Chapter 3 General Performance Capabilities

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3. General Performance Capabilities

This Chapter describes the performance of the *Rockot* launch vehicle into circular and elliptical low earth orbits from its launch site in Plesetsk, northern Russia as well as its planned launch base in Baikonur. Background information and the assumptions made for the performance curves are given.

3.1 Introduction

Launch vehicle payload performance is dictated by many variables and includes amongst others the specific launch vehicle characteristics, launch site location, allowable launch azimuths, drop zones, and the availability of ground measuring stations for telemetry information reception. The *Rockot* launch site, Plesetsk, historically the most active launch site in the world with over 1500 launches, is well situated for polar and high inclination launches due to its northerly latitude of 63°N. *Rockot* launched from Plesetsk and equipped with its modern restartable upper stage *Breeze* 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 62.7°N and 40.3°E. The location of populated areas dictates the allowable launch azimuths and drop zones available from this launch site and hence affects the payload performance of the *Rockot* vehicle. Launch azimuths and resulting orbital inclinations achievable from Plesetsk are listed in table 3-1.

Launch Azimuth	Corresponding Orbital Inclination
90°	63°
31.5	75.3°
15.2°	82°
15.2° to 4.8°	82° to 86.4°
4.8°	86.4°
341.5° (local launch azimuth only)	SSO and other retrograde orbits

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

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

In coordination with the Customer and their demands the *Breeze* upper stage enables high flexibility in the selection of the ascent profile provided by its attitude- and orbit correction systems, precise GN&C 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 or of other constraints.

To get the inclination that cannot be reached via dog-legs, *Breeze* also provides the possibility to change inclination up to ± 17° by the main engine ignition in the vicinity of the equatorial node of the transfer orbit. In such cases the possible decrease of the payloads mass should be determined for each specific situation. 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 62.7°.

Propellant consumed by *Breeze*-KM during possible payload collision avoidance- and contamination 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* vehicle has been calculated for both circular and elliptical orbits from the Plesetsk launch site in northern Russia. To attain maximum payload capacity for a dedicated mission, two *Breeze* injection schemes are generally used:

- When the target orbit is achieved via a single burn of the *Breeze-KM* Upper Stage main engine.
- When the *Breeze*-KM Upper Stage with a payload is injected into an elliptic parking orbit with the first burn of the main engine and then the target orbit is formed by one or several adjustment burns.

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*-KM (Commercial version) configuration including the enlarged payload fairing as described in chapter 2. The requisite payload adapter fitting/ dispenser masses plus the separation system must be subtracted from these figures.
- The payload fairing is never jettisoned until the free molecular heat-flow has dropped below 1135 W/m2.
- The performance values are confirmed by the data of the five *Rockot* KM commercial launches as well as the over 140 SS-19 missile flights.

It should be noted that the performances given in this user guide are generally conservative. 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 3-2 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 82° and 86.4° are possible but are subject to a dedicated internal Russian approval process for overflight permission. Inclinations other than these that are not shown on the performance graph can also be served by *Rockot* but only via a dog-leg during 2nd stage flight or a plane change manoeuvre. In these cases performances should be calculated on a case by case basis by EUROCKOT; 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

Rockot performance capabilities for elliptical orbits with inclinations of 63°, 75.3° and 82° are presented in Figures 3-3 to 3-5, respectively. The required argument of perigee for the orbits is achieved by injecting the *Breeze*-KM into a circular orbit corresponding to the perigee altitude. The *Breeze* main engine is then ignited upon reaching the argument of latitude (angle measured in the orbital plane counted from the ascending node) equivalent to the required argument of perigee and thus inserting it into its final elliptical orbit.

3.3.3 Sun-synchronous Orbits (SSO)

Sun-synchronous orbits 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 into a 341.5° launch azimuth from Plesetsk. Yaw manoeuvres during the second stage's flight allow the second stage's drop zone to be precisely positioned outside of any foreign country's territorial waters.

The upper composite comprised of *Breeze* and the payload is then 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* main engine ignition near the equator crossing.

The payload performance for SSO is depicted in Figure 3-2. It corresponds to the payload capacity into the required orbit with the SSO typical combination of target altitude - and 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 burnt-out *Rockot* stages.

The launch sequence begins with Stage 1 ignition. The first stage propels the vehicle to approximately 60 km height and impacts some 1000 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, the payload fairing can be jettisoned during Stage 2 burn.

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

The *Breeze*-KM upper stage's 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 a boost mode, directly following stage 2 separation. Further ignitions of the main engine are performed in accordance with the specific flight programme.

Between the main engine burns, during the coast phase, the upper composite follows a Sun-oriented flight programme. The Sun-oriented flight programme has a cycle mode: for 1 hour - the + X_{US} axis is oriented towards the Sun and for 0.5 hour - the - X_{US} axis is oriented towards the Sun. During the + X_{US} orientation phase, the angle between the + X_{US} axis and the direction to the Sun shall be not greater than 100 deg. During the - X_{US} axis orientation phase, the angle between the - X_{US} axis and the direction to the Sun shall be not greater than 50 deg (see Figure 3-1).

For a chosen orientation within the above mentioned cone, an orientation accuracy of 1 to 10° along all three axes of stabilisation can be provided. This orientation mode is predetermined in the flight programme for each specific flight case depending on the Customer's requirements.

On Customer request, the upper stage can also provide a spin manoeuvre for the payload before its deployment (see Section 3.6.2.1).

