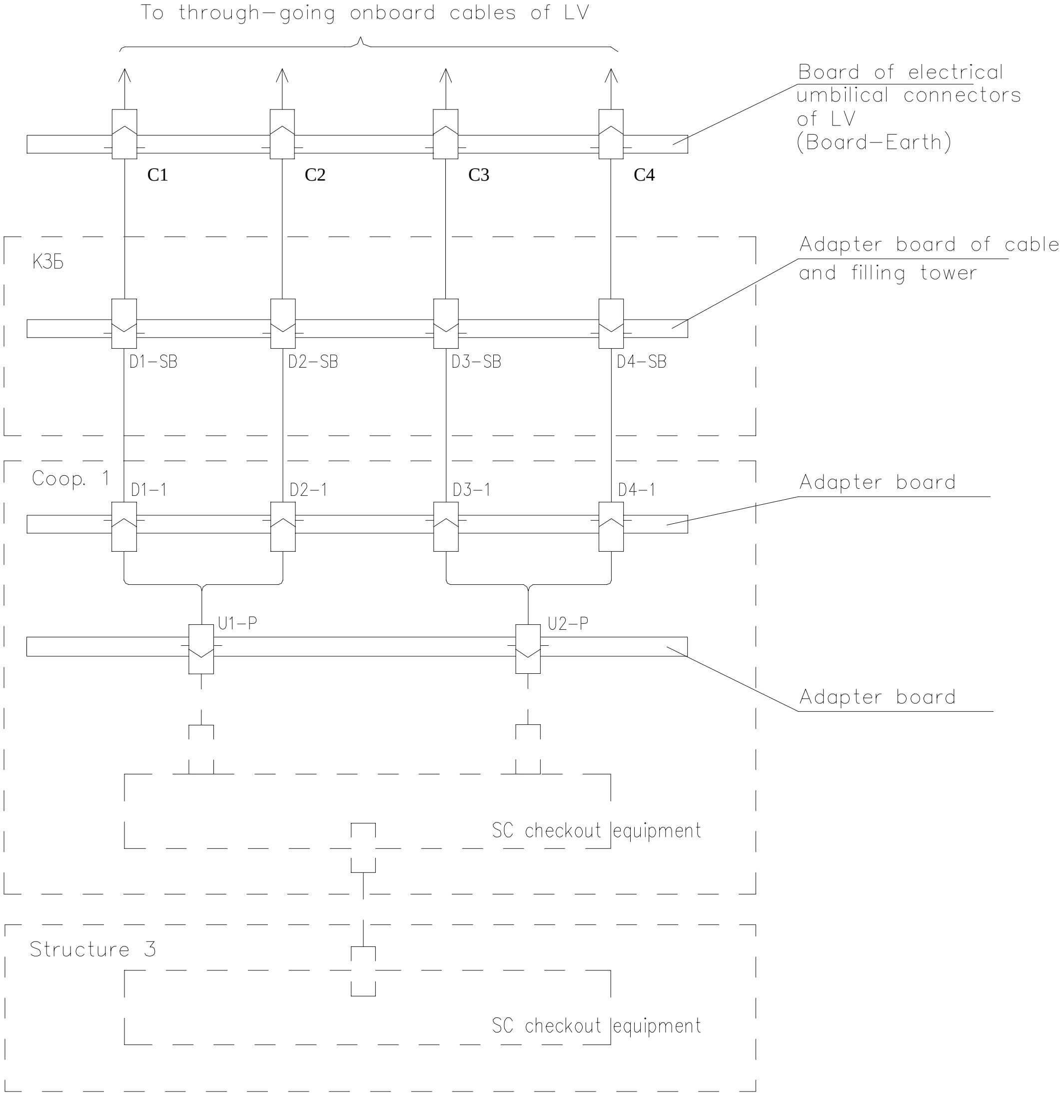


Figure 2.7.2.3-2: Ground Cable Network at Launch Complex



At the Customer's request, the organization of communications between the command post (Bunker) (Structure 3) and the Vault (Structure 1) may be any of the following:

- Electrical low frequency communications;
- Electrical high frequency communications;
- Telephone communications; or
- Fiber-optic communications.

Figure 2.7.2.3-3 presents a block diagram of the electrical connector between the SC and the SC checkout equipment.

The ground cable network is the electrical extension of the umbilical cables of the LV. The electrical parameters of the circuits meet all parameters imposed on circuits of SC on-board equipment. The length of the ground cable network from electrical connectors C1 through C4 to electrical connectors D1-1 through D6-1, per Figure 2.7.2.3-3, is approximately 60 meters.

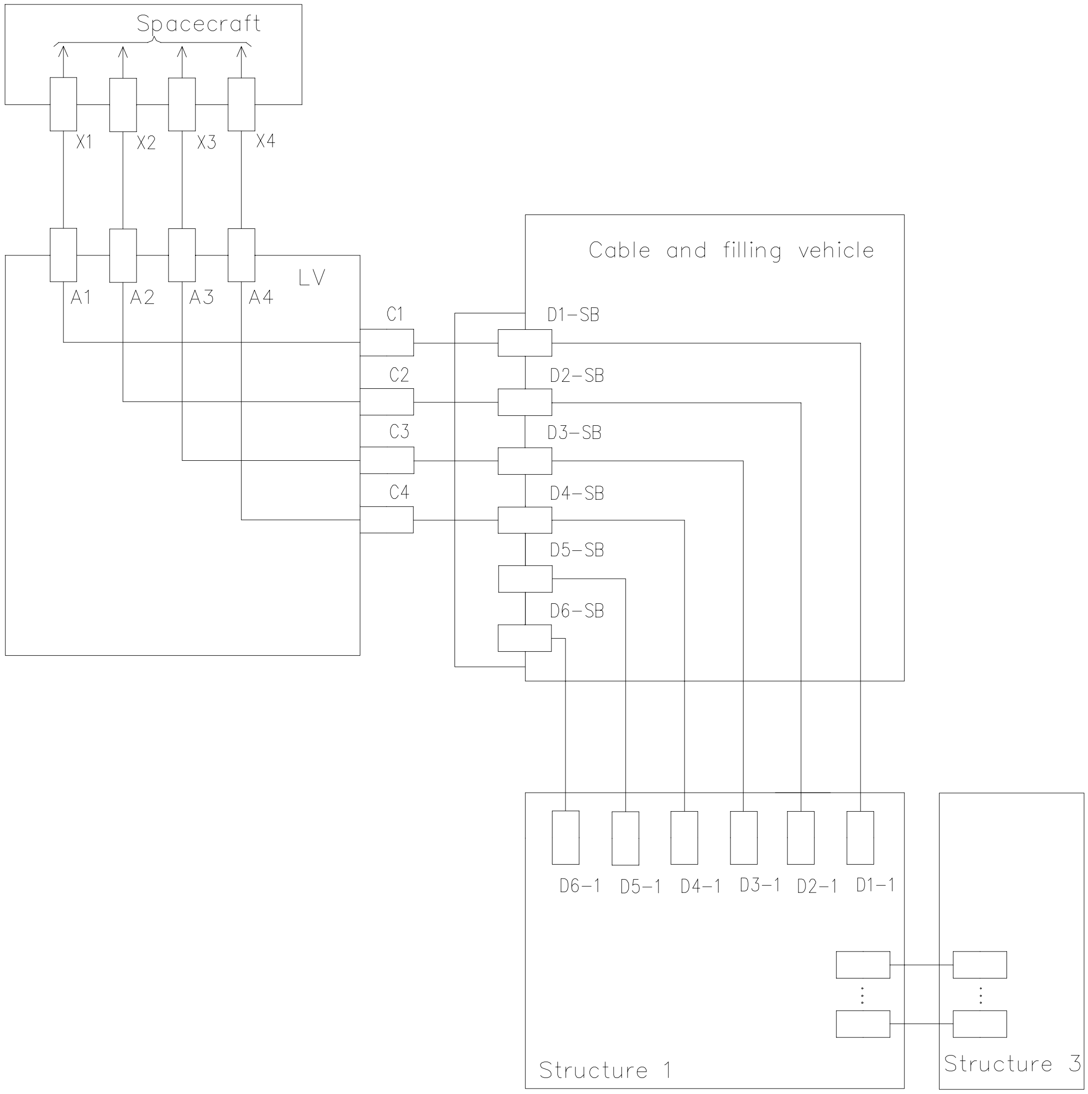
In all, there are 300 ground electrical communications lines for servicing SC on-board equipment and the SC ground checkout equipment, including:

- 100 with a cross-section of 2.5 mm for individual circuits;
- 100 with a cross-section of 1.5 mm for individual circuits in the shield;
- 48 with a core having a cross-section of 2.5 mm for twisted pairs in the shield; and
- 4 to provide static electricity protection.

At the launch complex, type SShR60P50 electrical connectors are installed on the adapter board of the cable and filling tower.

In enclosed areas of the launch complex and technical complex, the ground cable network may terminate with any electrical connector needed to connect to SC checkout equipment.

Figure 2.7.2.3-3: Schematic of Electrical Connectors Between SC and SC Checkout Equipment at Launch Complex



2.7.3 Telemetry Interface

The telemetry measurement system (STI) is designed to measure, collect, generate, and transmit the necessary amount of information during operation of the Angara 1.1, both directly from the LV and from a ascent unit consisting of the SC, adapter system, and PLF.

STI-1 equipment is installed on the first stage of the LV.

On the second stage of the LV, the telemetry measurement system is implemented with STI-2/1 and STI-2/2 equipment.

The STI-2/1 and STI-2/2 records low and high frequency parameters in direct transmission mode.

STI-2/1 equipment operates in direct transmission mode and in memory mode (in the absence of radio visibility), followed by playback, recording only low frequency parameters.

The following measurements can be obtained from the SC and adapter system:

Parameter Type	Qty.	Recording Frequency (Hz)	Recording Equipment
Vibrations	9	8000	STI-2/2
Acoustics	1	8000	STI-2/2
Analog data	8	200	STI-2/1
Temperature data	10	0.3	STI-2/1
Signal data	10	200	STI-2/1

The recording frequency is given for direct transmission mode at maximum capacity of the telemetry measurement system radio link.

For STI-2/1 in memory mode and direct transmission modes at minimum capacity of the radio link, the recording frequency is one-eighth the value indicated; in these modes, analog parameters are not recorded.

In addition to the measurements listed, the following PLF parameters are measured:

Parameter Type	Qty.	Recording Frequency (Hz)	Recording Equipment
Acoustics	8	8000	STI-2/2
Pressure	16	50	STI-2/1
Temperature data	24	0.3	STI-2/1
Signal data	16	50	STI-2/1

During pre-launch processing in the SC area, ground measurement hardware are used to monitor the following parameters:

- Relative air humidity (in the top part of the PLF);
- Air temperature under the PLF;
- Temperature of the adapter structure with the ascent unit assembled; and
- Vibration loading during transportation of the SC.

Information is transmitted from the ground measurement hardware sensors through the boards of the umbilical on-board electrical connector and is sent via the fiber-optic link to the ground measurement equipment.

2.7.4 Static Electricity Protection

The LV acquires an electrical charge and a consequent electrical potential on the surface relative to the environment when it is acted on by the charge of air flow, atmospheric electricity, and factors encountered in space (space plasma, electromagnetic radiation with various wavelengths, etc.), and also as a result of the operation of the LVs engines and on-board equipment.

The buildup of electrical potential in excess of some critical value (as determined computationally) results in a danger of electrostatic discharges, which act on components of electronic equipment and the on-board cable network.

The protection of the LV from electrostatic discharges is accomplished by the passive method, which involves uniform distribution of the acquired charge over the outside surface of the LV. The passive protection method consists in creating conductive surfaces, bonding, and grounding to meet the requirements of GOST 19005-81. The contact resistance at the bonding point does not exceed 2 mohm.

Electrical bonding between the SC and LV is accomplished either through detachable ground straps connecting the adapter structure to the SC interface ring, or by conductive coatings applied to the adapter interface structure.

The LV control system is made resistant to electrostatic discharges, and the on-board cable network is shielded.

Zond3M-Zaryad M sensors are installed on the PLF and LV to monitor the level of electrostatic and electromagnetic fields. The telemetry system is used for the sensors.

The SC being injected is grounded at the launch complex through the metal structure of the LV. This is accomplished by successive bonding of the LV to the stages of the LV, which are bonded to each other. The LV components have grounding points and are grounded during manufacture and transportation.

3. ANGARA A3 LAUNCH VEHICLE

3.1 DESCRIPTION OF DESIGN AND BASIC TECHNICAL CHARACTERISTICS

The two-stage Angara A3 LV is built on a "tandem" scheme made up of three common rocket modules (CRMs) and a second stage. A general view of the LV with a 4350-mm PLF and a Breeze M upper stage is presented in Figure
3.1-1.

The first stage booster consists of three CRMs. Each CRM is identical to the CRM which makes up the Angara 1.1 LV configuration. The CRMs are connected to each other by three spar booms. The upper spar boom is used to convey thrust forces to the second stage intermediate compartment.

The second stage booster uses kerosene and liquid oxygen propellants. The booster has a diameter of 3.6 m and consists of a fuel tank, an intertank compartment, an oxidizer tank, and an intermediate compartment. An RD-0124 four-chamber main propulsion engine is mounted at the base of the oxidizer tank in the intermediate compartment. Separation of the second stage from the first stage is "cold" and is driven by the solid retro-rocket motors installed on the intermediate compartment. After separation, the intermediate compartment remains on the jettisoned center CRM of the first stage booster. The RD-0124 main propulsion engine fires after the engine nozzles emerge from the intermediate compartment. The intertank compartment houses the control and telemetry system, and its frame carries the control components for communication between the LV and GSE.

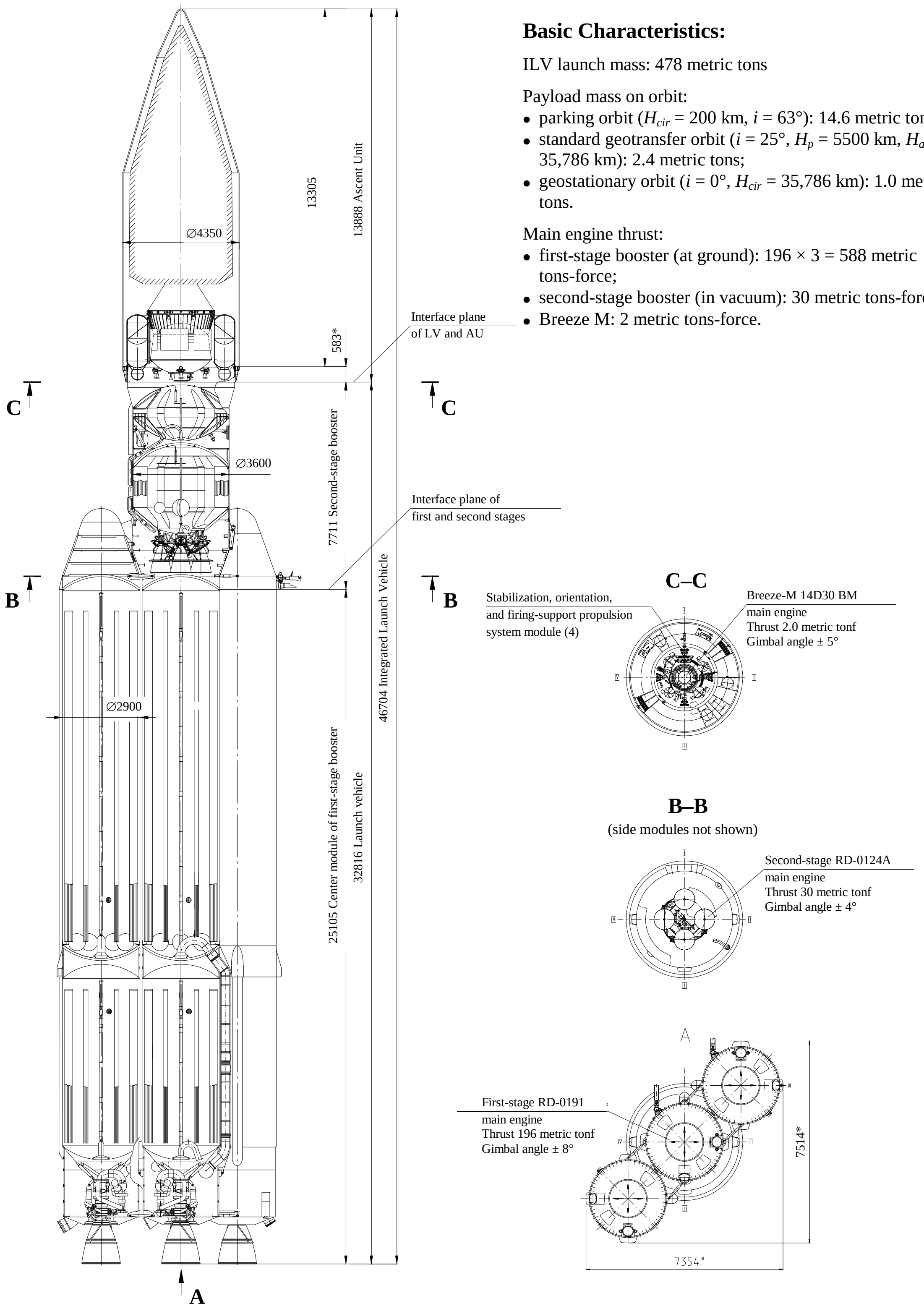
3.2 ASCENT UNIT WITH BREEZE M

The ascent unit (AU) is an independent assembly put together at the technical complex. The ascent unit includes:

- Breeze M upper stage
- SC and the SC adapter system
- PLF

The version of the PLF for the Angara A3/Breeze M is shown in Figure 3.2-1. Once assembled, the AU is secured at the interface of the second stage. Depending on LV performance requirements, the AU may or may not include an upper stage.

Figure 3.1-1: General View of Angara A3 LV



Basic Characteristics:

ILV launch mass: 478 metric tons

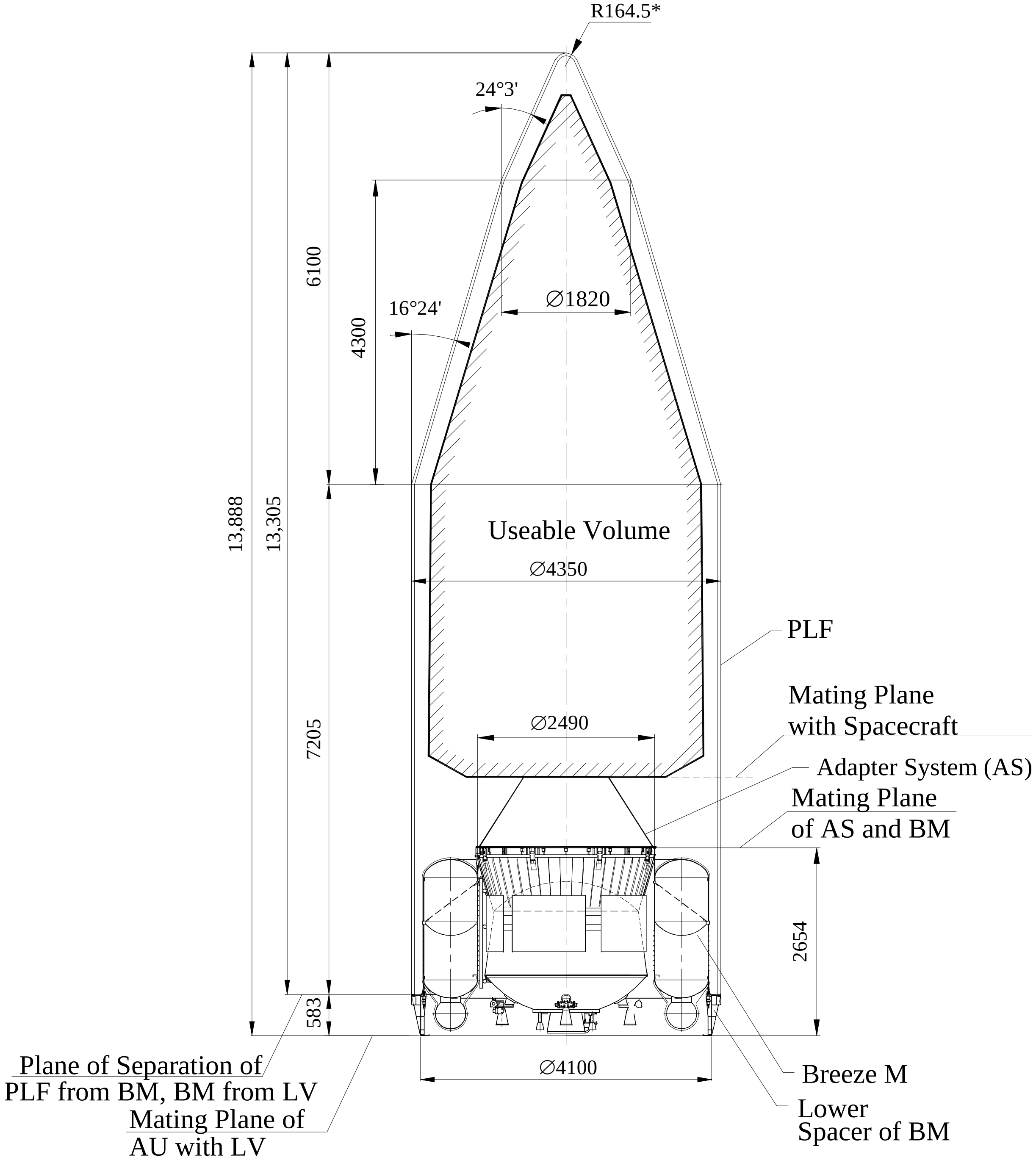
Payload mass on orbit:

- parking orbit (H_{cir} = 200 km, i = 63°): 14.6 metric tons;
- standard geotransfer orbit (i = 25°, H_p = 5500 km, H_a = 35,786 km): 2.4 metric tons;
- geostationary orbit (i = 0°, H_{cir} = 35,786 km): 1.0 metric tons.

Main engine thrust:

- first-stage booster (at ground): 196 × 3 = 588 metric tons-force;
- second-stage booster (in vacuum): 30 metric tons-force;
- Breeze M: 2 metric tons-force.

Figure 3.2-1: General View of the Angara A3/Breeze M 4-Meter PLF



3.3 BREEZE M UPPER STAGE

The Breeze M upper stage, which is derived from the Breeze K stage flown on the Rokot, offers substantially improved payload performance and operational capabilities over the Block DM flown on the Proton K and Proton M launch vehicles.

The Breeze M is 2.65 meters in height and 4.0 meters in diameter, with an inert mass of 2,370 kg and a total propellant mass of 19,800 kg. It consists of the following three main elements:

1) A core section (central block) derived from the original Breeze K stage that accommodates a set of propellant tanks, the propulsion system, and the avionics equipment bay. Total propellant capacity of the core is 5.2 metric tons.
2) A toroidal additional propellant tank that surrounds the core section, and which is jettisoned in flight following depletion of its 14.6 metric tons of propellant. This staging capability substantially improves the performance of the Breeze M stage.
3) A lower spacer used for mounting the Breeze M and PLF on the LV second stage; the spacer is jettisoned with the second stage.

Figures 3.3-1 and 3.3-2 illustrate the layout and dimensions of the Breeze M. Further details of the main elements of the Breeze M are provided below.

Figure 3.3-1: Breeze M General Layout With Toroidal Additional Propellant Tank (Cross-Section)

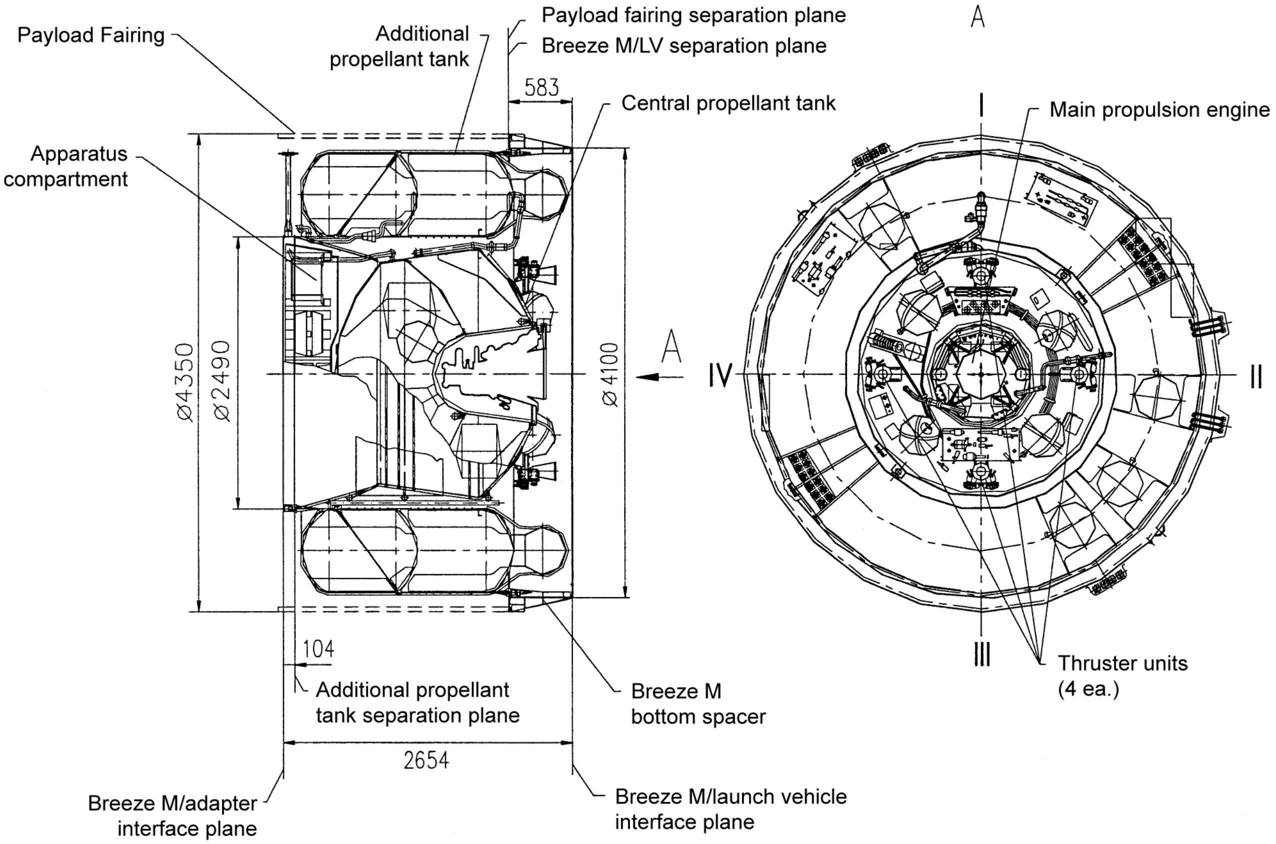
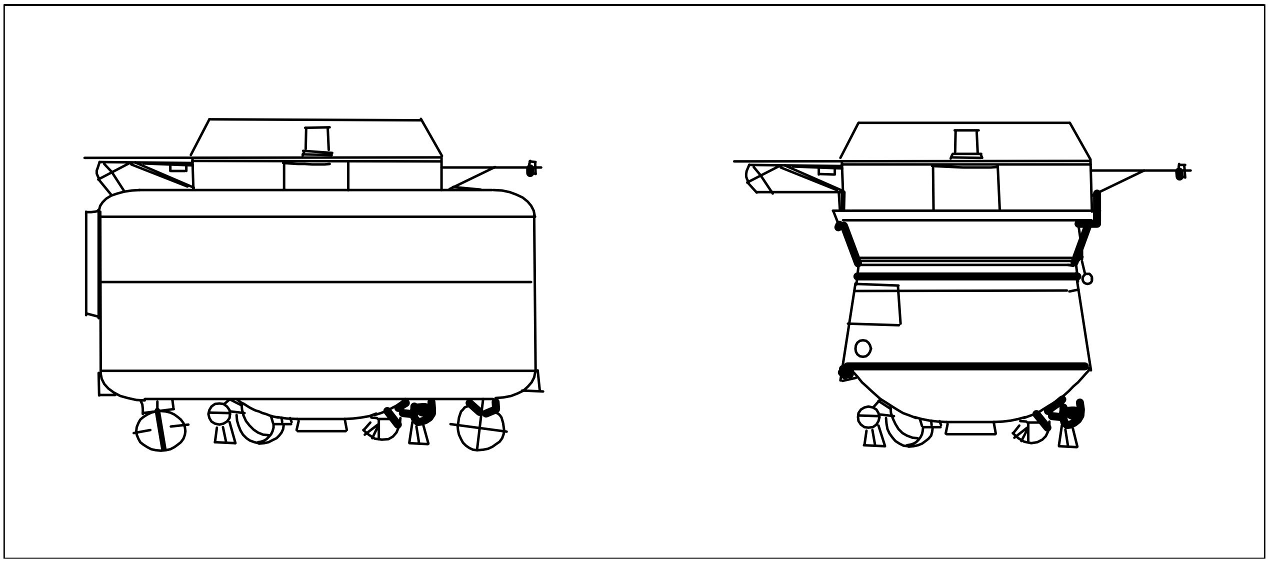


Figure 3.3-2: Breeze M in Flight With and Without Toroidal Additional Propellant Tank



3.3.1 Central Block

The central block consists of the central propellant tank with the propulsion system and the equipment bay, in which the equipment of on-board systems is installed.

The central propellant tank comprises the oxidizer and fuel tanks, which are separated by an intermediate bulkhead; the oxidizer tank is positioned on top, and the fuel tank below. The main propulsion engine is secured in the interior niche of the tanks. Inside the tanks are the pneumatic and hydraulic systems, as well as baffles to dampen propellant sloshing. In the lower section, there are four thruster units, spherical bottles containing helium for pressurization, and other elements of the pneumatic and hydraulic system. A hinged rotating heat-protective cover is secured to the lower surface to maintain the required temperature regime in the main propulsion engine in intervals between operations. The thermal control trunk lines are mounted on the conical shell of the center propellant tank, and the surface of the conical shell and the lower section are coated with screen vacuum thermal insulation.

Structurally, the un-pressurized equipment bay is an inverted truncated cone that is secured to the top frame of the central propellant tank. Inside the compartment is the primary sub-frame, on which are installed the electronic hardware for the control system, measurement system, thermal control system, and the on-board power sources. The adapter system for mounting of the SC is secured to the top frame of the equipment bay.

The Breeze M core structure provides the payload adapter and electrical interfaces to the Customer's SC. The interface between the stage and its payload adapter is 2490 mm in diameter, allowing the Breeze M to accommodate large diameter payload adapters. The SC static moment about this interface may be approximately 18,000 kg-m. The Breeze M is encapsulated within the payload fairing, along with the SC, allowing loads from the payload fairing to be borne by a short (600-mm) spacer ring attached to the second stage equipment section, rather than by the Breeze M. The Breeze M payload fairing is a derivative of the payload fairing currently in use with commercial SC on the Proton M/Breeze M.

3.3.2 Additional Propellant Tank

The additional propellant tank (APT) is positioned around the central block and is implemented as a toroidal compartment with cylindrical shells and an intermediate bulkhead that divides the compartment into the oxidizer tank (top) and fuel tank (bottom). Loads are conveyed from the SC and central block through the load-bearing cone inside the oxidizer tank and through the outer cylindrical shell of the fuel tank. Loads are then accepted by the bottom spacer of the upper stage. Inside the tanks are the pneumatic and hydraulic systems, as well as baffles to damp propellant sloshing. In the lower section of the APT are the pneumatic and hydraulic systems, including the spherical bottles for pressurization, automatic pneumatic and hydraulic equipment, and control components with electrical connectors.

When the APT is jettisoned, the pyrotechnic bolts that connect the tank to the central block are fired, and electrical and hydraulic connections are broken. Then the spring pushers are actuated, and the central block is separated by means of two guides on the APT and roller supports on the central block.

3.3.3 Propulsion System

The Breeze M uses nitrogen tetroxide (N_2O_4) and unsymmetrical-dimethylhydrazine (UDMH) as propellants. Propulsion for the Breeze M consists of one pump-fed, gimbaled main engine developing 19.62 kN of thrust, four "impulse adjustment thrusters" of 396 N thrust each for making fine corrections to the main engine impulse, and 12 attitude control thrusters of 13.3 N thrust each. The main engine can re-ignite up to eight times per mission, and is equipped with a backup restart system that can fire the engine in the event of a primary ignition sequence failure. The main engine can be commanded to shutdown either upon achieving a desired state vector or propellant depletion.

The propulsion system of the Breeze M is derived from, and has a high degree of commonality with, previous flight systems. During two flights of the Phobos space probes in 1988 and three flights of the Breeze K on the Rokot in 1990, 1991, and 1994 the main engine demonstrated up to five restarts in flight. Following minor modifications to adapt the engine for the Breeze M, eleven main engines have been ground tested, some up to 6,000 seconds total burn duration. The Breeze M attitude control thrusters were previously used on the Kvant, Kristall, Spektr, and Priroda modules of the MIR space station, and are used on the Russian FGB and Service Module components of the International Space Station.

The propulsion unit of the Breeze M has a high degree of continuity with existing designs.

The propulsion system of the Breeze M performs the following actions:

- provides thrust pulses specified in the flight program to trim velocity;
- controls the angular motion of the upper stage;
- performs repeated firings of the main propulsion engine under weightless conditions (including refiring, in the event of a failed firing);
- supplies propellant from the tanks to the engines; and
- pressurizes the propellant tanks.

Characteristics of the engines used in the Breeze M propulsion system are provided in Table 3.3-1.

Table 3.3-1: Basic Characteristics of the Breeze M Propulsion System

Main Propulsion Engine	
Designation	14D30
Vacuum Thrust	19.62 kN
Number of Firings Per Flight	Up to 8
Thrusters	
Vernier Engines:	
Designation	11D458
Number of	4
Vacuum Thrust	392 N
Orientation and Stabilization Engines:	
Designation	17D58E
Number of	12
Vacuum Thrust	13.3 N

3.3.4 Control System and Telemetry System

The control system of the Breeze M includes an on-board digital computer and three-axis gyro stabilized platform, and navigation systems. The following functions are performed by the control system.

- Inertial navigation
- Terminal guidance
- Angular motion control
- Control of the operating modes of the propulsion system and other upper stage on-board systems
- Information exchange with the SC and LV control systems
- Control of separation of the APT and SC
- Electrical power supply to upper stage on-board equipment

Breeze M can perform preprogrammed maneuvers about all axes during parking orbit and intermediate and transfer orbit coasts. The upper stage is normally three-axis stabilized during coast. During powered flight, the upper stage attitude is determined by mission specific pitch, yaw and roll programs. During non-powered flight, the Breeze M attitude can be controlled to an angular pointing accuracy of ±10 degrees in coarse pointing mode and ±1.0 degree in fine pointing mode, and an angular velocity accuracy of ±0.5 degree per second.

Thermal control of the SC can be provided through the use of a control maneuver, in which the Breeze M and SC rotate about the longitudinal X or transverse Z axis of the fourth stage. Maneuvers of 180 degrees lasting no more than 300 seconds about the longitudinal axis, or 900 seconds about the transverse axis, can be used. Alternatively, continuous rotation of the Breeze M is possible about the longitudinal axis, with an angular velocity of up to 1 degree per second.

The possibility of performing these maneuvers, as well as continuous rotation, will be defined by the SC sun exposure and launch window requirements.

Breeze M can perform separation of a Customer's SC in any one of three modes:

1) Three-axis stabilization mode, during which the angular rates in relation to any of the coordinate system axes will not exceed 2.0 degrees per second, and the spatial attitude error in relation to the inertial coordinate system will not exceed ±5 degrees, or

2) Longitudinal spin-up mode, during which the stage can achieve a maximum angular rate with respect to the upper stage longitudinal axis of 6.0 degrees per second, and the spin axis deflection from the upper stage longitudinal axis after SC separation will not exceed ±5 degrees, and will be determined by the SC characteristics and Customer requirements for SC separation dynamics, or

3) Transverse spin-up mode, in which the SC is spun around the transverse axis either by use of unsymmetrical springs or by rotation of the stage at an angular velocity of up to 2 degrees per second.

The Breeze M telemetry system (on-board measuring system) performs the following functions:

- Collection of data on the state of design elements and on the operation of the upper stage and SC systems and units (according to a coordinated list) in all flight phases and during launch processing.
- Transmission of telemetry data to ground measuring stations.
- Receiving and transmission of ground-based trajectory data.

All equipment in the on-board measuring system was especially developed for the Breeze M.

The telemetry data acquisition system operates in direct transmission mode (NP), memory mode (ZAP), playback mode (VOSPR), or the combined modes, NP + VOSPR or NP + ZAP, executing programs that differ in telemetered parameters and polling frequencies.

Radio frequency measurements are recorded by the upper stage telemetry system.

The parameters monitored by the telemetry system are summarized below:

- During the preparation, launching, and entire flight, the operation of upper stage systems and units is under constant monitoring by the telemetry measurement system and the control system.
- The load on and state of the upper stage structure are monitored for 120 parameters.
- The operation of the propulsion unit is monitored for 83 parameters.
- The operation of the thermal mode support system is monitored for 20 parameters.
- The operation of the control system is monitored for more then 200 parameters.

The data obtained, in the form of files of analog and digital parameters, are sent to ground measuring stations and put through careful analysis.

3.3.5 Thermal Control System

The thermal control system provides the active and passive temperature regulation that includes the following elements:

- The thermal control system, which maintains the specific temperature of the upper stage elements and radiates excess heat into space by means of the control system. The thermal control system consists of a hydraulic circuit, which includes a radioactive heat exchanger, an electrical pump unit, a switch, cold plates (heat sinks), heat pipes of the instrument subframe, and the coils of the instrument subframe and propellant compartment.
- Means of passive temperature regulation, which handle external heat exchange of the upper stage within the range determined by heat losses and heat influxes, as well as the thermal conditions of units by means of temperature-regulating coatings, thermostats, thermal resistances, and screen vacuum thermal insulation.

3.4 ADAPTER SYSTEMS

The adapter system is intended to provide mechanical and electrical connection between the SC and the LV. The standard adapter system, 1000 mm high, is shown in Figures 3.4-1a through 3.4-1e.

The adapter system consists of a structure with the following mounted on it: the separation system, passive thermostatic-control system, electrical umbilical cables, and telemetry monitoring system sensor equipment.

The structure is a conical mesh spacer made of polymer materials with an aluminum alloy ring in the upper part and an end ring in the lower part. The lower ring is joined by bolts and pins to the upper stage.

The SC is secured to the adapter system upper ring by a clampband separation system developed by Saab.

Depending on Customer requirements, a separation system with standard size 1194 or 1666 or other types of separation systems may be used.

