# Chapter 3 General Performance Capabilities

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# 3 General Performance Capabilities

This chapter describes the performance of the *Rockot/Breeze-KM* launch vehicle into circular and elliptical low earth orbits from its launch site in the Plesetsk Cosmodrome, Northern Russia, as well as its potential launch base in Baikonur. Background information and the assumptions made for the performance curves are presented.

## 3.1 Introduction

The launch vehicle payload performance is driven by many variables and includes amongst others the specific launch vehicle characteristics, launch pad location, allowable launch azimuths, drop zones, and the availability of ground measuring stations for telemetry information reception. The *Rockot* launch site in the Cosmodrome Plesetsk, historically the most active launch site in the world with over 1700 launches, is well situated for polar and high inclination launches due to its northerly latitude. *Rockot/Breeze-KM* launched from Plesetsk Cosmodrome and equipped with its modern restartable upper stage *Breeze-KM* can serve a wide range of both circular and elliptical orbits in the range from 200 km up to over 2000 km and a range of inclinations from 50° to SSO by direct injection or via orbital plane change.

## 3.2 Launch Azimuths and Orbit Inclinations from Plesetsk

The Plesetsk Cosmodrome is located about 200 km south of the port city of Archangel in Northern Russia at geographical coordinates 62.8°N and 40.3°E. The location of populated areas drives the allowable launch azimuths and drop zones available from this launch site. Launch azimuths and resulting orbital inclinations achievable from Plesetsk are listed in Table 3-1.

| Launch Azimuth | Corresponding Orbital Inclination |
|---|---|
| 76.2° | 63.2° |
| 41.6° | 72.0° |
| 13.7° | 82.5° |
| 15.2° to 4.8° | 82.0° to 86.4° |
| 4.8° | 86.4° |
| 341.5° | SSO and other retrograde orbits |

**Table 3-1 Allowable launch azimuths that can be served from Plesetsk.**

*Rockot/Breeze-KM*, equipped with its modern inertial based control system is able to perform dog-leg manoeuvres during the second stage operation so that inclinations beyond these allowable launch azimuths can be reached. The dog-leg manoeuvres may result in a decrease of payload mass.

In coordination with the Customer and their demands the *Breeze-KM* upper stage enables high flexibility in the selection of the ascent profile provided by its attitude- and orbit correction system, precise guidance, navigation and control electronics including a three-axis gyro system and long life batteries. This enables a Customer adapted ascent profile and payload deployment scheme under consideration of radiovisibility by Russian ground tracking stations, earth shadow phases, separation time and other constraints.

To achieve inclinations other than those indicated in Table 3-1, *Breeze-KM* also provides the possibility to change inclination up to ±17° by a main engine ignition in the vicinity of the equatorial node of the transfer orbit. In such cases the possible decrease of the payload mass has to be determined for each specific mission profile. The minimum possible orbital inclination for the launches from Plesetsk cosmodrome without dog-leg manoeuvres and/or main engine ignition in the vicinity of the nodes is 62.8°.

The propellant consumed by *Breeze-KM* during possible payload collision and contamination avoidance manoeuvres is minor and will not affect the payload performance. On the other hand, fuel consumption for possible *Breeze-KM* deorbitation must be subtracted from the performance capacity.

## 3.3 Low Earth Orbits

The payload performance of the *Rockot/Breeze-KM* vehicle has been calculated for both circular and elliptical orbits from the Plesetsk launch site. To attain the maximum payload capacity for a dedicated mission, two injection schemes are generally used:

- The target orbit is achieved via a single burn of the *Breeze-KM* upper stage main engine.
- The *Breeze-KM* upper stage with a payload is injected into an elliptic parking orbit with the first burn of the main engine and one or several adjustment burns to form the target orbit.

Note: If the required altitude of the orbit does not exceed 400 km, both injection schemes can be used, and if the orbit altitude is higher than 400 km, the second injection scheme is generally used.

All payload performances are calculated for the standard *Rockot/Breeze-KM* configuration including the payload fairing as described in chapter 2. The requisite payload adapter fitting/ dispenser masses plus the separation system must be subtracted from these figures.

Usually, the payload fairing is not jettisoned until the free molecular heat-flow has dropped below 1135 W/m$^2$.

The performance values are confirmed by the data of former *Rockot/Breeze-KM* commercial launches as well as the over 150 SS-19 missile flights.

It should be noted that the performances given in this user guide are generally based on conservative assumptions. Furthermore, due to mass saving measures such as incremental improvements to the upper stage, an increase in payload performance can be expected. In specific cases, where such additional performance is necessary, the Customer is invited to contact EUROCKOT directly for a dedicated mission analysis.

### 3.3.1 Payload Performance for Circular Orbits

Figure 3-1 illustrates the performance capabilities associated with the corresponding circular orbits that can be served from the launch site in Plesetsk using the allowable launch azimuths indicated in section 3.2. It should be noted that direct injection into inclinations that lie between *i* = 82.0° and 86.4° are possible but subject to a dedicated internal Russian approval process for the overflight permission. Inclinations not shown in the performance graphs can also be served by *Rockot/Breeze-KM*, but only via a dog-leg manoeuvre during the 2nd stage burn or a plane change manoeuvre performed by the upper stage. In these cases, performances should be calculated on a case by case basis by EUROCKOT, a linear interpolation between the curves is not possible. Some loss of performance can be expected due to the necessity to perform dog-leg or plane change manoeuvres.

### 3.3.2 Performance for Elliptical Orbits

The *Rockot/Breeze-KM* performance capabilities for elliptical orbits with inclinations of 63.2°, 72.0° and 82.5° are presented in Figure 3-2 to Figure 3-4. Any argument of perigee can be achieved according to the Customer's requirements.

### 3.3.3 Sun-Synchronous Orbits

Sun-synchronous orbits (SSO) can be served from the Plesetsk launch site via use of the 341.5° launch azimuth corridor. Different ascent trajectory options are available depending on the requirements of the dedicated mission.

The launch vehicle is initially launched with an azimuth of 341.5° from Plesetsk. Yaw manoeuvres during the second stage burn allow the second stage drop zone to be precisely positioned outside of any foreign country's territorial waters.

The upper composite comprised of *Breeze-KM* and the payload is injected into a 96.7° or 99.5° inclined parking orbit. Finally, the target orbit inclination is reached via a plane change manoeuvre carried out by a *Breeze-KM* main engine ignition near the equator crossing.

The payload performance for SSO is depicted in Figure 3-1. It corresponds to the payload capacity into the required orbit with the SSO typical combination of target altitude and inclination.