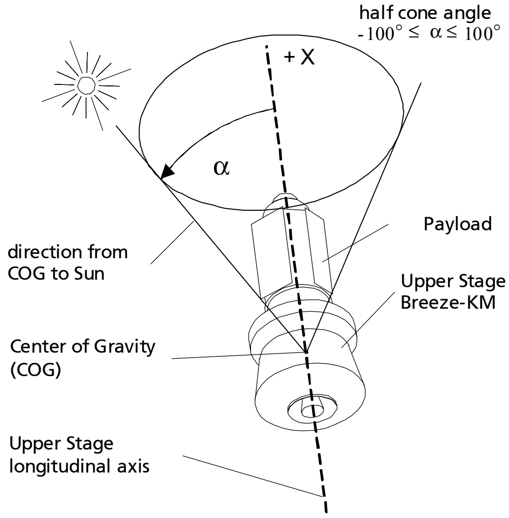

Figure 3-1 (1): *Breeze*-KM orientation during coast flight

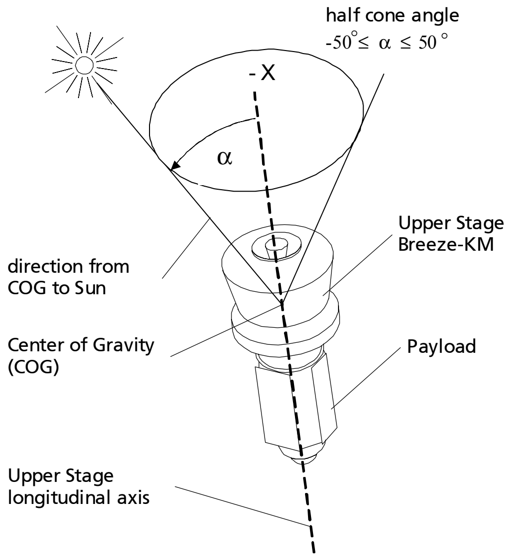

Figure 3-1 (2): *Breeze*-KM orientation during coast flight

Examples of Trajectories

Typical trajectories for *Rockot* missions with different numbers of *Breeze* upper stage ignitions are shown in the next section. Two *Breeze* ignition trajectories are shown:

- with 500 km altitude and an inclination of 89.0°,

- with 650 km altitude and an inclination of 86.583°,
- with 1000 km altitude and inclination of 99.52° (SSO)

see Figures 3-6, 3-8 to 3-10 respectively.

Injection trajectories with three burns of the *Breeze* upper stage main engine with:

- with 320 km perigee altitude, 820 km apogee altitude and inclination of 96.7°,
- with 820 km altitude and inclination of 98.6° (SSO)

are provided in Figure 3-12.

The figures show the main events of the mission: main engine burns and cut-offs, the Spacecraft separation and trajectory characteristics, such as:

- flight time counted from launch (t, s.)
- relative velocity (v, m/s.)
- relative flight path angle (Q, deg)
- dynamic pressure (q, kg/m^2)
- altitude (h, km)

Figure 3-7, 3-9, 3-11, 3-13 show the flight sequence for each of the presented trajectories. The abscissa shows the time in seconds after lift-off and the ordinate illustrates the engine operations of the various stages.