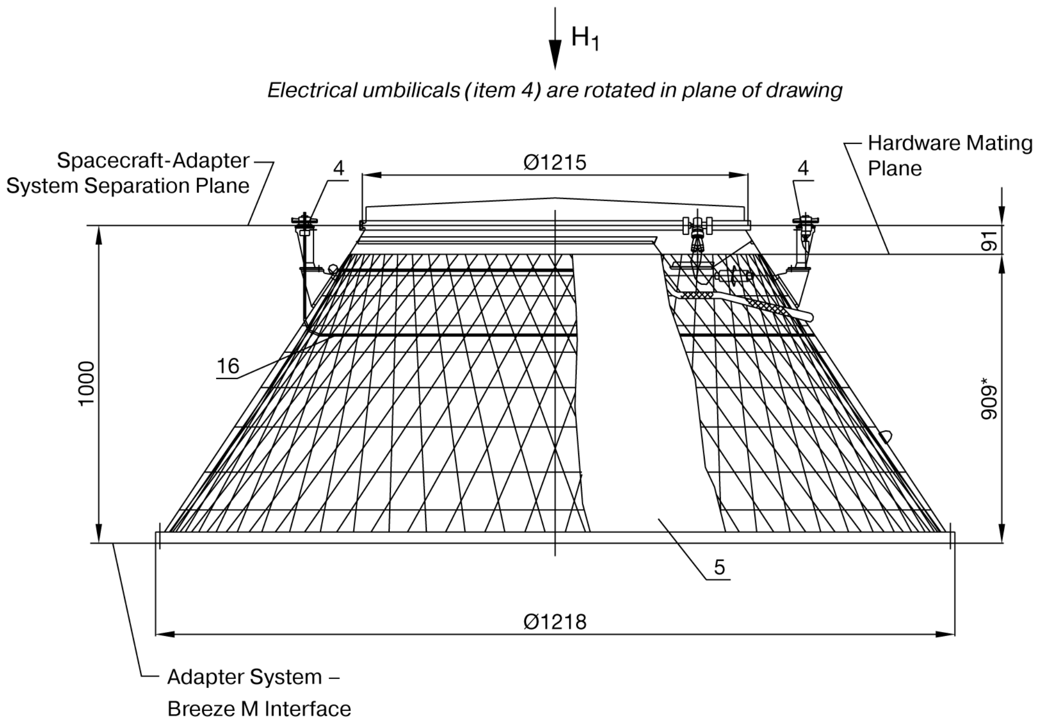
Spring pushers are installed on the top end ring to provide the initial impulse upon separation of the SC from the LV. The number of spring pushers and their force are determined by SC separation requirements. In all, up to 12 spring pushers may be installed on the adapter system.

Two lines of electrical umbilical cables that provide electrical connection between the SC and the LV are installed on the adapter system. The types of electrical connectors and their mounting coordinates are determined based on mission specific requirements.

At the request of the Customer, purge system hardware may be mounted on the adapter system for SC use.

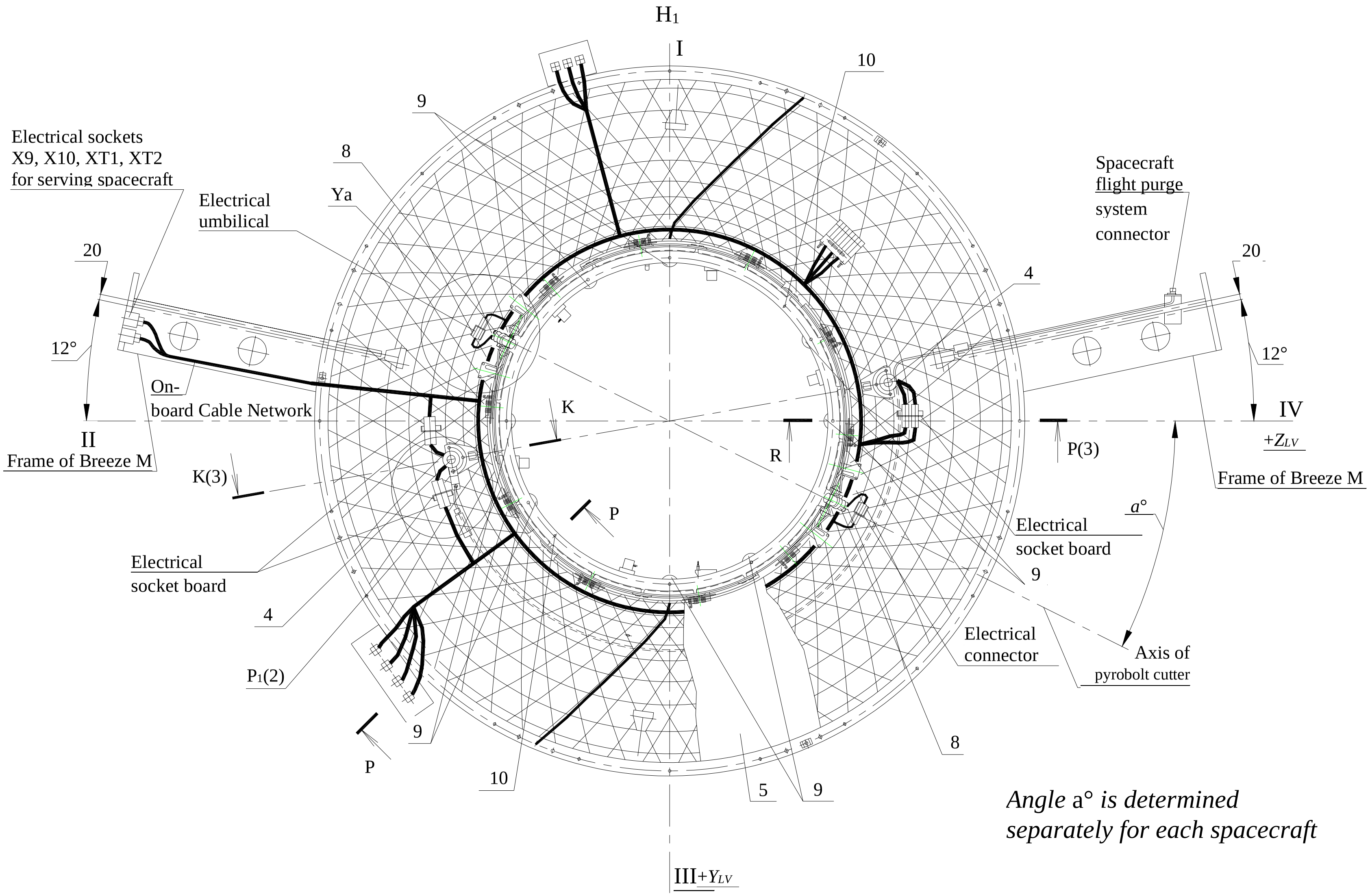
The SC is protected from static electricity either by tearaway bonding jumpers or by a special coating applied to the mating plane of the upper ring of the adapter system. The method of protection from static electricity is determined based on mission specific requirements.

Figure 3.4-1a. Breeze M Adapter System (Sheet 1 of 5)



Item	Description		Qty.	Mass	Remarks
1	Adapter system body		1		
2					
3					
4	Electrical umbilical		2		
5	Screen vacuum thermal insulation				
6	Bonding jumper		2		
7	Clampband		1		
8	Pyrobolt cutter		2		
9	Spring pusher		8		
10	Separation monitoring sensor	813LMI-4681-0	2		
11					
12					
13					
14					
15					
16	Purge system line		1		
17					
18	Purge system connector for mating with spacecraft		1		
19					
20					

Figure 3.4-1b. Breeze M Adapter System (Sheet 2 of 5)



Angle a° *is determined separately for each spacecraft*

Figure 3.4-1c. Breeze M Adapter System (Sheet 3 of 5)

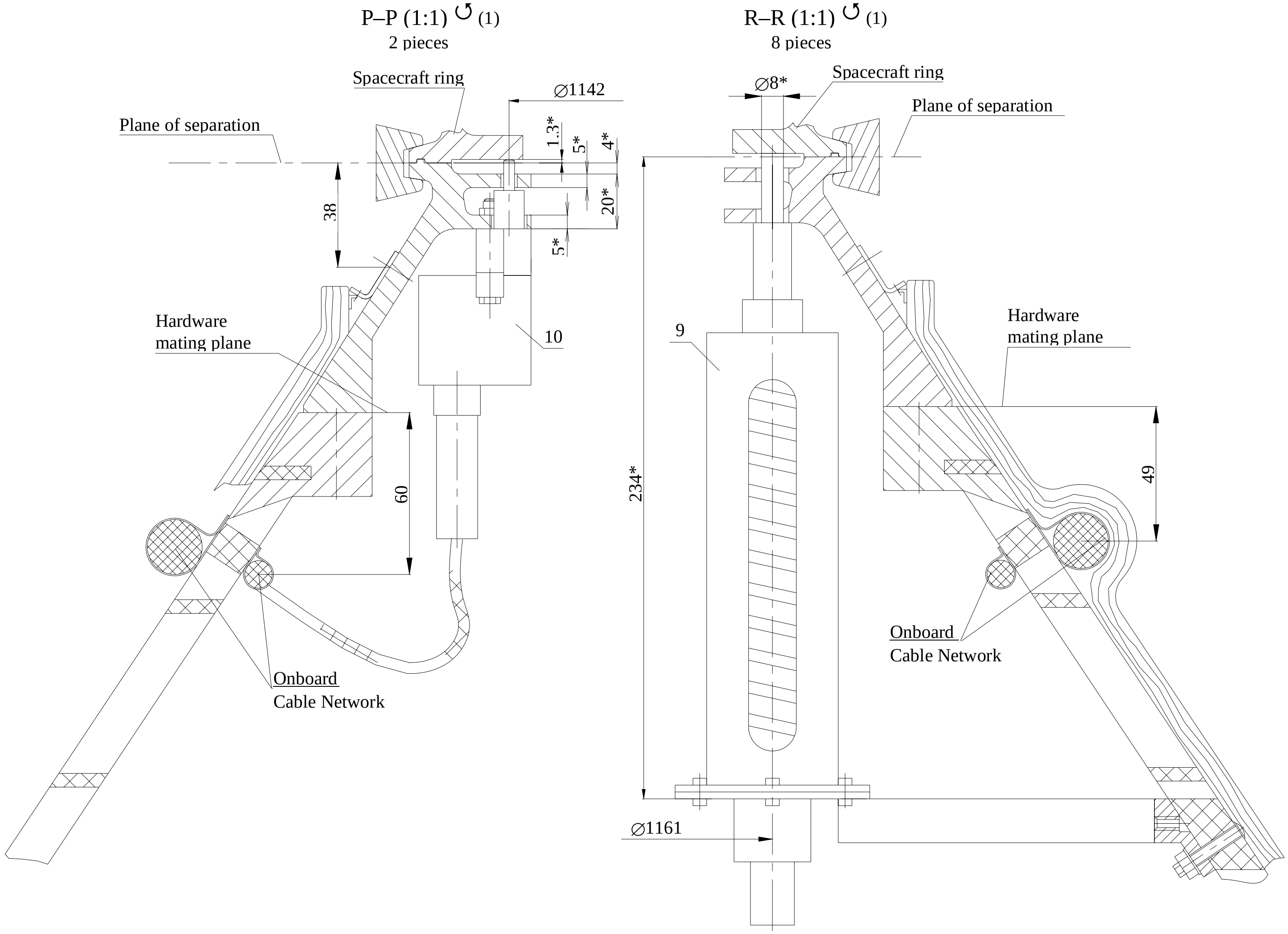


Figure 3.4-1d. Breeze M Adapter System (Sheet 4 of 5)

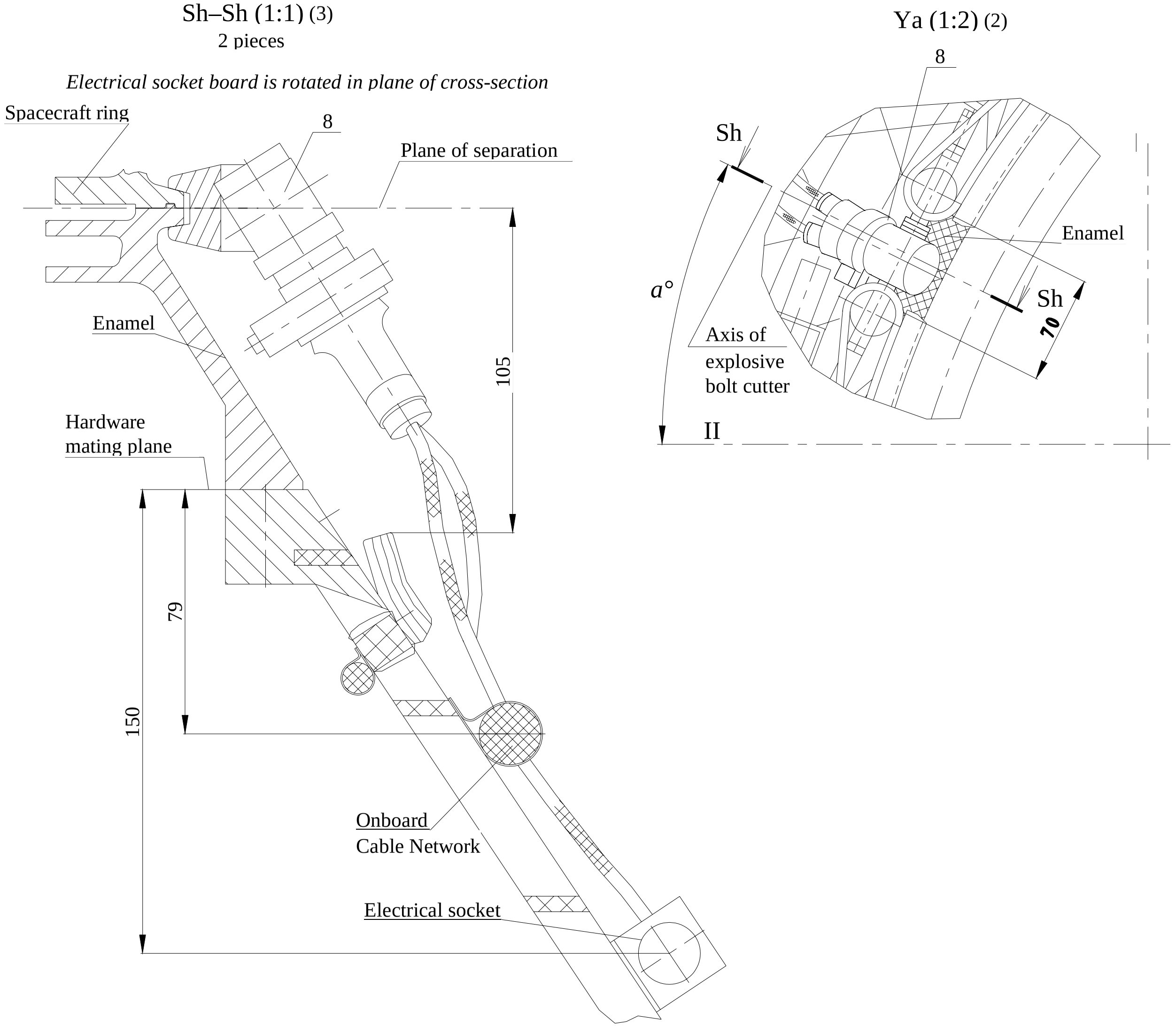
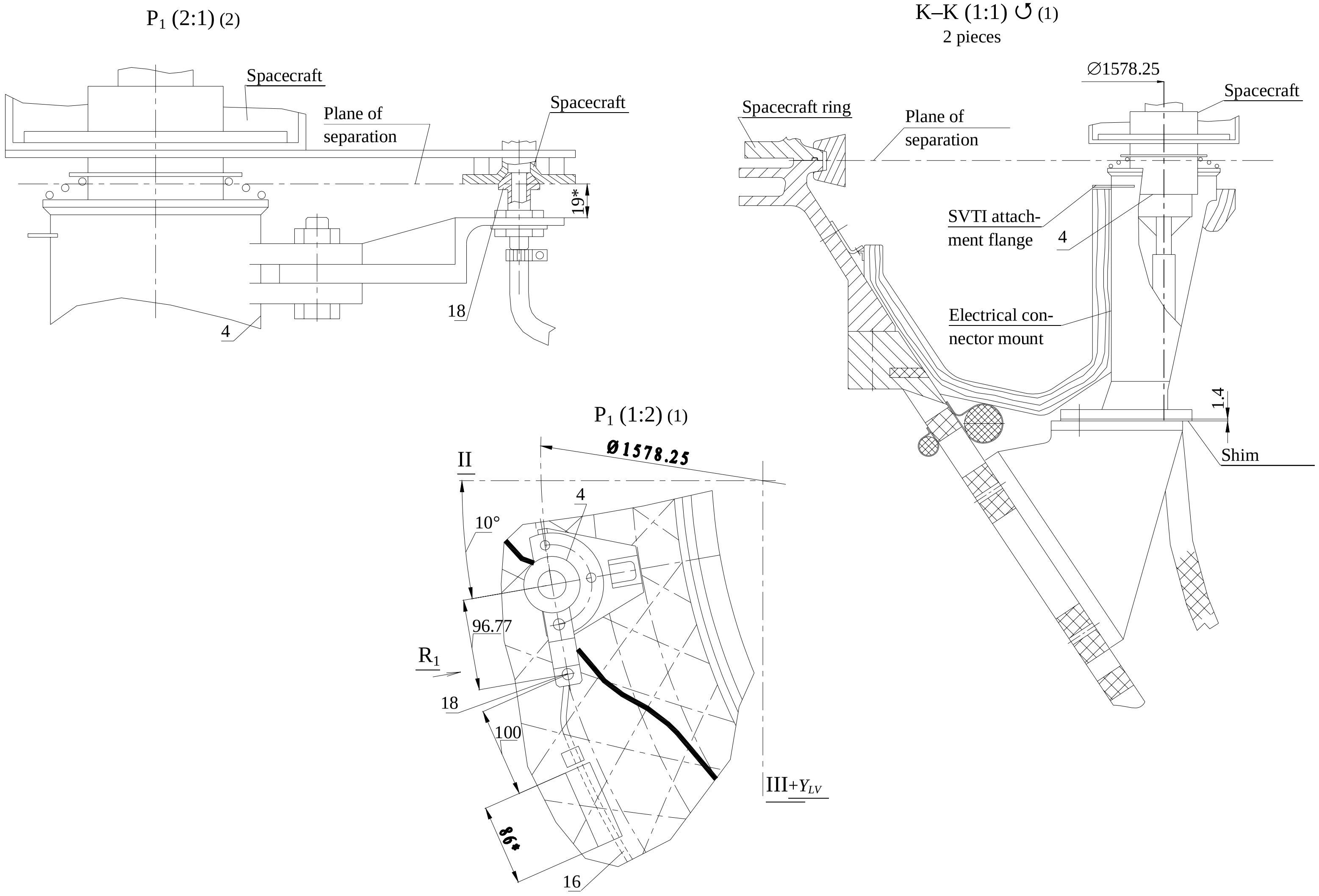


Figure 3.4-1e: Breeze M Adapter System (Sheet 5 of 5)



3.5 FAIRINGS AND SC USEABLE VOLUME

The PLF with the SC usable volume dimensions for the Angara A3/Breeze M LV is shown in Figure 3.5-1.

The PLF is designed to protect the SC and upper stage from aerodynamic forces in all phases of combined operation. The PLF consists of a bisector structure, a separation and jettison system, a vent system, and a passive temperature control system.

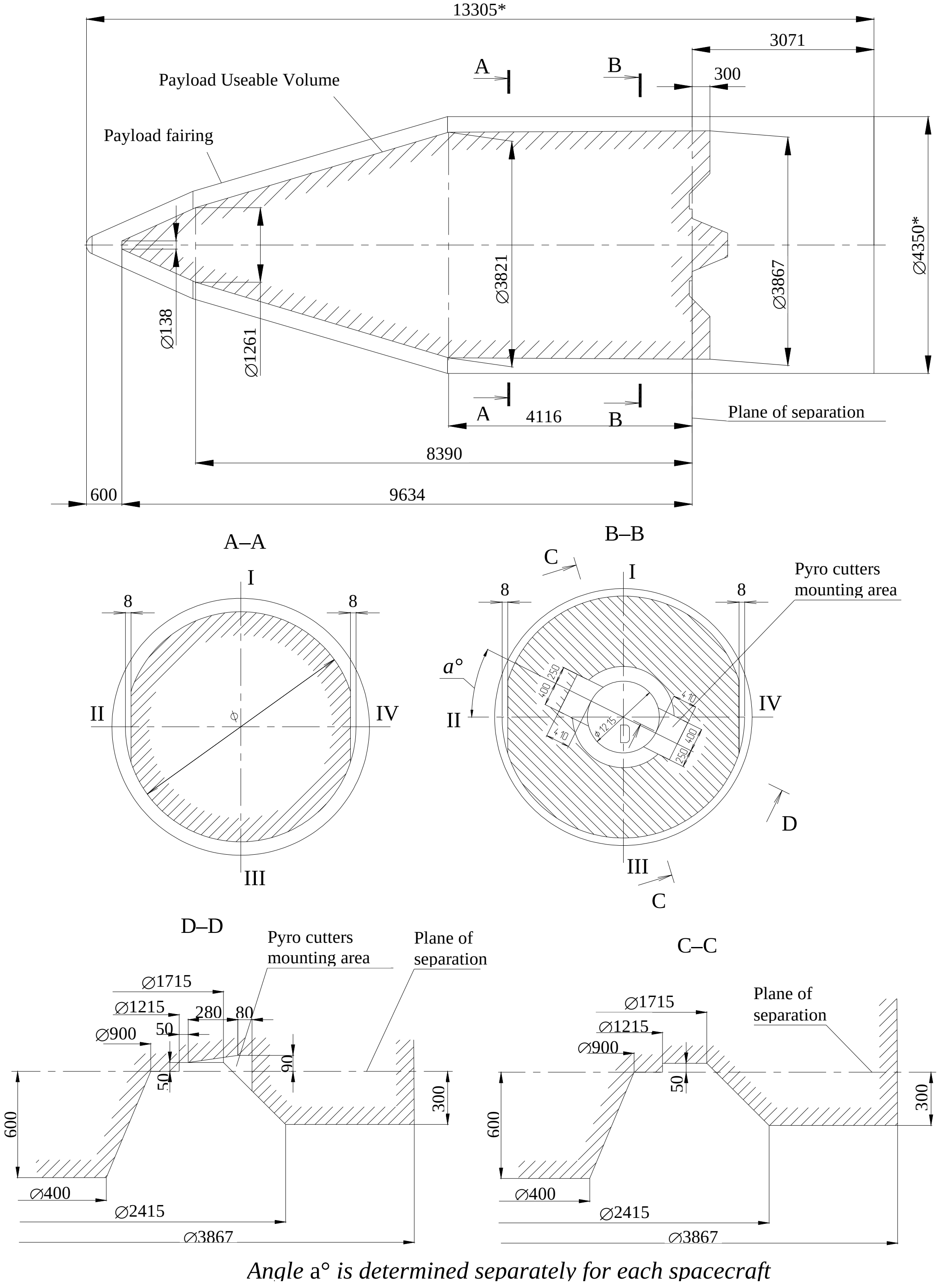
The fairing consists of a three-layer cylindrical shell with a double-cone upper section made of polymer materials. To support separation and jettisoning, the shell is divided into two halves attached by latches along a longitudinal joint on planes II through IV. The fairing is secured to the spacer of the upper stage by pyro bolts.

The fairing has upper stage service doors for access to electrical connectors used during ground processing of the SC.

At the Customer's request, radio-transparent windows and SC access doors may be placed in the fairing.

The outside dimensions are determined based on the use of an adapter system 1000 mm in height. The SC useable volume accounts for the thickness of the fairing structure, manufacturing tolerances, and dynamic motions of the fairing in flight.

Figure 3.5-1: Breeze M PLF Useable Volume



Angle a° is determined separately for each spacecraft

3.6 LV BASIC TRAJECTORY DESIGN AND PERFORMANCE PARAMETERS

3.6.1 Typical Flight Design and Orbit Parameters for Angara A3/Breeze M

Depending on the requirements for target orbit parameters, the A3 LV can be used for insertion into parking orbits with the following inclinations: $i = 63°$, $i = 76°$, $i = 82.5°$, or $i = 93.4°$ (see Figure 3.6.1-1).

A typical flight design of the A3 LV during injection of the Breeze M into a parking orbit with $H_{cir} = 200$ km and $i = 63°$ is presented in Figure 3.6.1-2.

Figure 3.6.1-1: Angara A3 Possible Orbital Inclinations and Impact Zones of Jettisoned Hardware

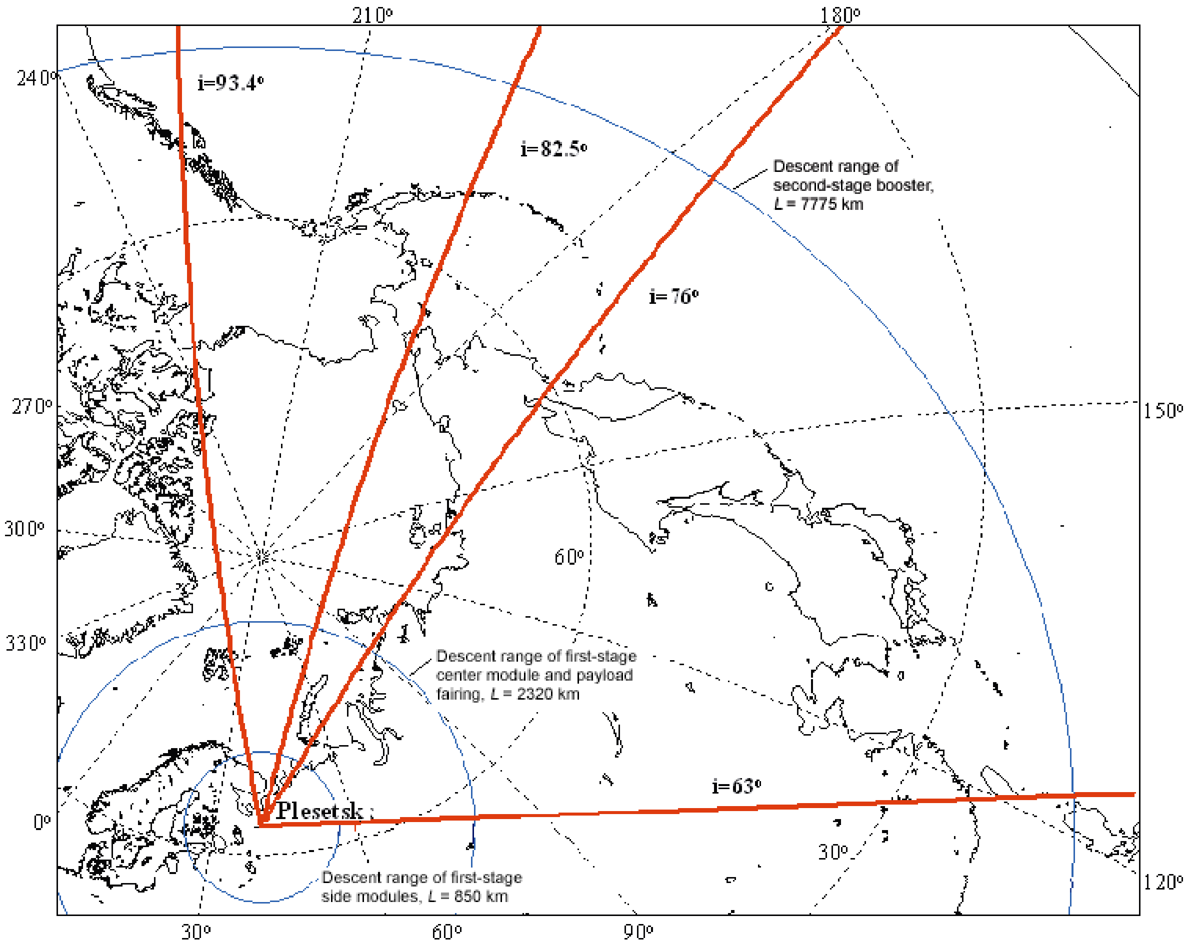
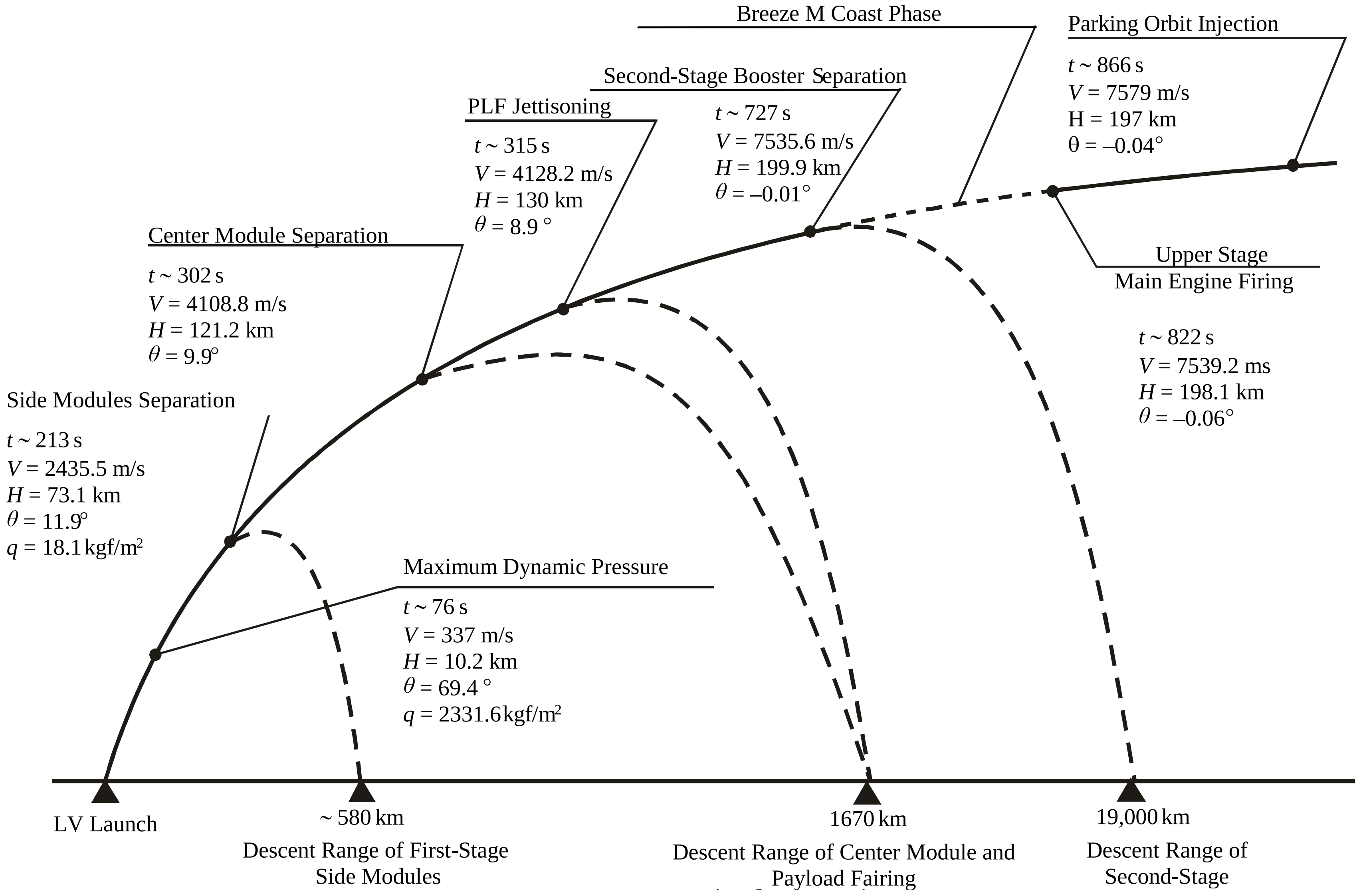


Figure 3.6.1-2: Typical Angara A3 LV Flight Path and Trajectory Parameters



The LV inserts the Breeze M into an intermediate elliptical orbit. During flight, the side CRMs of the first stage booster separate at 213 s, the center CRM of the first stage booster at 302 s, and the second stage booster at 727 s. Upon jettisoning of the PLF at 315 s, the free molecular heat flux density onto an area perpendicular to the velocity vector does not exceed 1135 W/m^2. It is possible for the PLF to separate at 220 seconds of the flight, which will result in an increase in the payload mass capability, but in this case, the free molecular heat flux density exceeds 1135 W/m^2. After separation from the LV second stage, Breeze M coasts for ~93 seconds then performs the first of 5 main engine burns that inject the Breeze M/SC into a standard low Earth parking orbit. The altitude of the parking orbit may range from 180 km to 250 km.

3.6.1.1 Launch to Geosynchronous Transfer Orbit (GTO)

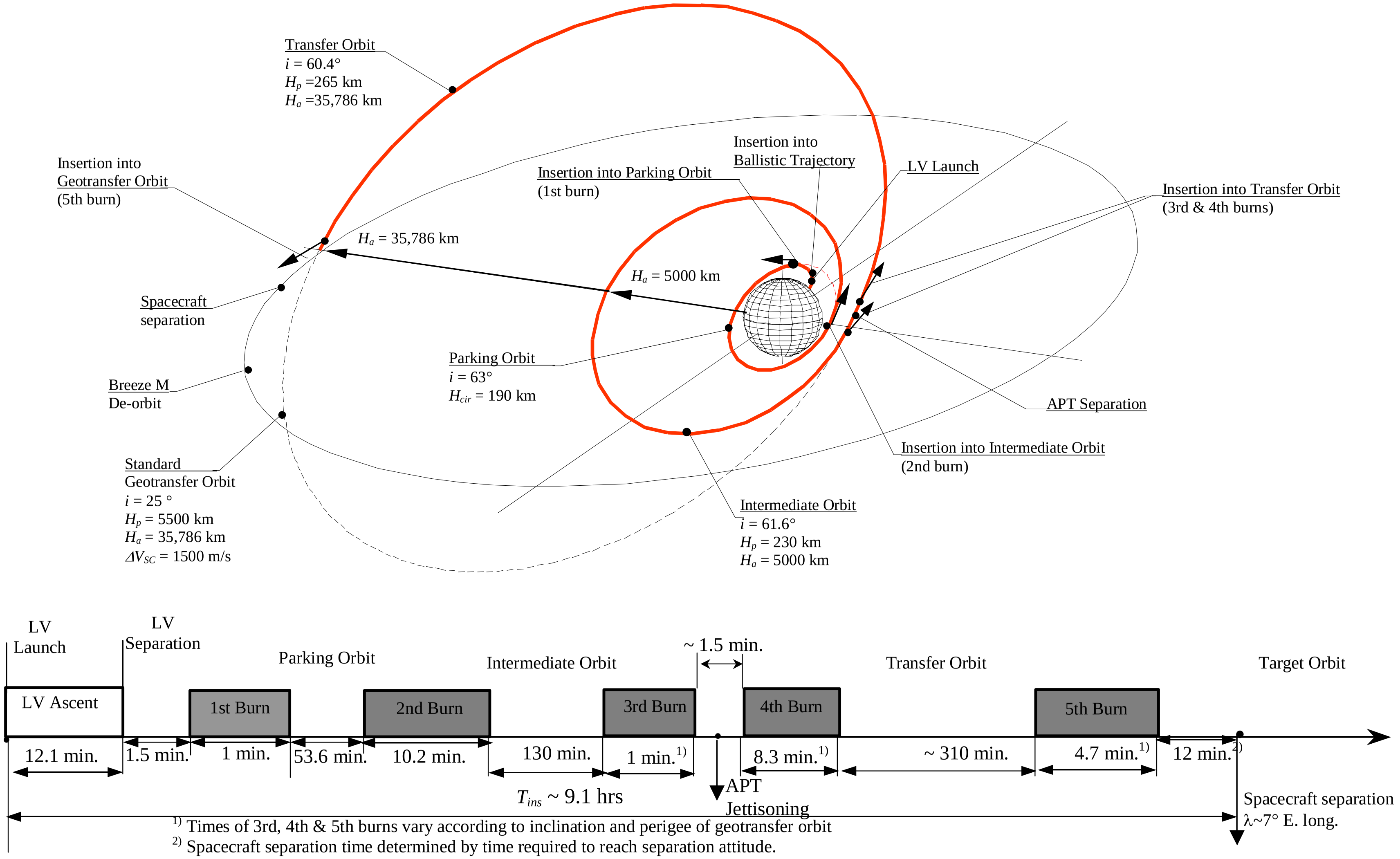
A typical flight design of the Breeze M during injection of a SC into GTO is shown in Figure 3.6.1.1-1. The transfer from parking orbit to the target orbit is achieved in four burns. After coasting in the support orbit for about 53.6 minutes, the second burn takes place near the first ascending node. This second burn serves as an initial phase of the process of raising the transfer orbit apogee to the geosynchronous apogee altitude. This burn transfers Breeze M into an intermediate transfer orbit with an apogee of 5000 km and an inclination of 61.6 degrees. The actual apogee altitude is determined by the optimized mission design and the final SC mass. After coasting for one revolution in the intermediate orbit, about 2 to 2.5 hours after the second burn, the third and the fourth burns take place across the second ascending node. The duration of the third burn is defined by the depletion of the propellant in the APT. When the propellant in this tank is depleted, the main engine cutoff takes place and the APT is jettisoned. The fourth burn occurs after APT separation. This fourth burn raises the apogee of the transfer orbit to the altitude of the apogee of the geosynchronous orbit. The perigee altitude, as well as the transfer orbit inclination, can be modified somewhat in the course of the mission optimization that takes place during the mission integration phase.

During Breeze M coasting along the intermediate and transfer orbits, the SC attitude can be changed to meet thermal environment and Sun exposure requirements. To ensure that the SC surface is evenly heated (or cooled), Breeze M can be preprogrammed to either roll 180 degrees about the Breeze M longitudinal X-axis over a period of 300 s, or its transverse Z-axis over a period of 900 s, or to roll continuously about the upper stage longitudinal X-axis with an angular rate of less than 1°/s.

After approximately 5.2 hours of coasting, Breeze M performs the fifth burn that circularizes the transfer orbit into the GTO with the desired target orbit parameters. When this burn is completed, the upper stage attitude is modified to satisfy the separation requirements, The Breeze M will coast in this orientation for approximately 15 minutes (typically) then commands SC separation. The coast to SC separation may last up to 40 minutes if the gyro compensation maneuver needs to be performed. The longitude at SC separation is 7° East. After separation, the Breeze M performs a maneuver to de-orbit to prevent recontact and possible SC contamination.

The overall maximum mission duration time for the Breeze M is 24 hours.

Figure 3.6.1.1-1: Breeze M Typical Injection Into Geosynchronous Transfer Orbit



[1] Times of 3rd, 4th & 5th burns vary according to inclination and perigee of geotransfer orbit

[2] Spacecraft separation time determined by time required to reach separation attitude.

3.6.1.2 Launch to Super-Synchronous Transfer Orbit (SSTO)

As a Customer option, use of a super-synchronous transfer trajectory is offered in the case where additional performance is needed to satisfy mission design requirements. The super-synchronous transfer trajectory takes advantage of the increased efficiency with which the inclination change can be performed by the LV at high altitudes. When such an injection scheme is used, the upper stage injects the SC into a transfer orbit with an apogee altitude greater than the standard geosynchronous apogee altitude. At apogee of this orbit, using its own propulsion system, the SC executes a maneuver to change its orbital inclination and increase the perigee altitude to the altitude of the geostationary orbit (the SC transfer orbit). At perigee of the resulting orbit, using its own propulsion system, the SC maneuvers into the geostationary orbit.