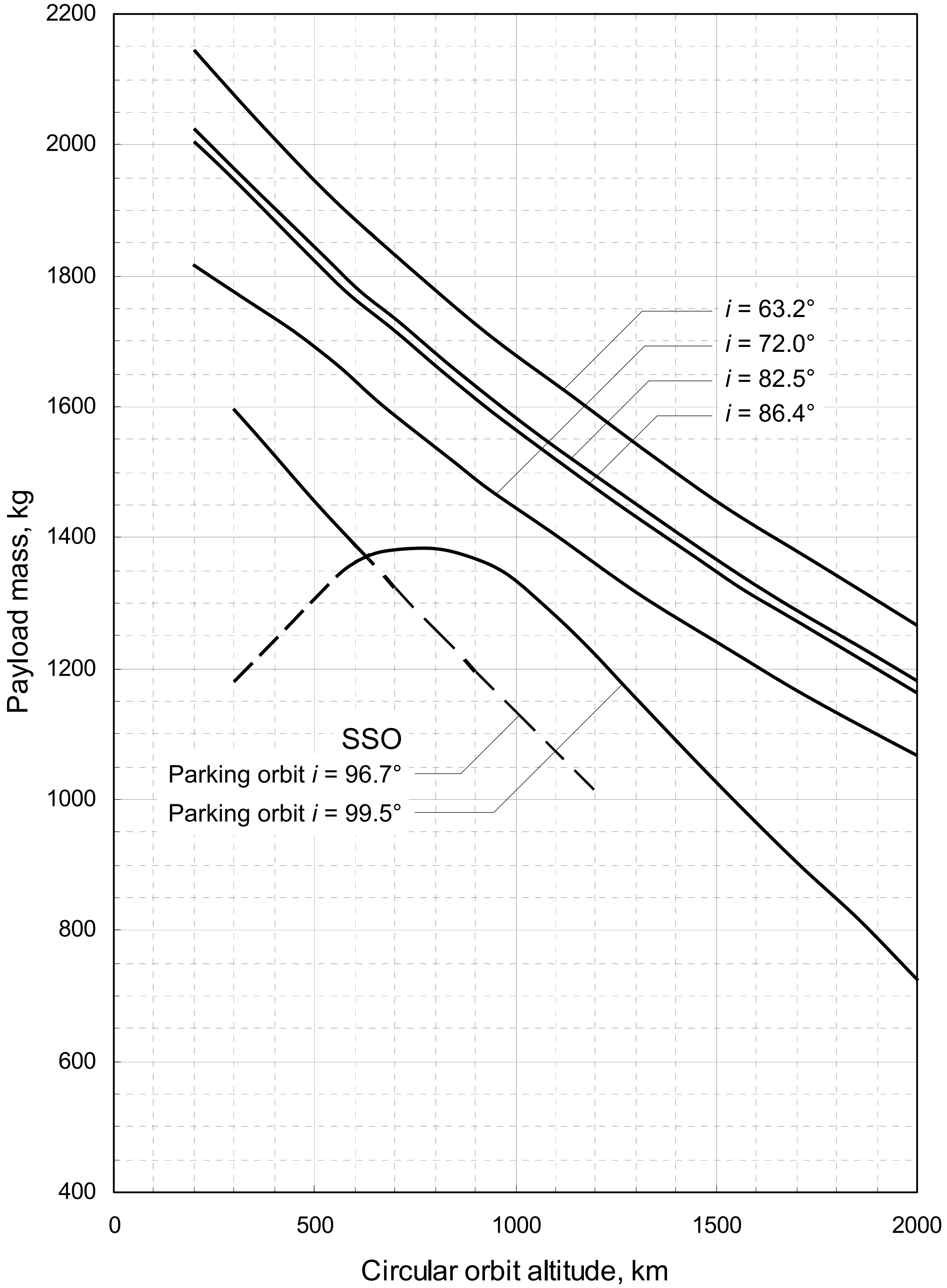

**Figure 3-1** ***Rockot/Breeze-KM* payload performance for circular orbits.**

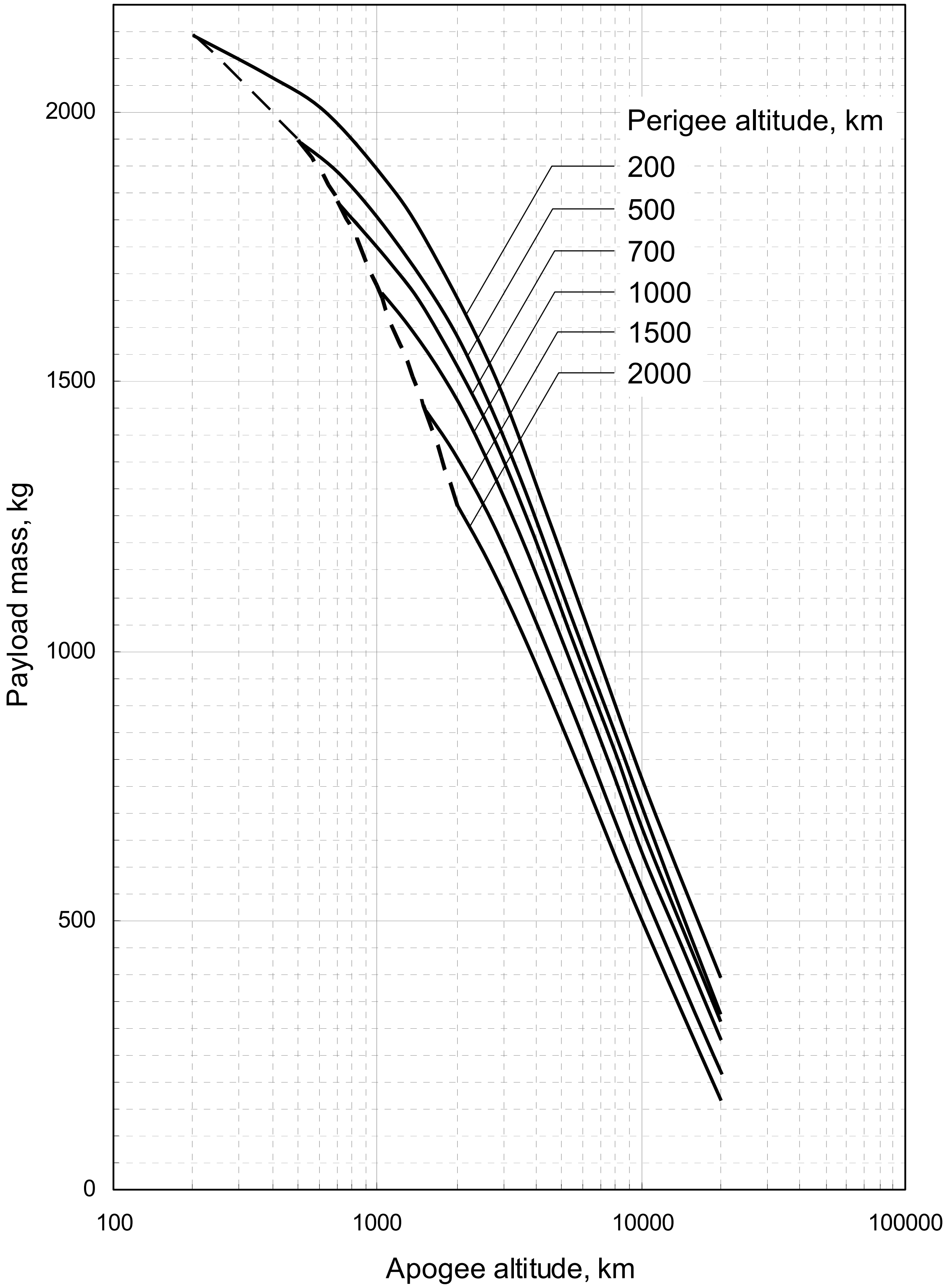

**Figure 3-2** ***Rockot/Breeze-KM* payload performance for elliptical orbits at 63.2° inclination.**

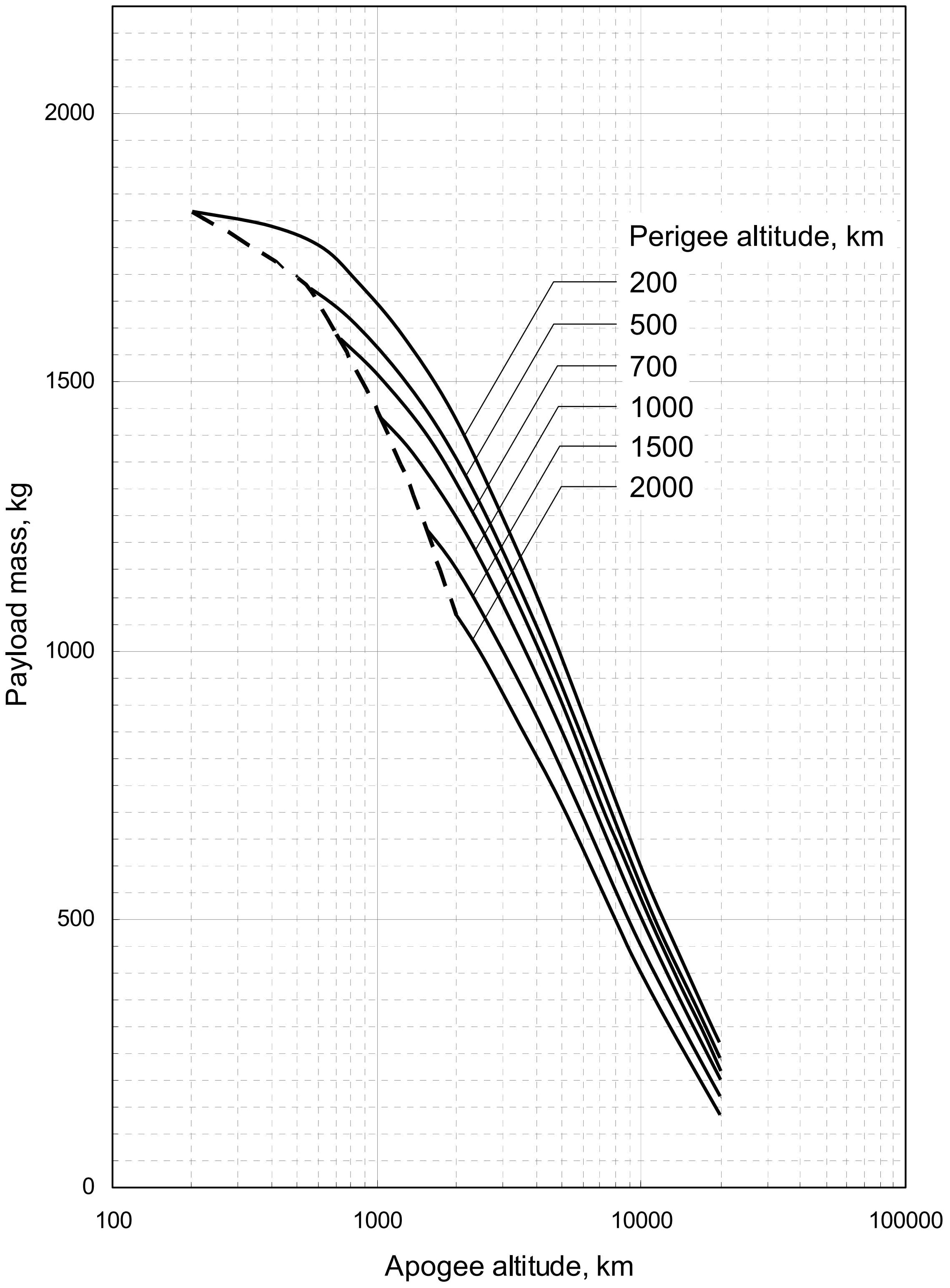

**Figure 3-3** ***Rockot/Breeze-KM*** **payload performance for elliptical orbits at 72.0° inclination.**

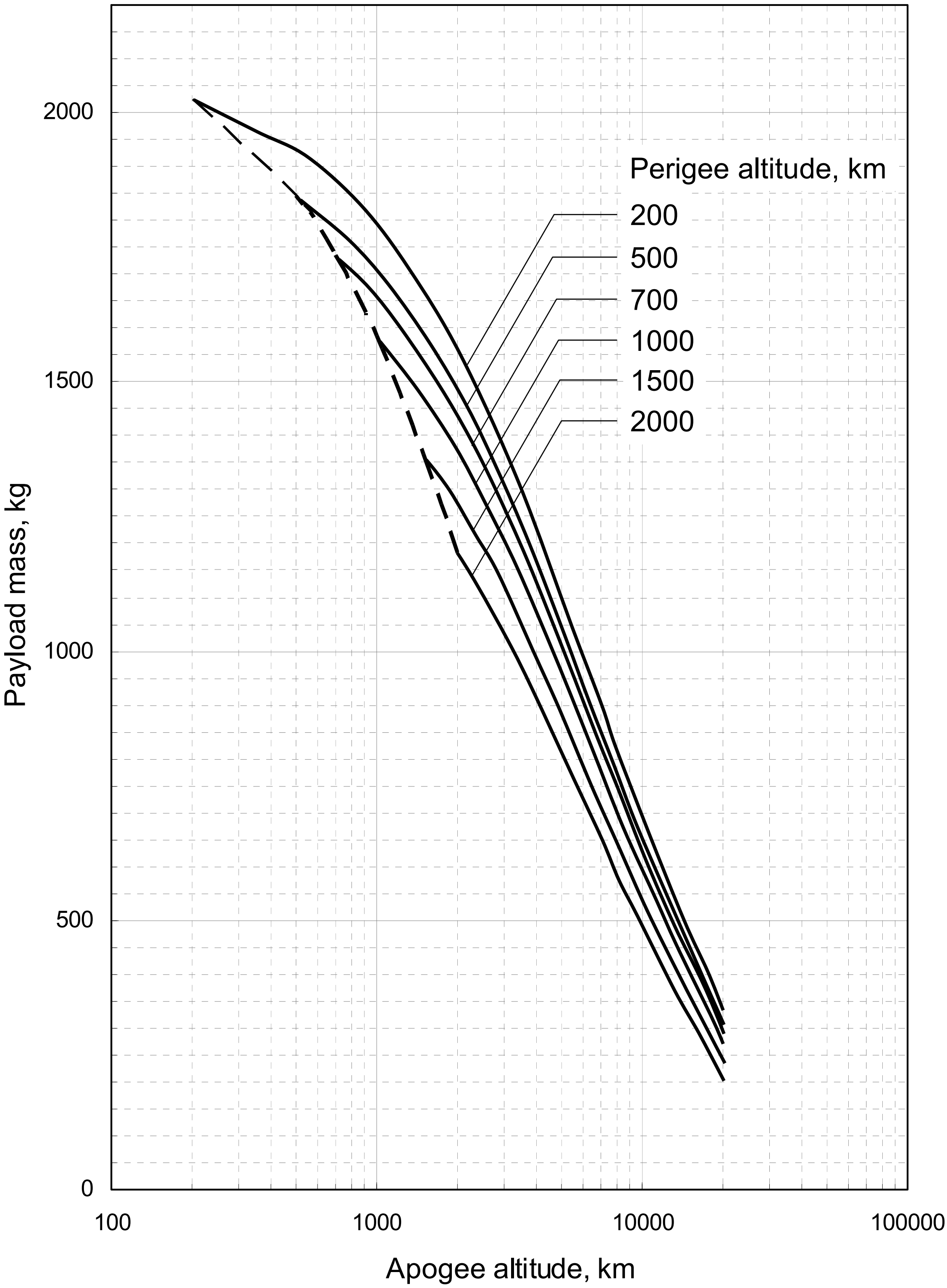

**Figure 3-4** ***Rockot/Breeze-KM*** **payload performance for elliptical orbits at 82.5° inclination.**

## 3.4 Mission Profile Description

This section describes typical circular low-earth mission profiles and presents examples of trajectories.

The selected flight trajectories take into account the dedicated impact sites permitted for *Rockot* elements.

The launch sequence begins with Stage 1 ignition. The first stage propels the vehicle to approximately 60 km height and impacts some 990 to 1100 km down range. The ignition of the Stage 2 vernier engines occurs shortly before Stage 1 burn-out.

After shut down of stage 1 engine, stage 1 is separated using its solid retro rockets. Once the free molecular heat-flow has fallen below 1135 $W/m^2$, usually, the payload fairing is jettisoned.