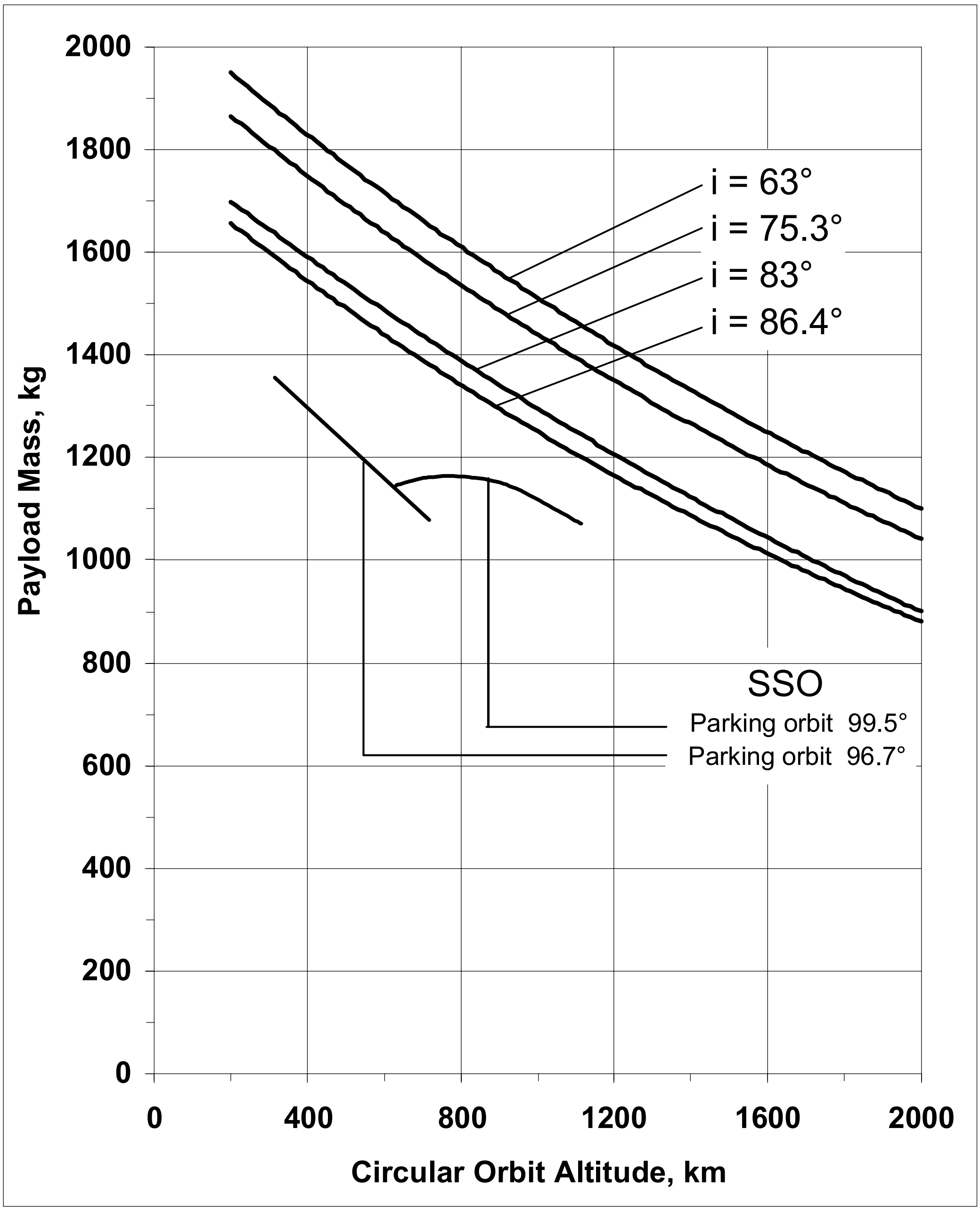

Figure 3-2: Performance Capabilities for Circular Orbits

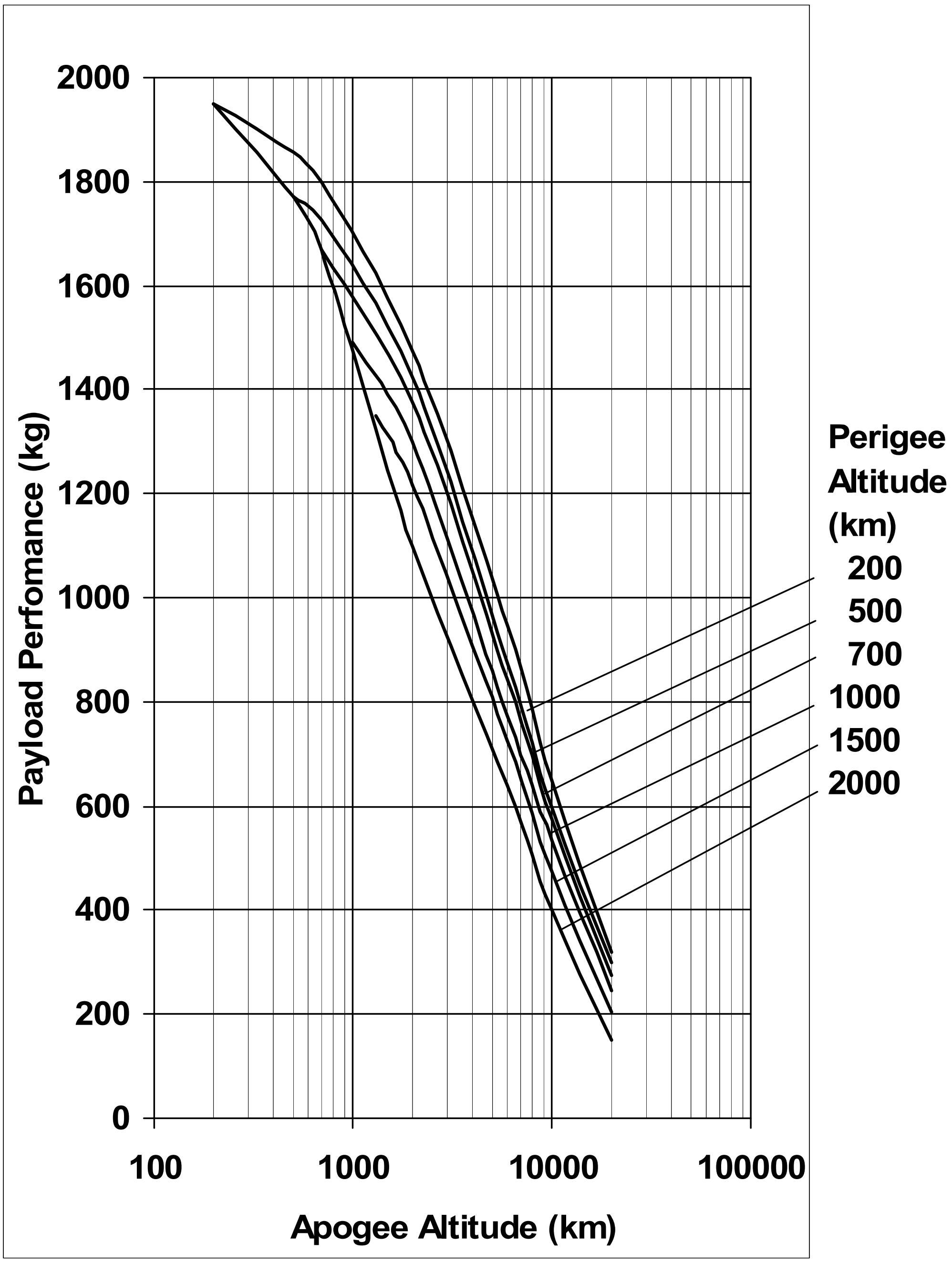

Figure 3-3: Performance for Elliptical Orbits at i = 63°