A typical flight design of the Breeze M during injection of a SC into a SSTO is shown in Figure 3.6.1.2-1.

In a SSTO mission design, the Angara A3 LV injects the Breeze M into a sub-orbital (open-loop) trajectory and the Breeze M first burn achieves a parking orbit with a circular altitude of 190 km and an inclination of 62.7°. The Breeze M second burn occurs near the first ascending node. This second burn results in raising the transfer orbit apogee and reducing the inclination to 62.2°. After coasting in the intermediate transfer orbit for approximately 2.2 hours, the Breeze M third burn occurs near the second ascending node resulting in an inclination of 61.7° and the apogee altitude close to the altitude of the SSTO. After this burn, the upper stage jettisons the additional propellant tank (APT). The fourth burn takes place near the apogee of the second transfer orbit, injecting the Breeze M into the SSTO with the target parameters.

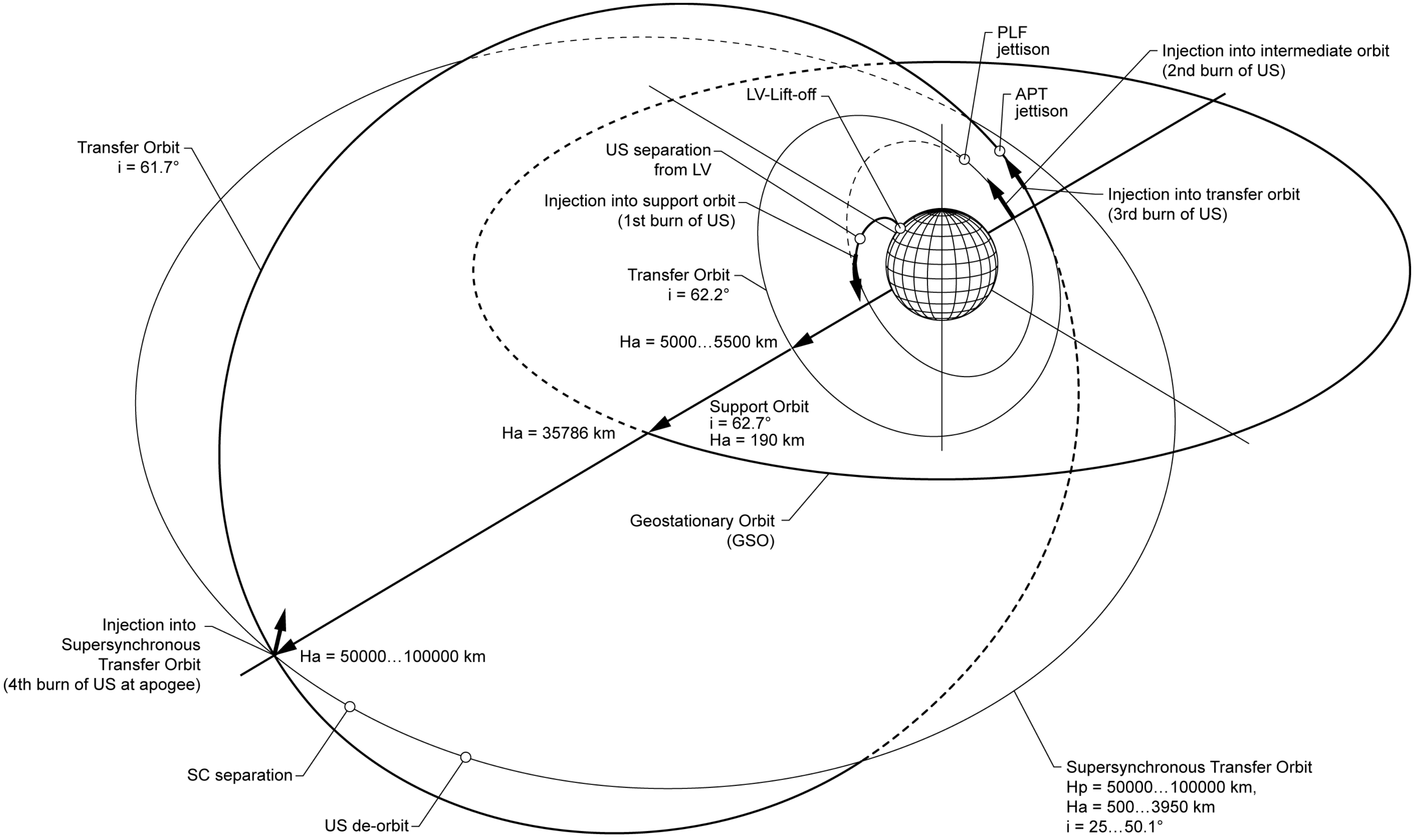
3.6.2 Dynamic Parameters of Upper stage

During coast phases, the upper stage can perform programmed turns relative to any of the body axes of the upper stage.

In general, the limitations on turning angles and on the spatial attitude of the upper stage are determined by the limitations of the gyro platform:

- There are no limitations with respect to two axes.
- There is a ±45° limitation with respect to one axis.

Figure 3.6.1.2-1: Breeze M Typical Injection at Apogee Into a Super-Synchronous Transfer Orbit - 4-Burn Scheme



The angular velocities of turns relative to any axis do not exceed 1-2°/s. While the main propulsion engine is in operation, control of booster inertial attitude is determined by the pitch, yaw, and roll programs selected for each specific flight program. Any inertial orientation of the upper stage can be effected prior to separation of the SC. At the time of SC separation, the upper stage may be either in 3-axis stabilized mode or, if necessary, in spinning mode. In 3-axis stabilized mode, the following can be provided:

- During coast phases attitude control can be effected with an angular accuracy of ±10° and an angular velocity accuracy of 0.5°/s.
- Angular velocities of the orbiter relative to any axis of the body axis coordinate system not exceeding 0.5°/s.
- An error in inertial attitude of upper stage axes relative to on-board inertial coordinate system of no more than 0.5°.

In spinning mode, an angular velocity of the upper stage relative to the longitudinal axis of the booster of up to 9°/s can be provided. The possibility of raising the angular velocity to 30°/s is being analyzed.

The maximum deviation of the longitudinal axis of the upper stage from the program position at the time of SC separation depends mainly on the mass and inertia characteristics of the specific SC, the required value of the angular velocity of SC spin, and the aggregate of the perturbing factors at work during spinning. An analysis will be performed prior to contract signing to determine if the SC will meet the requirements of the upper stage.

3.6.3 Injection Accuracy

The accuracy of payload injection into typical GTO is presented in Table 3.6.3-1 for the Angara A3/Breeze M.

Table 3.6.3-1: Breeze M Injection Accuracies

Orbital Parameters	Deviations of Orbital Parameters				
	Perigee	Apogee	Inclination	Argument of perigee	Period
Circular parking orbit, 200 km altitude	±2.0 km	±4.0 km	±0.03°	-	±3 s
Circular orbit, 10,000 km altitude	±20 km	±10 km	±0.1°	-	±100 s
GTO 5500 × 35,786 km, inclination 25.0°	±300 km	±100 km	±0.15°	±0.3	-

	Eccentricity	Longitude	Inclination	Period
Geostationary orbit	±0.0075	±0.7°	±0.25°	±550 s

3.7 PERFORMACE CHARACTERISTICS

The performance characteristics of the A3 are presented in Table 3.7-1 for payload systems mass (PSM) injection into a low circular orbit with $H_{cir} = 200$ km. Table 3.7-2 provides the Breeze M performance capability for injection into GTO and Table 3.7-3 provides the SSTO injection parameters.

These performance assessments are based on the use of the 4-meter (4350-mm) PLF with PLF jettison occurring at 315 second after LV liftoff. In this case, the free molecular heat flux density (q) does not exceed 1135 W/m^2. The PSM is determined based on a 3-sigma confidence level.

Table 3.7-1: Angara A3 LEO Performance Capability For Circular Orbit 200-km Altitude

Orbital Inclination (deg)	63		75	85.8	93.4
Payload Systems Mass (metric tons)	14.1	14.6*	TBD	TBD	TBD

*The payload mass was determined for PLF jettisoning at $t_j = 220$ s ($q > 1135$ W/m^2).

Table 3.7-2: Angara A3/Breeze M GTO Performance Capability

ΔV_{SC} for Transfer to GSO (m/s)	**GTO Parameters: $\omega_p = 0°$, $H_a = 35{,}786$ km**		**Payload Systems Mass (kg)**
	i (deg)	**H_p (km)**	
600	7	16,600	1435
700	8.2	14,400	1530
800	9.7	12,600	1630
900	11.3	11,000	1730
1000	13.1	9600	1830
1100	15.0	8300	1940
1200	17.0	7200	2050
1300	19.0	6100	2160
1400	21.1	5100	2280
1500	23.3	4200	2405
1600	25.7	3400	2530
1700	28.3	2700	2650
1800	31.0	2100	2770
1500	**25.0**	**5500**	**2400**

Table 3.7-3: Angara A3/Breeze M Performance Capability to Super-Synchronous Transfer Orbit

Delta-V to GSO (m/s)	Inclination (deg)	Perigee Altitude (km)	Payload Systems Mass (kg)	Injection Time (hours)
Apogee Altitude of 50000 km				
1500	25.15	3950	2420	11.6
1600	28.5	3100	2540	
1700	32.0	2300	2665	
1800	35.7	1600	2795	
Apogee Altitude of 60000 km				
1500	26.4	3700	2505	13.6
1600	30.4	2800	2630	
1700	34.6	2000	2755	
1800	39.2	1300	2890	
Apogee Altitude of 70000 km				
1500	27.6	3500	2570	15.6
1600	32.3	2500	2695	
1700	37.3	1700	2825	
1800	42.7	1000	2960	
Apogee Altitude of 80000 km				
1500	28.9	3300	2620	17.8
1600	34.2	2200	2750	
1700	40.05	1400	2880	
1800	46.3	700	3020	
Apogee Altitude of 90000 km				
1500	30.2	3100	2665	20.1
1600	36.1	1900	2795	
1700	42.8	1100	2925	
1800	50.1	500	3065	
Apogee Altitude of 100000 km				
1500	31.5	2900	2700	22.4
1600	38.1	1600	2830	
1700	45.75	830	2965	
1750	49.7	500	3035	

Perigee argument is 0°.

Maximum FMH after payload fairing jettison on 3-sigma $qV < 1135\ W/m^2$.

Payload mass includes the SC mass and the mass of an adapter.

Performance evaluated based on 2.33-sigma confidence level that mission objectives will be accomplished.

The delta-V to GSO values quoted in this table include approximately 15 m/s delta-V to account for inefficiencies during SC transfer from the point of separation to GSO.

3.8 SC ENVIRONMENTAL PARAMETERS

3.8.1 Pre-Launch Processing

3.8.1.1 Mechanical Loads

3.8.1.1.1 Transportation Loads

The following modes of transportation of the SC are provided during processing for the launch of the Angara A3 LV from the Plesetsk Cosmodrome:

- Transportation of the SC over a distance of ≈15 km from the Pero airport to Building 171V, independently by rail, at speeds of ≤15 km/hr.
- Transportation of the SC by rail as part of the AU over a distance of 40 km from Building 171V to Building 142-1 at speeds of ≤15 km/hr.
- Rail transportation of the SC as part of the integrated LV over a distance of ≈7 km at speeds of up to 5 km/hr.

The vibration regimes during transportation are specially formalized mechanical forces equivalent to the forces acting on the SC in the phase of transportation over the roadways of the Plesetsk Cosmodrome.

The actual conditions that apply to structural hardware that serve as attachment points for the SC are given for all transporting phases:

- For independent transportation - the attach points of the container with SC to the transporter.
- For transportation as part of the integrated LV - the location of the mechanical interface between the SC and the adapter.

The following orientation of axes has been adopted for load specification:

- X-X axis runs in the direction of motion.
- Y-Y axis runs vertically (up-down).
- Z-Z axis is the side axis in the right-handed coordinate system.

Vibration loads in the direction of the three axes in the form of the values of the spectral densities of vibration accelerations for each mode of rail transport are presented in Figures 3.8.1.1.1-1 through 3.8.1.1.1-3 and in Tables 3.8.1.1.1-1 through 3.8.1.1.1-5.

The spectral densities are probabilistic in character and are specified with a probability of 0.997 that the specified levels will not be exceeded.

Figure 3.8.1.1.1-1: Acceleration Spectral Density - SC Rail Transport

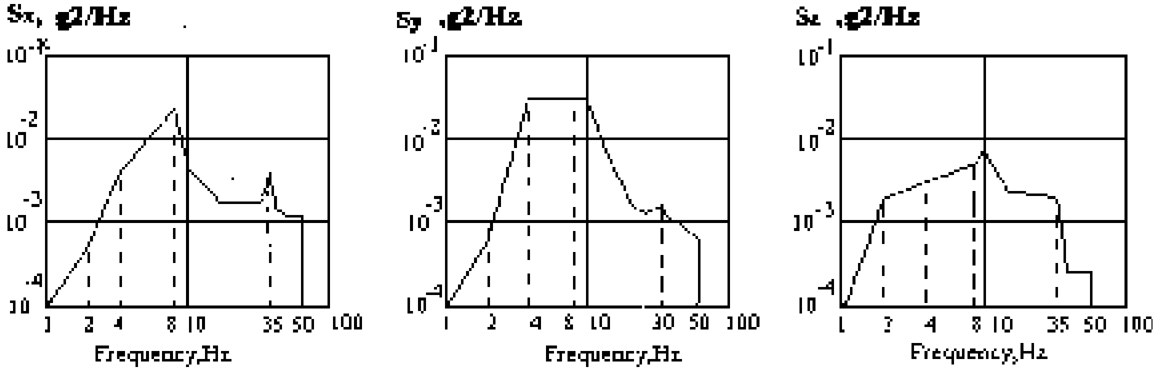


Figure 3.8.1.1.1-2: Acceleration Spectral Density - SC Motor Vehicle Transport

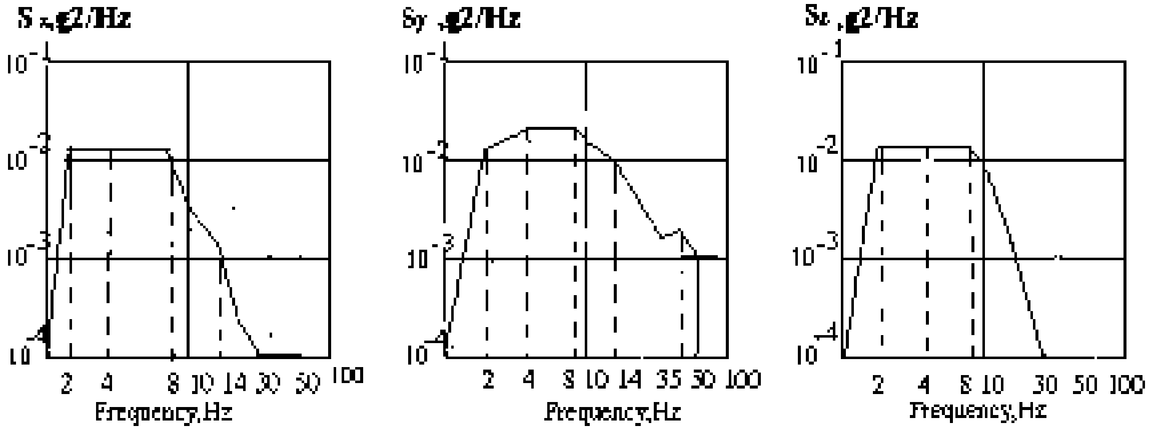


Figure 3.8.1.1.1-3: Power Spectra S (g^2/Hz) - SC Rail Transport

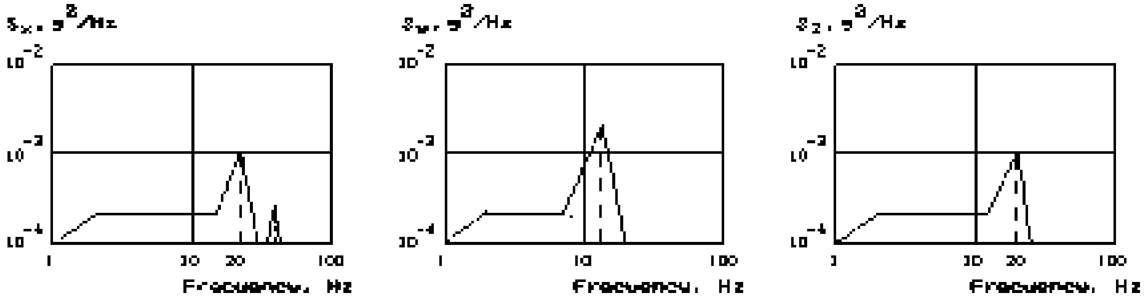


Table 3.8.1.1.1-1: Allowable Shock Loads on Container With SC

Mode of Transport	Direction of Axis	Amplitude (g)	Duration (ms)	Pulse Shape
Motor vehicle	±X	3.0	30	Sine half-wave
	±Y	2.0	30	Sine half-wave
	±Z	0.5	30	Sine half-wave
Rail	±X	2.5	30	Sine half-wave
	±Y	2.0	30	Sine half-wave
	±Z	0.5	30	Sine half-wave
Airplane	±X	3.0	100	Sine half-wave
	±Y	2.0	100	Sine half-wave
	±Z	1.7	100	Sine half-wave

Table 3.8.1.1.1-2: Loads on SC Container During Independent Transport by Rail

Frequency (Hz)	Direction of Axis		
	X-X	Y-Y	Z-Z
	Spectral Density (10^{-4} g^2/Hz)		
2	0.75	1.5	1.5
4	5.75	33.0	3.3
8	20.0	32.0	6.6
10	6.0	32.0	8.0
14	2.8	8.33	3.3
20	2.75	1.5	3.2
25	2.75	1.5	3.1
30	2.75	1.5	3.0
35	5.0	1.5	1.85
40	1.8	1.5	0.37
45	1.25	1.5	0.37
50	1.25	1.5	0.37
Time (min)	30	30	30

Table 3.8.1.1.1-3: Transient Dynamic Loads - SC Transport by Rail

Direction of Axis	Maximum Amplitude of Vibration Acceleration (g)	Pulse Length (ms)	Number of Loadings
X-X	1.5	0.16-0.035	100
Y-Y	1.1		
Z-Z	0.6		

Note: The pulse shape is triangular or a sinusoidal half-wave.

Table 3.8.1.1.1-4: Loads on SC During Ascent Unit Transport by Rail

Frequency (Hz)	Direction of Axis		
	X-X	Y-Y	Z-Z
	Spectral Density (10^{-4} g^2/Hz)		
2	0.75	1.5	1.5
4	5.75	33	3.3
8	20	32	6.6
10	6.0	32	8.0
14	2.8	8.33	3.3
20	2.75	1.5	3.2
25	2.75	1.5	3.1
30	2.75	1.5	3.0
35	5.0	1.5	1.85
40	1.8	1.5	0.37
45	1.25	1.5	0.37
50	1.25	1.5	0.37
Time (min)	70	70	70

Table 3.8.1.1.1-5: Loads on SC During LV Transport by Rail

Frequency (Hz)	Direction of Axis		
	X-X	Y-Y	Z-Z
	Spectral Density (10^{-4} g^2/Hz)		
2	2.0	2.0	2.0
4	2.0	2.0	2.0
8	2.0	2.0	2.0
10	2.0	2.0	2.0
14	2.0	20.0	2.0
20	10.0	1.0	10.0
25	1.0	1.0	1.0
30	1.0	1.0	1.0
35	3.0	1.0	1.0
40	1.0	1.0	1.0
45	1.0	1.0	1.0
50	1.0	1.0	1.0
Time (min)	20	20	20

3.8.1.1.2 Linear Loads During Transportation at Technical Area and During Handling Operations

The quasi-linear loads during transportation and handling operations are presented in Table 3.8.1.1.2-1.

Table 3.8.1.1.2-1: Quasi-Static Loads During Transport

Phase of Operation	Quasi-Static Loads (g)			Safety Factor (minimum)
	X	Y	Z	
Independent transportation at technical area	±1.0	1 ± 1.0	±0.4	1.5
Transportation as part of AU	±0.5	1 ± 0.5	±0.4	1.5
Transportation as part of integrated LV	±0.4	1 ± 0.3	±0.15	1.5
Handling operations	±0.15	1 ± 0.5	-	1.5

Notes:

1. For the transportation case, the axes are given in the coordinate system of the vehicle:

   X axis - in the direction of motion
   Y axis - directed vertically (up-down)
   Z axis - laterally in the right-handed coordinate system

2. For the "handling operations" case:

   Y axis - on vertical line of hoisting or lowering
   X axis - in any lateral direction

3. Accelerations act simultaneously in the directions of the X, Y, and Z axes.

4. Accelerations are given for wind velocities ≤20 km/hr.

3.8.1.2 Thermal Conditions of SC During Ground Operation

Ground thermal loads on the SC arise during transportation of the SC and during launch processing of the SC at the technical and launch areas.

Information on the environmental parameters around the SC in various phases of ground processing of the SC for launch and on the means used to maintain them are presented in Table 3.8.1.2-1.

Two air temperature sensors for the area of the SC and two temperature sensors for the adapter system (adapter) structure are installed to monitor the thermal state under the PLF. A sensor to measure relative humidity is provided to monitor air humidity in the area of the SC.

The technical data of the launch air thermal control system (ATCS) are presented in Table 3.8.1.2-2.

Table 3.8.1.2-1: Environmental Parameters Around SC

Processing Phase	Temperature (˚C)	Humidity (%)	Means Used to Maintain
Air transportation to Cosmodrome	Meets the conditions for transportation in an unsealed cabin		Container
Rail transportation to processing complex	10-30		Container, thermal control unit
Transportation of SC as part of integrated LV to launch complex	10-30	30-60	Thermal control unit
In SC processing and filling area	10-30	30-60	Technical systems of structures
In area of integration with upper stage and LV	15-25	30-60	Technical systems of structures
Erection of LV at launch complex	10-30	≤60	No active thermal control during 0.5 hr until ground air thermal control system is brought up.
Processing at launch complex	13-27	≤60	Air thermal control system
Launch abort	5-30	≤60	No active thermal control during 0.5 hr until thermal control unit is brought up.

Table 3.8.1.2-2: Technical Data on Launch Air Thermal Control System

Technical Data	Value
Temperature of supplied air	10-40°C
Accuracy of temperature maintenance at system outlet	± 2°C
Relative air humidity	≤60 %
Air flow	5000-12,000 m^3/hr
Purity of supplied air, class per Standard FS 209	100,000

The air temperature under the PLF is regulated by changing the airflow and temperature.

Thermal control of the AU from the ATCS is performed until the transporter/erector is removed. After the transporter/erector is removed, the thermal conditions of the SC up to the lift-off switch are maintained by air supply to the AU at a flow rate of up to 2000 m^3/hr, via a pipe laid on the cable and filling tower.

In case of launch abort while propellants are being drained and LV is removed from the launcher, thermal control of the AU is performed from the cable and filling tower (up until the time of de-mating of the connectors before the cable and filling tower is retracted). After the LV is transferred to the horizontal position on the transporter/erector, the mobile thermal control unit is connected. For ≈0.5 hr there is no active thermal control from the time air supply through the cable and filling tower is halted until the thermal control unit is connected.

Furthermore, additional air supply is provided from the air thermal control system via a separate line laid directly to the SC area, with the following parameters:

- Temperature of supplied air: 10-16°C
- Relative humidity: ≤60 %
- Air flow: up to 1000 m^3/hr
- Air pressure: 0.15 kgf/cm^2

The main characteristics of the thermal control unit are presented in Table 3.8.1.2-3.

Table 3.8.1.2-3: Characteristics of Thermal Control Unit

Parameter	Value
Temperature of supplied air	10-30°C
Minimum increment of temperature setting	2°C
Accuracy of temperature maintenance	±2°C
Relative humidity	30-60 %
Air flow	≤8000 m^3/hr
Air pressure	350 mm H_2O

3.8.1.3 Cleanliness

AU components (the upper stage, PLF, and adapter system) are wrapped and covered before transport.

The purity of the air in the SC processing and filling areas, the AU assembly area, and the final cleaning hall for the SC, upper stage, PLF, and adapter system is assured through multi-stage filtering of the supplied air and a pressure differential between the air inside the enclosed area [and the outside].

The specified cleanliness level is checked with an automated monitoring system every 10 minutes. Air purity must correspond to class R 8 per GOST R 50766-95 with parameters given in Table 3.8.1.3-1.

Final cleaning and inspection of AU components that come into contact with the SC environment consist of processing with an industrial vacuum cleaner and wiping with clean coarse calico filter cloth moistened with ethyl alcohol, per GOST 18300-87. The surface is inspected by sampling, using synthetic membrane filters. The surface cleanness must correspond to level 600 with parameters given in Table 3.8.1.3-2.

During transportation of the SC as part of the AU and LV, the SC receives thermal control from the rail car thermal control unit. The specified air-cleanliness level is attained and maintained by means of highly effective air filters (HEPA) with a mesh size of 0.5 μm, and must comply with the parameters given in Table 3.8.1.3-3.

The purity of the air used for thermal control is checked when the air ducts are connected, with aerosol particle counters mounted at the inlet to the thermal control railcar.

When the AU is mated to the LV, the cleanliness of the SC is assured by purging the PLF with clean air from the thermal control system.

While the SC is at the launch complex, its cleanliness is assured by using a dust-proof, moisture-proof PLF and supplying conditioned air under the PLF with gage pressure from the launch ATCS. The cleanness of the air supplied must meet the values given in Table 3.8.1.3-3.

Table 3.8.1.3-1: Class R 8 Cleanliness Parameters in SC Processing And Filling Areas

Maximum Allowable Counted Particle Concentration (Particles Per Liter) With a Size Equal to or Greater Than (μm)	
0.5	5.0
3500	25

Table 3.8.1.3-2: Level 600 Cleanliness Parameters for Ascent Unit

Particle Size (µm)	Number of Particles Per Square Meter
>100	30,139
>250	753
>500	32
600	10

Table 3.8.1.3-3: Air Cleanliness Parameters For SC Transport

Maximum Allowable Counted Particle Concentration (Particles Per Liter) With a Size Equal to or Greater Than (µm)	
0.5	5.0
3000	20

3.8.1.4 Electromagnetic Compatibility

3.8.1.4.1 General Requirements

An electromagnetic compatibility analysis of the LV and SC is performed for every launch. The Customer must submit data on SC radiation during processing of the SC at the technical complex, during ground operations at launch, and in flight up until separation from the LV. The Customer must also provide data on the maximum possible irradiation of the SC with radio frequency emissions.

3.8.1.4.2 LV Electromagnetic Radiation/Electromagnetic Compatibility

The electrical field strengths generated by the Angara LV and launch equipment in the plane of the LV/SC interface at a distance of 1 m from the outside surface of the SC are presented in Figure 3.8.1.4.2-1.

Figure 3.8.1.4.2-1: Electrical Field Strength Levels Generated By Angara A3/Breeze M and GSE

TBD

3.8.2 Flight Environments

3.8.2.1 Mechanical Loads

Mechanical loads are given for the plane of the interface between the SC and the adapter system with 1194-mm diameter and include the values of the linear loads, as well as the parameters of vibration, vibration and shock, and transient dynamic loads and acoustic pressure on the injection and independent phases of flight of the upper stage.

The vibration loads are given in two forms:

1. Harmonic vibration
2. Random vibration

The following orientation of axes is assumed:

- X - longitudinal axis of SC
- Y - lateral axis of SC (plane I-III)
- Z - lateral axis of SC (plane II-IV)

The loads may be revised on the basis of additional calculations, laboratory/bench development, flight and structural tests, and full-scale operation.

3.8.2.1.1 Vibration Loading

Vibration loads that act under steady-state conditions in flight in the direction of the three axes are presented in Table 3.8.2.1.1-1 in the form of harmonic vibration, and in Table 3.8.2.1.1-2 in the form of the spectral density distribution of random vibration.

The transient non-stationary dynamic loads in flight under transient operating conditions of the propulsion system are presented in Table 3.8.2.1.1-3. These conditions are specified for functional tests of any attached equipment.

Table 3.8.2.1.1-1: Mechanical Loads - Harmonic Vibration (Values TBD)

Loading Case	Frequency Range (Hz)	Vibration Acceleration (m-s $^{-2}$ (g)		Action Time (s)
Operation of LV first stage	1.5-50	9.81-29.43	(1-3)	
	50-600	29.43-98.1	(3-10)	
	600-2000	98.1	(10)	
Operation of LV second stage	1.5-50			
	50-600			
	600-2000			
Breeze M independent flight	1.5-50			
	50-600			
	600-2000			

Note: The vibration loads vary linearly between the indicated frequencies.

Table 3.8.2.1.1-2: Mechanical loads - Random Vibration (Values TBD)

Loading Case	Frequency (Hz)							Action Time (s)
	20	50	100	200	500	1000	2000	
	Spectral Density of Vibration Acceleration (m^2 s^{-4}/Hz (g^2/Hz))							
Operation of LV first stage	6.549 (0.068)	7.7 (0.08)	5.54 (0.058)	5.13 (0.053)	6.47 (0.067)	4.28 (0.044)	2.14 (0.022)	
Operation of LV second stage								
Breeze M independent flight								

Notes:

1. The change in spectral densities between the indicated frequencies is linear.
2. In the frequency range up to 20 Hz, the conditions of vibration loading are represented as harmonic vibration (see Table 3.8.2.1.1-1).

Table 3.8.2.1.1-3: Transient Non-Stationary Dynamic Loads in Flight

Frequency Range (Hz)	Maximum Amplitude of Vibration Acceleration n_{max} (m-s $^{-2}$ (g))	Duration of Process (s)	Number of Loadings
10-30	$n_x^{max} = 58.86$ (6)	2.5-0.8	4
1.5-10	$n_{y,z}^{max} = 14.7$ (1.5)	6.0-2.0	2

Notes:

1. The qualification coefficient is 1.5.
2. The maximum load lasts no more than 2-3 periods.
3. By the duration of the process is meant the time over which the load rises and falls from n_{max} to $0.1n_{max}$.
4. The duration of the process is linearly dependent on the frequency (in inverse proportion).

3.8.2.1.2 Vibration and Shock Loading

The vibration and shock loads in the direction of the three axes upon separation of the Breeze M from the LV are presented in the form of shock spectrum values in Table 3.8.2.1.2-1.

There are two shocks. The vibration and shock loads upon jettisoning of the PLF in the direction of the three axes are presented in the form of shock spectrum values in Table 3.8.2.1.2-2.

There are five shocks. The vibration and shock loads upon separation of the SC (preliminary values) in the directions of the three axes are presented in the form of the shock spectrum values in Table 3.8.2.1.2-3.

The values of the shock spectrum and the number of shocks are revised during the design of the adapter system and separation hardware for the SC.

Table 3.8.2.1.2-1: Shock Loads at Stage Separation (Values TBD)

Frequency Sub-Range (Hz)					
35-50	50-100	100-200	200-500	500-1000	1000-2000
Value of Shock Spectrum (m-s^{-2} (g))					

Table 3.8.2.1.2-2: Shock Loads at PLF Jettison (Values TBD)

Frequency Sub-Range (Hz)					
35-50	50-100	100-200	200-500	500-1000	1000-2000
Value of Shock Spectrum (m-s^{-2} (g))					

Table 3.8.2.1.2-3: Shock Loads at SC Separation

Frequency Sub-Range (Hz)					
35-50	50-100	100-200	200-500	500-1000	1000-2000
Value of Shock Spectrum (m-s^{-2} (g))					
245-490 (25-50)	490-1470 (150-400)	1470-3930 (150-400)	3930-17,200 (400-1750)	17,200-49,000 (1750-5000)	49,000 (5000)

3.8.2.1.3 Linear Loads

The linear loads in flight in the directions of the three axes (operational values) are presented in Table 3.8.2.1.3-1.

The linear loads of independent flight of the upper stage in the directions of the three axes (operational values) are presented in Table 3.8.2.1.3-2.

Table 3.8.2.1.3-1: Quasi-Static Loads in Flight (Values TBD)

n_x^{op} **(m-s^{-2} (g))**	n_y^{op} **(m-s^{-2} (g))**	n_z^{op} **(m-s^{-2} (g))**	**f**
			1.3

Note: The quantity *f* is the safety factor.

Table 3.8.2.1.3-2: Quasi-Static Loads of Upper Stage (Values TBD)

n_x^{op} **(m-s^{-2} (g))**	n_y^{op} **(m-s^{-2} (g))**	n_z^{op} **(m-s^{-2} (g))**	**f**
			1.3

Note: The quantity *f* is the safety factor.

3.8.2.1.4 Operational Loads at the SC Center of Gravity During Flight of the A3 LV

The maximum (static and dynamic) operational loads on the SC at launch and during flight of the Angara A3 LV + AU with Breeze M are presented in Table 3.8.2.1.4-1. Lateral loads may act in any direction perpendicular to the longitudinal axis of the LV.

The quasi-static load n_x^{op} is the sum of the static load n_{x-st}^{op} and the dynamic load n_{x-dy}^{op}:

$$n_x^{op} = n_{x-st}^{op} \pm n_{x-dy}^{op}.$$

Table 3.8.2.1.4-1: Maximum Flight Loads on the SC

Loading Case	Safety Factor f	Quasi-Static Loads (g)	
		Longitudinal	Lateral
Launch	1.3	Max compression 2.1 Max tension 0.0	±1.5 ±1.5
Flight at $q_{\max}$	1.3	1.5	±1.2
Flight at $n_{x\max}$ with side modules	1.3	4.5	±0.6
Separation of side modules	1.3	1.8	±1.5
Flight at $n_{\max}$ without side modules	1.3	TBD	TBD
Separation of 1st and 2nd stages	1.3	Max compression +3.0 Max tension -1.6	±0.7 ±0.7
Flight of 2nd stage	1.3	TBD	TBD
Flight of Breeze M	1.3	TBD	TBD

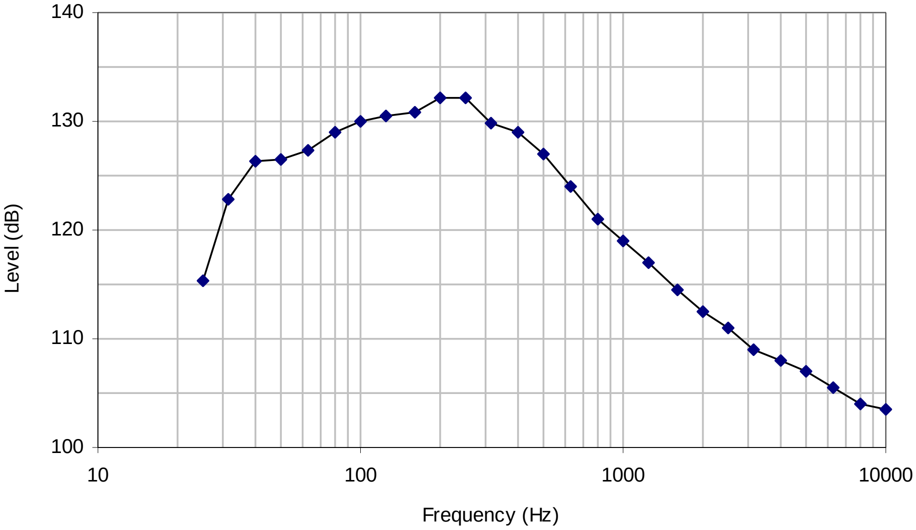
Notes:

1. In each design case, the longitudinal and lateral loadings act simultaneously.
2. The quasi-static loads are given for the preliminary estimate of the strength of the SC/LV unit; this does not rule out a complete coupled loads analysis.

3.8.2.1.5 Acoustic Loads

The acoustic loads under the PLF do not exceed the values presented in Figure 3.8.2.1.5-1.

Figure 3.8.2.1.5-1: Angara LV Max Expected Acoustic Environment in SC Area (Third Octave)



1/3 Octave Band Center Frequency (Hz)	Acoustic Levels on Spacecraft (dB)	Octave Frequency Range (dB)
25	115.4	128.8
31.5	122.9	
40	126.3	
50	126.5	134
63.5	127.3	
80	129	
100	130	136.7
125	130.5	
160	130.8	
200	132.1	136.3
250	132.1	
315	129.9	
400	129	131.9
500	127	
630	124	
800	121	124.1
1000	119	
1250	117	
1600	114.5	117.7
2000	112.5	
2500	111	
3150	109	112.8
4000	108	
5000	107	
6300	105.5	109.2
8000	104	
10000	103.5	
OASPL	**140.8**	**140.8**

3.8.2.2 Thermal Conditions

During flight, up until the PLF is jettisoned, the SC is in radiative heat transfer with the inside surface of the PLF. The allowable temperature level of the PLF structure is maintained by application of a thermal protective material onto the PLF. A thermal insulation material lined with a film with low radiant emissivity ($\varepsilon < 0.1$) is mounted on the inside surface of the PLF. The value of the maximum radiant heat flux from the inside surface of the PLF to the SC will not exceed 300 W/m^2 from the time of launch until the PLF separates. Based on a separate requirement by the SC manufacturer, the level of radiant heat flux to the SC can be lowered to 150-180 W/m^2.

For the injection trajectory of the LV with early PLF jettisoning, the maximum value of the aerodynamic heat flux onto an area measuring 1 m × 1 m perpendicular to the velocity vector will not exceed 10,000 W/m^2 after jettisoning of the PLF.

For the injection trajectory of the LV with late jettisoning of the PLF, the maximum value of the free molecular heat flux onto an area perpendicular to the velocity vector will not exceed 1135 W/m^2 after jettisoning of the PLF.

The temperature for specific areas on the SC adapter could be in the range from -5°C to +50°C, not taking into account the impact of the SC. This range may be adjusted for a specific SC as a result of a thermal analysis using the SC thermal model provided by the Customer.

3.8.2.3 Electromagnetic Compatibility

The characteristics of the A3 LV telemetry system are presented in Table 3.8.2.3-1.

3.8.2.4 Pressure in Payload Compartment

From LV ascent to the time of jettisoning of the PLF, the payload compartment is vented by opening the vent ports. In absolute value, the maximum rate of pressure drop does not exceed $dP/dt \leq 5$ kPa/s.