The second stage's propelled flight phase is completed by the successive shut down of the main engine and vernier thrusters. The following stage separation is assisted by use of the second stage's retro rockets.

The *Breeze-KM* upper stage manoeuvres begin immediately after stage 2 separation and are performed by the upper stage main engine, which can be ignited several times, if required. An initial burn is performed in the boost mode directly following stage 2 separation. Further ignitions of the main engine are performed in accordance with the specific flight programme.

During the coast phase between the main engine burns *Breeze-KM* generally follows a sun-oriented flight programme to meet the Customer's specific requirements between the main engine burns. For instance, for thermal sensitive payloads, a step-wise rotation about any axis can be performed. In the absence of any specific requirements, *Breeze-KM* performs manoeuvres to meet its own thermal requirements. For 1 hour the $+X_{US}$ axis is oriented towards the sun. If coasting continues for more than one hour, the $-X_{US}$ axis is oriented towards the sun for the next half an hour. During $+X_{US}$ orientation, the angle between the $+X_{US}$ axis and the direction of sun light should be $\alpha \leq 100°$. During $-X_{US}$ orientation, the angle between the $-X_{US}$ axis and the sun direction should be $\alpha \leq 50°$ (Figure 3-5).

For a chosen orientation, an accuracy of 10° about each of the three axes of stabilisation can be provided during the coast phase.

Typical trajectories for *Rockot* missions with different numbers of upper stage ignitions are shown in Figure 3-6 to Figure 3-8. These figures show the main events of the mission: main engine burns and cut-offs, the Spacecraft separation and trajectory characteristics, such as:

- flight time $t$ counted from launch, s
- relative velocity $v$, m/s
- relative flight path angle $\theta$, deg
- dynamic pressure $q$, $kg/m^2$
- altitude $h$, km

Figure 3-9 shows a typical injection scheme for sun-synchronous orbits.

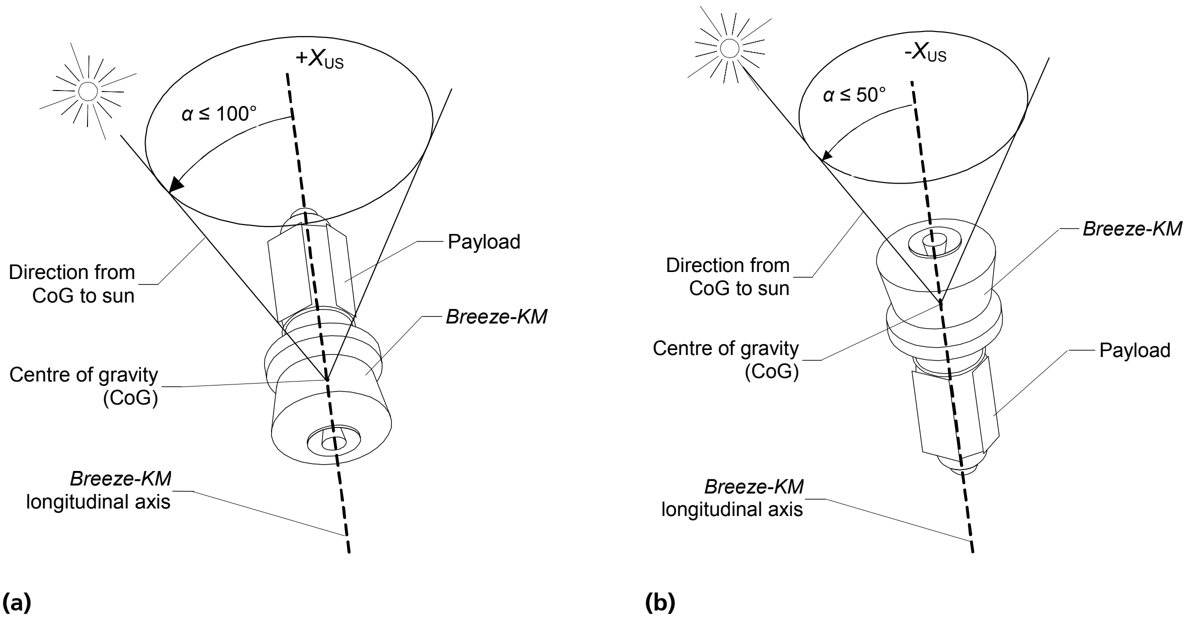

**Figure 3-5** **Cycling orientation of *Breeze-KM* relative to the sun during coast flight maintained for one hour (a), and for half an hour (b).**