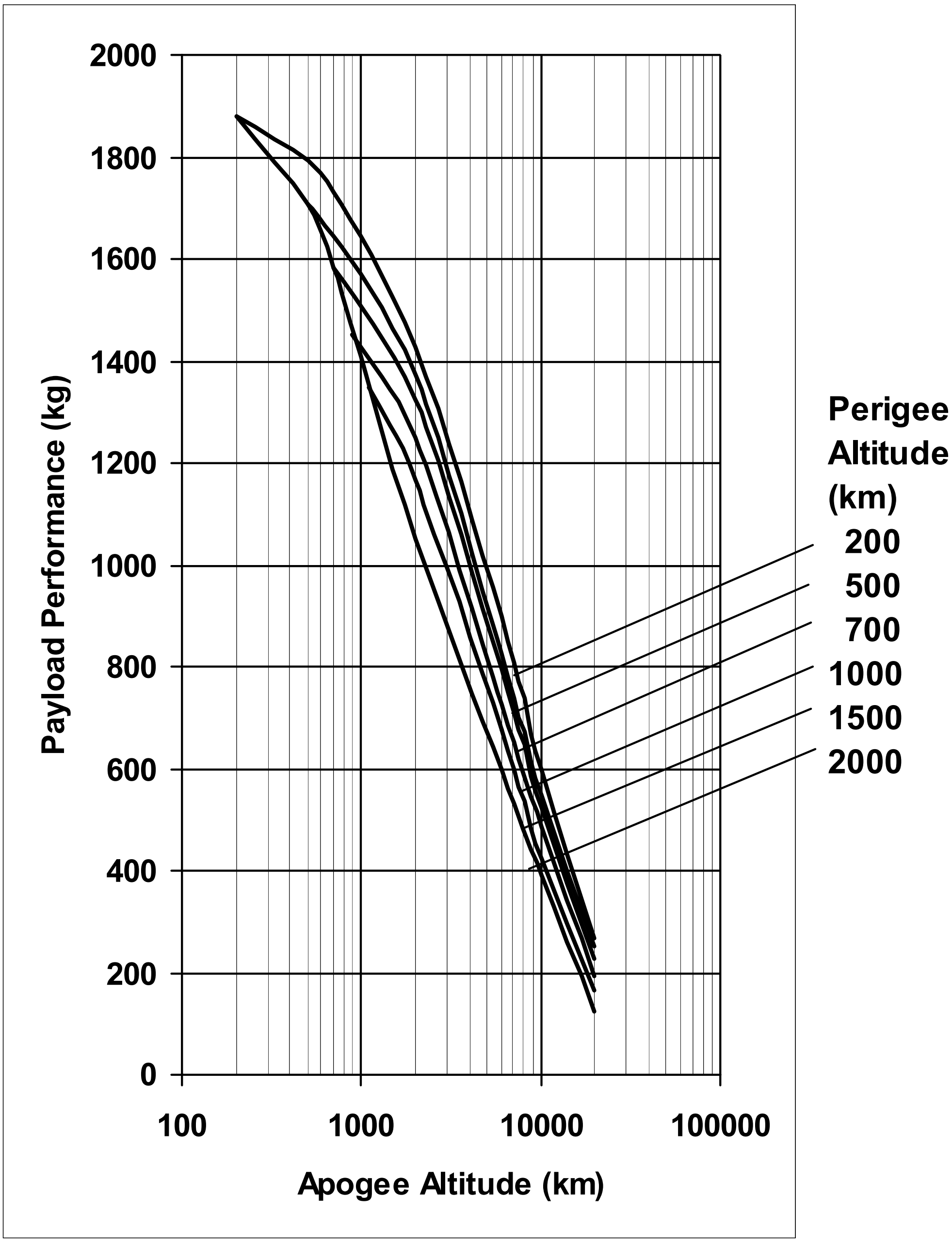

Figure 3-4: Performance for Elliptical Orbits at i = 75.3°

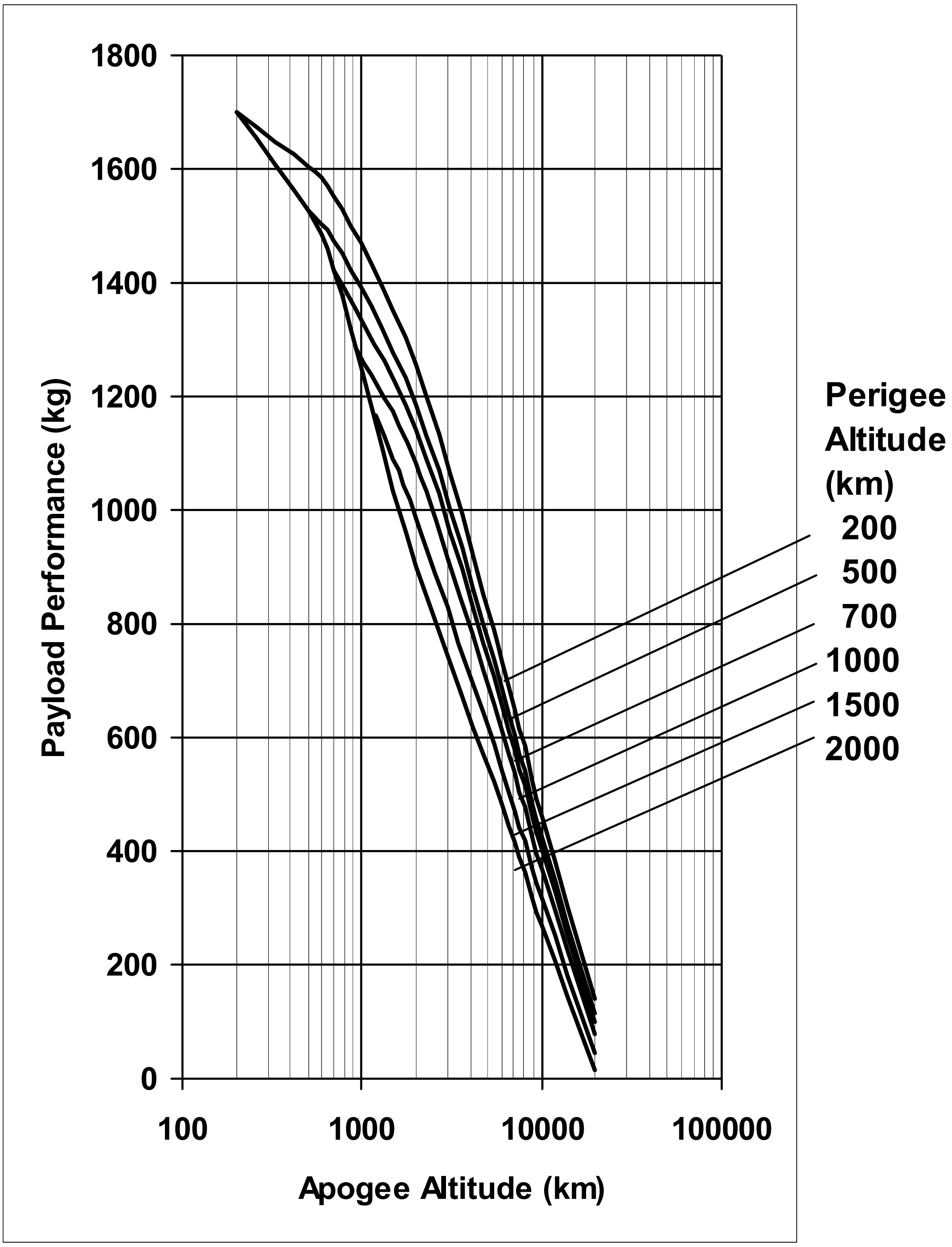

Figure 3-5: Performance for Elliptical Orbits at i = 82°

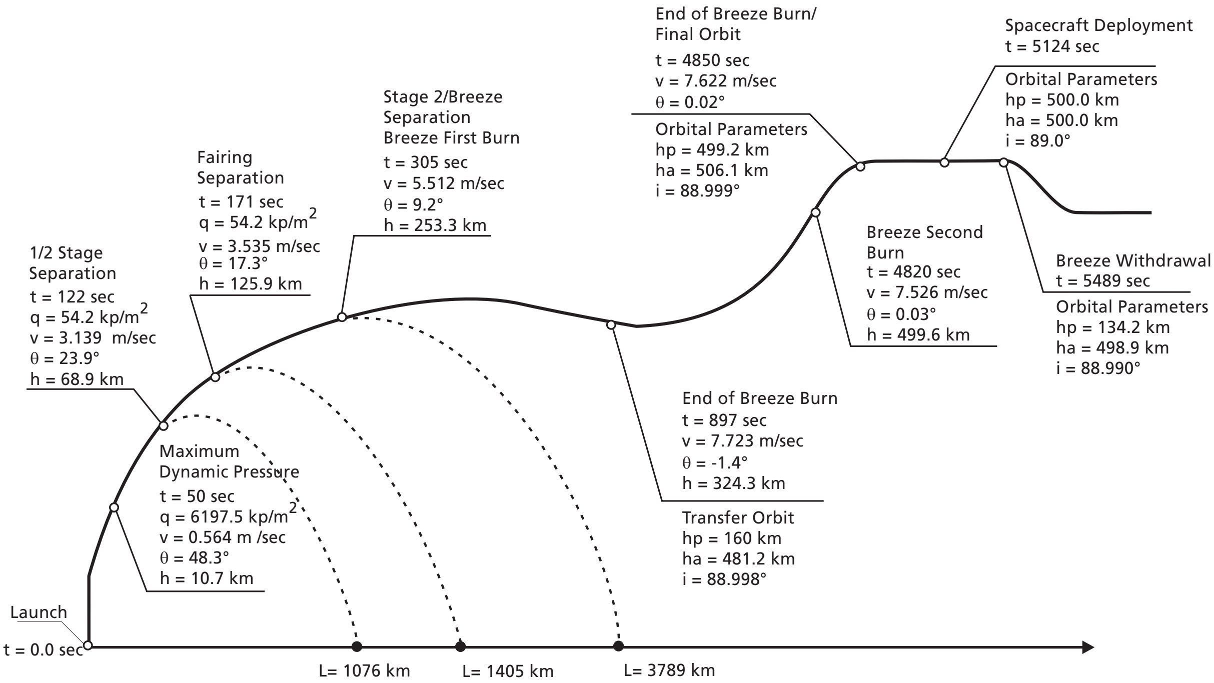