Table 3.8.2.3-1: Angara A3 LV Telemetry System Characteristics

Class	Stage	System Designation	Frequency
Angara A3	1	Transmitter Telemetry 1-1	1042.5 1044.56
		Transmitter Telemetry 2-1	1026.5 1023.94
		Transmitter Telemetry 3-1	1002.5 999.94
	2	Transmitter Telemetry 1-2	1010.5 1013.06
		GLONASS/GPS Receiver	1570-1640
Breeze M	3	Transmitter Telemetry RB-1	1018.5
		Transmitter Telemetry RB-2	1020.5
		Transmitter Telemetry RB-3	1515.0
		Transmitter Trajectory Control RB-1	2805
		Transmitter Trajectory Control RB-2	3410
		GLONASS/GPS Receiver	1570-1640
		Receiver Trajectory Control RB-1	2720-2730
		Receiver Trajectory Control RB-2	5750-5760

3.9 SPACECRAFT INTERFACES

3.9.1 Mechanical Interface

3.9.1.1 Separation System For SC With Adapter System

The following separation systems components are used to separate the SC from the LV adapter system:

- Separation assembly
- Spring pushers
- Electrical umbilicals
- Bonding elements (two each)
- Pneumatic umbilical

The ring-type separation assembly provides, until the time of separation, a structural mechanical link between parts that are to be separated. The assembly comprises a shroud that spans the outside conical surfaces of the SC and adapter system rings that are to be separated. The structural mechanical link is separated upon an electrical command received from the Breeze M control system. On this command, the shroud is separated into two arcs by two diameter-spanning pyro mechanical assemblies (pyro bolt cutters). The arcs are retracted to the periphery and secured in the retracted position to prevent their return to the center by a multi-sectional spring unit. The electrical umbilicals of the bonding elements and pneumatic connector are separated by the motion of the parts being separated.

The separation of the aforementioned links is accompanied by the conveyance to the parts being separated of a relative longitudinal velocity of ~0.6 m/s by the spring pushers. The conveyance of linear velocity may be accompanied by transverse stabilization spinning of the SC (by the same spring pushers) with an angular velocity of no more than ~3°/s. Longitudinal stabilization spinning of the SC is possible by using jet assists from the upper stage.

Depending on the SC design, it is possible to use SC separation hardware developed by KhSC, off-the-shelf hardware, or hardware furnished by the SC manufacturer.

Up until separation, the separation system for the structural link can convey either dispersed or concentrated forces between the SC and adapter system.

The functioning of the separation system operating between the SC and the adapter system is monitored by circuitry. The use of (two) contact sensors is also possible.

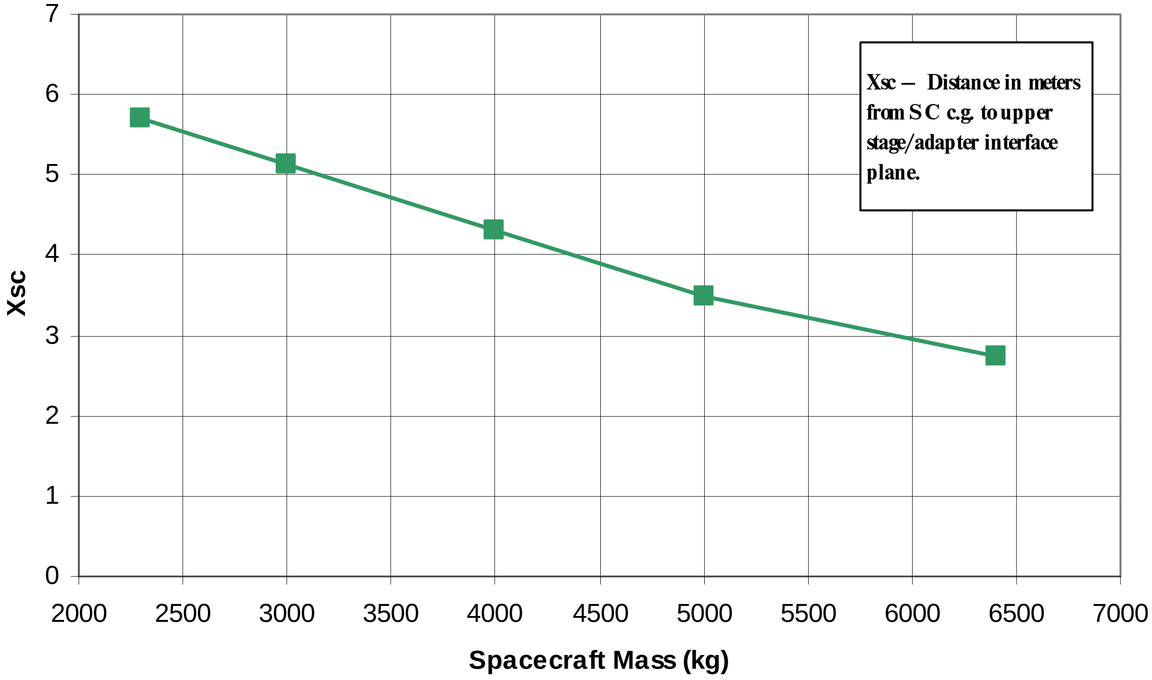
3.9.1.2 Allowable Payload Center of Mass

Allowable SC mass and CG offset values relative to the Breeze M upper stage load carrying capability are shown in Figure 3.9.1.2-1. The position of the center of mass is determined by the interface between the adapter system and the upper stage.

To ensure the upper stage controls operate effectively, the SC CG displacement from the LV longitudinal X axis along the lateral Y and Z axes (pitch and yaw) must not exceed ±25 mm.

Actual SC design allowable CG offset values may vary depending on mission specific coupled loads analysis. The upper stage mechanical interface flexibility makes it possible to consider cases that exceed the typical CG locations.

Figure 3.9.1.2-1: Breeze M Allowable SC Mass and CG Offset Values



3.9.1.3 Static Electricity Protection

In all stages of the functioning of the Angara LV, electrical charge builds up on the LV surface as a result of the following physical mechanisms: the operation of the engines; the operation of on-board equipment; interaction with gas and solid particles during passage through dense layers of the atmosphere; interaction with space plasma; the action of high energy electron and ion fluxes at high altitudes, especially in circumpolar regions; exposure to solar electromagnetic radiation; and so forth.

The buildup of electrical charge on the surface of the Angara LV is a source of electrical charges of different kinds, accompanied by the generation of impulsive currents and electromagnetic fields that act on electronic components and that can cause breakdowns and disruptions in the operation of on-board systems.

The passive protection method is used on the Angara LV to prevent differential charge buildup, that is, a potential difference between different sections of the LV surface, and thereby to prevent the occurrence of discharge processes. The means used in the passive method are bonding, the creation of conductive surfaces and their connection to a metal structure, and the grounding of LV components and of the LV as a whole during manufacture, transportation, and preparatory work and at launch.

Bonding and grounding are performed to meet the requirements of GOST 19005-81. The contact resistance at bonding points does not exceed 2 mohm.

The Angara LV is attached to the SC by two non-detachable jumpers between the upper stage and the adapter system and by two detachable straps, or by direct surface contact between the adapter system and the SC.

A continuous electrically-conductive coating with a volume resistivity of no more than 10^5 ohm-m is applied to the outside dielectric surfaces of the PLF, followed by connection of this coating to the common "electrical mass" of the LV.

The control system of the Angara LV is made resistant to electrostatic discharges. The noise immunity of electronic equipment with respect to static electrical discharges is checked separately and with the equipment installed on the LV. The external on-board cable network is shielded.

Zond 3M-Zaryad M measurement systems are mounted on the first and second stages of the LV, on the upper stage, and on the PLF to check the level of electrostatic and electromagnetic fields.

At the launch complex, the SC is grounded through the metal structure of the Angara LV. The components of the Angara LV have ground points, which are grounded during assembly and transport.

3.9.1.4 Lightning Protection

The Angara LV is protected from a direct hit by lightning while at the launch complex, and during thunderstorm activity, the launch process would be delayed.

3.9.2 Electrical Interface

3.9.2.1 Layout of LV Umbilical Cables For Interface Between the GSE and SC

Umbilical cables are used for servicing the SC (X1-X4) at the technical complex and launch complex.

A diagram showing the layout of the LV cables is presented in Figure 3.9.2.1-1. Electrical connectors X1-X4 have 50 contacts each. Table 3.9.2.1-1 shows the pin assignments for the umbilical cables.

In all there are 100 umbilical electrical connecting lines for servicing of on-board equipment of the SC as part of the A3 LV with the Breeze M. Of these:

- 21 are unshielded conductors;
- 19 (e) are shielded conductors;
- 52 (26 pairs of 2Ze) are shielded twisted conductor pairs;
- six (2 groups of 3Ze) are three twisted conductors in a common shield; and
- two shields (body).

Two connectors (X4 and C4) are provided in the design to lay backup circuits (50 circuits), if needed. The umbilical cable electrical circuits have the following characteristics:

- I_{min} = 1 μA for U_{min} = 1 mV for one contact circuit;
- I_{op} = 1.5 A for each conductor;
- I_{max} = 225 A maximum current load on umbilical cable for 1000 hr; and
- U_{max} = 100 V (on SC umbilicals) with consideration for voltage peaks in transients.

Figure 3.9.2.1-1: Diagram Showing Layout of the Umbilical Cables

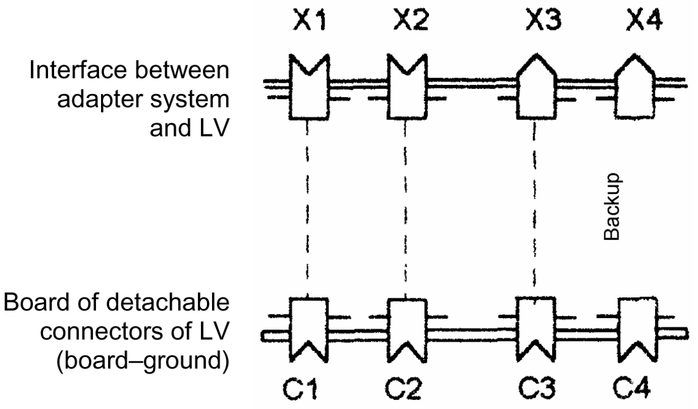


Table 3.9.2.1-1: Umbilical Cable Electrical Connecting Lines - Pin Assignments

X1, C1 Contact No.	Cross Section	Special Reqs.	X2, C2 Contact No.	Cross Section	Special Reqs.	X3, C3 Contact No.	Cross Section	Special Reqs.
1, 2	0.5	2Ze	1, 2	0.5	2Ze	1	2 × 0.5	
3	0.5	body	3	0.5	body	2	0.5	
4, 5	0.5	2Ze	4, 5	0.5	2Ze	3	2 × 0.5	
6, 7	0.5	2Ze	6, 7	0.5	2Ze	4	2 × 0.5	
8, 9	0.5	2Ze	8, 9	0.5	2Ze	5	2 × 0.5	
10, 11	0.5	2Ze	10, 11	0.5	2Ze	6-12	0.5	
12, 13	0.5	2Ze	12, 13	0.5	2Ze	13	2 × 0.5	
14, 15	0.5	2Ze	14, 15	0.5	2Ze	14-37	0.5	
16, 17	0.5	2Ze	16, 17	0.5	2Ze	38, 39	2 × 0.5	
18, 19	0.5	2Ze	18, 19	0.5	2Ze	40-50	0.5	1
20, 21	0.5	2Ze	20, 21	0.5	2Ze			
22	0.5	e	22	0.5	e			
23	0.5	e	23	0.5	e			
24	0.5	e	24	0.5	e			
25	0.5	e	25	0.5	e			
26	0.5	e	26	0.5	e			
27	0.5	e	27	0.5	e			
28	0.5	e	28	0.5				
29	0.5	e	29	0.5				
30, 31	0.5	2Ze	30	0.5				
32, 33	0.5	2Ze	31	0.5				q
34	0.5		32, 33, 34	0.5	3Ze			
35	0.5		35, 36, 37	0.5	3Ze			
36	0.5		38	0.5	e			
37	0.5		39	0.5	e			
38	0.5		40	0.5	e			
39	0.5		41	0.5	e			
40	0.5		42, 43	0.5	2Ze			
41	0.5		44, 45	0.5	2Ze			
42	0.5		46, 47	0.5	2Ze			
43	0.5		48, 49	0.5	2Ze			
44	0.5		50	0.5	e			
45	0.5							
46	0.5							
47	0.5							
48	0.5							
49	0.5							
50	0.5							

Note: Connectors X1, X2, X3, C1, C2, and C3 are circuit designations. The markings of the connectors will be determined in the course of development.

The cross section of all umbilical connecting lines is $S = 0.5$ mm^2. All umbilical connecting lines are galvanically isolated from the LV structure.

Electrical connectors X2, C1, C2, and C3 are of type 2RMD45B50G8A1.

X1 is of type 2RM42B50G2A1.

X3 is of type 2RM42B50Sh2A1.

For protection from interference and static electricity, the cables are protected with shielding and braiding, which is electrically connected to the LV structure to ensure continuity of shielding, and the inner shielding and braiding is electrically connected to the sleeve terminals of the electrical connectors.

The shields of the conductors are galvanically isolated from the external braiding of the cable and from the electrical connectors.

3.9.2.2 Control-Command Interface

Information exchange between the control system and the SC occurs on the SC from the time of launch until separation of the SC.

Electrical connectors RSh3A/PPS2 and 4RSh8A/PPS2, which are mounted on the PPS1 board of connectors of the upper stage, are used for communications between the control system and the SC.

The RSh3A/PPS1 uses the OS PS50ATV plug (GEO.364.047 TU, bRO364.045TU), and the 4RSh8A/PPS1 uses the OS PS32ATV plug. (GEO.364.047 TU, bRO364.045TU),

The pinouts of electrical connector RSh3A/PPS1, the conditions of command generation, and the designations of the commands are provided in Table 3.9.2.2-1.

Commands VM1-VM6 are output through three independent channels by closure of the dry contacts. The load current does not exceed 0.15-1.0 A for a voltage of no more than 34 V. The duration of command output is 0.2-1.0 s.

Table 3.9.2.2-1: Pinouts of Electrical Connector RSh3A/PPS1

Contact Numbers	Designation of Command	Condition for Generation	Channel
26, 28, 27, 29, 5, 8	VM1	First firing of stabilization, orientation, and firing support system propulsion system (for settling of the propellants)	1 2 3
14, 16 15, 17 1, 3	VM2	First shut-off of main propulsion engine	1 2 3
18, 20, 19, 21, 2, 4	VM3	Any firing of stabilization, orientation, and firing support system propulsion system	1 2 3
30, 32 31, 33 7, 9	VM4	Any shut-off of main propulsion engine	1 2 3
40, 42 41, 43 34, 37	VM5	Last firing of stabilization, orientation, and firing support system propulsion system (for settling of propellants)	1 2 3
44, 46, 45, 47, 11, 13	VM6	Last shut-off of main propulsion engine	1 2 3
39, 48, 6, 10, 36, 50	AVD1	SC emergency	1 2 3
12, 35	KS	Monitoring of mating (strap on SC side)	

The pinouts of electrical connector RSh8A4/PPS1, the conditions of command generation, and the designations of the commands are provided in Table 3.9.2.2-2.

The "KP," "PK," "SGO," and "PKO" commands are output from the Breeze M control system over three independent channels, with a voltage of 27+7 V relative to the common negative of the upper stage ("-"27 V). The allowable current load on each contact does not exceed 0.5 A. The duration of the commands is at least 0.1 s.

The "RKA" and "RRB" commands are executed by breaking the straps when the SC separates from the upper stage. The current load on the straps does not exceed 0.5 A for a supply voltage of up to 34 V. The duration is at least 0.1 s.

The "GKO" command is output from the upper stage control system by closing "dry" contacts. The current load is 0.15-1.0 A for a supply voltage of up to 34 V per contact. The duration of the command is 0.2-1.0 s.

Table 3.9.2.2-2: Pinouts of Electrical Connector RSh8A4/PPS1

Contact Numbers	Designation of Command	Condition for Generation	Channel
4 5 6	AK1	LV accident.	1 2 3
10 11 12	KP	Output upon receipt from LV control system.	1 2 3
24 25 26	SGO	Jettisoning of PLF. Output upon receipt from LV control system.	1 2 3
23 28 32	PK	Preliminary command to prepare for ascent unit separation. Output upon receipt from LV control system.	1 2 3
20, 22 21, 27 29, 30	GKO	Ready for SC separation.	1 2 3
14, 17	KS	Straps on upper stage side.	
1 2 3	"-" 27 V "-" 27 V "-" 27 V	Common negative of upper stage.	

* If a second SC is present.

3.9.3 Telemetry Interface

The on-board telemetry monitoring system of the Angara LV with the Breeze M is implemented by using telemetry equipment installed on the Breeze M (TA-RB) and on the second stage booster (TA-2RN/1 and TA-2RN/2).

The TA-2RN/1 handles recording of high frequency parameters and the TA-2RN/2 handles recording low frequency parameters.

The TA-2RN/1 and TA-2RN/2 operates in direct transmission (NP). The TA-RB system operates in direct transmission (NP), and under conditions of no radio visibility it operates in record (ZAP) and playback (VOSPR) modes. The TA-1 shuts off after completion of the de-orbit of the upper stage (1 hour after SC separation).

The NP mode coincides with the VOSPR mode and it is possible to make coincident with the ZAP mode.

The TA-RB handles recording of only low frequency parameters with a radio link capacity of 256 kbit/s at a range of up to 10,000 km and 32 kbit/s at a range of up to 37,000 km. The TA-RB shuts off after the completion of the de-orbit of the upper stage (1 hr after SC separation).

The recorded parameters originating at the SC and the adapter system are provided in Table 3.9.3-1.

TA-RB system does not record analog parameters in the NP mode, when the radio link capacity is minimal for data throughput, and in the ZAP mode. The sampling frequency for temperature and signal parameters is as stated.

The distribution of the recorded parameters between the SC and the adapter system will be defined based on SC requirements.

Measurements conducted at the PLF are provided in Table 3.9.3-2.

Table 3.9.3-1: SC Recorded Parameters

Types of Parameters	Number (units)	Sampling Frequency (Hz)	Recording Device
Vibrations	5	8,000	TA-2RN/1
Stress Impact	2	8,000	TA-2RN/1
Acoustical	1	8,000	TA-2RN/1
Analog	5 3	200 400	TA-2RB
Temperature	8	0.3	TA-2RB
Signal	16	100	TA-2RB

Table 3.9.3-2: PLF Recorded Measurements

Types of Parameters	Number (units)	Sampling Frequency (Hz)	Recording Device
Acoustical	7	8,000	TA-2RN/1
Pressure	16	50	TA-2RN/2, TA-2RB
Temperature	24	0.3	TA-2RN/2, TA-2RB
Signal	16	50	TA-2RN/2, TA-2RB

When the SC is injected into a geosynchronous orbit, the following TA-RB operating modes are implemented:

- During joint flight of the upper stage with the LV and during the first burn into the parking orbit, the NP1 mode is used when the radio link capacity of the TA-RB is 256 kbit/s.
- After the first burn into the parking orbit (when the radio link is functioning), the NP1 mode is used when the radio link capacity for the TA-RB channel is 256 kbit/s; otherwise, the NP2 mode is used when the radio link capacity for the TA-RB channel equals 32 kbit/s.
- When the upper stage main engine is activated, either NP1 or NP2 modes are used if the radio link is available; otherwise, the ZAP1 mode is used.
- Upon SC separation, coincident modes NP1 + ZAP2 or NP2 + ZAP2 are used.

Table 3.9.3-3 presents the TA-RB equipment information characteristics for recorded parameters of the SC and adapter system; specifically, the operating modes, the output data rates of the measurement programs, number of channels for SC and adapter system parameters, and recording frequency information characteristics for the above mentioned modes

The TA-RB equipment handles monitoring of SC signal parameters, and signals indicating that the SC has separated are generated by the separation sensors at the interface between the adapter system and the SC, as well as by the jumpers in the electrical connectors between the SC and the adapter system.

Table 3.9.3-3: TA-RB Recording Parameters of the SC and Adapter System

Operating Modes	Data Rates of Measurement Programs (byte/s)	Data Rates of Parameters Allocated for SC and Adapter System (byte/s)	Number (N) and Frequency (F) of Recorded Parameters					
			Signal Parameters		Analog Parameters		Temperature Parameters	
			N (units)	F (Hz)	N (units)	F (Hz)	N (units)	F (Hz)
NP1	12,800	2,403	16	100	5 3	200 400	8	0.3
NP2	1,600	203	16	100	-	-	8	0.3
ZAP1	2,200	203	16	100	-	-	8	0.3
ZAP2	2,800	203	16	100	-	-	8	0.3
VOSPR1	12,800	203	*F* and *N* correspond to record modes					
VOSPR2	1,600	203	*F* and *N* correspond to record modes					

4. ANGARA A5 LAUNCH VEHICLE

4.1 DESCRIPTION OF DESIGN AND BASIC TECHNICAL CHARACTERISTICS

The two-stage Angara A5 LV is built on a "tandem" scheme made up of five common rocket modules (CRMs) and a second stage. A general view of the LV with a 5100-mm PLF and a KVRB upper stage is presented in Figure 4.1-1.

The first stage booster consists of five CRMs. Each CRM is identical to the CRM which makes up the Angara 1.1 LV configuration. The CRMs are connected to each other by three spar booms. The upper spar boom is used to convey thrust forces to the second stage intermediate compartment.

The second stage booster uses kerosene and liquid oxygen propellants. The booster has a diameter of 3.6 m and consists of a fuel tank, an intertank compartment, an oxidizer tank, and an intermediate compartment. An RD-0124 four-chamber main propulsion engine is mounted at the base of the oxidizer tank in the intermediate compartment. Separation of the second stage from the first stage is "cold" and is driven by the solid retro-rocket motors installed on the intermediate compartment. After separation, the intermediate compartment remains on the jettisoned center CRM of the first stage booster. The RD-0124 main propulsion engine fires after the engine nozzles emerge from the intermediate compartment. The intertank compartment houses the control and telemetry system, and its frame carries the control components for communication between the LV and GSE.

4.2 ASCENT UNIT WITH KVRB OR BREEZE M

The ascent unit (AU) is an independent assembly put together at the technical complex. The AU includes:

- KVRB or Breeze M upper stage
- SC and the SC adapter system
- PLF (4350 mm or 5100 mm)

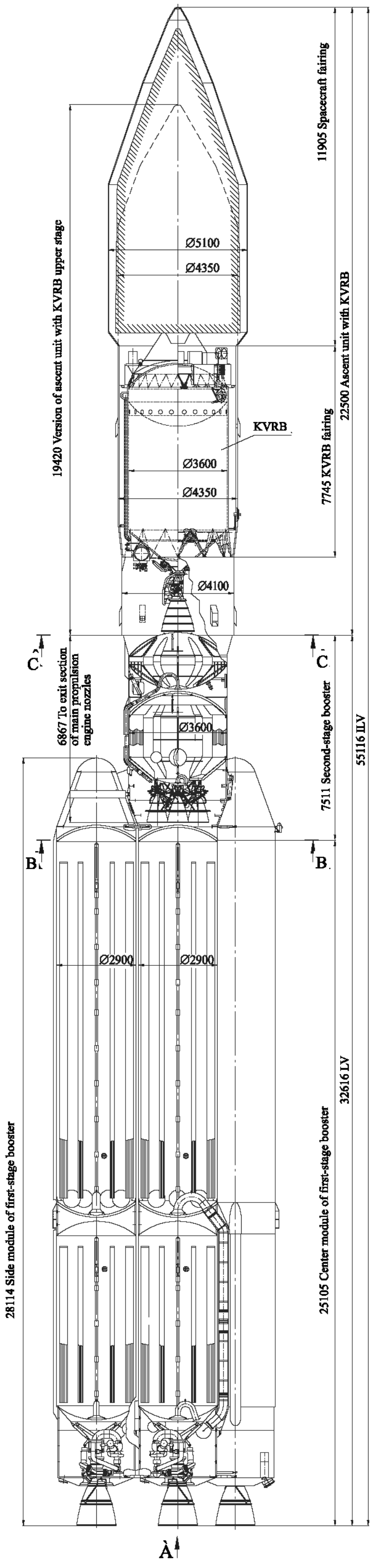
Once assembled, the AU is secured at the interface of the second stage. Depending on LV performance requirements, the AU may or may not include an upper stage.

4.3 KVRB UPPER STAGE

The KVRB upper stage is a single stage booster built on a tandem scheme. The general layout of the KVRB upper stage is shown in Figure 4.3-1.

The KVRB upper stage consists of the propellant compartment, which includes the fuel tank, oxidizer tank, and upper (equipment) and lower (engine) compartments. On the outside, the KVRB upper stage is encapsulated.

Figure 4.1-1: General View of Angara A5 LV



Basic characteristics:

Launch mass of integrated launch vehicle: 773 metric tons

Mass of payload on orbit (for $\varnothing_{NF} = 4.35$ m):
— on parking orbit ($H_{cir} = 200$ km, $i = 63°$): 24.5 metric tons
— on standard geotransfer orbit ($i = 25°$, $H_p = 5500$ km, $H_a = 35,786$ km): 6.6 metric tons

Main propulsion engine thrust:
— first-stage booster (at ground): 196 metric tons-force × 5 = 980 metric tons-force
— second-stage booster (in vacuum): 30 metric tons-force
— KVRB: 10.5 metric tons-force

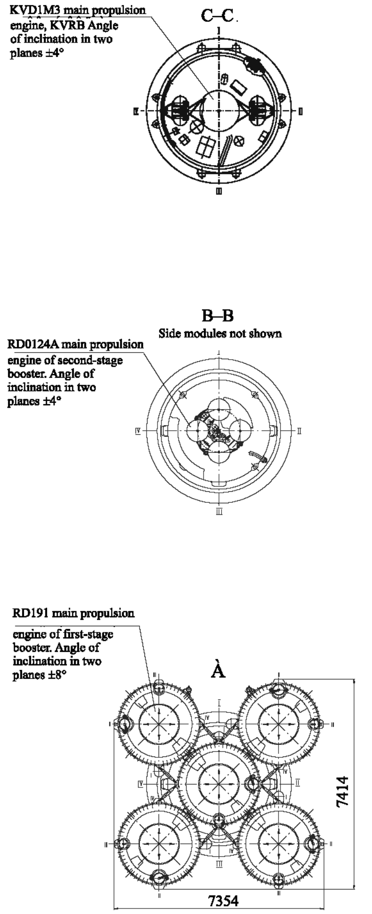
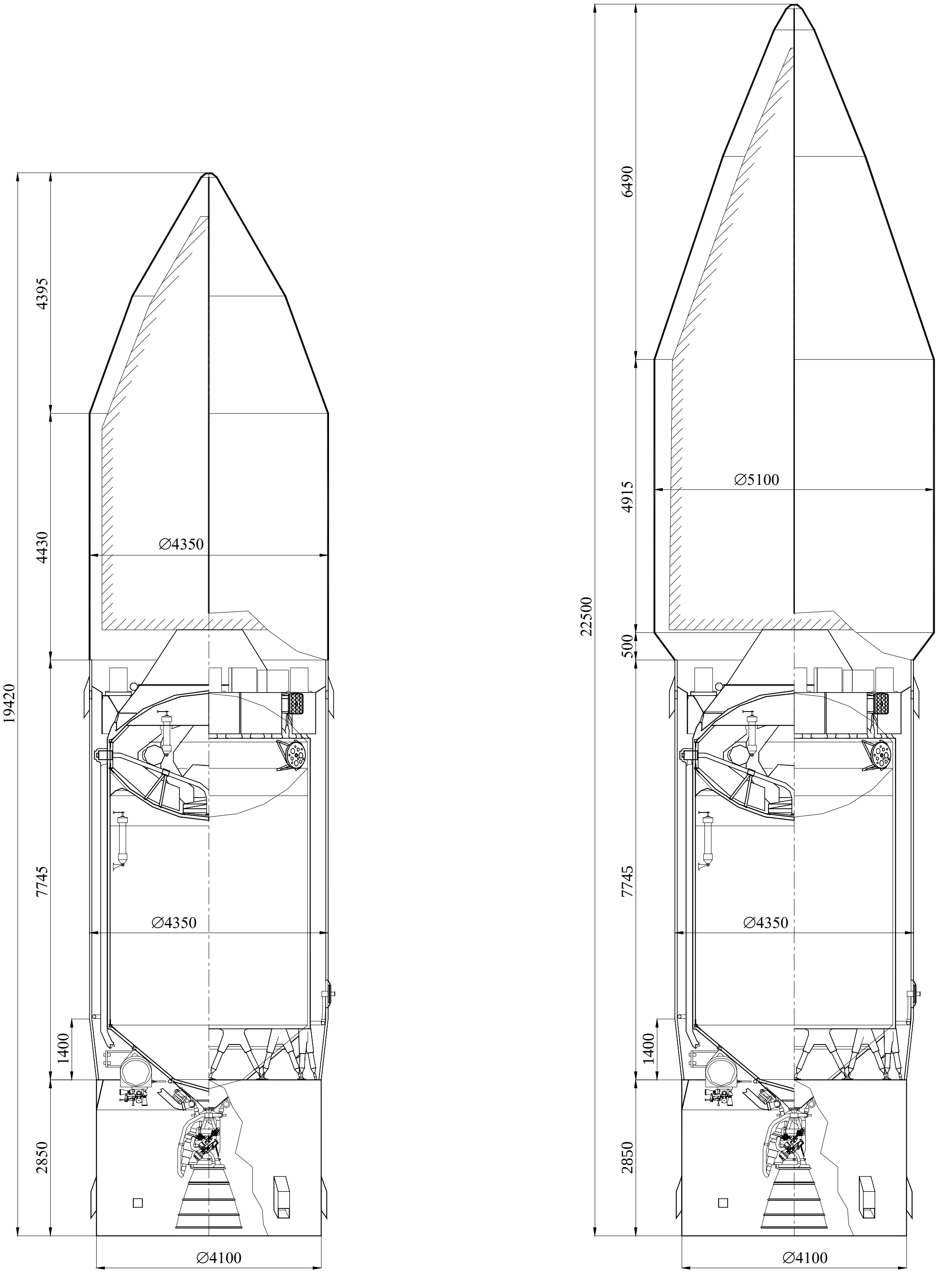


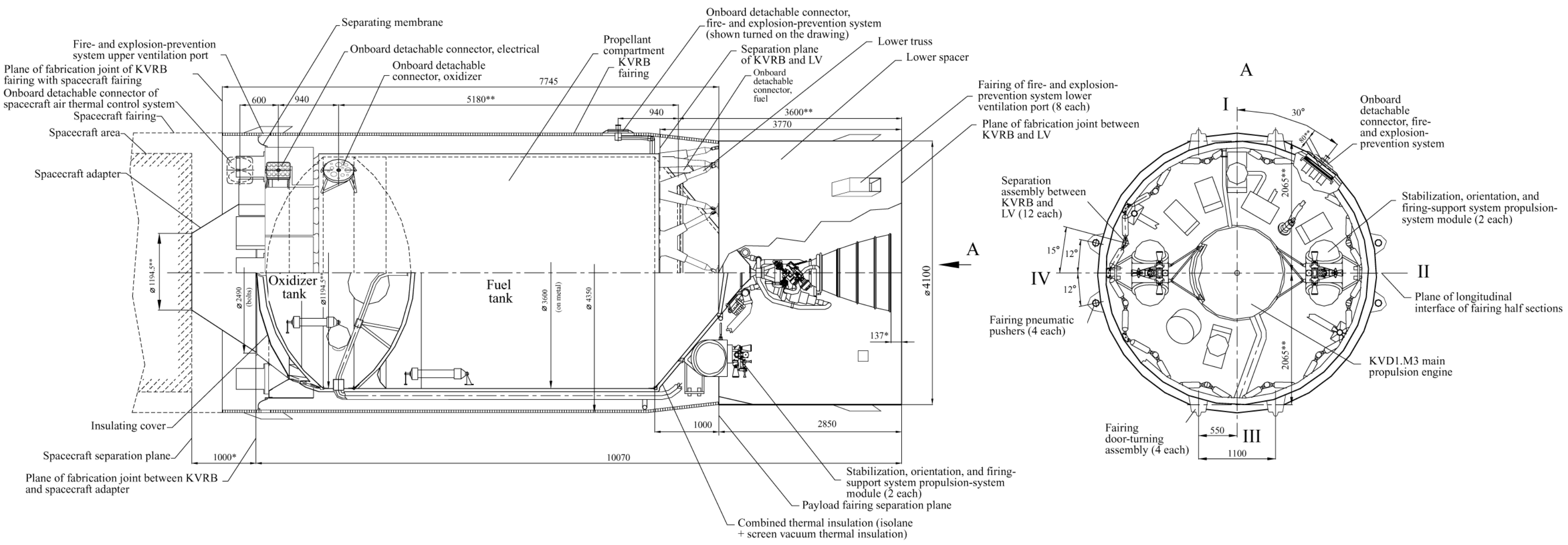
Figure 4.2-1: Angara A5 PLF - 4350 mm and 5100 mm Diameters



4350 mm PLF

5100 mm PLF

Figure 4.3-1: Layout of KVRB Upper Stage



The top compartment houses devices of the KVRB on-board systems (control system, on-board measurement complex) and is used to secure the payload. This compartment consists of an upper truss and a conical spacer, as well as an instrument board. The adapter system and SC are mounted on the top end frame of the conical spacer. Based on conditions of fire and explosion safety and cleanliness, the areas of the payload and upper stage are separated by an isolating membrane.

The propellant compartment is built on a load-bearing scheme and is used to house propellant components and elements of the propulsion system pneumatic and hydraulic delivery system. The propellant compartment consists of two tanks: the oxidizer tank and the fuel tank, which are separated by spherical bottoms (the lower bottom of the oxidizer tank and the top bottom of the fuel tank) with a standard radius of 2265 mm. The oxidizer and fuel tanks have a cylindrical shell 3600 mm in diameter. The main propulsion engine and two units of stabilization, orientation, and firing support propulsion system thrusters are mounted on the lower conical bottom of the fuel tank and propellant compartment. The propellant compartment and the piping are covered on the outside with combined thermal insulation consist of isolane and screen thermal vacuum insulation.

The lower compartment, which consists of the lower truss and lower spacer, is designed to mount the KVRB on the LV, and also (together with the PLF) to protect propulsion system units located on the lower section of the fuel tank from external exposure to the environment during ground operations and during flight.

The lower spacer of the KVRB is a framed compartment 2850 mm high and 4100 mm in diameter. At the bottom plane the spacer has an interface with the LV. At the top plane the spacer has an interface with the lower truss and the KVRB fairing.

The BRS-SPVP is intended to maintain thermal conditions and ensure fire and explosion safety of the KVRB at the launch complex during launch processing of the LV.

The BRS-VSOTR-KA is located in stabilization plane I of the LV in the vicinity of the interface between the KVRB and the SC, and is intended to maintain the thermal conditions of the SC.

Electrical connections between the KVRB and the GSE are made through the BRS-E on-board detachable connector and the POS-1.1, POS-1.2, POS-2, POS-3 umbilical connectors.

POS-1.1 and POS-1.2 provide electrical connections between the KVRB and the lower spacer (and also, through the spacer, between the KVRB and the second stage of the LV and the GSE).

POS-2 and POS-3 provide electrical connections between the KVRB fairing and the lower spacer (and also, through the lower spacer, between the PLF and the second stage of the LV and the GSE).

Pneumatic and hydraulic connections between the KVRB and the GSE are made through the BRS-O and BRS-G on-board detachable connections, which are on the KVRB.

The through connections of the ascent unit to be injected by the Angara A5 LV are provided by intermediate handling connectors located in the plane of the interface between the ascent unit and the LV (the interface between the KVRB adapter spacer and the LV).

4.4 ADAPTER SYSTEMS

The adapter system is intended to provide mechanical and electrical connection between the SC and the LV. The standard adapter system 1000 mm high is shown in Figure 4.4-1a through 4.4-1d.

It consists of a structure with the following mounted on it: the separation system, passive thermal control system, electrical umbilical cables, and telemetry monitoring system sensor equipment.

The structure is a conical mesh spacer made of aluminum alloy with two end rings. The lower ring is mated with bolts and pins to the upper stage. The SC is secured to the upper ring by the clampband separation system.

Depending on Customer requirements, a separation system with standard size 1194 or 1666 or with the Customer's standard size may be used.

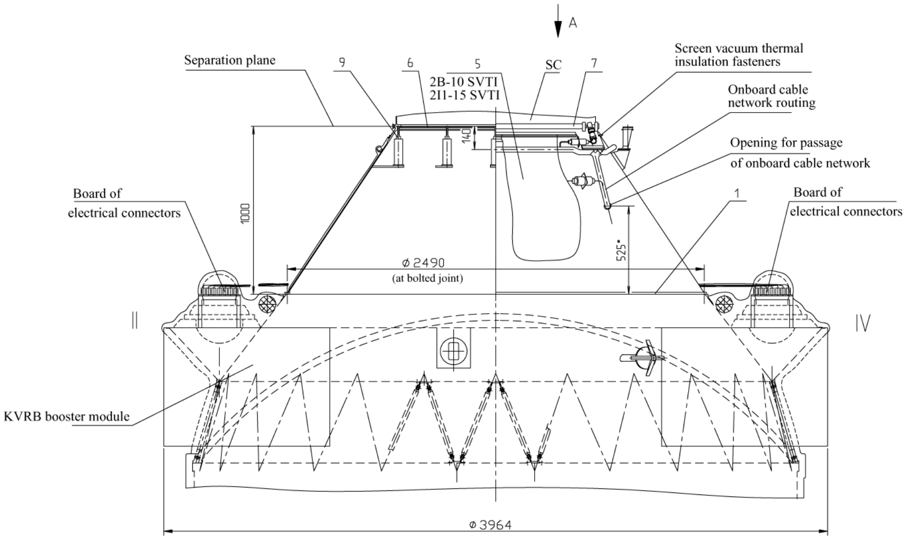
Spring pushers are installed on the top end ring to provide the initial impulse upon separation of the SC from the LV. The number of spring pushers and their force are determined by SC separation requirements and consented to by the Customer. In all, up to 12 spring pushers may be installed on the adapter system.

Two arms with electrical umbilical cables that provide electrical connection between the SC and the LV are installed on the adapter system. The type of electrical connectors and their mounting coordinates are determined with the consent of the Customer.

4.5 FAIRINGS AND SC USEABLE VOLUME

The fairings for the Angara A5/KVRB are shown in Figure 4.2-1. The fairings are designed to protect the SC and upper stage from external exposure to the environment during ground operations and in flight. The fairings are mounted on the lower spacer of the KVRB at the 4100-mm diameter interface plane, and consist of the KVRB fairing and the SC fairing.

Figure 4.4-1a: KVRB Adapter System (Sheet 1 of 4)



No.	Name	Qty	Mass	Remarks
26	Mating board	1		
24	Mating board	1		
23	Board of electrical adapter/connectors	1		
22				
21	Band separation unit	2		
20	Sparkproof power-supply and checkout unit	1	1,6	
19	Bracket	3		
18				
17				
16				
15				
14				
13				
12				
11	Electrical umbilicals	2		
10				
9	Spring pushers	8		
8				
7	Separation aids	1		
6	Upper ring	1		
5	Thermal insulation	1		
4				
3				
2				
1	Lower ring	1		

1. *Dimensions for reference.
2. This adapter system uses the 1194AX separation system.
3. Dimension B (section J–J) is determined by the spacecraft simulator.
4. The positioning of the umbilicals at angle □* is determined by the spacecraft.
5. When the spacecraft is mounted on the adapter system of the LV, the gap between the frame of the spacecraft and the adapter system of the LV (in the separation plane) before the clampband is tightened must not exceed 0.6 mm, and after tightening must not exceed 0.2 mm.