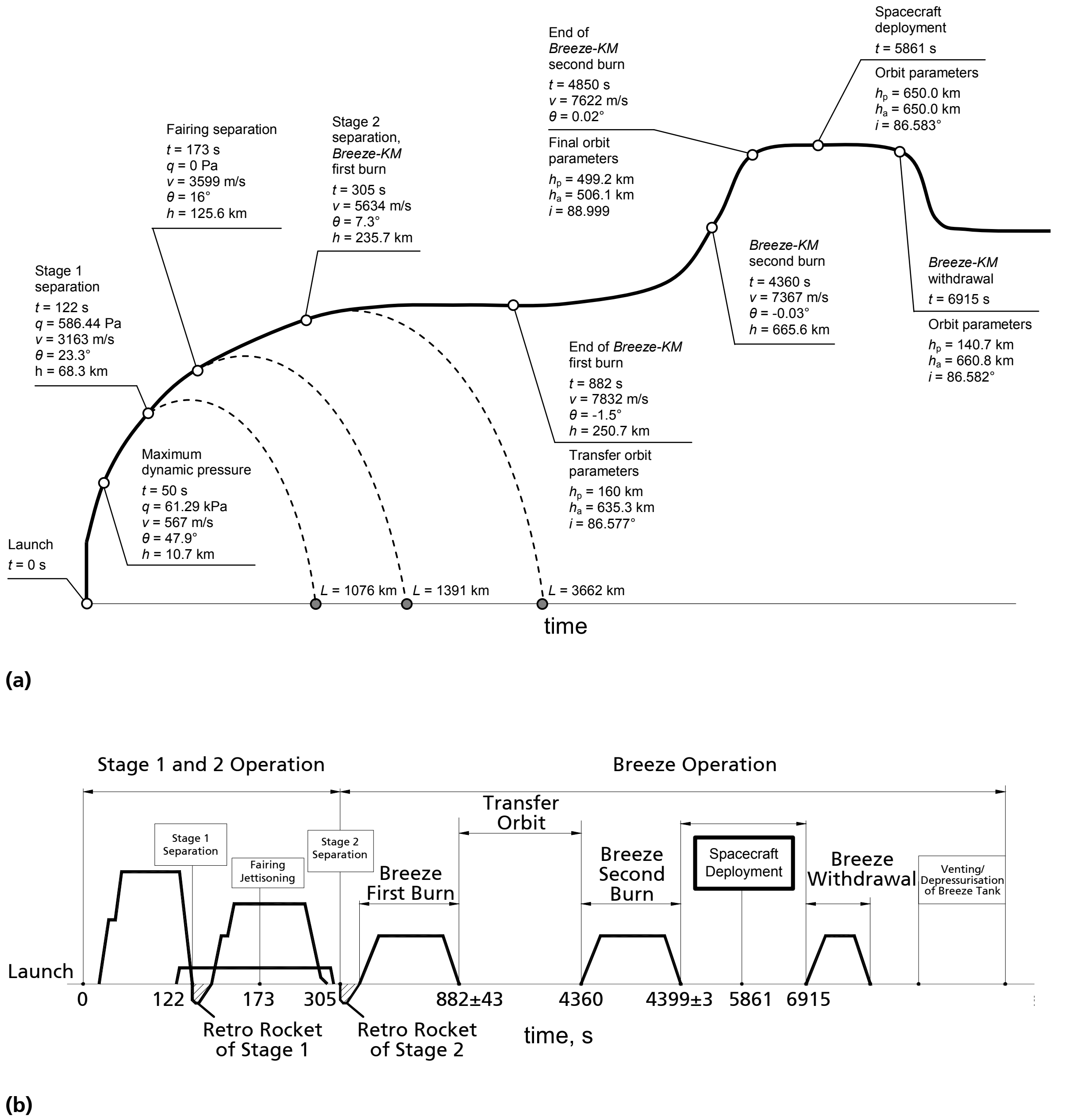

**Figure 3-6** **Typical *Rockot/Breeze-KM* ascent (650 km circular, 86.583° inclination). (a) Trajectory. (b) Acceleration timeline.**