Figure 3-6: Ascent trajectory for an orbit of 500 km altitude and inclination of 89°

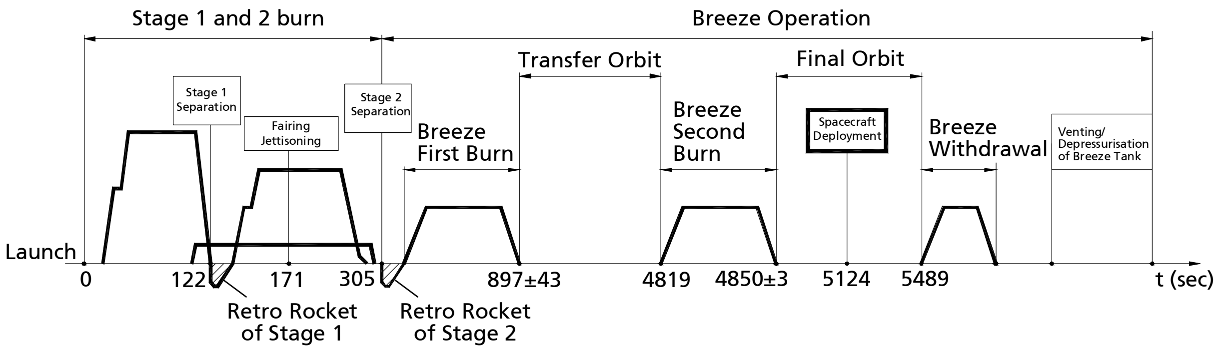

Figure 3-7: Flight sequence for the orbit of 500 km altitude and inclination of 89°