Figure 4.4-1b: KVRB Adapter System (Sheet 2 of 4)

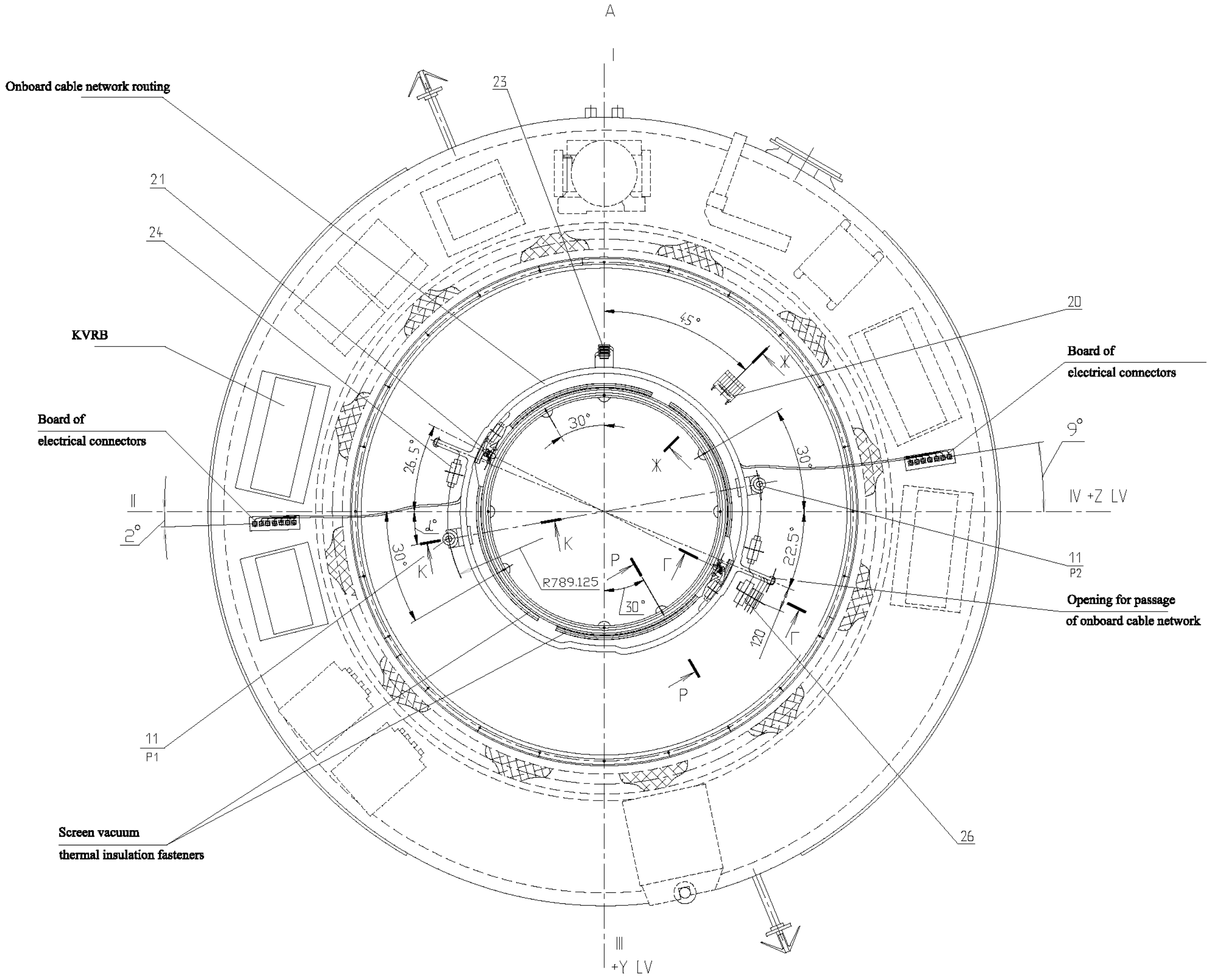


Figure 4.4-1c: KVRB Adapter System (Sheet 3 of 4)

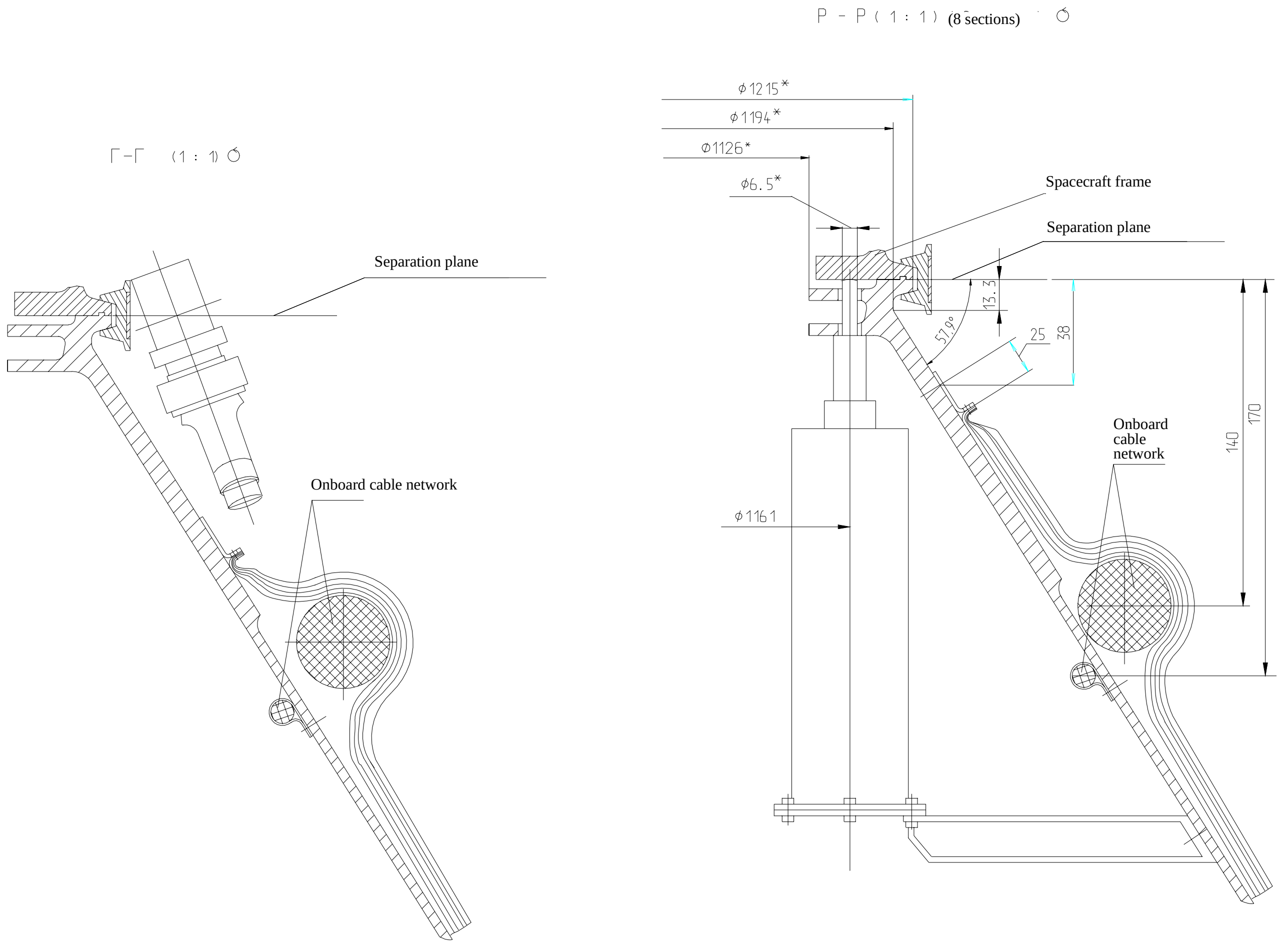
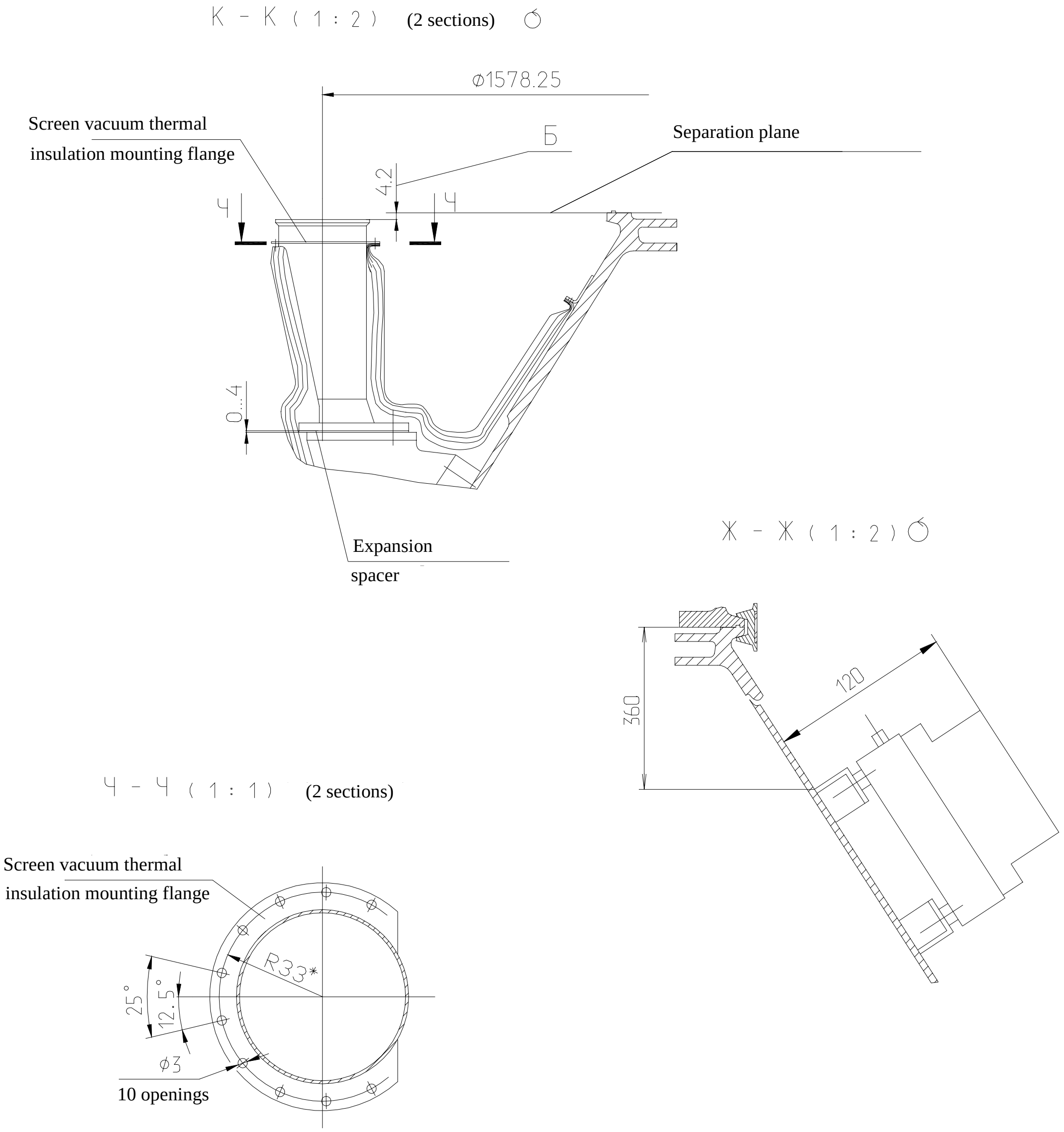


Figure 4.4-1d: KVRB Adapter System (Sheet 4 of 4)



The SC fairing is available in two cylindrical diameters, 4350 and 5100 mm. The dimensions of the SC areas under the PLF are shown in Figures 4.5-1 and 4.5-2. The Angara A5/Breeze M PLFs are shown in Figure 4.5-3. The overall dimensions of the areas were determined on the basis of the use of an adapter system with a height of 1000 mm.

At the Customer's request, radio transparent windows and SC access doors may be placed on the SC fairing. The PLF carries two detachable connectors: the BRS-SPVP [for the fire and explosion prevention system], which performs nitrogen and air purges of the KVRB area, and the BRS-VSOTR-KA [for the SC air thermal control system], which performs air thermal control of the SC area. The required pressure level under the PLF while it is at the launch complex is maintained by using the ports of the fire and explosion prevention system, and in flight by using the vent ports. Thermal insulation is mounted on the inside surface of the SC fairing and in the top part of the KVRB fairing.

The PLF is jettisoned at the transverse joint with the lower spacer, after first being separated into two halves on plane II-IV.

4.6 LV BASIC TRAJECTORY DESIGN AND PERFORMANCE PARAMETERS

4.6.1 Typical Flight Design and Orbit Parameters for Angara A5/KVRB

Depending on the requirements for target orbit parameters, the A5 LV can be used for insertion into parking orbits with the following inclinations: $i = 63°$, $i = 76°$, $i = 82.5°$, or $i = 93.4°$ (see Figure 4.6.1-1).

A typical flight design of the A5 LV during injection of the KVRB (upper stage + SC + adapter system) into a parking orbit with $H_{\text{cir}} = 242$ km and $i = 63°$ is presented in Figure 4.6.1-2, and the change in relative velocity, flight altitude, dynamic pressure, and axial load factor are shown in Figure 4.6.1-3.

The LV inserts the KVRB into an intermediate elliptical orbit. During flight, the side CRMs of the first stage booster separate at 213 s, the center CRM of the first stage booster at 325 s, and the second stage booster at 750 s. Upon jettisoning of the PLF at 340 s, the free molecular heat flux density onto an area perpendicular to the velocity vector does not exceed 1135 W/m^2. It is possible for the PLF to separate at 230 seconds of the flight, which will result in an increase in the payload mass capability, but in this case, the free molecular heat flux density exceeds 1135 W/m^2. The KVRB first burn occurs at 220 seconds after separation from the LV to carry out the "additional boost" maneuver, injecting the KVRB into a circular parking orbit. The altitude of the parking orbit may range from 180 km to 250 km.

Figure 4.5-1: KVRB/SC PLF - Useable Volume for 4350-mm Diameter

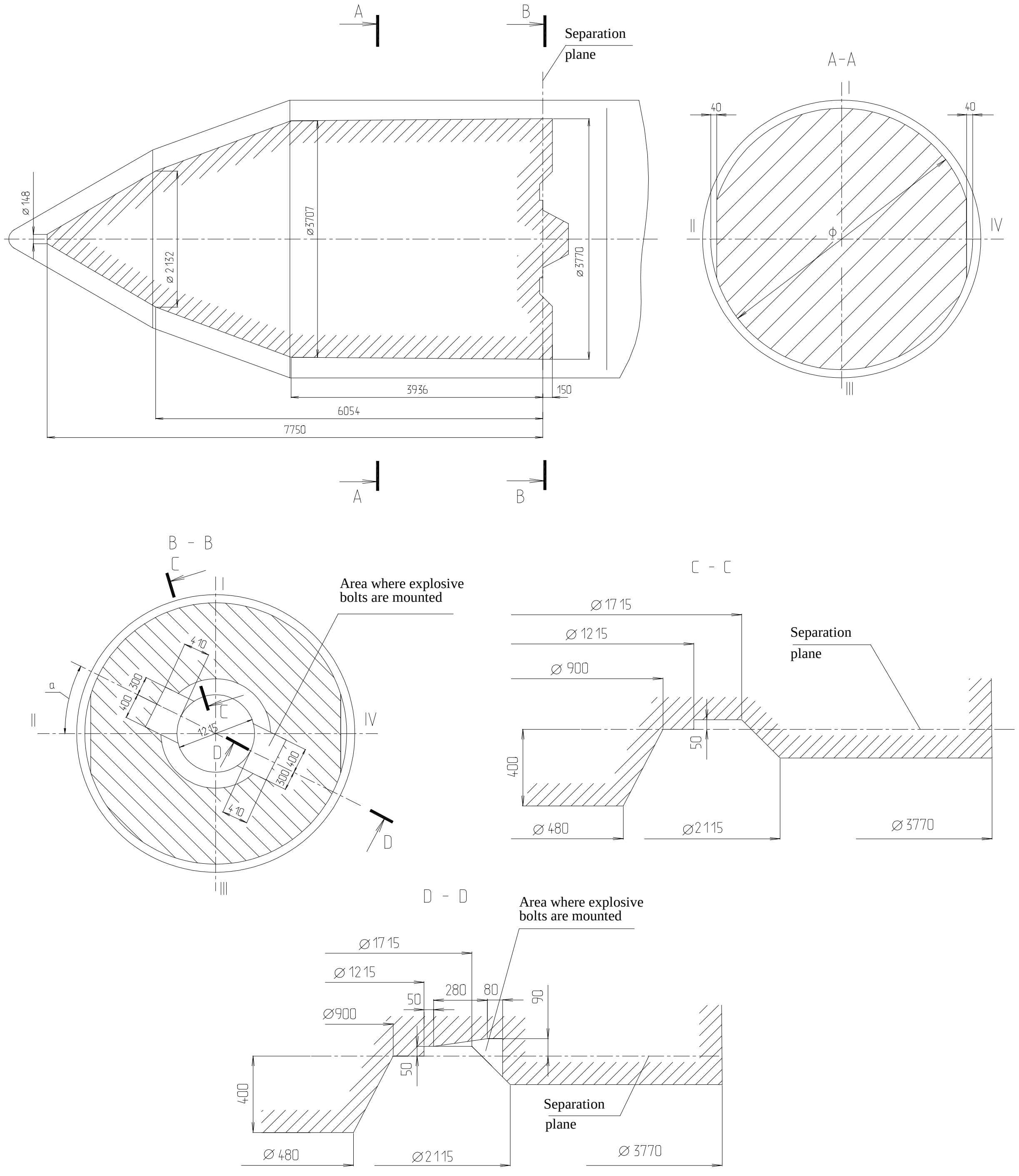


Figure 4.5-2: KVRB/SC PLF - Useable Volume for 5100-mm Diameter

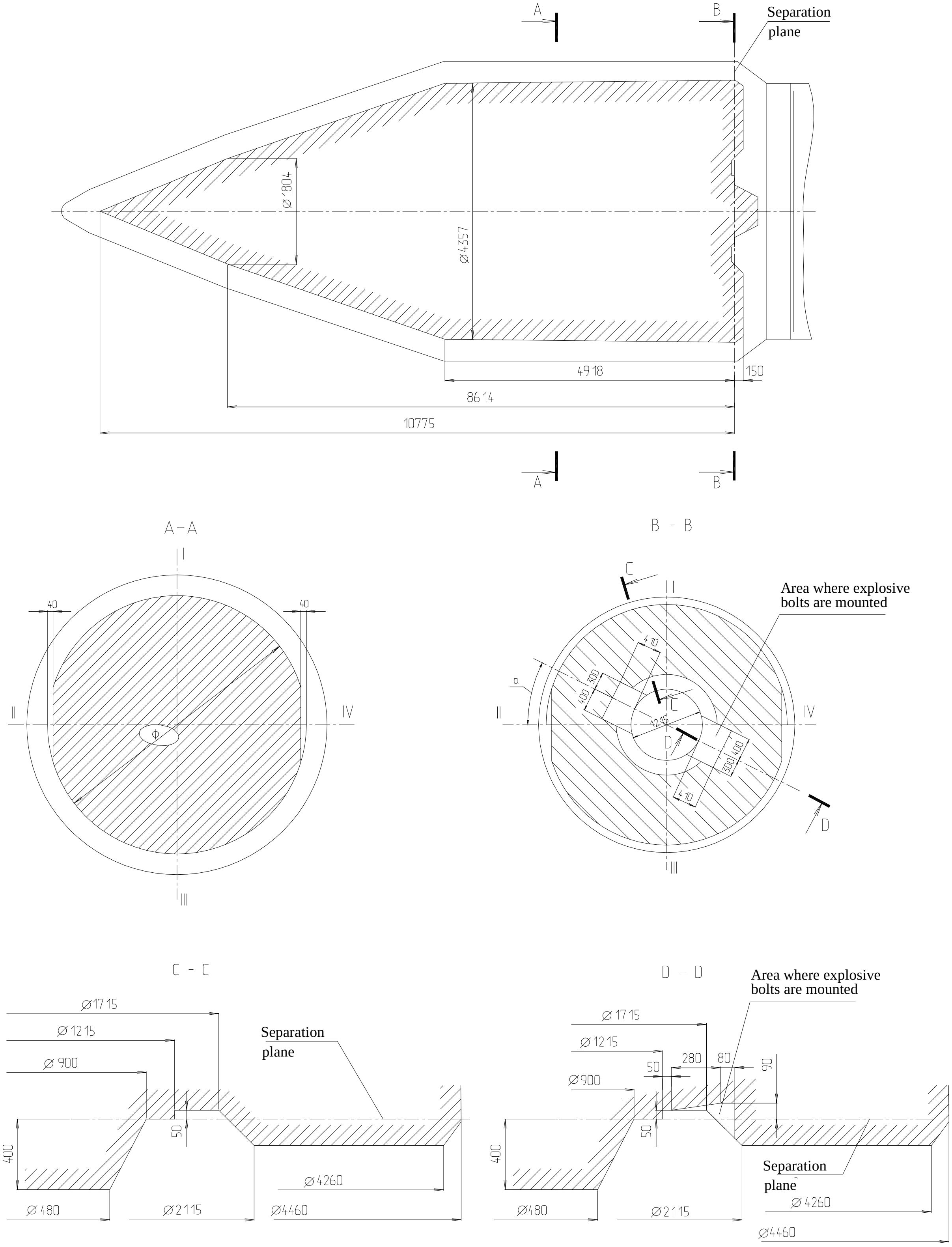
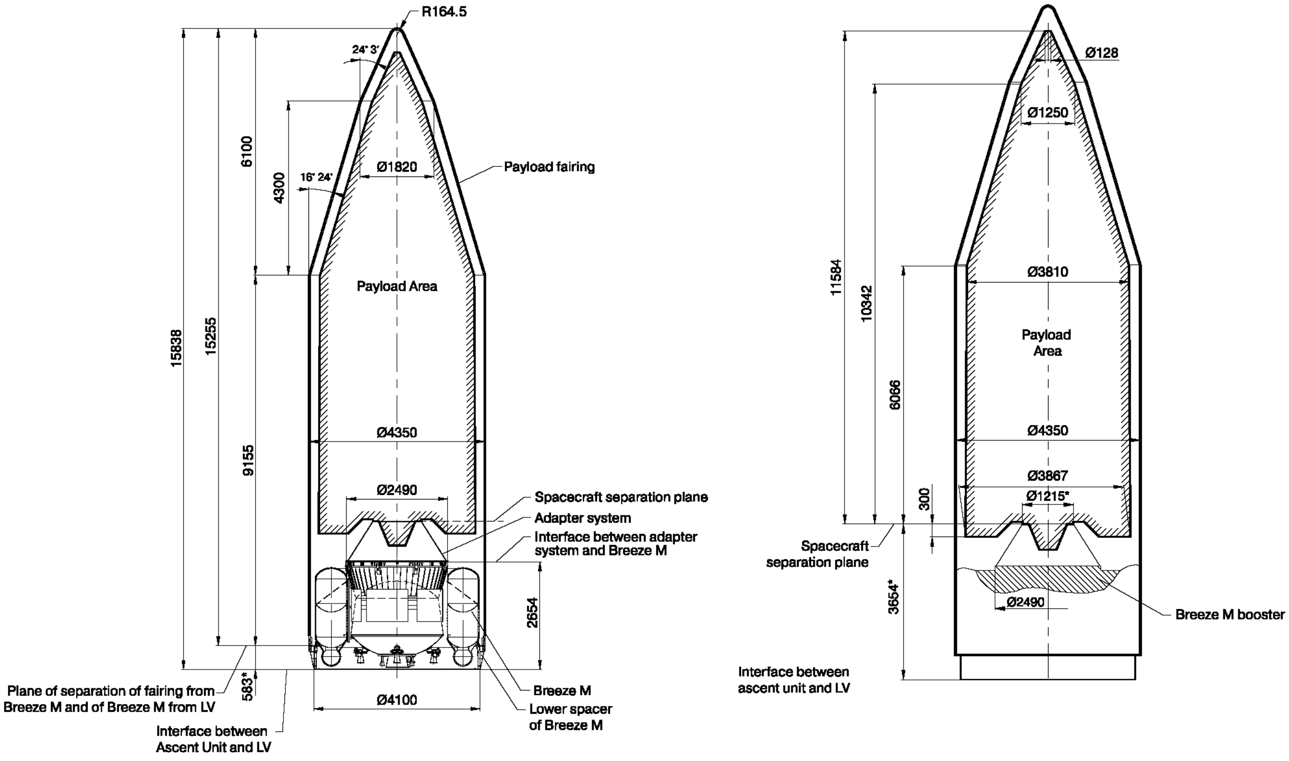


Figure 4.5-3: Angara A5/Breeze M PLF General Dimensions and SC Useable Volume



Notes: *Size for reference.

The dimensions of the adapter system are determined by the type of SC.

Figure 4.6.1-1: Angara A5 Possible Orbital Inclinations and Impact Zones of Jettisoned Hardware

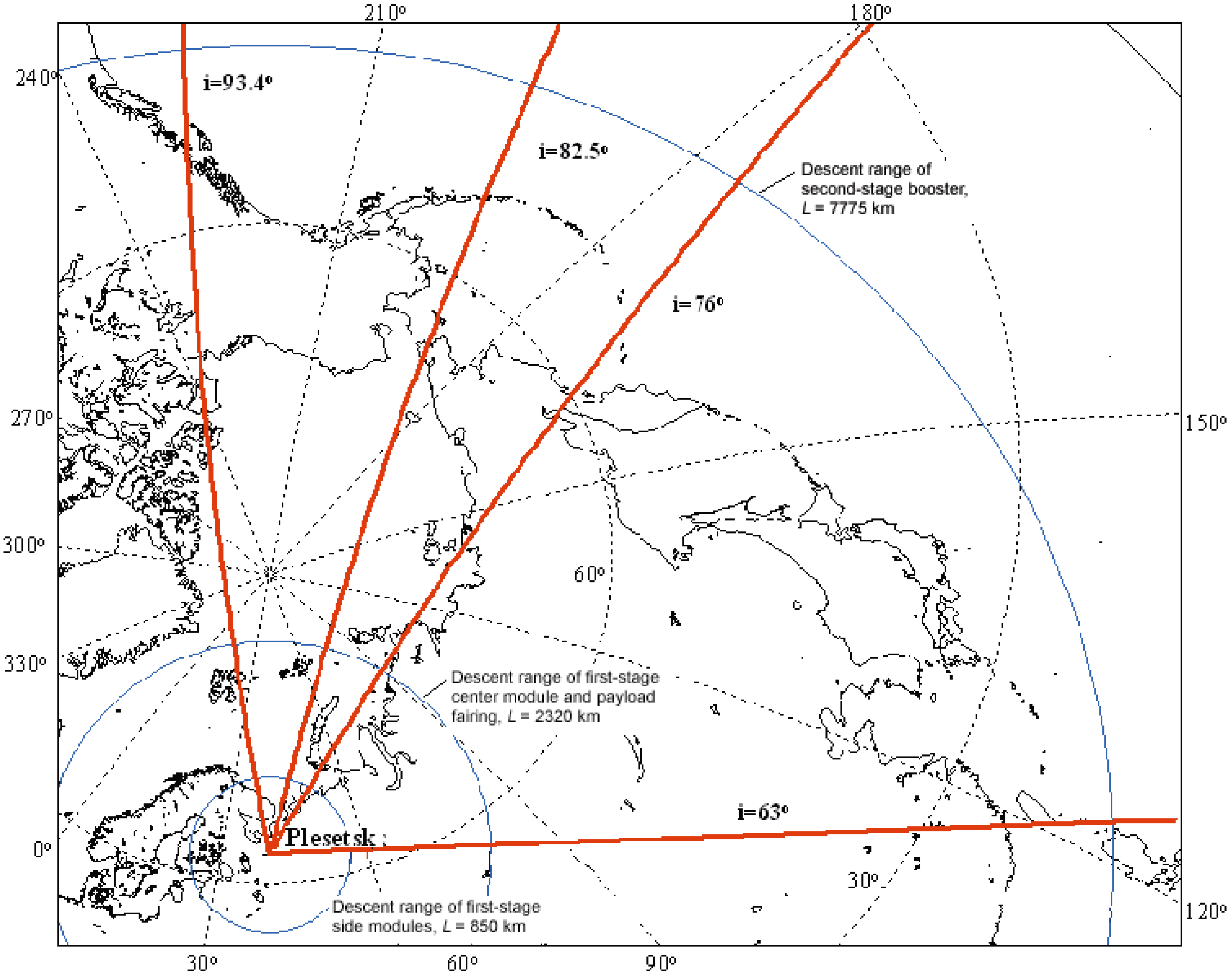


Figure 4.6.1-2: Typical Angara A5 LV Flight Path and Trajectory Parameters

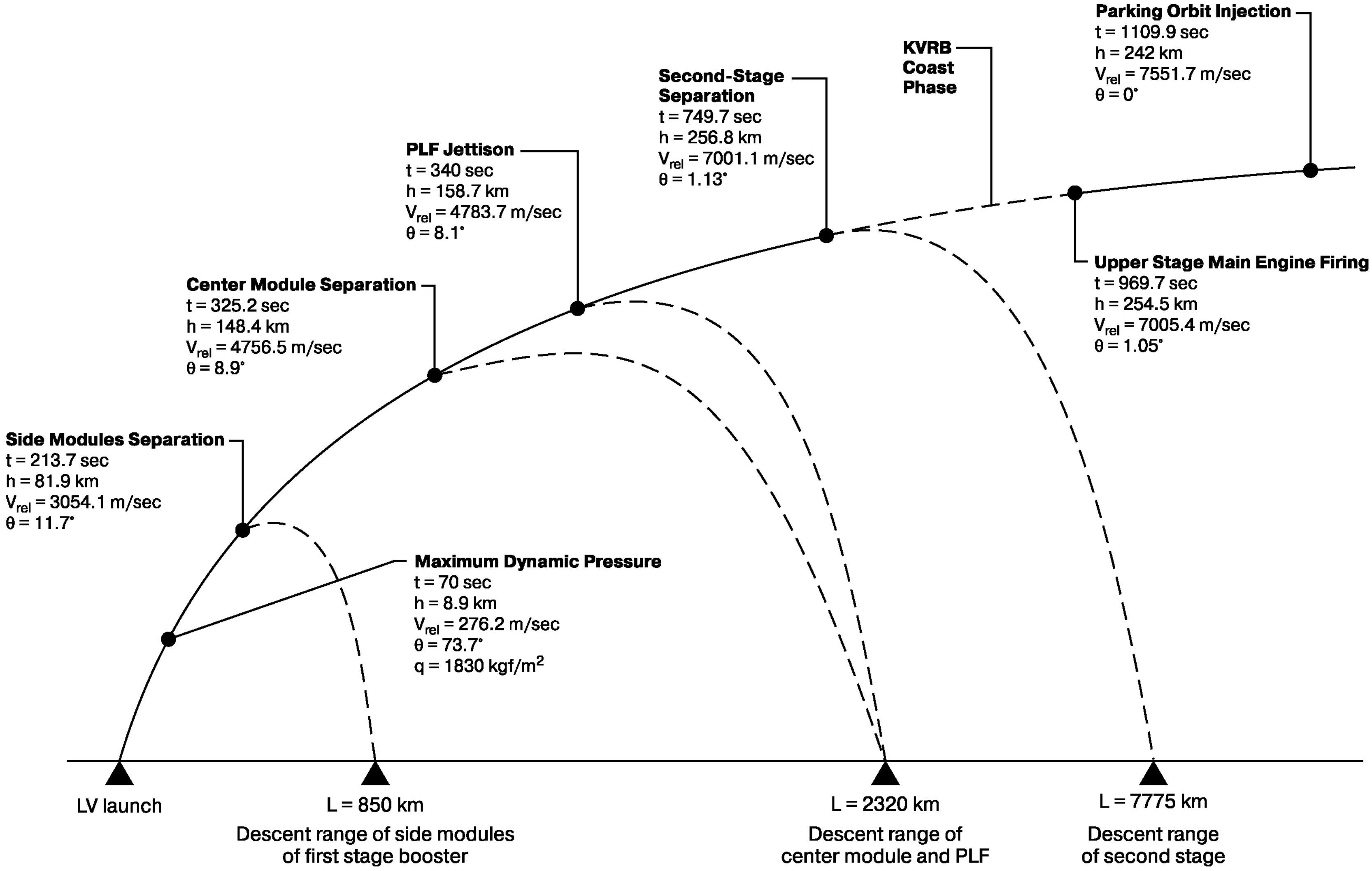
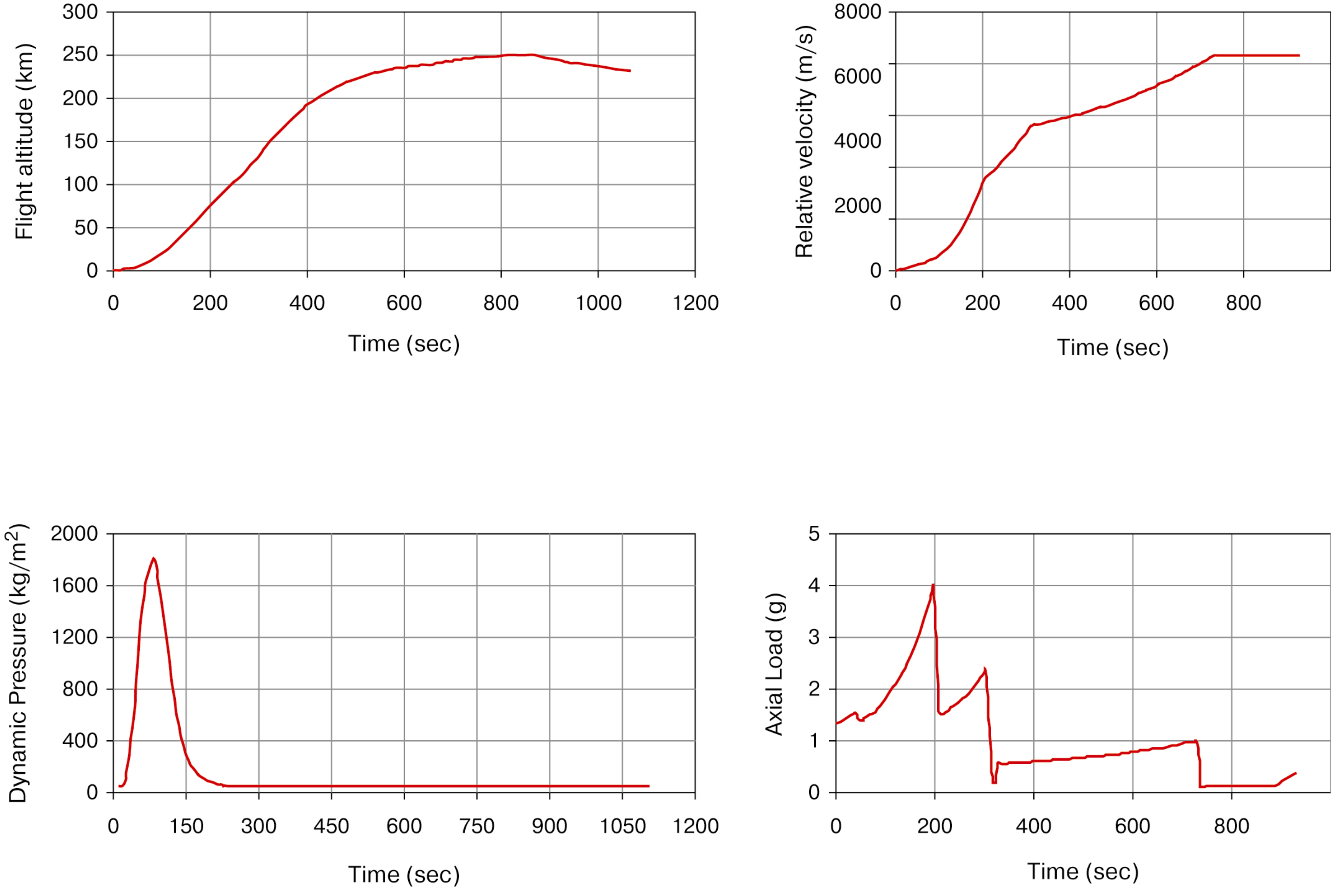


Figure 4.6.1-3: Angara A5 LV Ascent Flight Characteristics



A typical flight design of the KVRB during injection of a SC into GTO is shown in Figure 4.6.1-4. The transfer from parking orbit to the target orbit is achieved in two burns. After coasting in the parking orbit for ~51 minutes, the second burn occurs placing the KVRB in a transfer orbit with an apogee altitude of 35,786 km and an inclination of 60 degrees. The third burn occurs at apogee of the transfer orbit. The length of the third burn depends on the parameters of the GTO. All velocity impulses are applied on the line of nodes. After injection into GTO, the SC separates and the upper stage moves away. The longitude of SC injection is ~43 degrees east longitude. A typical flight path of the Angara A5/KVRB for injection of the SC into GTO is shown in Figure 4.6.1-5.

For transferring from GTO to the geostationary orbit, the SC uses its own propulsion system to generate the necessary delta velocity (ΔV_{SC}) at apogee of the GTO.

Use of a super-synchronous transfer trajectory can increase performance into GSO. The super-synchronous transfer trajectory takes advantage of the increased efficiency with which the inclination change can be performed by the LV at high altitudes. When such an injection scheme is used (see Figure 4.6.1-6), the KVRB injects the SC into a transfer orbit with an apogee altitude greater than the standard geosynchronous apogee altitude. At apogee of this orbit, using its own propulsion system the SC executes a maneuver to change its orbital inclination and increase the perigee altitude to the altitude of the geostationary orbit (the SC transfer orbit). At perigee of the resulting orbit, using its own propulsion system the SC maneuvers into the geostationary orbit.

4.6.2 Dynamic Parameters of Upper stage

During coast phases, the upper stage can perform programmed turns relative to any of the body axes of the upper stage.