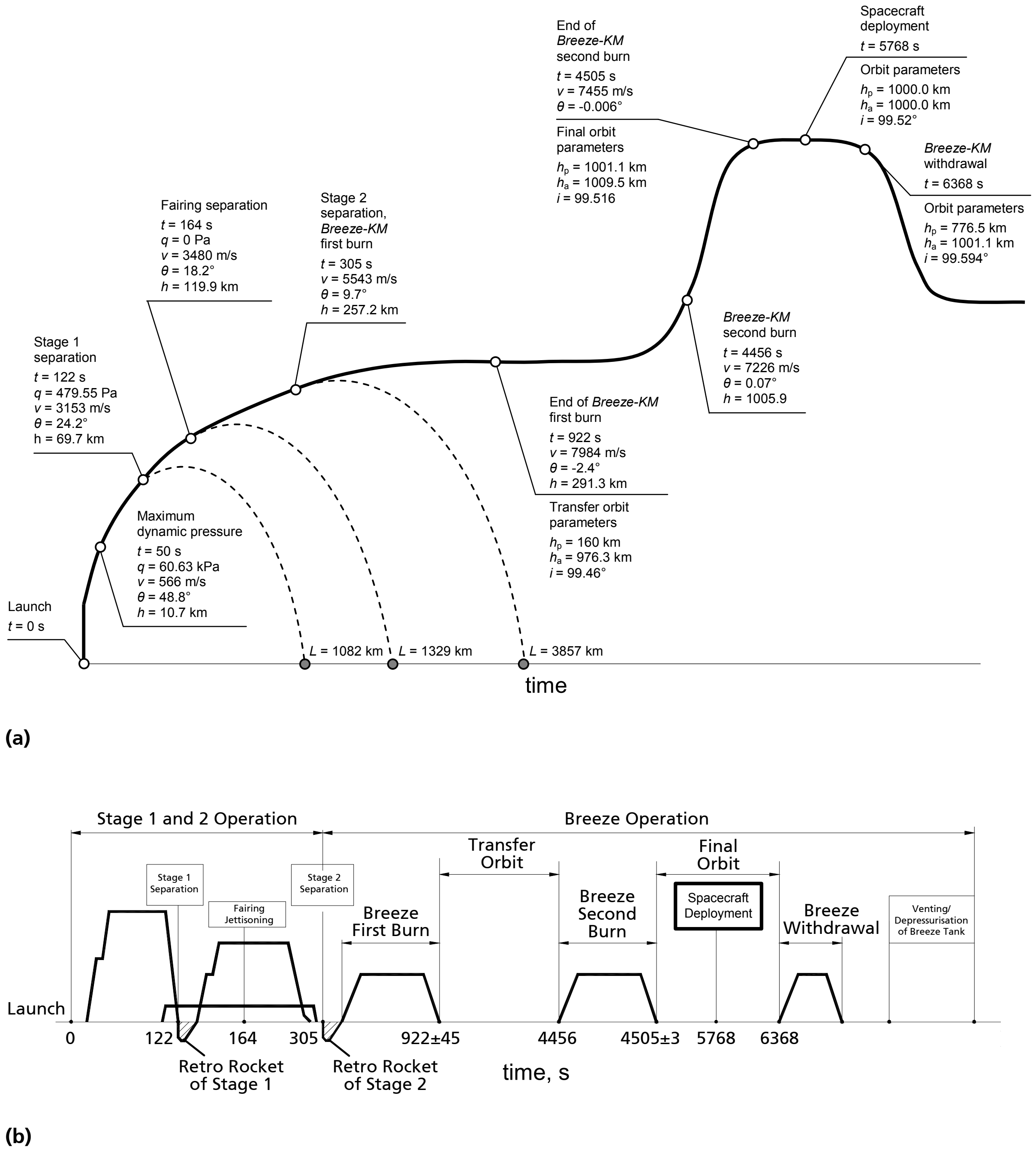

**Figure 3-7** **Typical *Rockot/Breeze-KM* ascent (1000 km circular, 99.52° inclination). (a) Trajectory. (b) Acceleration timeline.**

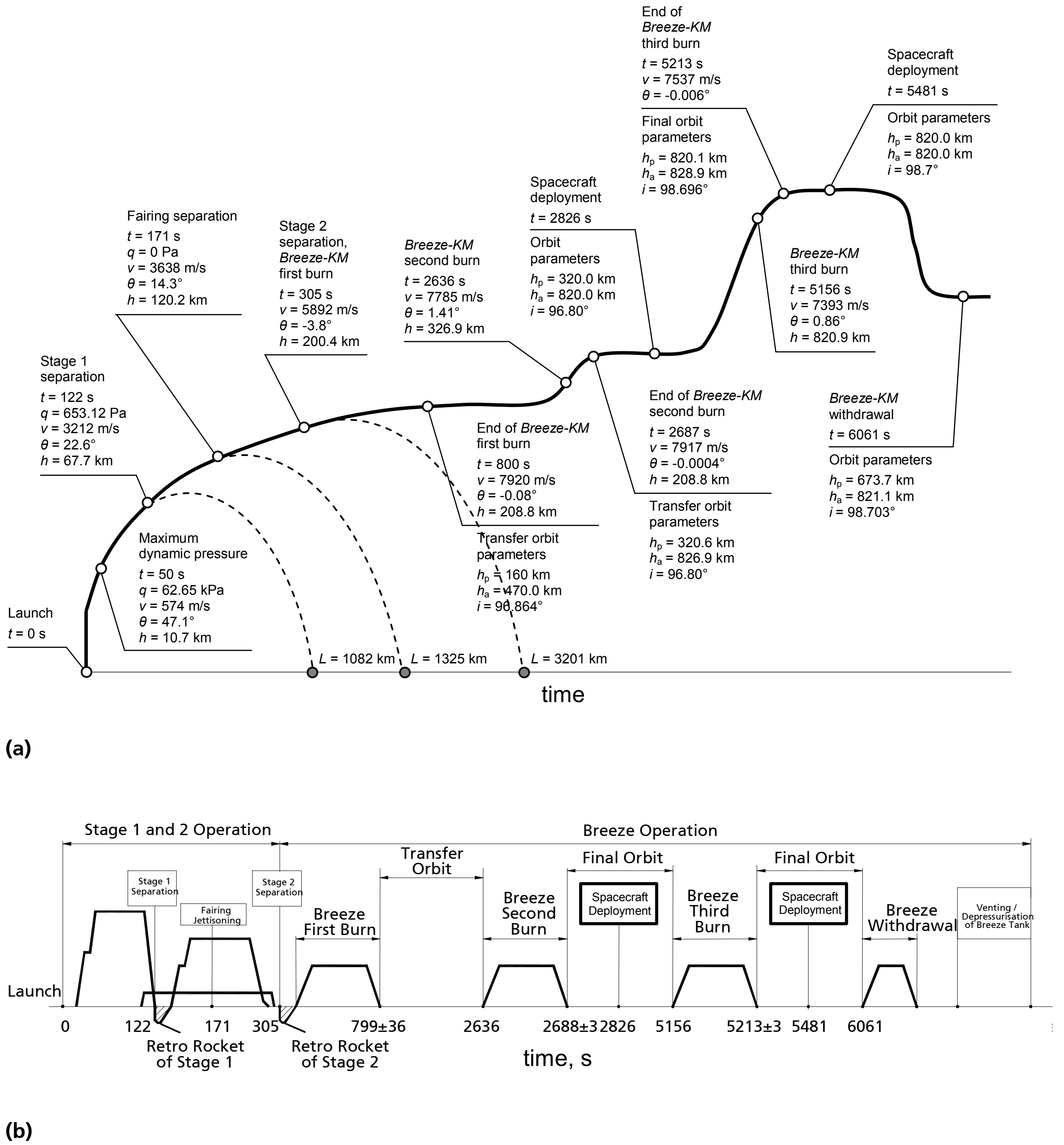

**Figure 3-8** **Typical *Rockot/Breeze-KM* ascent (320 km perigee, 820 km apogee at 96.8° inclination and SSO 820 km, at 98.7° inclination). (a) Trajectory. (b) Acceleration timeline.**