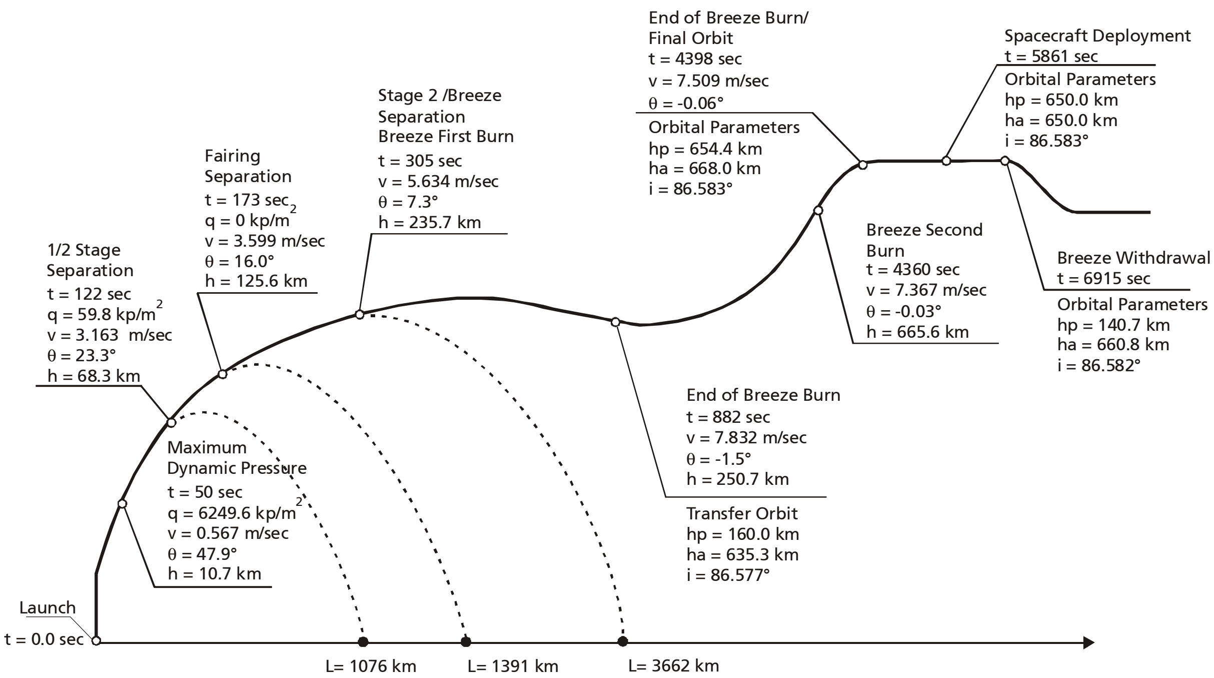

Figure 3-8: Ascent trajectory for the orbit of 650 km and inclination of 86.583°

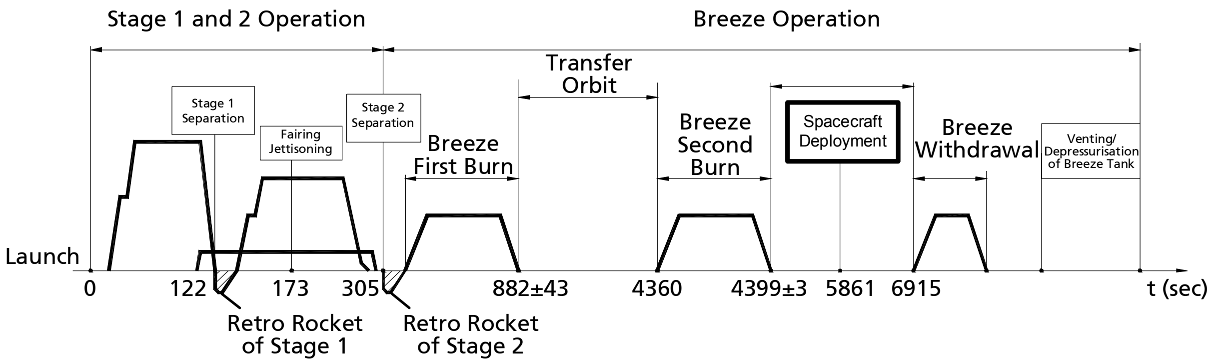

Figure 3-9: Flight sequence for the orbit of 650 km and inclination of 86.583°

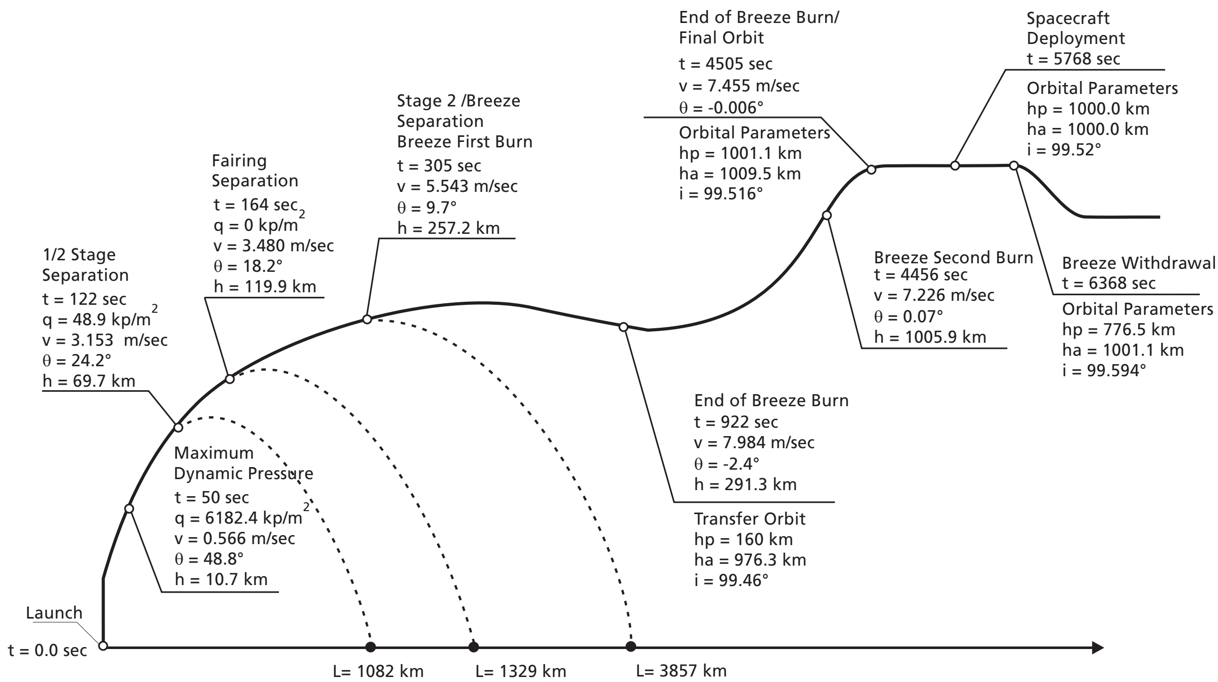

Figure 3-10:Ascent Trajectory for SSO of 1000 km altitude and inclination of 99.52°