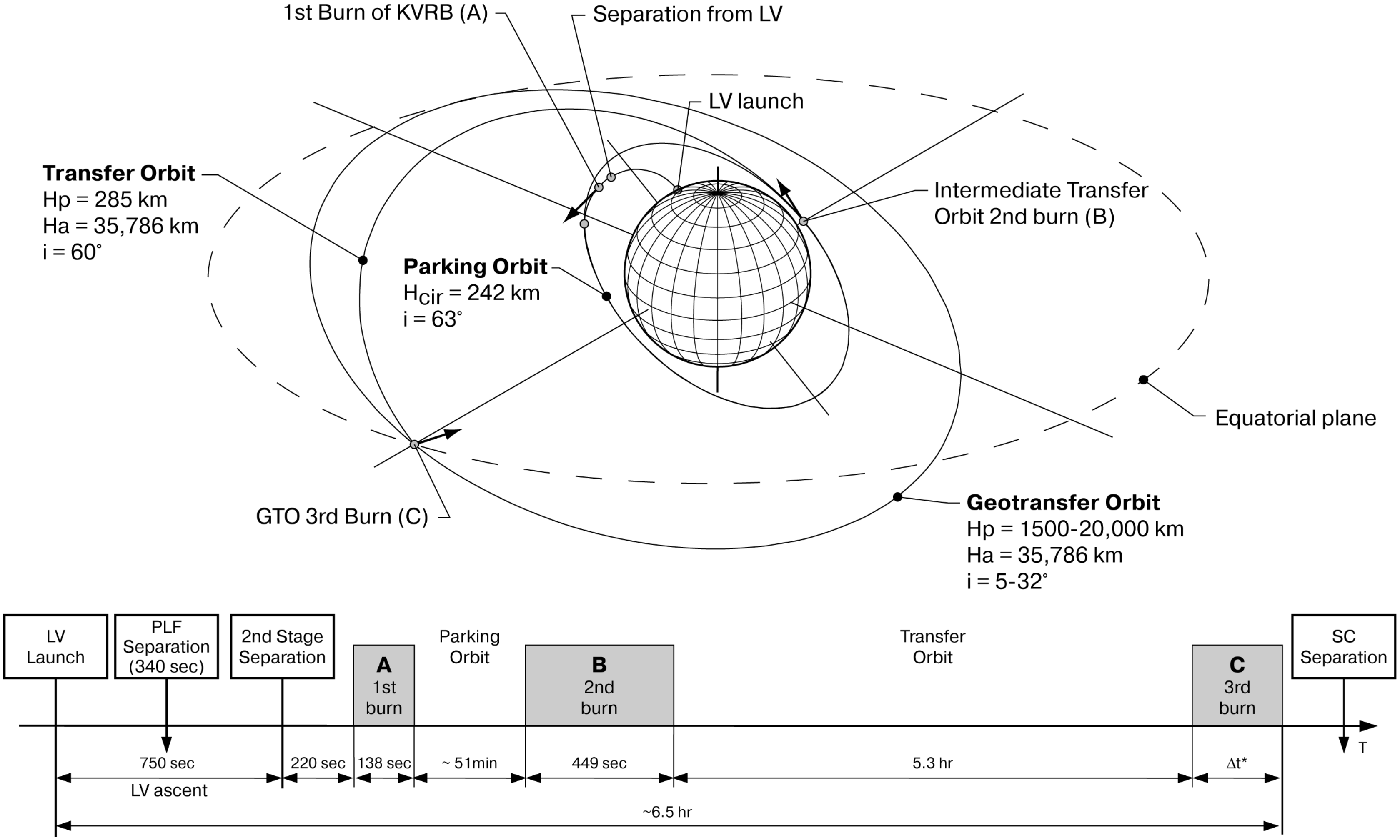
In general, the limitations on turning angles and on the spatial attitude of the upper stage are determined by the limitations of the gyro platform:

- There are no limitations with respect to two axes.
- There is a ±45° limitation with respect to one axis.

The angular velocities of turns relative to any axis do not exceed 1-2°/s. While the main propulsion engine is in operation, control of booster spatial attitude is determined by the pitch, yaw, and roll programs selected for each specific flight program. Any spatial orientation of the upper stage can be effected prior to separation of the SC. At the time of SC separation, the upper stage may be either in stabilization mode or, if necessary, in spinning mode. In stabilization mode the following can be provided:

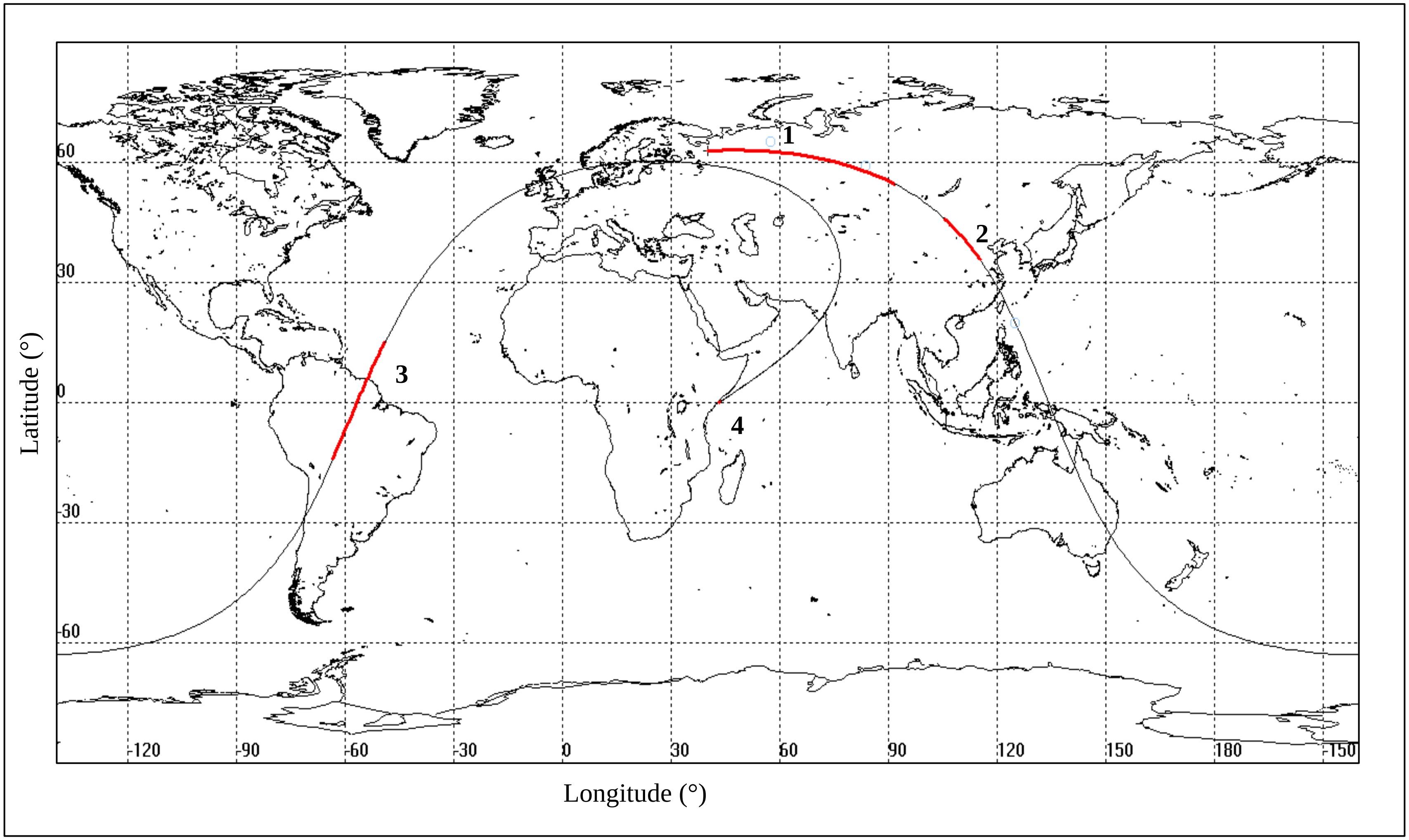
- Angular velocities of the orbiter relative to any axis of the body axis coordinate system not exceeding 0.5°/s.
- An error in spatial attitude of upper stage axes relative to the on-board inertial coordinate system of no more than 0.5°

Figure 4.6.1-4: Typical Flight Path of KVRB Upper Stage During Injection into GTO



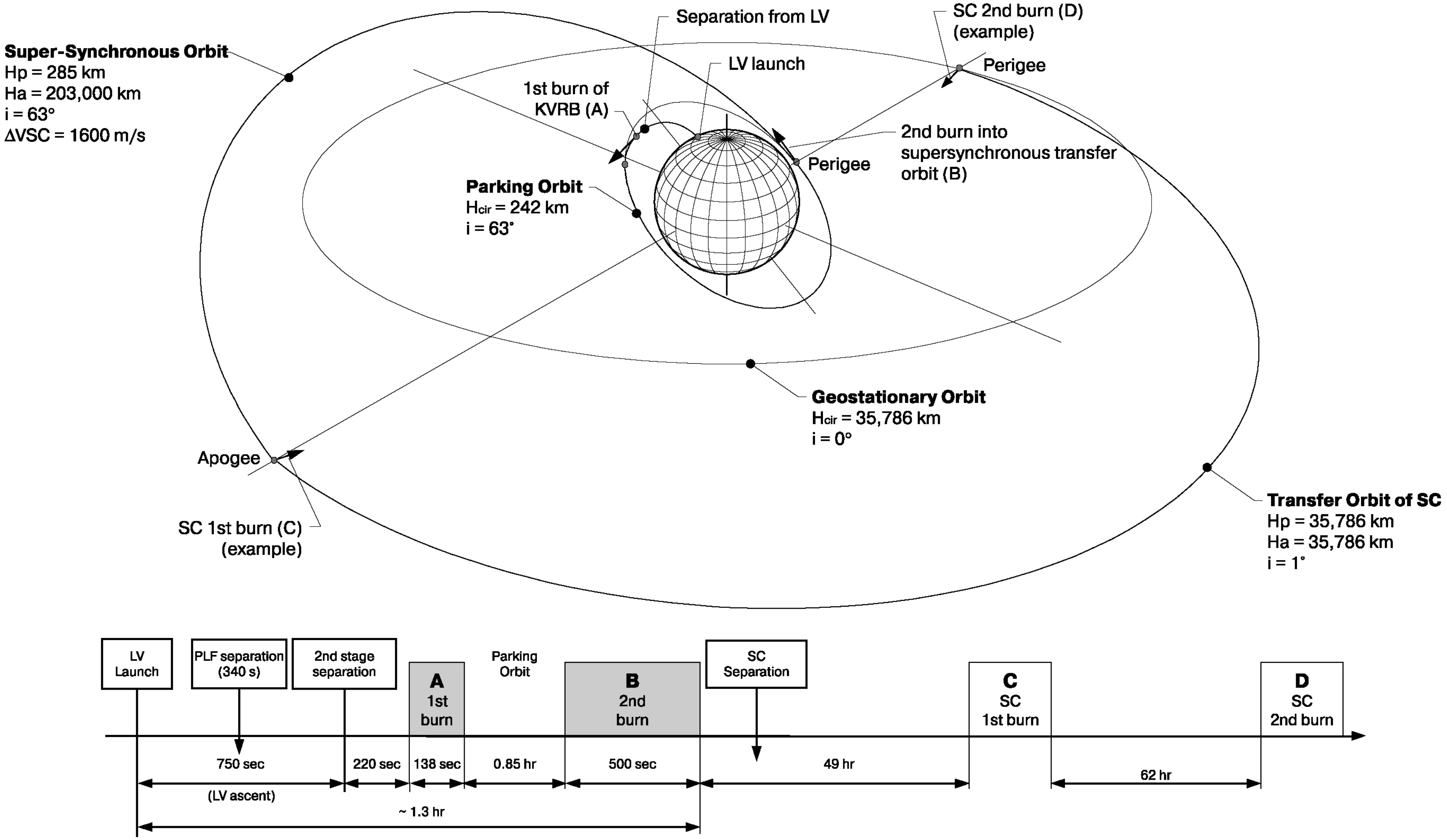
* Δt varies as a function of the inclination and perigee altitude of the GTO.

Figure 4.6.1-5: Ground Trace of Angara A5/KVRB to GTO



1. LV ascent
2. KVRB first engine burn - injection into parking orbit
3. KVRB second engine burn - injection into intermediate transfer orbit
4. KVRB third engine burn - injection into final GTO

Figure 4.6.1-6: Typical Flight Path of KVRB Injection into Super-Synchronous Transfer Orbit



In spinning mode, an angular velocity of the upper stage relative to the OX longitudinal axis of the booster of up to 12°/s can be provided. The possibility of raising the angular velocity to 30°/s is being analyzed.

The maximum deviation of the longitudinal axis of the upper stage from the program position at the time of SC separation depends mainly on the mass and inertia characteristics of the specific SC, the required value of the angular velocity of SC spin, and the aggregate of the perturbing factors at work during spinning. An analysis will be performed prior to contract signing to determine if the SC will meet the requirements of the upper stage.

4.6.3 Injection Accuracy

The accuracy of payload injection into typical GTO is presented in Table 4.6.3-1 for the Angara A5/KVRB.

Table 4.6.3-1: KVRB Injection Accuracies

Orbital Parameters	Deviations of Orbital Parameters				
	Perigee	Apogee	Inclination	Argument of perigee	Period
Circular parking orbit, 200 km altitude	±2.0 km	±4.0 km	±0.03°	-	±3 s
Circular orbit, 10,000 km altitude	±20 km	±10 km	±0.1°	-	±50 s
GTO 5500 × 35,786 km, inclination 25.0°	±200 km	±100 km	±0.15°	±0.3	-

	Eccentricity	Longitude	Inclination	Period
Geostationary orbit	±0.003	±0.7°	±0.15°	±300 s

4.7 PERFORMACE CHARACTERISTICS

The performance characteristics of the A5 are presented in Table 4.7-1 for payload (SC + adapter system) injection into a low circular orbit with H_{cir} = 200 km, in Table 4.7-2 for the KVRB, and Table 4.7-3 for the Breeze M for injection into GTO, and in Table 4.7-4 for the KVRB for injection into a super-synchronous orbit.

For determination of the performance capability of the LV, the PLF was jettisoned at 340 second. In this case, the free molecular heat flux density (q) does not exceed 1135 W/m^2.

Table 4.7-1: Angara A5 LEO Performance Capability for Circular Orbit 200-km Altitude

Orbital Inclination (deg)	63		76	82.5	93.4
Payload Systems Mass (metric tons)	23.8	24.5*	22.9	22.3	21.4

Note: PLF diameter = 4350 mm; q < 1135 W/m^2
*The payload mass was determined for PLF jettisoning at t_j=230s ; q>1135 W/m^2

Table 4.7-2: Angara A5/KVRB GTO Performance Capability

ΔV_{SC} for Transfer to GSO (m/s)	**GTO Parameters: $\omega_p = 0°$, H_a = 35,786 km**		**Payload Systems Mass (metric tons)**
	i (deg)	**H_p (km)**	
600	7	16,600	4.75
700	8.2	14,400	4.94
800	9.7	12,600	5.13
900	11.3	11,000	5.33
1000	13.1	9600	5.53
1100	15.0	8300	5.74
1200	17.0	7200	5.95
1300	19.0	6100	6.17
1400	21.1	5100	6.39
1500	23.3	4200	6.61*
1600	25.7	3400	6.84
1700	28.3	2700	7.08
1800	31.0	2100	7.31

Note: PLF diameter = 4350 mm; q < 1135 W/m^2
*If a PLF with a diameter of 5100 mm is used, the payload mass will be 6.45 metric tons.

Table 4.7-3: Angara A5/Breeze M GTO Performance Capability

ΔV_{SC} for Transfer to GSO (m/s)	GTO Parameters: $\omega_p = 0°$, $H_a = 35{,}786$ km		Payload Systems Mass (metric tons)
	i (°)	H_p (km)	
600	7.0	16,600	3.70
700	8.2	14,400	3.86
800	9.7	12,600	4.02
900	11.3	11,000	4.20
1000	13.1	9600	4.38
1100	15.0	8300	4.58
1200	17.0	7200	4.78
1300	19.0	6100	4.98
1400	21.1	5100	5.19
1500	23.3	4200	5.41
1600	25.7	3400	5.64
1700	28.3	2700	5.87
1800	31.0	2100	6.11
1500	**25.0**	**5500**	**5.40**

Note: PLF diameter = 4350 mm; q < 1135 W/m^2

Table 4.7-4: Angara A5/KVRB Performance Capability Into Super-Synchronous Orbits

ΔV_{SC} for Transfer to GSO (m/s)	Orbital Parameters			Payload Systems Mass (kg)
	i (°)	H_p (km)	H_a (km)	
1550	63	286	243,000	7870
1600	63	285	203,000	7940
1700	63	283	152,000	8080
1800	63	281	121,000	8220

Note: PLF diameter = 4350 mm; q < 1135 W/m^2

4.8 SC ENVIRONMENTAL PARAMETERS

4.8.1 Pre-Launch Processing

4.8.1.1 Mechanical Loads

4.8.1.1.1 Transportation Loads

The following modes of transportation of the SC are provided during processing for launch of the Angara A5 LV from the Plesetsk Cosmodrome:

- Transportation of the SC over a distance of ≈15 km from the Pero Airport to Building 171V, independently by rail, at speeds of ≤15 km/hr.
- Rail transportation of the SC with the AU over a distance of ≈40 km from Building 171V to Building 142-1 at speeds of up to 5 km/hr.
- Rail transportation of the SC as part of the integrated LV over a distance of ≈7 km at speeds of up to 5 km/hr.

The vibration regimes during transportation are specially formalized mechanical forces equivalent to the forces acting on the SC in the stage of transportation over the roadways of the Plesetsk Cosmodrome.

The actual conditions that apply to structural members that serve as attachment points for the SC are given for all transporting phases:

- For independent transportation - the attachment point of the container with SC to the transporter.
- For transportation as part of the integrated LV - the location of the interface between the SC and the adapter.

The following orientation of axes has been adopted for load specification:

- X-X axis runs in the direction of motion.
- Y-Y axis runs vertically (up-down).
- Z-Z axis is the side axis in the right-handed coordinate system.

Vibration loads in the direction of the three axes in the form of the values of the spectral densities of vibration accelerations for each mode of transport and as transient loads for independent transportation are presented in Figures 4.8.1.1.1-1 through 4.8.1.1.1-3 and in Tables 4.8.1.1.1-1 through 4.8.1.1.1-5.

The spectral densities are probabilistic in character and are specified with a probability of 0.997 that the specified levels will not be exceeded.

Figure 4.8.1.1.1-1: Acceleration Spectral Density - SC Rail Transport

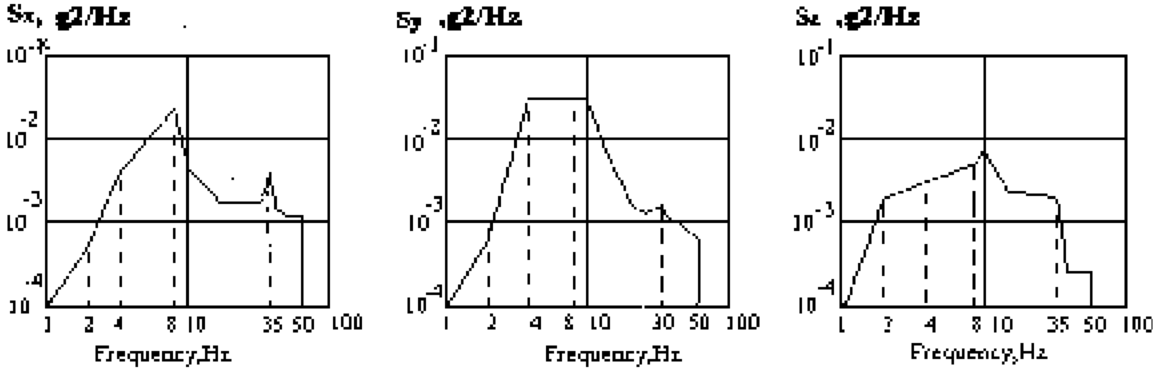


Figure 4.8.1.1.1-2: Acceleration Spectral Density - SC Motor Vehicle Transport

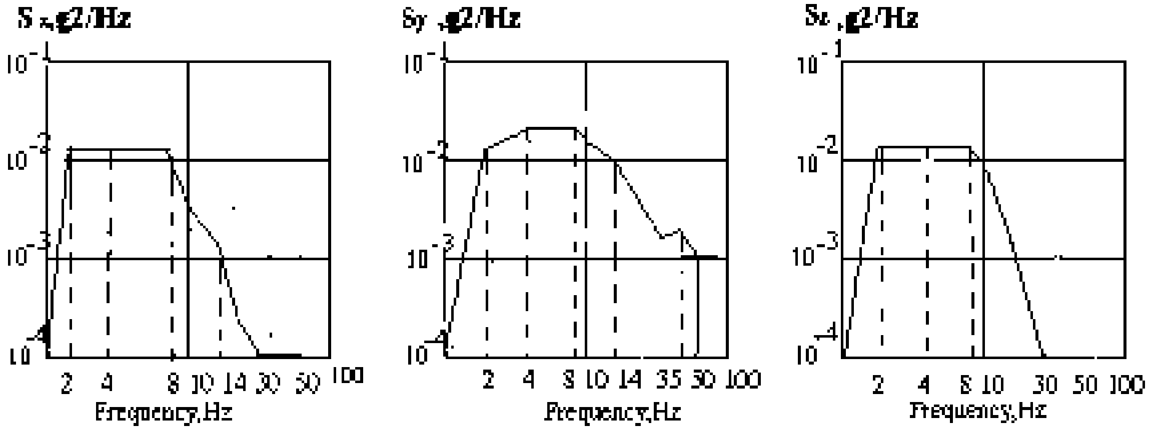


Figure 4.8.1.1.1-3: Power Spectra S (g^2/Hz) - SC Rail Transport

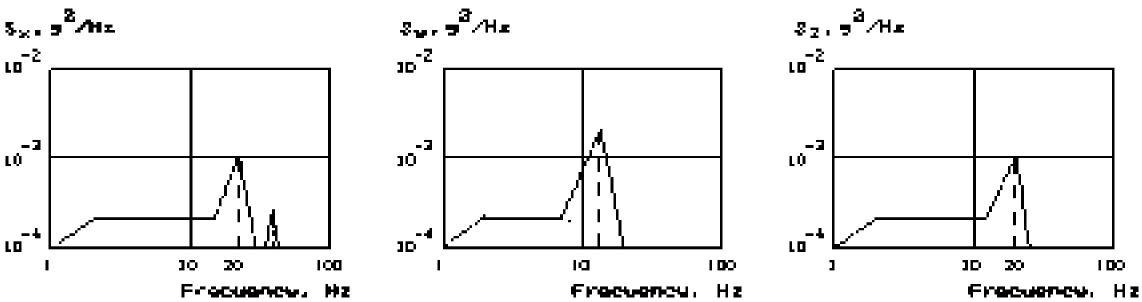


Table 4.8.1.1.1-1: Allowable Shock Loads on Container With SC

Mode of Transport	Direction of Axis	Amplitude (g)	Duration (ms)	Pulse Shape
Motor vehicle	±X	3.0	30	Sine half-wave
	±Y	2.0	30	Sine half-wave
	±Z	0.5	30	Sine half-wave
Rail	±X	2.5	30	Sine half-wave
	±Y	2.0	30	Sine half-wave
	±Z	0.5	30	Sine half-wave
Airplane	±X	3.0	100	Sine half-wave
	±Y	2.0	100	Sine half-wave
	±Z	1.7	100	Sine half-wave

Table 4.8.1.1.1-2: Maximum Random Vibration Loads on SC Container During Independent Rail Transport

Frequency (Hz)	Direction of Axis		
	X–X	Y–Y	Z–Z
	Spectral Density (10^{-4} g^2/Hz)		
2	7.5	7.5	15.0
4	57.5	330.0	33.0
8	200.0	320.0	66.0
10	60.0	320.0	80.0
14	28.0	83.3	33.0
20	27.5	15.0	32.0
25	27.5	12.0	31.0
30	2.75	15.0	30.0
35	50.0	11.0	18.5
40	18.0	10.0	3.7
45	12.5	8.3	3.7
50	12.5	7.5	3.7
Time (min)	420	420	420

Table 4.8.1.1.1-3: Transient Dynamic Loads - SC Rail Transport

Direction of Axis	Maximum Amplitude of Vibration Acceleration (g)	Pulse Length (ms)	Number of Loadings
X–X	1.5	0.16–0.035	100
Y–Y	1.1		
Z–Z	0.6		

Note: The pulse shape is triangular or a sinusoidal half-wave.

Table 4.8.1.1.1-4: Maximum Random Vibration Loads on SC Container During Independent Transportation by Motor Vehicle

Frequency (Hz)	Direction of Axis		
	X–X	Y–Y	Z–Z
	Spectral Density (10^{-3} g^2/Hz)		
2	15	15	15
4	15	30	15
8	15	30	15
10	6.0	20	10.0
14	1.4	10	1.5
20	0.42	5	0.5
25	0.18	3.2	0.18
30	0.1	2.5	0.1
35	0.1	2.8	0.1
40	0.1	1.4	0.1
45	0.1	1.2	0.1
50	0.1	1.0	0.1
Time (min)	10	10	10

Note: The values of the spectral densities are specified with a probability of 0.997 that they will not be exceeded.

Table 4.8.1.1.1-5: Loads on SC During LV Rail Transport

Frequency (Hz)	Direction of Axis		
	X–X	Y–Y	Z–Z
	Spectral Density (10^{-4} g^2/Hz)		
2	2.0	2.0	2.0
4	2.0	2.0	2.0
8	2.0	2.0	2.0
10	2.0	2.0	2.0
14	2.0	20.0	2.0
20	10.0	1.0	10.0
25	1.0	1.0	1.0
30	1.0	1.0	1.0
35	3.0	1.0	1.0
40	1.0	1.0	1.0
45	1.0	1.0	1.0
50	1.0	1.0	1.0
Time (min)	10	10	10

Note: The values of the spectral densities are specified with a probability of 0.997 that they will not be exceeded.

4.8.1.1.2 Linear Loads During Transportation at Technical Area and During Handling Operations

The quasi-linear loads during transportation and handling operations are presented in Table 4.8.1.1.2-1.

Table 4.8.1.1.2-1: Quasi-Static Loads During Transport

Phase of Operation	Level of vibration acceleration (m/s^2 (g))			Safety Factor
	X	Y	Z	
Independent transportation at technical area	±9.8 (±1.0)	9.81 ± 4.9 (1 ± 0.5)	±3.9 (±0.4)	1.5
Transportation as part of integrated LV	±4.9 (±0.5)	9.81 ± 1.8 (1 ± 0.2)	±0.98 (±0.1)	1.5
Handling operations	±1.8 (±0.2)	9.81 ± 2.94 (1 ± 0.3)	±1.8 (±0.2)	1.5

Notes:

1. For the transportation case, the axes are given in the coordinate system of the vehicle:

   X axis - in the direction of motion
   Y axis - directed vertically (up-down)
   Z axis - laterally in the right-handed coordinate system

2. For the "handling operations" case:

   Y axis - on vertical line of hoisting or lowering
   X axis - in any lateral direction

3. Accelerations act simultaneously in the directions of the X, Y, and Z axes.

4.8.1.2 Thermal Conditions of SC During Ground Operation

Ground thermal loads on the SC arise during transportation of the SC and during launch processing of the SC at the technical and launch areas.

Information on the environmental parameters around the SC in various phases of ground processing of the SC for launch and on the means used to maintain them are presented in Table 4.8.1.2-1.

Two air temperature sensors for the area of the SC and two temperature sensors for the adapter system (adapter) structure are installed to monitor the thermal state under the PLF. A sensor to measure relative humidity is provided to monitor air humidity in the area of the SC.

The technical data of the launch air thermal control system (ATCS) are presented in Table 4.8.1.2-2.

Table 4.8.1.2-1: Environmental Parameters Around SC

Processing Phase	Temperature (˚C)	Humidity (%)	Means Used to Maintain
Air transportation to Cosmodrome	Meets the conditions for transportation in an unsealed cabin		Container
Motor vehicle transportation to processing complex	10-30		Container
Transportation of SC as part of integrated LV to launch complex	10-30	30-60	Thermal control unit
In SC processing and filling area	15-25	30-60	Technical systems of structures
In area of integration with upper stage and LV	15-25	30-60	Technical systems of structures
Erection at launch complex	10-30	30-60	No active thermal control during 0.5 hr until ground air thermal control system is brought up
Processing at launch complex	13-27	≤60	Air thermal control system
Processing at launch complex following transporter/erector removal	10-30	30-60	Air supply through cable and filling tower (flow is up to 2000 m^3/hr)
Launch abort	5-30	≤60	No active thermal control during 0.5 hr until thermal control unit is brought up

Table 4.8.1.2-2: Technical Data on Launch Air Thermal Control System

Technical Data	Value
Temperature of supplied air	10-40°C
Accuracy of temperature maintenance at system outlet	± 2°C
Relative air humidity	≤ 60%
Air flow	5000-13,000 m^3/hr
Purity of supplied air, class per Standard FS 209	100,000

The air temperature under the PLF is regulated by changing the airflow and temperature.

Thermal control of the AU from the ATCS is performed until the transporter/erector is removed. After the transporter/erector is removed, the thermal conditions of the SC up to the lift-off switch are maintained by air supply to the AU at a flow rate of up to 2000 m^3/hr via a pipe laid on the cable and filling tower.

In case of launch abort, while propellants are being drained and LV is removed from the launcher, thermal control of the ascent unit is performed from the cable and filling tower (up until the time of de-mating of the connectors before the cable and filling tower is retracted). After the LV is transferred to the horizontal position on the transporter/erector, the mobile thermal control unit is connected. For ≈0.5 hr there is no active thermal control from the time air supply through the cable and filling tower is halted until the thermal control unit is connected.

Furthermore, additional air supply is provided from the air thermal control system via a separate line laid directly to the SC area, with the following parameters:

- Temperature of supplied air: 10-16°C
- Relative humidity: ≤60%
- Air flow: up to 1000 m^3/hr
- Air pressure: 0.15 kgf/cm^2

The main characteristics of the thermal control unit are presented in Table 4.8.1.2-3.

Table 4.8.1.2-3: Characteristics of Thermal Control Unit

Parameter	Value
Temperature of supplied air	10-30°C
Minimum increment of temperature setting	2°C
Accuracy of temperature maintenance	±2°C
Relative humidity	30-60%
Air flow	≤8000 m^3/hr
Air pressure	350 mm H_2O

4.8.1.3 Cleanliness

AU components (the upper stage, PLF, and adapter system) are transported from the manufacturer in a packaged, shrouded form.

The purity of the air in the SC processing and filling areas, the AU assembly area, and the final cleaning hall for the SC, upper stage, PLF, and adapter system is assured through multi-stage filtering of the supplied air and a pressure differential between the air inside the enclosed area [and the outside].

The specified cleanliness level is checked with an automated monitoring system every 10 minutes. Air purity must correspond to class R 8 per GOST R 50766-95 with parameters given in Table 4.8.1.3-1.

Final cleaning and inspection of AU components that come into contact with the SC environment consist in processing with an industrial vacuum cleaner and wiping with clean coarse calico filter cloth moistened with ethyl alcohol, per GOST 18300-87. The surface is inspected by sampling using synthetic membrane filters. The surface cleanness must correspond to level 600 with parameters given in Table 4.8.1.3-2.

During transportation of the SC as part of the AU and LV, the SC receives thermal control from the railroad thermal control unit. The specified air-cleanliness level is attained and maintained by means of highly effective air filters (HEPA) with a mesh size of 0.5 μm, and must comply with the parameters given in Table 4.8.1.3-3.

The purity of the air used for thermal control is checked when the air ducts are connected, with aerosol particle counters mounted at the inlet to the thermal control railcar.

When the AU is mated to the LV, the cleanliness of the SC is assured by purging the PLF with clean air from the thermal control system.

While the SC is at the launch complex, its cleanliness is assured by using a dust-proof, moisture-proof PLF and supplying conditioned air under the PLF with gage pressure from the launch ATCS. The cleanness of the air supplied must meet the values given in Table 4.8.1.3-3.

Table 4.8.1.3-1: Class R 8 Cleanliness Parameters in SC Processing And Filling Areas

Maximum Allowable Counted Particle Concentration (Particles Per Liter) With a Size Equal to or Greater Than (μm)	
0.5	5.0
3500	25

Table 4.8.1.3-2: Level 600 Cleanliness Parameters for Ascent Unit

Particle Size (μm)	Number of Particles Per Square Meter
>100	30,139
>250	753
>500	32
600	10

Table 4.8.1.3-3: Air Cleanliness Parameters For SC Transport

Maximum Allowable Counted Particle Concentration (Particles Per Liter) With a Size Equal to or Greater Than (μm)	
0.5	5.0
3000	20

4.8.1.4 Electromagnetic Compatibility

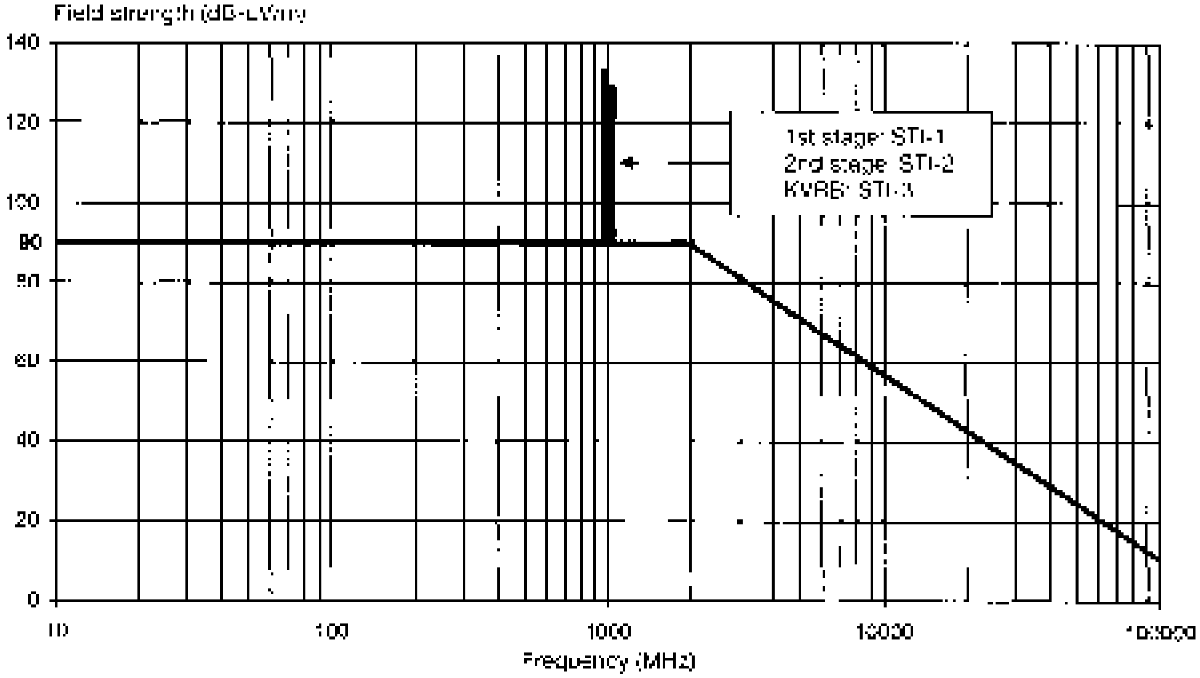
4.8.1.4.1 General Requirements

An electromagnetic compatibility analysis of the LV and SC is performed for every launch. The Customer must submit data on SC radiation during processing of the SC at the technical complex, during ground operations at launch, and in flight up until separation from the LV. It also must provide data on the maximum possible irradiation of the SC with radio frequency emissions.

4.8.1.4.2 LV Electromagnetic Radiation/Electromagnetic Compatibility

The electrical field strengths generated by the Angara A5 LV and launch equipment in the plane of the LV/SC interface at a distance of 1 m from the outside surface of the SC are presented in Figure 4.8.1.4.2-1.

Figure 4.8.1.4.2-1: Electrical Field Strengths Generated By Angara A5/KVRB and GSE



STI-1: Skut-174 (1042.5 MHz); Skut-134 (1026.5 MHz); Skut-074 (1002.5 MHz); Skut-034 (986 MHz); and Skut-014 (978 MHz).
STI-2: Skut-094 (1010.5 MHz).
STI-3: Pirit (1018.5 MHz, 1020.5 MHz).
(STI –telemetry measurement system)

4.8.2 Flight Environment

4.8.2.1 Mechanical Loads

Mechanical loads are given for the plane of the interface between the SC and the adapter system with 1194 mm diameter and include the values of the linear loads, as well as the parameters of vibration, vibration and shock, and transient dynamic loads and acoustic pressure on the injection and independent phases of flight of the upper stage.

The vibration loads are given in two forms:

1. Harmonic vibration
2. Random vibration

The following orientation of axes is assumed:

- X - longitudinal axis of SC
- Y - lateral axis of SC (plane I-III)
- Z - lateral axis of SC (plane II-IV)

The loads may be revised on the basis of additional calculations, laboratory/bench development, flight and structural tests, and full-scale operation.

4.8.2.1.1 Vibration Loading

Vibration loads that act under steady-state conditions in flight in the direction of the three axes are presented in Table 4.8.2.1.1-1 in the form of harmonic vibration, and in Table 4.8.2.1.1-2 in the form of the spectral density distribution of random vibration.

The transient non-stationary dynamic loads in flight under transient operating conditions of the propulsion system are presented in Table 4.8.2.1.1-3. These conditions are specified for functional tests of any attached equipment.

Table 4.8.2.1.1-1 Mechanical Loads - Harmonic Vibration

Loading Case	Frequency Range (Hz)	Vibration Acceleration ($m\text{-}s^{-2}$ (g)		Action Time (s)
Operation of LV first stage	1.5-50	9.81-29.43	(1-3)	330
	50-600	29.43-98.1	(3-10)	
	600-2000	98.1	(10)	
Operation of LV second stage	1.5-50	9.81-29.43	(1-3)	425
	50-600	29.43-98.1	(3-10)	
	600-2000	98.1-117.72	(10-12)	
KVRB independent flight	1.5-50	1.18-16.7	(0.12-1.7)	820
	50-600	16.7-82.5	(1.7-8.4)	
	600-2000	82.5-117.72	(8.4-12)	

Note: The vibration loads vary linearly between the indicated frequencies.

Table 4.8.2.1.1-2 Mechanical loads - Random vibration

Loading Case	Frequency (Hz)							Action Time (s)
	20	50	100	200	500	1000	2000	
	Spectral Density of Vibration Acceleration ($m^2\ s^{-4}$/Hz (g^2/Hz))							
Operation of LV first stage	6.549 (0.068)	7.7 (0.08)	5.54 (0.058)	5.13 (0.053)	6.47 (0.067)	4.28 (0.044)	2.14 (0.022)	330
Operation of LV second stage	6.549 (0.068)	7.7 (0.08)	5.54 (0.058)	5.13 (0.053)	6.47 (0.067)	4.806 (0.050)	3.08 (0.032)	425
KVRB independent flight	3.08 (0.032)	2.47 (0.026)	2.67 (0.028)	7.95 (0.083)	5.26 (0.055)	6.15 (0.064)	3.08 (0.032)	820

Notes:

1. The change in spectral densities between the indicated frequencies is linear.

2. In the frequency range up to 20 Hz, the conditions of vibration loading are represented as harmonic vibration (see Table 4.8.2.1.1-1).