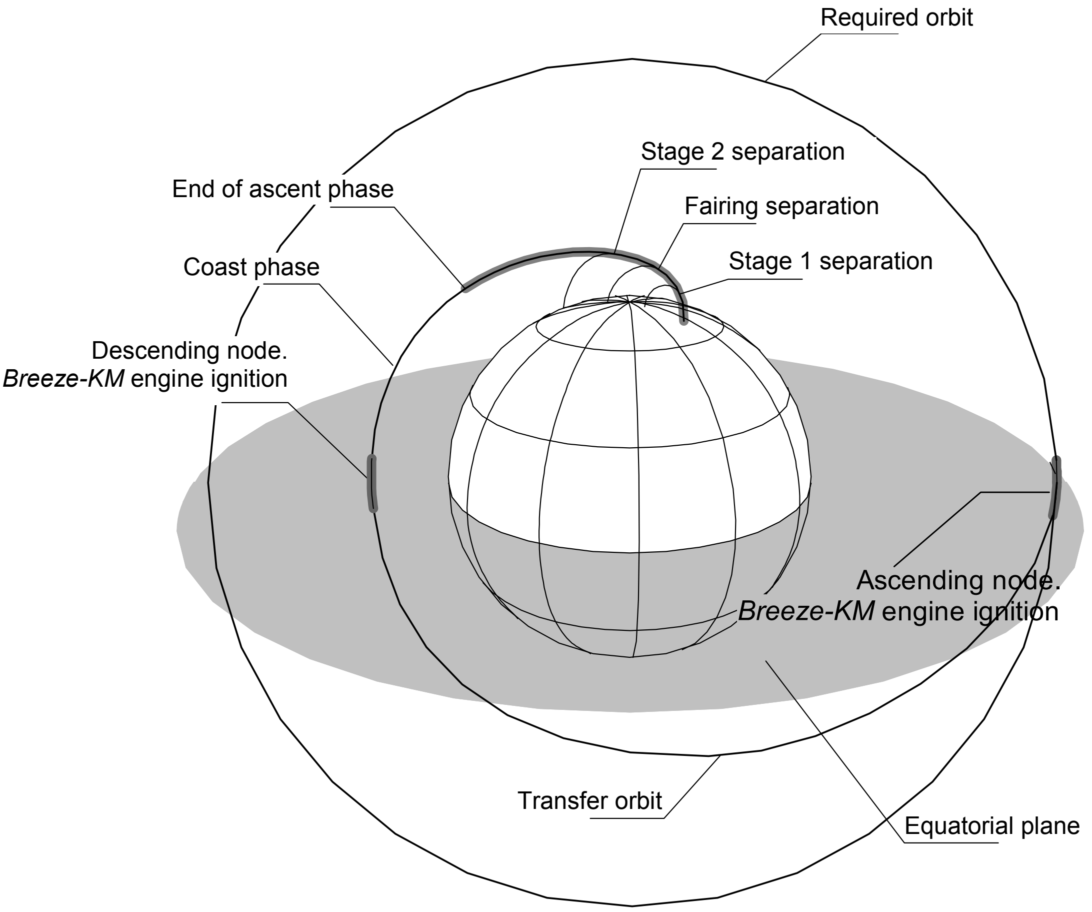

**Figure 3-9** **Sun-synchronous orbit injection scheme.**

## 3.5 Baikonur Performance

Although *Rockot* launches have occurred in the past from Baikonur cosmodrome, it is currently no longer operational for *Rockot* launches. An activation of the site for *Rockot* requires extensive upgrades and modifications to existing facilities. A decision for site activation will be made on a case-by-case basis, should the need arise. The information contained in this section is for customers interested in the potential use of this launch site for their missions. Baikonur is particularly suited for serving inclinations in the 50° range, which cannot be efficiently reached from Plesetsk due to its northerly latitude. The achievable mass performances from Baikonur for inclinations from about 50° to about 65° are subject to detailed analyses. However, they can be assumed to be slightly above the mass performance for launches from Plesetsk. For more detailed information regarding Baikonur launch performance, EUROCKOT should be contacted, directly.

## 3.6 Spacecraft Injection and Separation

*Rockot*, equipped with the *Breeze-KM* upper stage allows a large variety of options with regard to spacecraft orbital injection and separation. The following sections provide information about the orbital injection conditions and the separation possibilities for payloads.

### 3.6.1 Injection Accuracy

Table 3-2 provides 3-sigma orbital injection errors depending on the average altitude of the target orbit ensured by accuracy properties of the *Rockot/Breeze-KM* launch vehicle control system.

In particular cases the injection accuracies given in Table 3-2 can be improved after the specific trajectory analysis.

### 3.6.2 Spacecraft Separation

The spacecraft separation from *Breeze-KM* can take place in a number of different ways and is driven primarily by the

- characteristics of the separation system, e.g. stiffness of spring pushers,
- type of release mechanism,
- the direction of the separation impulse of the payload,
- payload mass, moments of inertia,
- the *Breeze-KM* burn-out mass

Spacecraft can either be spun-up along the *Breeze-KM* longitudinal axis or released from the upper stage in a three-axis stabilised mode.

#### 3.6.2.1 Spin Stabilised Separation

Spin stabilisation is performed around the upper stage longitudinal axis with rates of up to 10°/min. Higher spin rates may be considered upon Customer's request.

Spin parameters are to be agreed individually for each specific payload taking into account:

- Payload mass distribution (MoI), centre of mass (CoM) position and spacecraft dynamic properties
- Customer requirements for the spin regime such as:
  - attitude orientation and its accuracy during upper stage spin manoeuvre
  - orientation accuracy of the payload after its separation
  - other payload requirements for the Breeze-KM upper stage
- Necessity to continue flight control of the upper stage after payload separation

Controlled deorbiting of the upper stage after separation can be provided, if required. On the completion of the mission, *Breeze-KM* vents all its tanks to put the stage in a safe mode.

| Orbital parameters error type | 3-Sigma error |
|---|---|
| Average orbital altitude | ±1.5% |
| Inclination | ±0.06° |
| Eccentricity (for circular orbits) | ≤0.0025 |
| Right ascension of ascending node | ±0.05° |
| Argument of perigee (for elliptical orbits) | depends on eccentricity |

**Table 3-2 Orbital injection accuracy.**

#### 3.6.2.2 Three-Axis Stabilised Separation

In general, any required payload attitude can be provided. Following orbit insertion, the *Breeze-KM* avionics subsystem can execute a series of pre-programmed commands to provide the desired initial payload attitude prior to its separation.

This capability can also be used to reorient *Breeze-KM* for the deployment of multiple payloads with independent attitude requirements.

The 3-sigma attitude error about each spacecraft geometrical axis will not exceed 1.5° - 3° depending on the spacecraft properties.

The maximum angular velocities of the combined *Breeze-KM* / spacecraft prior to the payload deployment are:

$\omega_x = \pm 1°/s$
$\omega_y = \pm 0.5°/s$
$\omega_z = \pm 0.5°/s$

The spacecraft separation scheme system design including the number of pushers, their allocation and energy is developed in accordance with the requirements for ensuring the spacecraft normal operations. The schemes are selected by EUROCKOT and agreed with the Customer.

As a possible way to reduce potential disturbances acting on the spacecraft during separation, the following measures shall be applied:

- Selection of pusher with optimal characteristics including their energy
- Adjustment of pusher position for compensation of lateral offset of the CoM

Besides, electrical connectors can be selected taking into account their separation forces characteristics.