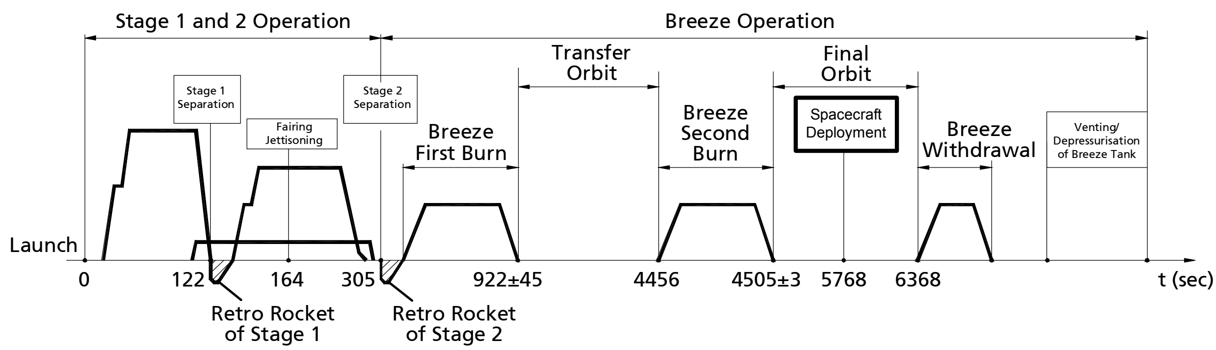

Figure 3-11: Flight Sequence for SSO of 1000 km altitude and inclination of 99.52°

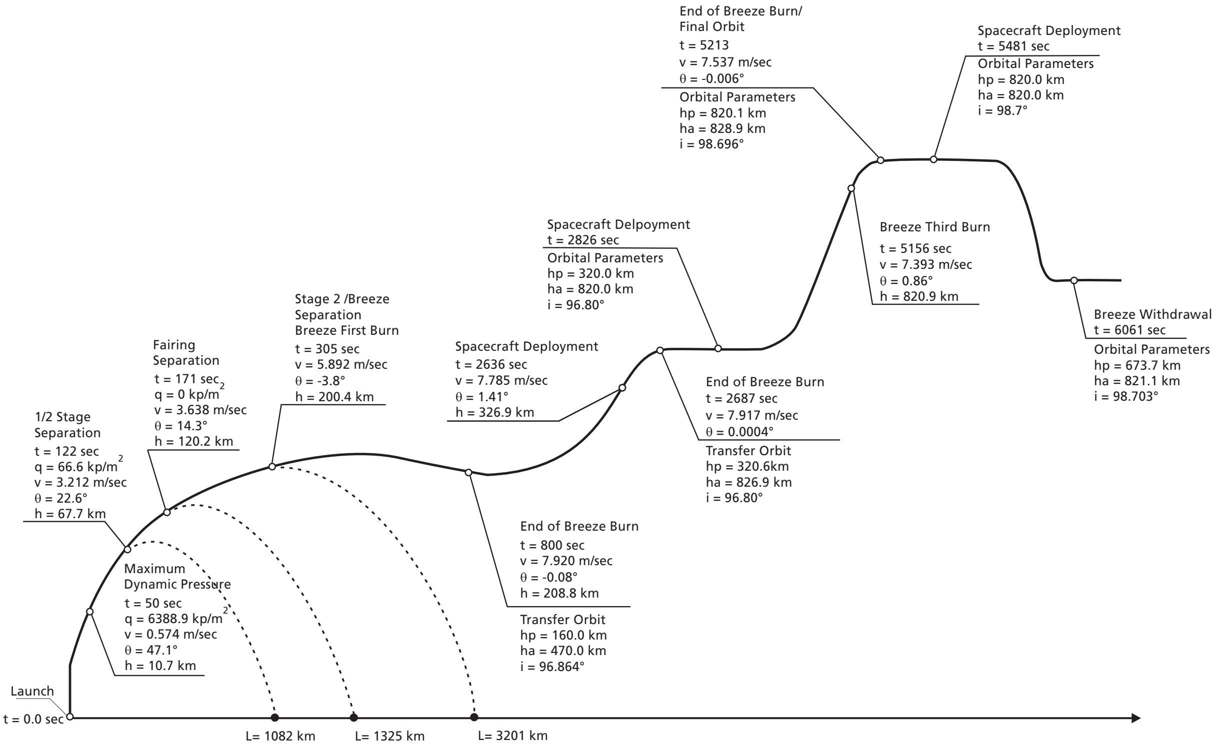

Figure 3-12: Ascent Trajectory for an elliptical orbit of 320 km perigee altitude, 820 km apogee altitude and inclination of 96.8° and SSO of 820 km altitude and inclination of 98.7°

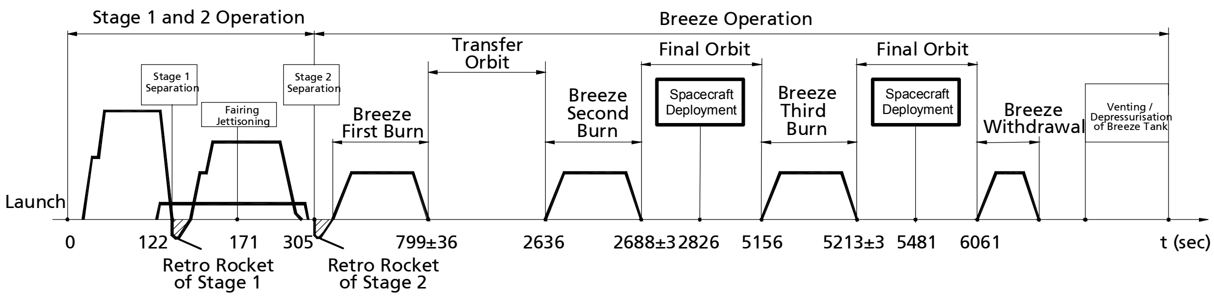

Figure 3-13: Flight Sequence for: elliptical orbit of 320 km perigee altitude, 820 km apogee altitude and inclination of 96.8° and SSO of 820 km altitude and inclination of 98.7°