Table 4.8.2.1.1-3: Transient Non-Stationary Dynamic Loads in Flight

Frequency Range (Hz)	Maximum Amplitude of Vibration Acceleration n_{max} (m-s $^{-2}$ (g))	Duration of Process (s)	Number of Loadings
10-30	$n_x^{max} = 58.86$ (6)	2.5-0.8	4
1.5-10	$n_{y,z}^{max} = 14.7$ (1.5)	6.0-2.0	2

Notes:

1. The qualification coefficient is 1.5.
2. The maximum load lasts no more than 2-3 periods.
3. By the duration of the process is meant the time over which the load rises and falls from n_{max} to $0.1n_{max}$.
4. The duration of the process is linearly dependent on the frequency (in inverse proportion).

4.8.2.1.2 Vibration and Shock Loading

The vibration and shock loads in the direction of the three axes upon separation of the KVRB from the LV are presented in the form of shock spectrum values in Table 4.8.2.1.2-1.

There are two shocks. The vibration and shock loads upon jettisoning of the PLF in the direction of the three axes are presented in the form of shock spectrum values in Table 4.8.2.1.2-2.

There are five shocks. The vibration and shock loads upon separation of the SC (preliminary values) in the directions of the three axes are presented in the form of the shock spectrum values in Table 4.8.2.1.2-3.

The values of the shock spectrum and the number of shocks are revised during the design of the adapter system and separation hardware for the SC.

4.8.2.1.3 Linear Loads

The linear loads in flight in the directions of the three axes (operational values) are presented in Table 4.8.2.1.3-1.

The linear loads of independent flight of the upper stage in the directions of the three axes (operational values) are presented in Table 4.8.2.1.3-2.

Table 4.8.2.1.2-1: Shock Loads at Stage Separation

Frequency Sub-Range (Hz)					
35-50	50-100	100-200	200-500	500-1000	1000-2000
Value of Shock Spectrum (m-s^{-2} (g))					
-	-	29.4-78.5 (3-8)	78.5-343 (8-35)	343-981 (35-100)	981 (100)

Table 4.8.2.1.2-2: Shock Loads at PLF Jettison

Frequency Sub-Range (Hz)					
35-50	50-100	100-200	200-500	500-1000	1000-2000
Value of Shock Spectrum (m-s^{-2} (g))					
-	-	29.4-78.5 (3-8)	78.5-343 (8-35)	343-981 (35-100)	981 (100)

Table 4.8.2.1.2-3: Shock Loads at SC Separation

Frequency Sub-Range (Hz)					
35-50	50-100	100-200	200-500	500-1000	1000-2000
Value of Shock Spectrum (m-s^{-2} (g))					
245-490 (25-50)	490-1470 (150-400)	1470-3930 (150-400)	3930-17,200 (400-1750)	17,200-49,000 (1750-5000)	49,000 (5000)

Table 4.8.2.1.3-1: Quasi-Static Loads in Flight

n_x^{op} **(m-s^{-2} (g))**	n_y^{op} **(m-s^{-2} (g))**	n_z^{op} **(m-s^{-2} (g))**	**f**
49.05 (5.0)	±14.72 (±1.5)	±14.72 (±1.5)	1.3

Note: The quantity *f* is the safety factor.

Table 4.8.2.1.3-2: Quasi-Static Loads of Upper Stage

n_x^{op} **(m-s^{-2} (g))**	n_y^{op} **(m-s^{-2} (g))**	n_z^{op} **(m-s^{-2} (g))**	**f**
9.81 (1.0)	±3.43 (±0.35)	±3.43 (±0.35)	1.3

Note: The quantity *f* is the safety factor.

4.8.2.1.4 Operational Loads at the SC Center of Gravity During Flight of the A5 LV

The maximum (static and dynamic) operational loads on the SC at launch and during flight of the Angara A5 LV + AU with KVRB are presented in Table 4.8.2.1.4-1. Transverse loads may act in any direction perpendicular to the longitudinal axis of the LV.

The quasi-static load n_x^{op} is the sum of the static load n_{x-st}^{op} and the dynamic load n_{x-dy}^{op}: $n_x^{op} = n_{x-st}^{op} \pm n_{x-dy}^{op}$.

Table 4.8.2.1.4-1: Maximum Flight Loads on the SC

Loading Case	Safety Factor f	Longitudinal Loads (n_x^{op})		Transverse Loads $n_{y(z)}^{op}$
		Static	Dynamic	Quasi-Static
Launch	1.3	1.29	±1.29	±1.5
Flight at $q_{\max}$	1.3	1.5	-	±0.6
Flight at $n_{x\max}$ with side modules	1.3	4.5	±0.45	±0.6
Separation of side modules	1.3	1.5	±0.3	±1.2
Flight at $n_{\max}$ without side modules	1.3	2.7	±0.27	±0.9
Separation of 1st and 2nd stages	1.3	0.1	±2.7	±0.7
Flight of 2nd stage	1.3	1.05	-	±0.16
Flight of KVRB	1.3	1	-	±0.35

4.8.2.1.5 Acoustic Loads

The acoustic loads under the PLF do not exceed the values presented in Figure 4.8.2.1.5-1 and Table 4.8.2.1.5-1.

4.8.2.2 Thermal Conditions

During flight, up until the PLF is jettisoned, the SC is in radiative heat transfer with the inside surface of the PLF. The allowable temperature level of the PLF structure is maintained by application of a thermal protective material onto the PLF. A thermal insulation material lined with a film with low radiant emissivity ($\varepsilon < 0.1$) is mounted on the inside surface of the PLF. The value of the maximum radiant heat flux from the inside surface of the PLF to the SC will not exceed 250 W/m^2 from the time of launch until the PLF separates. Based on a separate requirement by the SC developer, the level of radiant heat flux to the SC can be lowered to 160-180 W/m^2.

For the injection trajectory of the LV with early PLF jettisoning, the maximum value of the aerodynamic heat flux onto an area measuring 1 m × 1 m perpendicular to the velocity vector will not exceed 10,000 W/m^2 after jettisoning of the PLF.

For the injection trajectory of the LV with late jettisoning of the PLF, the maximum value of the free molecular heat flux onto an area perpendicular to the velocity vector will not exceed 1135 W/m^2 after jettisoning of the PLF.

4.8.2.3 Electromagnetic Compatibility

The characteristics of the A5 LV telemetry system are presented in Table 4.8.2.3-1.

The electrical field strengths generated by the Angara A5 LV in flight are presented in Figure 4.8.2.3-1.

4.8.2.4 Pressure in Payload Compartment

On the LV ascent to the time of jettisoning of the PLF, the payload compartment is drained by opening the drain ports. In absolute value, the maximum rate of pressure drop does not exceed $dP/dt \leq 5$ kPa/s.

Figure 4.8.2.1.5-1: Acoustic Loads in SC Area

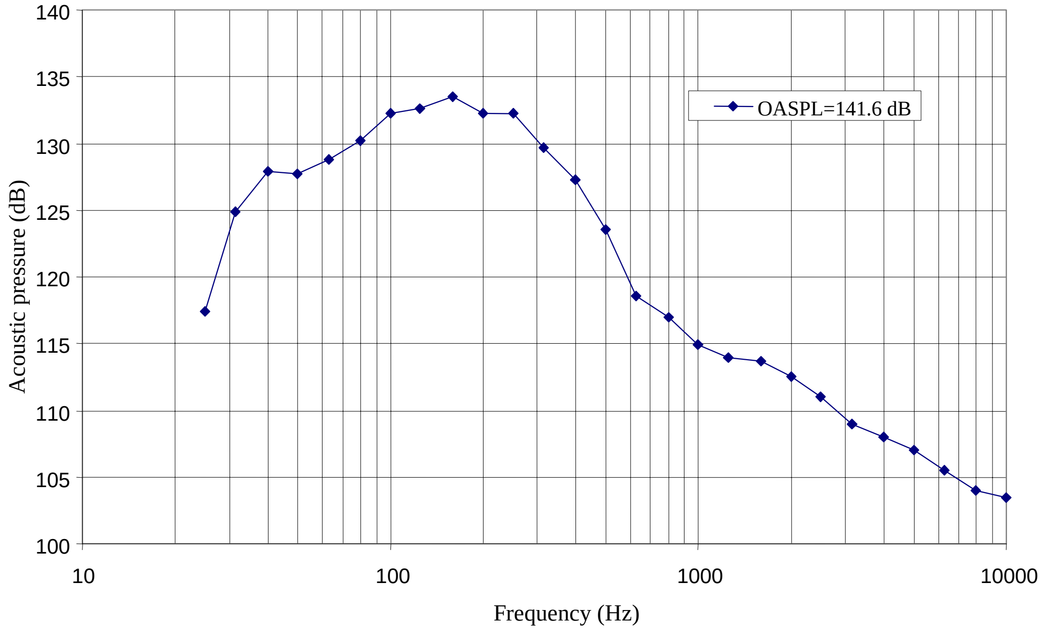


Table 4.8.2.1.5-1: Angara LV Acoustic Loads in SC Area

Structural Zone	Center Frequency of 1/3-Octave Frequency Band (Hz)	SPL (dB)	Action Time (s)
Under PLF in SC mounting area	25	117.4	60
	31.5	124.9	
	40	127.9	
	50	127.7	
	63	128.8	
	80	130.2	
	100	132.3	
	125	132.6	
	160	133.5	
	200	132.3	
	250	132.3	
	315	129.7	
	400	127.3	
	500	123.6	
	630	118.6	
	800	117.0	
	1000	114.9	
	1250	114.0	
	1600	113.7	
	2000	112.5	
	2500	111.0	
	3150	109.0	
	4000	108.0	
	5000	107.0	
	6300	105.5	
	8000	104.0	
	10,000	103.5	
	OASPL (dB)	141.6	

Note:

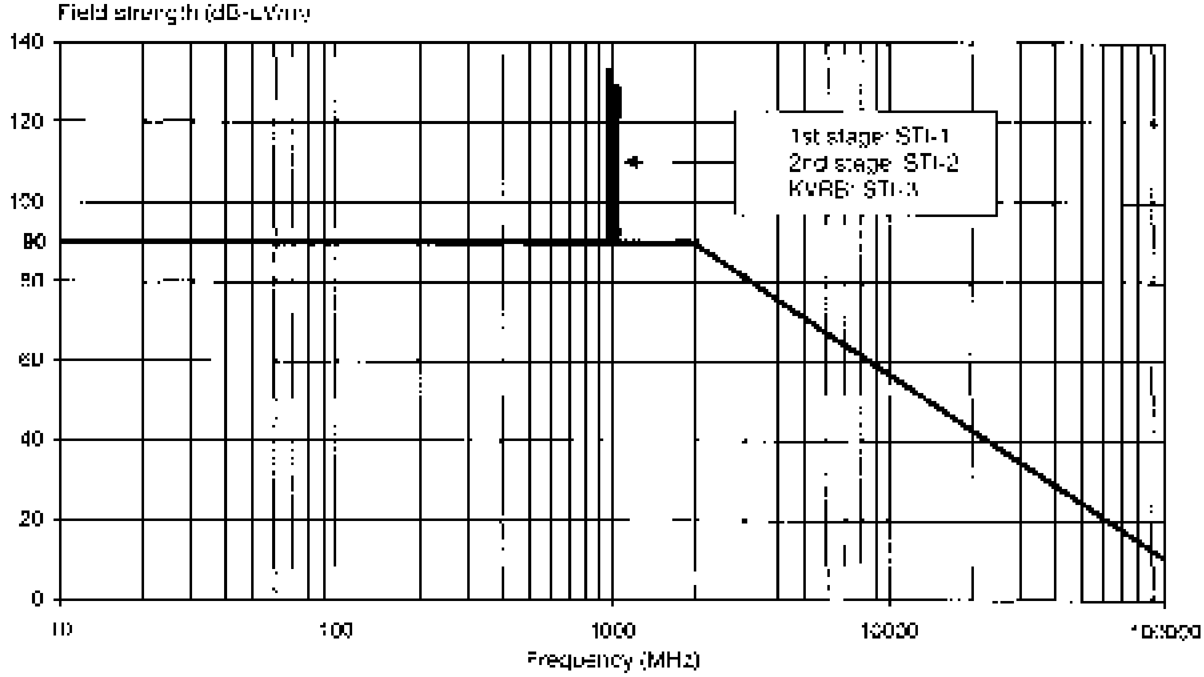
SPL - sound pressure level

OASPL - overall sound pressure level

Table 4.8.2.3-1. Angara A5 LV Telemetry System Characteristics

Class	Stage	Designation	System	Frequency
Angara A5	1	STI-1	Skut-174	1042.5
			Skut-134	1026.5
			Skut-074	1002.5
			Skut-034	986
			Skut-014	978
	2	STI-2	Skut-094	1010.5
	Upper stage	STI-3	Pirit	1018.5
				1020.5

Figure 4.8.2.3-1: Electrical Field Strengths Generated by Angara A5/KVRB in Flight



STI-1: Skut-174 (1042.5 MHz); Skut-134 (1026.5 MHz); Skut-074 (1002.5 MHz); Skut-034 (986 MHz); and Skut-014 (978 MHz).

STI-2: Skut-094 (1010.5 MHz).

STI-3: Pirit (1018.5 MHz, 1020.5 MHz).

STI - telemetry measurement system

4.9 SPACECRAFT INTERFACES

4.9.1 Mechanical Interface

4.9.1.1 Separation System for SC With Adapter System

The following separation systems components are used to separate the SC from the LV adapter system:

- Separation assembly
- Spring pushers
- Electrical umbilicals
- Bonding elements (two each)
- Pneumatic umbilical

The ring-type separation assembly provides, until the time of separation, a structural mechanical link between parts that are to be separated. The assembly comprises a shroud that spans the outside conical surfaces of the SC and adapter system rings that are to be separated. The structural mechanical link is separated upon an electrical command received from the KVRB control system. On this command, the shroud is separated into two arcs by two diameter-spanning pyro mechanical assemblies (pyro bolt cutters). The arcs are retracted to the periphery and secured in the retracted position to prevent their return to the center by a multi-sectional spring unit. The electrical umbilicals of the bonding elements and pneumatic connector are separated by the motion of the parts being separated.

The separation of the aforementioned links is accompanied by the conveyance to the parts being separated of a relative longitudinal velocity of ~0.6 m/s by the spring pushers. The conveyance of linear velocity may be accompanied by transverse stabilization spinning of the SC (by the same spring pushers) with an angular velocity of no more than ~3°/s. Longitudinal stabilization spinning of the SC is possible by using jet assists from the upper stage.

Depending on the SC design, it is possible to use SC separation hardware developed by KhSC, off-the-shelf hardware, or hardware furnished by the SC manufacturer.

Up until separation, the separation system for the structural link can convey either dispersed or concentrated forces between the SC and adapter system.

The functioning of the separation system operating between the SC and the adapter system is monitored by circuitry. The use of (two) contact sensors is also possible.

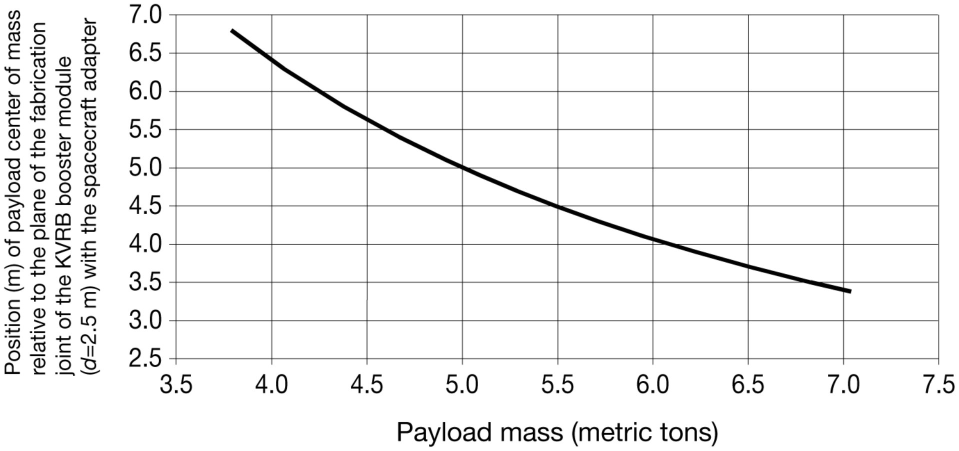
4.9.1.2 Allowable Payload Center of Mass

It is required by the need to ensure the strength of the upper stage, that the position of the center of mass of the payload (SC + adapter system) along the longitudinal axis did not exceed the allowable position shown in Figure 4.9.1.2-1. The position of the center of mass is determined from the plane of the interface between the adapter system and the upper stage (at the 2500-mm diameter). Figure 4.9.1.2-1 shows the allowable SC mass and c.g. locations for the KVRB upper stage.

To ensure the effectiveness of the upper stage's controls in the roll channel, the maximum allowable lateral positions of SC being injected relative to the Y and Z axes of the upper stage must not exceed ±25 mm.

The possibility of expanding the allowable lateral positions of the SC may be subject to additional scrutiny with consideration for the specific flight program.

Figure 4.9.1.2-1: Allowable SC Mass and CG Location



4.9.1.3 Static Electricity Protection

In all stages of the functioning of the Angara LV, electrical charge builds up on the LV surface as a result of the following physical mechanisms: the operation of the engines; the operation of o-board equipment; interaction with gas and solid particles during passage through dense layers of the atmosphere; interaction with space plasma; the action of high energy electron and ion fluxes at high altitudes, especially in circumpolar regions; exposure to solar electromagnetic radiation; and so forth.

The buildup of electrical charge on the surface of the Angara LV is a source of electrical charges of different kinds, accompanied by the generation of impulsive currents and electromagnetic fields that act on electronic components and that can cause breakdowns and disruptions in the operation of on-board systems.

The passive protection method is used on the Angara LV to prevent differential charge buildup, that is, a potential difference between different sections of the LV surface, and thereby to prevent the occurrence of discharge processes. The means used in the passive method are bonding, the creation of conductive surfaces and their connection to a metal structure, and the grounding of LV components and of the LV as a whole during manufacture, transportation, and preparatory work and at launch.

Bonding and grounding are performed to meet the requirements of GOST 19005-81. The contact resistance at bonding points does not exceed 2 mohm.

The Angara LV is attached to the SC by two non-detachable jumpers between the upper stage and the adapter system and by two detachable straps, or by direct surface contact between the adapter system and the SC.

In view of the use of cryogenic fuel by the KVRB, which has an ignition energy of 0.19×10^{-4} J, the structure of the Angara LV has an electrostatically spark proof design per GOST 12.1.018-93. A continuous electrically conductive coating with a volume resistivity of no more than 10^5 ohm-m is applied to the outside dielectric surfaces of the Angara LV, followed by connection of this coating to the common "electrical mass" of the LV.

The control system of the Angara LV is made resistant to electrostatic discharges. The noise immunity of electronic equipment with respect to static electrical discharges is checked separately and with the equipment installed on the LV. The external on-board cable network is shielded.

Zond 3M-Zaryad M measurement systems are mounted on the first and second stages of the LV, on the upper stage, and on the PLF to check the level of electrostatic and electromagnetic fields.

At the launch complex, the SC is grounded through the metal structure of the Angara LV.

4.9.2 Electrical Interface

4.9.2.1 Layout of LV Umbilical Cables For Interface Between the GSE and SC

Umbilical cables are used for servicing the SC (X1-X4) at the technical complex and launch complex.

A diagram showing the layout of the LV cables is presented in Figure 4.9.2.1-1. Electrical connectors X1-X4 have 50 contacts each. Table 4.9.2.1-1 shows the umbilical cables electrical connecting lines.

In all there are 150 umbilical electrical connecting lines for servicing of on-board equipment of the SC as part of the A5 LV with the KVRB. Of these:

- 71 are unshielded conductors;
- 19 (e) are shielded conductors;
- 52 (26 pairs of 2Ze) are shielded twisted conductor pairs;
- six (2 groups of 3Ze) are three twisted conductors in a common shield; and
- two shields (body).

In all there are 150 cable circuits. Two connectors (X4 and C4) are provided in the design to lay backup circuits (50 circuits), if needed. The umbilical cable electrical circuits have the following characteristics:

- $I_{min} = 1\ \mu A$ for $U_{min} = 1$ mV for one contact circuit;
- $I_{op} = 1.5$ A for each conductor;
- $I_{max} = 225$ A maximum current load on umbilical cable for 1000 hr; and
- $U_{max} = 120$ V (on SC umbilicals) with consideration for voltage peaks in transients.

The cross section of all umbilical connecting lines is $S = 0.5\ mm^2$. All umbilical connecting lines are galvanically isolated from the LV structure.

Electrical connectors X2, C2, and C4 are of type 2RMD45B50G8A1.

X1, C1, and C3 are of type 2RM42B50G2A1.

X3 is of type 2RM42B50Sh2A1.

X4 is of type 2RMD45B50Sh8A1.

For protection from interference and static electricity, the cables are protected with shielding and braiding, which is electrically connected to the LV structure to ensure continuity of shielding, and the inner shielding and braiding is electrically connected to the sleeve terminals of the electrical connectors.

The shields of the conductors are galvanically isolated from the external braiding of the cable and from the electrical connectors.

Figure 4.9.2.1-1: Diagram Showing Layout of the Umbilical Cables

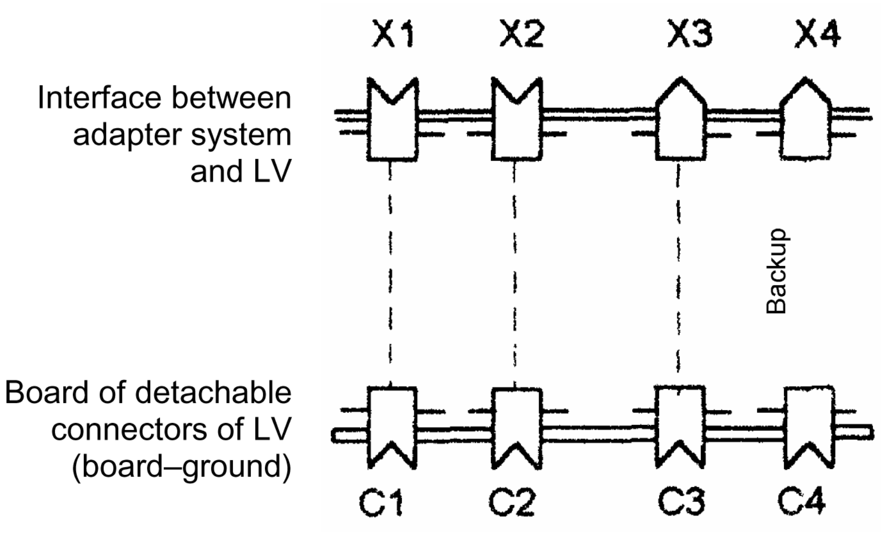


Table 4.9.2.1-1: Umbilical Cable Electrical Connecting Lines

X1, C1	Cross Section	Special Reqs.	X2, C2	Cross Section	Special Reqs.	X3, C3	Cross Section	Special Reqs.
Contact No.			Contact No.			Contact No.		
1, 2	0.5	2Ze	1, 2	0.5	2Ze	1	2 × 0.5	
3	0.5	body	3	0.5	body	2	0.5	
4, 5	0.5	2Ze	4, 5	0.5	2Ze	3	2 × 0.5	
6, 7	0.5	2Ze	6, 7	0.5	2Ze	4	2 × 0.5	
8, 9	0.5	2Ze	8, 9	0.5	2Ze	5	2 × 0.5	
10, 11	0.5	2Ze	10, 11	0.5	2Ze	6-12	0.5	
12, 13	0.5	2Ze	12, 13	0.5	2Ze	13	2 × 0.5	
14, 15	0.5	2Ze	14, 15	0.5	2Ze	14-37	0.5	
16, 17	0.5	2Ze	16, 17	0.5	2Ze	38, 39	2 × 0.5	
18, 19	0.5	2Ze	18, 19	0.5	2Ze	40-50	0.5	1
20, 21	0.5	2Ze	20, 21	0.5	2Ze			
22	0.5	e	22	0.5	e			
23	0.5	e	23	0.5	e			
24	0.5	e	24	0.5	e			
25	0.5	e	25	0.5	e			
26	0.5	e	26	0.5	e			
27	0.5	e	27	0.5	e			
28	0.5	e	28	0.5				
29	0.5	e	29	0.5				
30, 31	0.5	2Ze	30	0.5				
32, 33	0.5	2Ze	31	0.5				q
34	0.5		32, 33, 34	0.5	3Ze			
35	0.5		35, 36, 37	0.5	3Ze			
36	0.5		38	0.5	e			
37	0.5		39	0.5	e			
38	0.5		40	0.5	e			
39	0.5		41	0.5	e			
40	0.5		42, 43	0.5	2Ze			
41	0.5		44, 45	0.5	2Ze			
42	0.5		46, 47	0.5	2Ze			
43	0.5		48, 49	0.5	2Ze			
44	0.5		50	0.5	e			
45	0.5							
46	0.5							
47	0.5							
48	0.5							
49	0.5							
50	0.5							

Note: Connectors X1, X2, X3, C1, C2, and C3 are circuit designations. The markings of the connectors will be determined in the course of development.

4.9.2.2 Interface for Circuits of the Separation System Between the Adapter System and the SC

The electrical interface between the control system and the SC includes:

- Information exchange, and
- Control of the pyrotechnic devices used to separate the SC.

The pyrotechnic devices for SC separation are controlled through electrical connectors 1/PPS2 and 2/PPS2, which are mounted on the PPS1 board of connectors of the upper stage.

Connector 1/PPS2 uses socket OS 2RM42B50G8A1 (GEO.364.126 TU, bRO.364.045 TU), as does connector 2/PPS2.

The pinouts of electrical connector 1/PPS2 (first lines of the pyrotechnic cartridges) are presented in Table 4.9.2.2-1.

The pinouts of electrical connector 2/PPS2 (the second lines of the pyrotechnic cartridges) are presented in Table 4.9.2.2-2.

The control system of the KVRB makes it possible to perform simultaneous detonation (of up to 24 pyrotechnic devices) in groups: two groups of two pyrotechnic cartridges each, two groups of eight pyrotechnic cartridges each, one group of four pyrotechnic cartridges, and two groups of type PDO and DP4-2 pyrotechnic devices.

The 24 pyrotechnic cartridges are activated by two commands. The first activates the fire lines of the 24 pyrotechnic cartridges of a group, and the second activates the second pyro lines of 24 pyrotechnic cartridges. These two commands can be executed separately at an interval of at least 0.1 s.

4.9.2.3 Control-Command Interface

Information exchange between the control system and the SC occurs on the SC from the time of launch until separation of the SC.

Electrical connectors 3/PPS2 and 4/PPS2, which are mounted on the PPS2 board of connectors of the upper stage, are used for communications between the control system and the SC.

The 3/PPS2 uses the OS 2RM42B50Sh5V1 plug (GEO.364.126 TU, bRO364.045TU), as does the 4PPS2.

The pinouts of electrical connector 3/PPS2, the conditions of command generation, and the designations of the commands are presented in Table 4.9.2.3-1.

Table 4.9.2.2-1: Pinouts of Electrical Connector 1/PPS2

Pyrotechnic Device No.	Contacts		Group
	"+"	"–"	
1	1	27	A
2	2	28	A
3	3	29	B
4	4	30	B
5	6	31	C
6	7	32	C
7	8	33	C
8	9	34	C
9	10	35	D
10	12	36	D
11	13	37	D
12	14	38	D
13	15	39	D
14	16	40	D
15	17	41	D
16	18	42	D
17	19	43	E
18	20	44	E
19	21	45	E
20	22	46	E
21	23	47	E
22	24	48	E
23	25	49	E
24	26	50	E
KC	5	11	Strap on the SC side

Table 4.9.2.2-2: Pinouts of Electrical Connector 2/PPS2

Pyrotechnic Device No.	Contacts		Group
	"+"	"–"	
1	1	27	A
2	2	28	A
3	3	29	B
4	4	30	B
5	6	31	C
6	7	32	C
7	8	33	C
8	9	34	C
9	10	35	D
10	12	36	D
11	13	37	D
12	14	38	D
13	15	39	D
14	16	40	D
15	17	41	D
16	18	42	D
17	19	43	E
18	20	44	E
19	21	45	E
20	22	46	E
21	23	47	E
22	24	48	E
23	25	49	E
24	26	50	E
KC	5	12	Strap on the SC side

Table 4.9.2.3-1: Pinouts of Electrical Connector 3/PPS2

Contact Nos.	Designation of Command	Condition for Generation	Channel
26, 28, 27, 29, 5, 8	VM1	First firing of stabilization, orientation, and firing support system propulsion system (for settling of the propellants)	1 2 3
14, 16 15, 17 1, 3	VM2	First shut-off of main propulsion engine	1 2 3
18, 20, 19, 21, 2, 4	VM3	Any firing of stabilization, orientation, and firing support system propulsion system	1 2 3
30, 32 31, 33 7, 9	VM4	Any shut-off of main propulsion engine	1 2 3
40, 42 41, 43 34, 37	VM5	Last firing of stabilization, orientation, and firing support system propulsion system (for settling of propellants)	1 2 3
44, 46, 45, 47, 11, 13	VM6	Last shut-off of main propulsion engine	1 2 3
22, 23, 24, 25, 38, 49	AK1S	SC emergency	1 2 3
12, 35	KS	Monitoring of mating (strap on SC side)	1 2 3

Commands VM1-VM6 are output through three independent channels by closure of the dry contacts. The load current does not exceed 0.5 A for a voltage of no more than 36 V, or 0.1 A for a voltage of no more than 120 V_{eff} for each contact. The duration of command output is 0.2-0.9 s.

Command AK1S is output from the SC over three independent circuits by closure of the "dry" contacts. Its duration is at least 0.1 s. The load current does not exceed 0.5 A for a voltage of up to 34 V to each contact.

The pinouts of electrical connector 4/PPS2, the conditions of command generation, and the designations of the commands are presented in Table 4.9.2.3-2.

The "KP," "PK," "SGO," and "PKO" commands are output from the KVRB control system over three independent channels, with a voltage of 27 + 7 V relative to the common negative of the upper stage ("-" 27 V). The allowable current load on each contact does not exceed 0.5 A. The duration of the commands is at least 0.1 s.

The "RKA" and "RRB" commands are executed by breaking the straps when the SC separates from the upper stage. The current load on the straps does not exceed 0.5 A for a supply voltage of up to 34 V. The duration is at least 0.1 s.

Table 4.9.2.3-2: Pinouts of Electrical Connector 4/PPS2

Contact Nos.	Designation of Command	Condition for Generation	Channel
10, 31, 11, 32, 12, 33	AK1	LV and/or KVRB upper stage accident.	1 2 3
1 2 3	KP	Output upon receipt from LV control system.	1 2 3
16 17 18	SGO	Jettisoning of PLF. Output upon receipt from LV control system.	1 2 3
4 5 6	PK	Preliminary command to prepare for ascent unit separation. Output upon receipt from LV control system.	1 2 3
7 8 9	PKO	Preliminary command to prepare for SC separation. Output from KVRB upper stage control system.	1 2 3
13, 22, 14, 23, 15, 24	RKA 1	Separation from SC 1. Straps on SC side.	1 2 3
19, 22, 20, 23, 21, 24	RKA 2*	Separation from SC 2. Straps on SC side.	1 2 3
25, 28, 26, 29, 27, 30	RRB	Separation of SC from KVRB upper stage. Straps on KVRB upper stage side.	1 2 3
34, 35	KS	Straps on KVRB upper stage side.	

Contact Nos.	Designation of Command	Condition for Generation	Channel
46, 47, 48, 49, 50	"-" 27 V "-" 27 V "-" 27 V	Common negative of upper stage.	

* If a second SC is present.

4.9.3 Telemetry Interface

The on-board telemetry monitoring system of the Angara LV with the KVRB is implemented by using telemetry equipment installed on the KVRB (TA-1) and on the second stage booster (TA-2).

The TA-1 handles recording of low frequency parameters with a radio link capacity of 256 kbit/s at a range of up to 10,000 km and 32 kbit/s at a range of up to 37,000 km.

The TA-1 operates in direct transmission (NP), record (ZAP), and playback (VOSPR) modes. The TA-1 shuts off after the completion of the drifting away of the upper stage (1 hour after separation of the SC).

The capacity of the memory unit is 15.5 megabytes. The following have been allocated in the TA-1 equipment set for parameters measured on the SC and adapter system:

- 16 signal channels (eight for the SC and eight for the adapter system);
- 18 analog channels (11 for the SC and seven for the adapter system); and
- 14 temperature channels (two for the SC and 12 for the adapter system).

When the SC is injected into geostationary orbit, the following TA11 operating modes are implemented, in which the aforementioned parameters of the SC and adapter system are recorded:

- NP1: during flight of the LV/upper stage and during the upper stage first burn
- NP2: during coast phase of flight after the first burn of the upper stage
- ZAP3: during the second burn of the upper stage
- ZAP6: during the third burn of the upper stage
- NP5 and ZAP7: upon SC separation (coincident mode)

Table 4.9.3-1 presents for the TA-1 equipment the information characteristics for the recorded parameters of the SC and adapter system, specifically the operating modes, the output data rates of the measurement programs, number of channels for SC and adapter system parameters, and recording frequency.

With the consent of the SC manufacturer, it is possible to reallocate the channels assigned to the SC and adapter system.

In modes ZAP3, ZAP6, ZAP7, and NP5 for analog parameters, the number of channels assigned to the SC and adapter system can be traded off against the polling frequencies within the following overall data rates: 1.6 kbyte/s for ZAP3; 0.13 kbyte/s for ZAP6; 0.98 kbyte/s for ZAP7; and 1.0 kbyte/s for NP5.

Table 4.9.3-1: Information Characteristics of TA-1 Equipment for Recording the Parameters of the SC and Adapter System

Operating Modes	Data Rates of Measurement Programs (kbyte/s)	Data Rates of Parameters Allocated For SC and Adapter System (kbyte/s)	Number (N) and Frequency (F) of Recorded Parameters (No More Than)					
			Signal Parameters		Analog Parameters		Temperature Parameters	
			N (units)	F (Hz)	N (units)	F (Hz)	N (units)	F (Hz)
NP1	17.83	3.4	16	200	11 7	200 100	14	0.5
NP2	15.21	3.4	16	200	11 7	200 100	14	0.5
ZAP3	9.68	2.1	16	200	3 5 10	200 100 50	14	0.5
ZAP6	2.31	0.253	16	12.5	6 5 7	12.5 6.25 3.12	14	0.5
NP5	3.2	1.166	8	50	3 3 4	200 100 25	14	0.5
ZAP7	2.67	1.0	8	25	3 3 1 1	200 100 50 25	-	-
VOSPR	10.39; 1.6	*F* and *N* correspond to write modes						

When the SC is injected into other orbits (e.g., a GTO orbit), the information characteristics of TA-1 will be no worse than those given above.

The TA-1 equipment handles monitoring of SC separation; signals indicating that the SC has separated are generated by the separation sensors at the interface between the adapter system and the SC.

In addition to the channels indicated, the TA-1 equipment operating in NP1 mode has 30 channels allocated with a polling frequency of 0.5 Hz for measurements of PLF temperatures.

The TA-2 equipment handles the recording of both low and high frequency parameters with a radio link capacity of 640 kbit/s and is in operation until the time of separation of the upper stage from the second stage booster.

In the TA-2 equipment, three high frequency channels with a recording frequency of at least 8 kHz, one for acoustic pressure alone (up to 100 s of flight) and two for vibration, have been allocated for the adapter system. With the consent of the SC manufacturer, it is possible to redistribute these channels between the SC and the adapter system.

In addition to the indicated channels in the TA-2 equipment, the following have been allocated for the PLF:

- 30 channels each for analog and signal parameters with a polling frequency of 50 Hz; and
- 10 channels for high frequency parameters with a polling frequency of 8 kHz, of which seven are for acoustic pressure (up to 100 s of flight) and three for vibration.

5. INFRASTRUCTURE AND SERVICES AT PLESETSK COSMODROME

5.1 SC AND LAUNCH FACILITIES

All Angara LV configurations are carried out from the Plesetsk Cosmodrome, which is located about 800 km (500 miles) north-northeast of Moscow (62.7° north latitude, 40.3° east longitude). There are sizable seasonal fluctuations of temperature and climatic conditions in this zone, which has a continental climate. Table 5.1-1 provides the mean climatic data for this region.

The Angara launch complex is designed for reliable operation in this wide range of climatic conditions.

Table 5.1-1: Climatic Conditions in the Plesetsk Cosmodrome Zone

Mean winter air temperature	-28°C
Mean summer air temperature	23°C
Maximum rate of precipitation	0.04 mm/min
Mean annual precipitation	398 mm
Average monthly (June) integrated surface density of direct solar radiation flux (*S*)	816.6 W/m^2
Total radiation at ground surface in the absence of clouds (*Q*)	844.6 W/m^2

5.1.1 Plesetsk Cosmodrome Facilities Overview

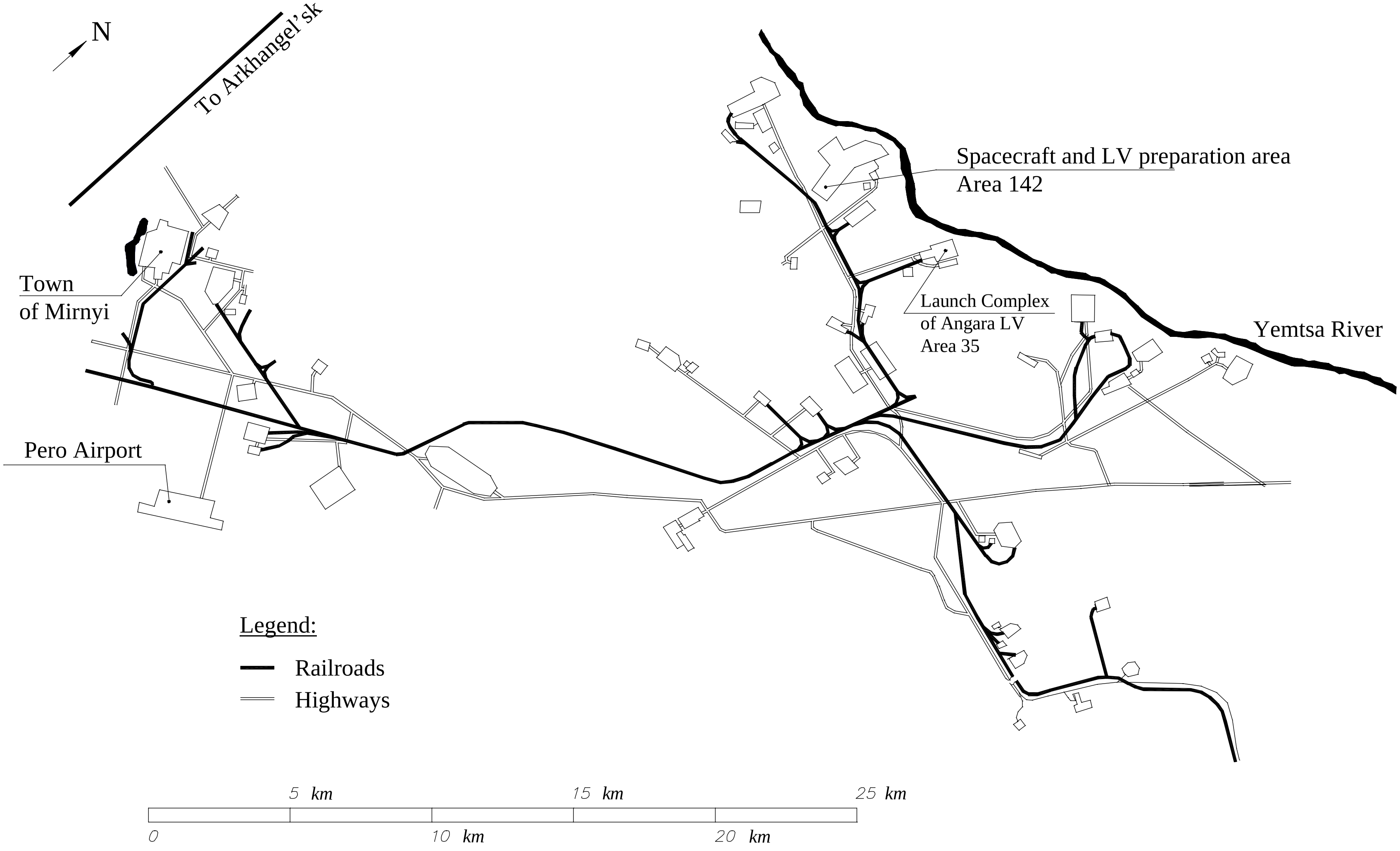
All basic infrastructures of the Cosmodrome's launch complexes are maintained in accordance with standard instructions of the Russian Space Force in regard to the efficient operation and safety of systems. A number of facilities used in launch campaigns for SC using the Angara LV will be upgraded or rebuilt in order to conduct the Customer's launch campaigns. The modernization of the launch complex for the Angara LV and the construction of new facilities for integrated processing of ascent units and their components are of fundamental importance.