Analysis shows that even for light spacecraft having a mass of not more than 500 kg and moments of inertia of up to 50 kg·m$^2$ the total angular velocities $\omega_y$ and $\omega_z$ will not exceed 2.5°/s and the longitudinal component of $\omega_x$ will not exceed 1.5°/s after separation, if the above methods are combined. For spacecraft of larger size and higher inertia the disturbance values are smaller.

Please note that these values shall be considered as conservative ones. The actual parameters can be smaller depending on the properties of the specific spacecraft.

To fulfil the Customer's requirements for the spacecraft separation, EUROCKOT selects the best suited of above methods to provide an optimal solution.

### 3.6.2.3 Typical Multiple Satellite Deployment Scenarios

*Breeze-KM* is able to perform a wide variety of complex pre-programmed manoeuvres using a combination of its main, vernier and attitude control engines, that allow to implement injection of several payloads into specified target orbits.

Depicted in the figures below are two typical payload deployment schemes. Figure 3-10 shows the sequential separation of three spacecraft with Δv added to each spacecraft to aid in-orbit plane phasing. Figure 3-11 shows a sequence in which six spacecraft are released simultaneously.

The separation scenario of the spacecraft is laid out in accordance with number, arrangement and energy of the pushers and their requirements for normal operation of the satellite. The separation scenario is selected in cooperation with the Customer.

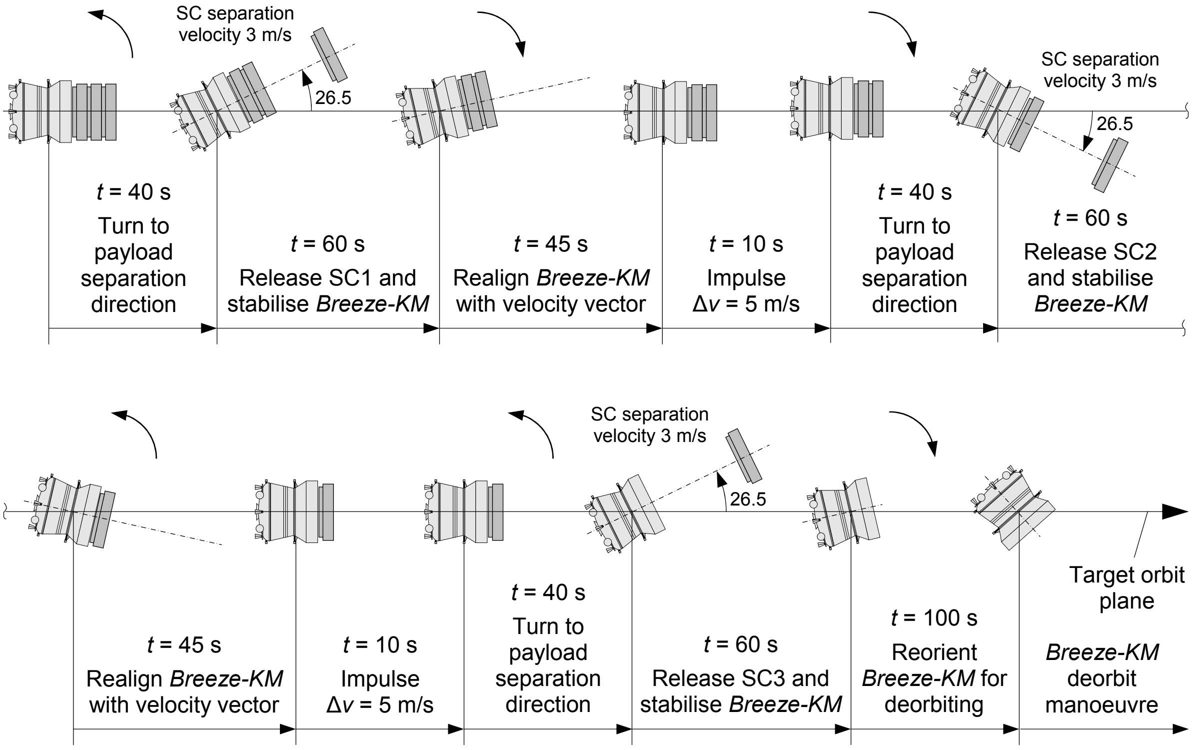

**Figure 3-10 Example of sequential deployment of three spacecraft.**

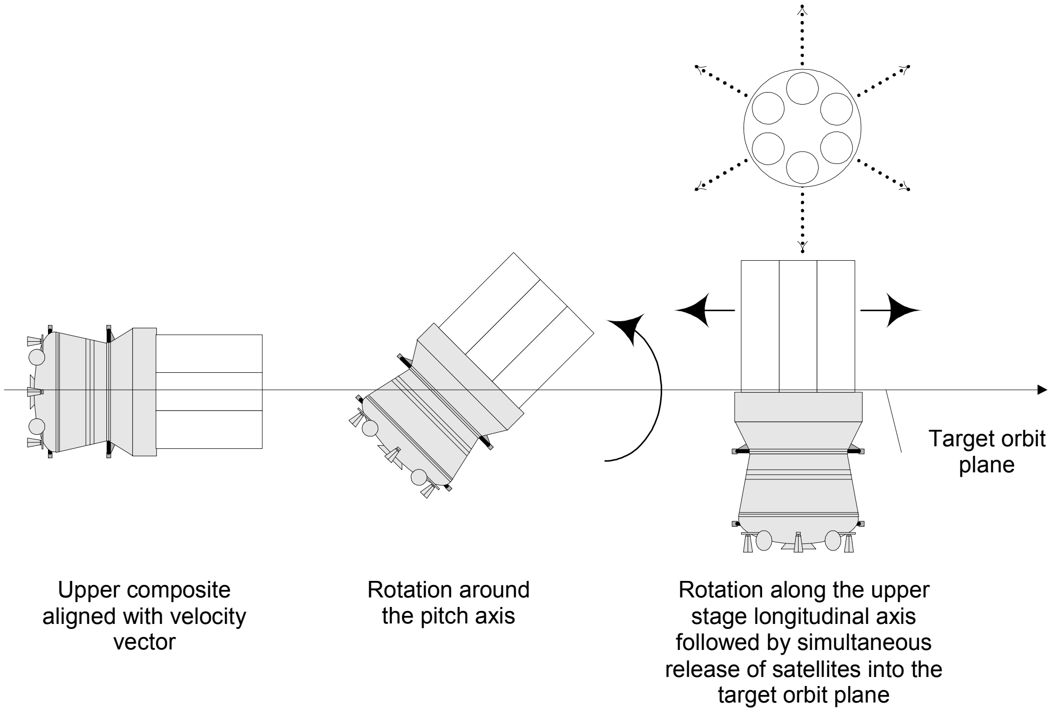

**Figure 3-11** Example of simultaneous deployment of six spacecraft.