The main infrastructure facilities at the Cosmodrome that are used for independent processing of the SC and joint processing of the SC, together with the upper stage and LV are:

- Pero Airport, which handles the arrival and departure of the SC and GSE;
- Area 142, which handles SC processing and filling, mating to the upper stage and encapsulation of the SC, and mating of the AU to the LV;
- Area 35 (launch complex), which handles SC launch; and
- Mirnyi, which provides living accommodations for personnel during the launch campaign.

Figure 5.1.1-1 shows the locations of the main facilities of the Plesetsk Cosmodrome that are used for SC processing.

Figure 5.1.1-1: Technical Areas Used During SC Processing



5.1.1.1 Pero Airport

Pero Airport is a complex of facilities with engineering structures, systems, and equipment that support the receiving, landing, servicing, parking, taxiing, and takeoff of AN-12, YaK-40, and AN-24 aircraft with a landing weight up to 51 metric tons. The approaches are open in both directions from the landing strip. The air situation at the airfield meets the requirements of flight operations manual. Communications with the crew are maintained until on-board systems are shut off after the airplane comes to a stop. The length of the landing strip is 2000 m, with 200-m stopways, and is 40 m wide with safety shoulders 20 m wide. The area is fitted with lighting towers to allow for night operations.

The airfield is to be renovated to allow for heavy airplanes to use the runway. As part of the upgrade, rail tracks will be laid from the airport directly to the payload processing facility.

The Pero Airport will be used to receive charter aircraft delivering SC and GSE, as well as charter runs carrying campaign personnel.

5.1.1.2 Payload Processing Area

The main facilities for processing the SC and assembly of the ascent units, including the Breeze M upper stage, the SC and the PLF, are located at Area 171V. Upper stages will undergo independent processing in the assembly and test building of the reconstructed facility 171V. At the same facility, horizontal assembly of the ascent units for the Federal Space Programs will also be carried out.

The high bay part of the new construction is necessary for vertical mating of the SC with booster modules, as well as for AU assembly.

The building for receiving, preparing and filling the SC is adjacent to the high bay and is also a new construction project. Creating a second work place for autonomous SC processing and filling is planned in the future.

Main facilities for Angara A3 LV processing are located at Area 142. LV assembly and checkout operations, as well as mating operations with ascent units, will be conducted in the assembly and test building of the reconstructed Building 142-1.

Area 171V facilities are located approximately 15 km from the Pero Airport, and Area 142-1 facilities are about 40 km from Area 171V.

5.1.1.3 Launch Complex

The universal launch complex is located at Area 35. The distance from the technical complex to the launch complex is about 7 km. The launch complex will be redesigned and updated to support launches of the Angara LV family.

5.1.1.4 Transportation Lines

All Cosmodrome facilities used in payload processing are connected to each other by 1524-mm gage railroad tracks and roadways.

5.1.1.5 Living Conditions

The Plesetsk Cosmodrome is located in picturesque northern terrain rich in forests and lakes. The climate is continental with a maximum summer temperature of 30°C and a minimum winter temperature of -40°C.

Living conditions are provides by hotels and multiplexes in the town of Mirnyi. The residential area is about 15 km from the Pero Airport and about 45 km from the payload processing area. Whatever vehicles are needed - a bus or minibuses - are provided to the Customer to carry its personnel to the work area for the duration of the launch campaign.

In addition to upgrading of residential quarters, steps are planned to improve the operation of public dining facilities and municipal infrastructure so that they better meet Customer requirements.

5.1.2 Facilities and Equipment for SC Processing and Launch

The facilities used for launch campaigns at the Plesetsk Cosmodrome are shown in Figure 5.1.2-1. These include the following:

- Pero Airport, for arrival and departure of the SC and GSE;
- Area 171V, for SC processing and filling, mating to the upper stage, and encapsulation;
- Building 142-1, for mating of the ascent unit to the LV; and
- Area 35 (launch complex), for Breeze M filling and SC launch.

5.1.2.1 SC and Personnel Arriving at Pero Airport

All personnel participating on launch campaigns, the GSE, and the SC are delivered to the Cosmodrome by air transport arriving at the Pero Airport.

After the SC and support equipment are unloaded, ground-handling equipment is used to mount the containers and pallets on a flatbed railcar. The process of unloading the aircraft and loading the railcar may take up to 8 hours. To maintain the specified thermal conditions in the SC transport container, a refrigerator car may be used or the internal thermal control equipment of the transport container may be activated. The cargo is delivered via the railroad 10 km from the airport to the SC processing facility (the SC and LV processing area; Area 142).

The following equipment can be provided at the airport:

- Forklifts
- Cranes
- Railcars and road vehicle transport

In addition to the Pero Airport, the modern airport at Arkhangel'sk, may be used. In this case, the SC can be delivered in 1 hour from the Arkhangel'sk Airport by MI-26T helicopter to the helipad near the technical complex and then to the SC processing facility by vehicle within 30 minutes.

5.1.2.2 SC Assembly and Test Building

This building houses all facilities needed for SC processing from the time of arrival of the AC until it is mated to the upper stage and encapsulated. The SC and GSE are delivered to the receiving hall, where the containers are cleaned. The receiving hall is an airlock. The SC container is transported by rail flatcar to the unloading hall, where the container with the SC and equipment are unloaded. Here too the container can be opened and the SC transferred to the handling dolly after the cleanliness conditions are stabilized following removal of the vehicles. Then the SC on the dolly is moved into the processing and filling hall. The SC remains in this hall throughout subsequent testing and filling operations. After being filled with propellant components, the SC is moved on the special handling dolly to the ascent unit assembly hall, where it is mated to the adapter system and upper stage and encapsulated. If necessary, the Customer may be provided with a transporter to move the SC into the processing and filling hall or to the ascent unit assembly hall, and also with an electrical forklift, a hydraulic dolly for moving equipment, and any needed maintenance facilities.

Figure 5.1.2.2-1 presents a general layout of all areas of this building that are used for SC processing.

5.1.2.2.1 Receiving Hall

The receiving hall is intended for preliminary cleaning of vehicles and equipment prior to movement into the unloading hall, and is an airlock.

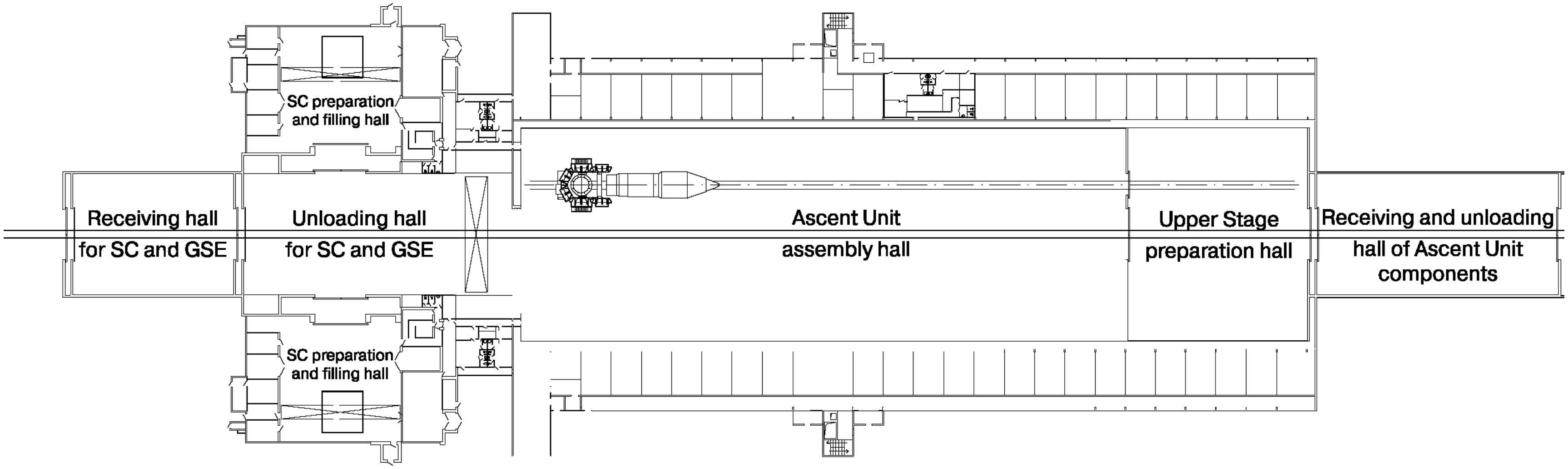
5.1.2.2.2 Unloading Hall

The unloading hall is an enclosed area with the following controlled environmental conditions.

Environmental Parameters	Values
Temperature	15-25°C
Relative humidity	35-60%
Dust content of air per Fed Std 209E, class no worse than	100,000

These conditions are assured when the gate to the receiving hall is closed after cleanliness conditions are stabilized.

Figure 5.1.2.2-1: General Layout of Processing Areas of Assembly and Test Building



The hall is intended for unloading of the container with the SC and GSE, for final cleaning thereof, for unloading of the SC from the container, and for mounting of the SC onto a transport dolly for transportation to the processing and filling hall.

The hall is equipped with a traveling crane with a capacity of 50 metric tons. There is an auxiliary hook with a capacity of 10 metric tons.

This hall has areas for storage of non-hazardous items, equipment, and materials for which a class 100,000 cleanroom is required.

Equipment intended to operate in the control room of the SC processing and filling hall is moved through a separate entrance directly into the control room.

5.1.2.2.3 SC Processing and Filling Hall

The processing and filling hall is an enclosed area with the following controlled environmental parameters.

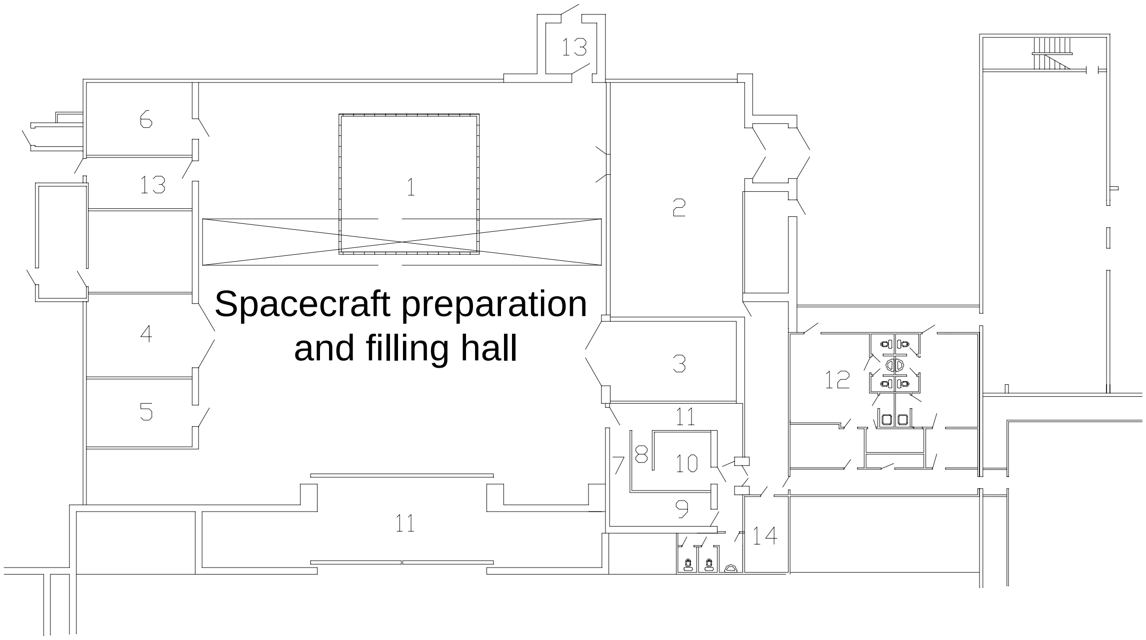
Environmental Parameters	Values
Temperature	15-25°C
Accuracy of temperature maintenance	±2°C
Relative humidity	35-60%
Dust content of air per Fed Std 209E, class no worse than	100,000

The hall, shown in Figure 5.1.2.2.3-1, is used to prepare the SC before encapsulation, including propellant filling and servicing of the SC pneumatic and hydraulic systems. Access to the processing and filling hall is effected through a gate from the unloading hall or through the decontamination center. A traveling crane with a capacity of 15 metric tons is provided.

The propellant filling area, measuring 8 × 8 m, is used for the operations of filling the SC with oxidizer and fuel. It is surrounded by a grated channel, which drains any spilled fuel or oxidizer into separate tanks for later recycling. The grate allows passage of wheeled dollies.

An anti-static covering is applied to the floor of the hall, which is rated for a load of 10 metric tons (3000 kgf/cm^2) on the load axis. The finishing of the hall contains no materials that could react with propellant components.

Figure 5.1.2.2.3-1: SC Processing and Filling Hall



1.	Propellant filling area
2.	Control room
3.	Oxidizer conditioning room
4.	Fuel conditioning room
5.	Fuel filling equipment neutralization room
6.	Oxidizer filling equipment neutralization room
7./8.	Showers for washing protective suits (SCAPE)
9./10.	Rooms for taking off protective suits (SCAPE)
11.	Airlocks
12.	Decontamination center
13.	Emergency exits
14.	Recreation room

The hall has emergency evacuation routes. It also has showers for washing in emergencies and fountains for rinsing the eyes. The shower fittings are connected to collection tanks for the corresponding liquid waste. Parking for first-aid vehicles and fire trucks is provided near the emergency evacuation routes. To isolate the hall from other enclosed areas while propellant component filling operations are under way, pressurization of special airlocks with clean air is provided.

The fuel conditioning room is used for thermal conditioning of the fuel (MMH, hydrazine) delivered for the campaign, prior to filling.

The oxidizer conditioning room is used for thermal conditioning of the oxidizer (e.g., MON3) delivered for the campaign, prior to filling.

In each of these rooms, it is possible to collect and remove spilled fuel and oxidizer, respectively. No materials that would react with the fuel or oxidizer are used in these rooms.

An anti-static covering is applied to the floor of the hall, which is rated for a load of 10 metric tons (3000 kgf/cm^2) on the load axis. The floor height is the same as in the processing and filling hall.

The room where equipment that has come into contact with fuel is neutralized is used to neutralize fuel loading equipment.

The room where equipment that has come into contact with oxidizer is neutralized is used to neutralize oxidizer loading equipment.

In each of these rooms, it is possible to collect and remove spilled fuel and oxidizer, respectively. No materials that would react with the fuel or oxidizer are used in these rooms.

The control room is used to observe and manage work on SC processing and filling in the hall.

A blast-proof observation window for observation of all propellants preparation and filling operations is provided between the control room and the hall. The wall between the hall and the control room is a welded, reinforced steel structure that ensures leak-tightness.

The floor of the control room and connected access corridors is designed to allow unhindered movement of wheeled dollies. Forklifts can be used to deliver equipment to the vestibule of the enclosed area, but they are not allowed in the control room itself. Temporary ramps are provided to facilitate the movement of cargo from the entry vestibule into the control room.

The following enclosed areas are provided in the area of the entrance and corridor:

- Street-level entrance
- A corridor
- Cloakroom
- Security passageway for the SC Customer with observation windows and a panel of security sensors
- Storage area for tools
- Restroom

Since these areas are used to perform shop-wide administrative functions, they have an environment typical of offices.

The decontamination center consists of several rooms, including separate men's and women's restrooms, dressing rooms, and showers, areas for storage and issuance of special clothing for the clean rooms, a room for storing and putting on individual protective gear, and a corridor with an air shower. From the dressing rooms there is a clear passage to either the ascent unit assembly hall or the SC processing and filling hall.

The pressurized airlock provides clear access between the air shower and the SC processing and filling hall. When propellant filling operations are under way, a slightly higher pressure is maintained in the airlock than in the hall in order to prevent the escape of fumes from the hall. Personnel wearing SCAPE suits use the airlock to travel into the rooms; the airlock and corridor leading to the air shower and dressing rooms can be used, if necessary, as an emergency escape route from the processing and filling hall.

The rooms where the SCAPE suits (for fuel and oxidizer) are removed are used to put on and take off individual protective gear for the purpose of conducting propellant component filling operations.

A gas monitoring system is provided in the SC processing and filling hall, in the thermal conditioning rooms for propellant components, and in the filling equipment neutralization rooms.

A refrigerator with a 1-m^3 freezer is provided for storage of consumables.

A limited number of pyrotechnic devices needed to meet the requirements of the launch campaign may be stored. The pyrotechnic devices allowed for storage must meet the following criteria.

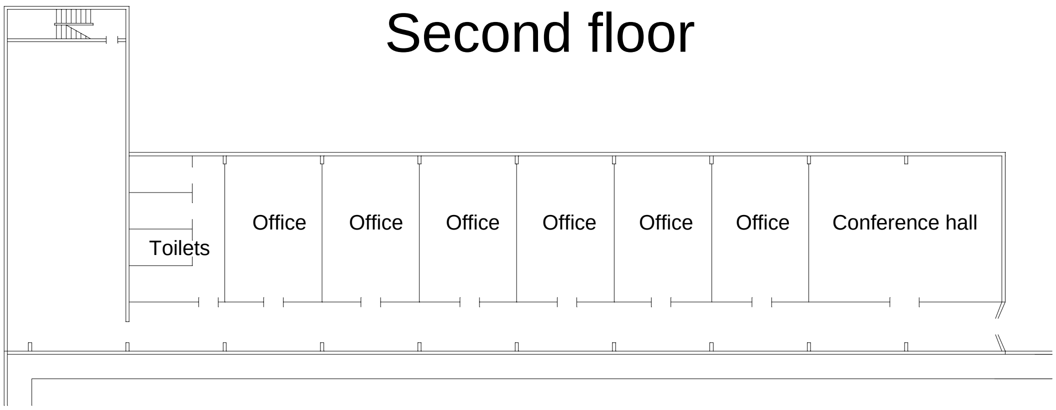
- In accordance with Russian Federation standards, a maximum (TNT equivalent) of 50 g may be stored, with a volume not to exceed 60 cm × 60 cm × 60 cm.
- Only non-detonating explosives may be stored, and each device must be individually packaged in a cargo container approved by the vendor’s ministry of transportation.
- The SC Customer must submit for all pyrotechnic devices a certificate of compliance with the standard for safe exposure to electromagnetic radiation.

The administrative office area and conference hall, shown in Figure 5.1.2.2.3-2, are located on the second floor of the building. The seven rooms have the following functions:

- Facility management office, security dispatch room, and medical center
- SC launch program management office
- Recreation room
- ILS office
- SC contractors’ office
- Office of the SC Customer/owner
- Conference hall

Only essential personnel may be present in the area of the administrative offices and conference hall when work is under way to load the SC with propellant components.

Figure 5.1.2.2.3-2: Administrative Offices and Conference Hall



5.1.2.2.4 Ascent Unit Assembly Hall

After the SC is filled with propellants in the processing and filling hall, it is transported to the ascent unit assembly hall, which is an enclosed area with the following controlled environmental parameters.

Environmental Parameters	**Values**
Temperature	22°C
Accuracy of temperature maintenance	±5°C
Relative humidity	35-60%
Dust content of air per Fed Std 209E, class no worse than	100,000

The hall is used for independent processing of the adapter system and PLF and for assembly of the AU, including the following operations:

- Mating of the SC, adapter system, and upper stage
- Check of the integrity of through circuits and of the quality of mating of on-board connectors
- Encapsulation

These operations are carried out with a tilter and servicing stand. Traveling cranes with a capacity of 50/10 metric tons are used to transfer the SC from the handling dolly to the manipulator with the upper stage installed, and also to transfer the assembled AU from the handling stand to the rail transporter for transportation to the LV assembly building so that they can be mated.

This hall has a full-height lining and ceiling covering, as well as door seals and thermal insulation.

An anti-static covering is applied to the floor of the hall, which is rated for a load of 10 metric tons (3000 kgf/cm^2) on the load axis. The floor height is the same as in the processing and filling hall.

During work in the AU assembly hall, the Customer is provided with any maintenance aids needed. An electrical transporter in the form of a prime mover or a handling dolly may be provided for transportation of the filled SC from the processing and filling hall to the AU assembly hall.

A separate control room to house checkout equipment is provided in the AU assembly hall for electrical checks of the SC.

5.1.2.3 Propellant Storage

Storage of propellant components for the SC consists of separate areas (for fuel and oxidizer) located outside the assembly and test building, and is intended for long-term storage of propellant filling containers with propellants from their arrival at the Cosmodrome until their departure from the Cosmodrome, excluding the time for preparation for filling and actual filling of the SC.

These rooms are equipped with all necessary systems for safe storage of propellant.

5.1.2.4 Building 142-1 and the Universal Launch Complex of the Angara LV Family (Area 35)

After encapsulation, the AU is delivered to Building 142-1 for mating to the LV. A diagram of the building is shown in Figure 5.1.2.4-1. During transportation, a rail thermal control unit is used to maintain temperature and humidity conditions around the SC. Conditioned air is supplied from the unit to beneath the PLF and is cleaned with highly efficient fine filters corresponding to a class no worse than 100,000 per FedStd 209E.

The building is an unshielded industrial building about 50 m wide and about 110 m long made of concrete, brickwork, and welded and riveted metal structures. The building contains an erection and assembly room and two built-on laboratories bordering on the assembly room. The building is equipped with heating, ventilation, and fire suppression systems, fire and security alarm systems, and special lighting. Traveling cranes are provided for work with the assembled LV.

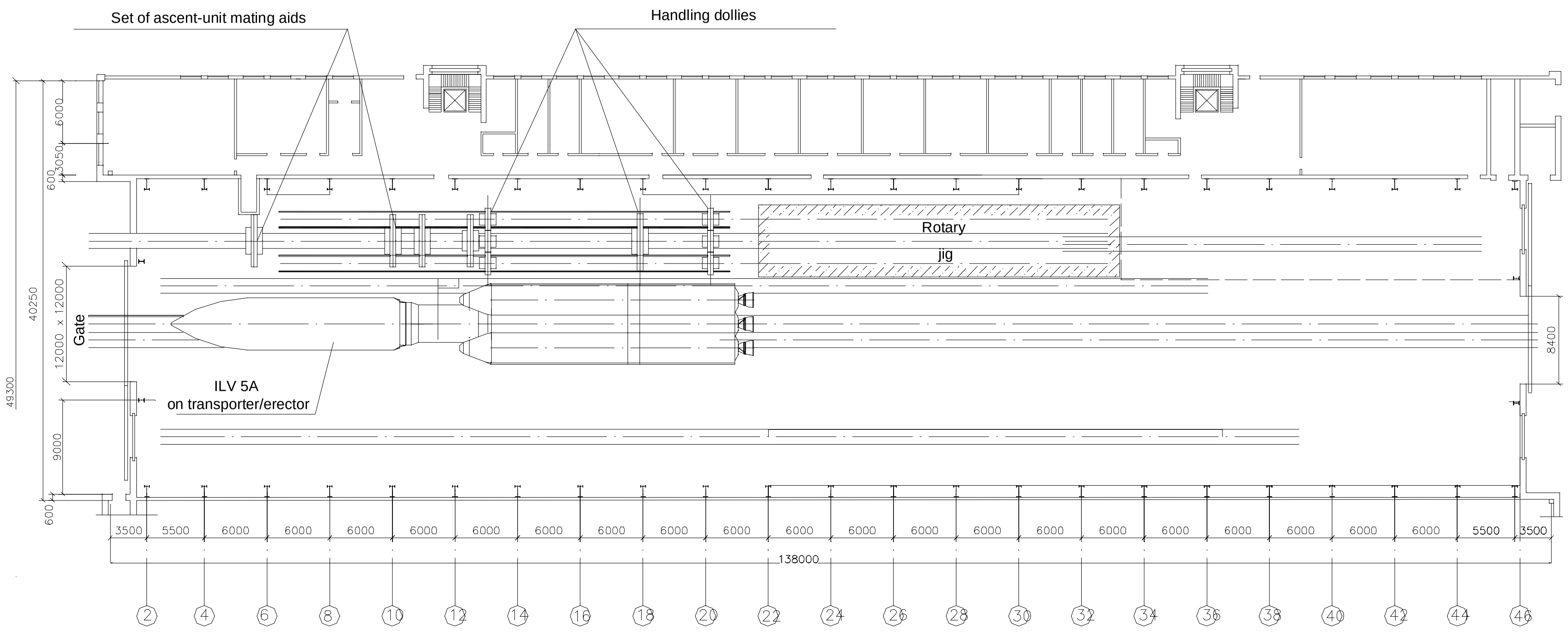
The LV assembly room in the building is used for the following work with the SC:

- Transfer of the AU from the rail transport unit to the mating stand.
- Mating of the AU with the Angara LV.
- Electrical checks of through circuits of the LV and checkout of the communication wires between the AU and the LV.
- Charging of the on-board storage batteries of the SC (if necessary).
- Transfer of the LV, assembled with the AU, onto the transporter/erector.
- Processing of the LV, assembled with the AU, for transportation to the launch complex.

The processing room for the Angara LV has a width of about 36 m and a length of 108 m. The room is equipped with 1524-mm gage railroad tracks intended for ingress/egress and for erection and mating operations.

The temperature, relative humidity, and dust content of the environment of a SC in this room are kept in the required ranges by means of the rail thermal control unit.

Figure 5.1.2.4-1: LV Assembly and Test Building



During mating of the AU to the Angara LV, the Customer is provided areas to house GSE during electrical checks, as well as the necessary transport equipment and servicing hardware.

After mating to the AU and the necessary electrical checks are performed, the LV is transported to the launch complex (Area 35) for erection and launch. Figure 5.1.2.4-2 shows an overview of the launch complex. Two rooms used to house GSE for the SC have been set aside at the launch complex. The Vault houses SC Customer equipment that supplies power to the SC while it is present at the launch area. A room in the Bunker is used to install SC Customer electrical GSE that is essential for launch.

The temperature, relative humidity, and dust content of the environment of a SC during erection and launch processing are kept in the required ranges by means of the launch thermal control system. The dust content of the air supplied beneath the PLF is no worse than class 100,000 per FedStd 209E.

Handling and transport equipment and servicing aids are provided to the Customer to allow GSE to be kept in rooms at the launch complex.

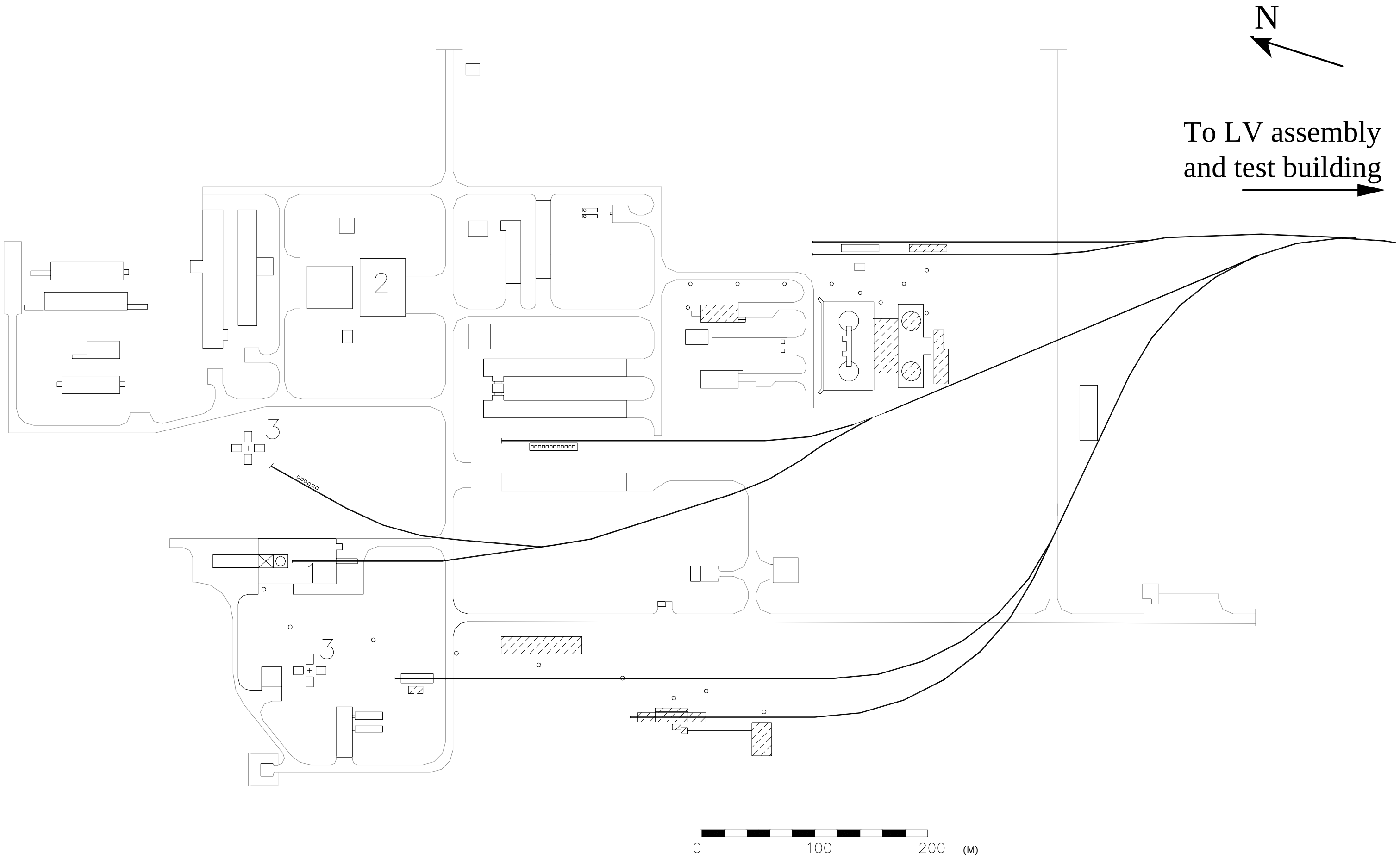
5.1.2.5 Electrical Grounding

All payload processing sections used for work with the SC and electrical GSE will be equipped with metal ground buses on which points (threaded studs) will be provided for connection of equipment. The circuit resistance between every point on these buses and the grounding system of the structure does not exceed 4 ohms. The floor surfaces in payload processing sections and in the section where hazardous work with the payload is carried out are equipped with an anti-static covering and are connected to the ground system of the structure. The launch complex will be equipped with the ground loop to provide the grounding of the SC at the launch complex via the metal components of the LV. The SC manufacturer will provide all cables and accessories needed to connect the SC and GSE to the electrical grounding of the structure.

5.1.2.6 Lightning Protection

All payload processing sections used for work on the SC are equipped with a lightning protection system designed to withstand a direct or nearby lightning strike.

Figure 5.1.2.4-2: Launch Complex



1. Launcher with launch structure
2. Command post
3. Diverters

5.2 SC AND LV PROCESSING AT TECHNICAL COMPLEX AND LAUNCH COMPLEX

The processing of the Angara LV includes work on the processing of the integrated LV components, integrated LV assembly, and integrated LV launch. The processing of the integrated LV components consists of the independent processing of the LV and AU.

The following work is carried out during LV processing:

- Processing and filling of the SC
- Processing of the upper stage
- Processing of the PLF for the SC and adapter system
- Assembly of the AU

The prepared AU is delivered to the assembly and test building for LV processing, where the AU is mated to the LV, followed by horizontal transport of the integrated LV to the launch complex in preparation for launch.

5.2.1 SC Processing and Filling

The following operations are carried out at the technical complex during SC processing:

- Delivery of the SC and equipment to the unloading hall of the assembly and test building;
- Unloading of the container with SC and equipment in the unloading hall;
- Cleaning of the container with SC and equipment;
- Unloading of the SC from the container and mounting on the handling dolly;
- Preparation of the SC for transportation to the processing and filling hall;
- Transportation of the SC to the processing and filling hall on the handling dolly;
- Transport of SC equipment to the processing and filling hall;
- Transfer of the SC from the handling dolly and mounting of it on the processing and filling workplace;
- Independent processing of the SC;
- Delivery of propellants to the processing and filling hall;
- Filling of the SC with propellants; and
- Preparation of the SC for transportation to the AU assembly hall.

5.2.2 Upper Stage Processing

The following work is carried out during independent processing of the Breeze M upper stage:

- Delivery and unloading of the upper stage and assembly components from the transporter to the unloading hall of the assembly and test building;
- Mounting of the upper stage on the work station in the processing hall;
- Checkouts of upper stage systems and hardware units;
- Prepare and transport the upper stage to the filling and neutralization station;
- Pressurizing the propellant tank and the spherical cylinders of the upper stage with gaseous helium while the upper stage is in vertical position on the transporter; and
- Transporting the upper stage from the filling and neutralization station to the assembly and test building while maintaining temperature control.

5.2.3 Independent Processing of the SC PLF and Adapter System

The following work is carried out during independent preparation of the SC PLF:

- Delivering the fairing half sections, mounted on flatcars, to integrated technical complex;
- Removal of manufacturer's packing material;
- Cleaning external and internal surfaces;
- Perform pressurizing tests of the fairing;
- Checking out the value of the force for moving the covers of the vent ports;
- Checking out onboard cable networks;
- Test telemetry monitoring system;
- Checkout of the onboard cable networks and sensor devices of the ground measurement system;
- Testing pyrotechnical devices in the reinforced chamber (armored enclosure);
- Transferring the fairing into the tilting device and tilting it with plane III downward;
- Transferring fairing into the jig;
- Preparing fairing for assembly, checkout and arming the separation mechanism of the longitudinal interface plane;
- Installation of the pyrotechnical devices for separation system; and
- Fairing storage (if necessary)

The following work is carried out during independent preparation of the SC adapter system:

- Delivering the adapter system mounted on a flatcar to the workplace of the integrated technical complex;
- Opening the container with the adapter system and cleaning the protection packaging of the adapter system;
- Removal of the protection packaging of the adapter system;
- Transferring the adapter system onto the stand and attaching it;
- Cleaning the surface of the adapter system;
- Checkout of the separation monitoring sensors;
- Setting up the layout for the electrical testing of the adapter system circuits;
- Testing through circuits of the adapter system and disassembly of the layout;
- Testing the onboard cable network of the adapter system as well as sensor devices and the telemetry monitoring system of the adapter system;
- Testing the onboard cable network and the sensor devices of the ground measurement system;
- Mounting handling and tilting arrangement on the adapter system; and
- Adapter system storage (if necessary).

5.2.4 AU Assembly

The following work is carried out during AU assembly:

- Delivery of the SC and equipment to the AU assembly hall;
- Unloading the AU and mounting it onto the work place;
- Transportation of the upper stage to the AU assembly hall;
- Transfer of the upper stage to the intermediate spacer stand;
- Mounting a stiffening ring onto the lower spacer;
- Removal of the protective cover from the upper stage;
- Removal of the LPT loop, checking for leaks in the DPU, and pressuring low pressure tanks to filling pressure;
- Mounting intermediary frame onto the stand;
- Mounting and fixing the upper stage onto the intermediary frame;

- Mounting of the SC onto the adapter system assembly;
- Mating of the SC to the adapter system in the vertical position, and joint checks of the SC and adapter system;
- Mating of the SC + adapter system assembly to the upper stage;
- Mating of the SC + adapter system assembly with the upper stage in the vertical position, and joint checks of the SC + adapter system + upper stage assembly;
- Tilting of the SC + adapter system + upper stage assembly to the horizontal position;
- Mating of the fairing to the SC + adapter system + upper stage assembly;
- Joint checks of the AU;
- Transfer of the AU to the transporter; and
- Transportation of the AU to the integrated LV assembly hall.

5.2.5 LV Processing

The following work is carried out at the technical complex during processing of the Angara A3 LV:

- Unloading of LV modules from transport vehicles;
- Independent checks of hardware units of the first and second stage boosters;
- Assembly of the first stage booster;
- Mating of the second stage to the first stage of the LV;
- Check of the mating of connecting lines;
- Integrated checks of the assembled LV; and
- Final operations on the LV.

5.2.6 Integrated LV Assembly

The following work is carried out during assembly of the LV:

- Processing of the AU and LV for mating, and mating of the AU and LV;
- Interface checks of the newly formed connections of the integrated LV;
- Transfer of the integrated LV to the transporter/erector for transportation to the launch complex;
- Connection of the thermal control and of vibration load [monitoring] systems; and
- Final operations on the integrated LV before transfer to the launch complex.

5.2.7 Integrated LV Handling at the Launch Complex

The following work is carried out during assembly of the Angara A3 integrated LV:

- Transportation of the integrated LV to the fuel filling station, with thermal control;
- Filling Breeze M with propellants;
- Transportation of the integrated LV to the launch complex, with thermal control;
- Mounting of the integrated LV on the launcher;
- Mating of the GSE to the integrated LV;
- Connection of the launch complex thermal control system to the AU;
- Thermal control of the AU as part of the integrated LV;
- Functional checks of the integrated LV at the launch complex;
- Filling of the LV with propellant and compressed gases;
- Pre-launch preparation of the LV control system and propulsion system; and
- Launch of the integrated LV.

The master schedule for processing of the Angara A3 LV with the Breeze M at the technical complex and launch complex is presented in Figure 1.10.3-4.