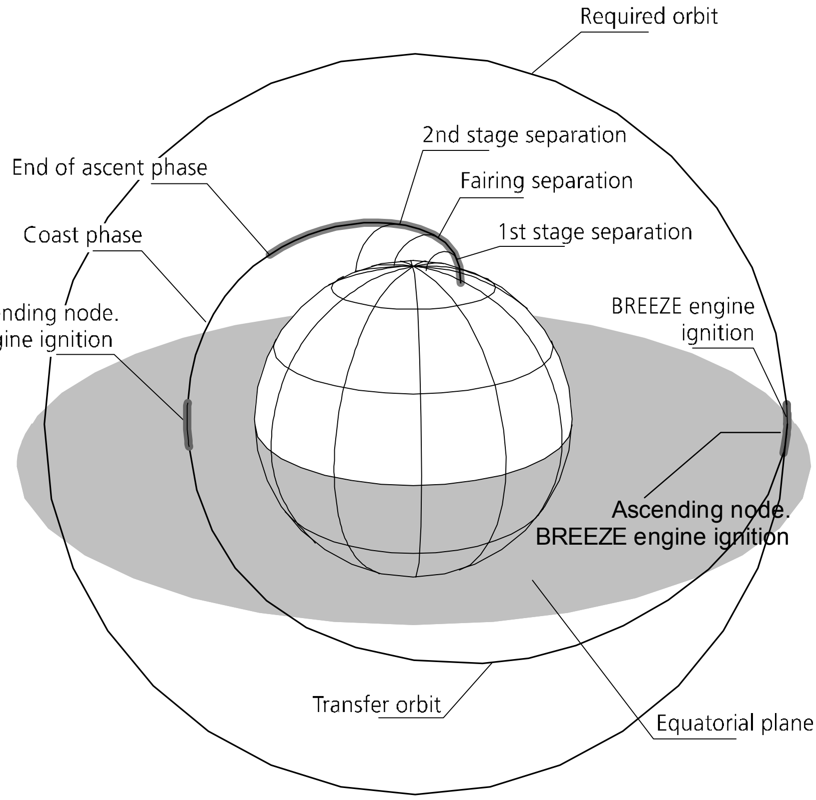

Figure 3-14: Sun-synchronous Orbit Injection Scheme

3.5 Baikonur Performance

The following section provides performance curves for *Rockot* launches from Baikonur Cosmodrome in Kazakhstan. Although *Rockot* launches have occurred in the past from Baikonur cosmodrome, it is currently no longer operational for *Rockot* launches. Activation of the site for *Rockot* requires upgrades and modifications to existing facilities which will take at least 18 months to complete. A decision for site activation will be made on a case by case basis should the need arise to use this site. 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; these cannot be efficiently reached from Plesetsk due to its northerly latitudes. Figure 3-13 depicts circular payload performance for *Rockot* from Baikonur. In all cases, approved drop zones have been taken into account. Figure 3-14 shows elliptical payload performance again using approved drop zones. In both cases the calculations use the same assumptions as used for the Plesetsk low earth orbit curves described within section 3.4, i.e. payload fairing release not before FMH is below 1135 W/m2 and using the standard *Rockot Breeze*-KM configuration. Customers are advised not to interpolate performance for inclinations not expressly shown as they are strongly dependant on the drop zones. EUROCKOT should be contacted directly in such cases.

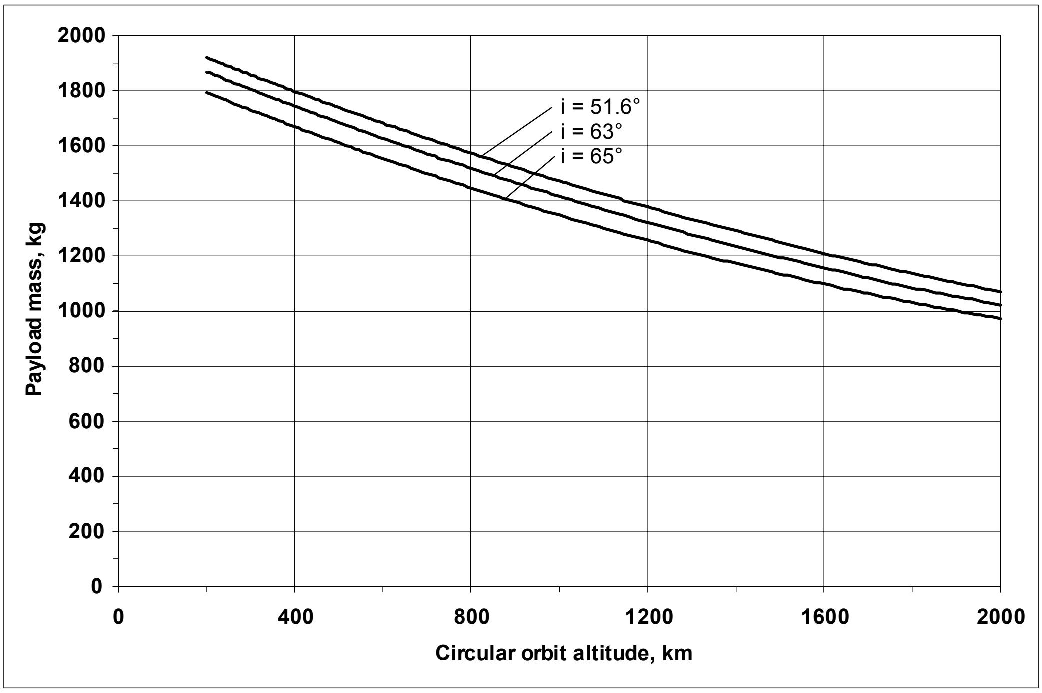

Figure 3-15: Payload Performance for Circular Orbits from Baikonur Cosmodrome

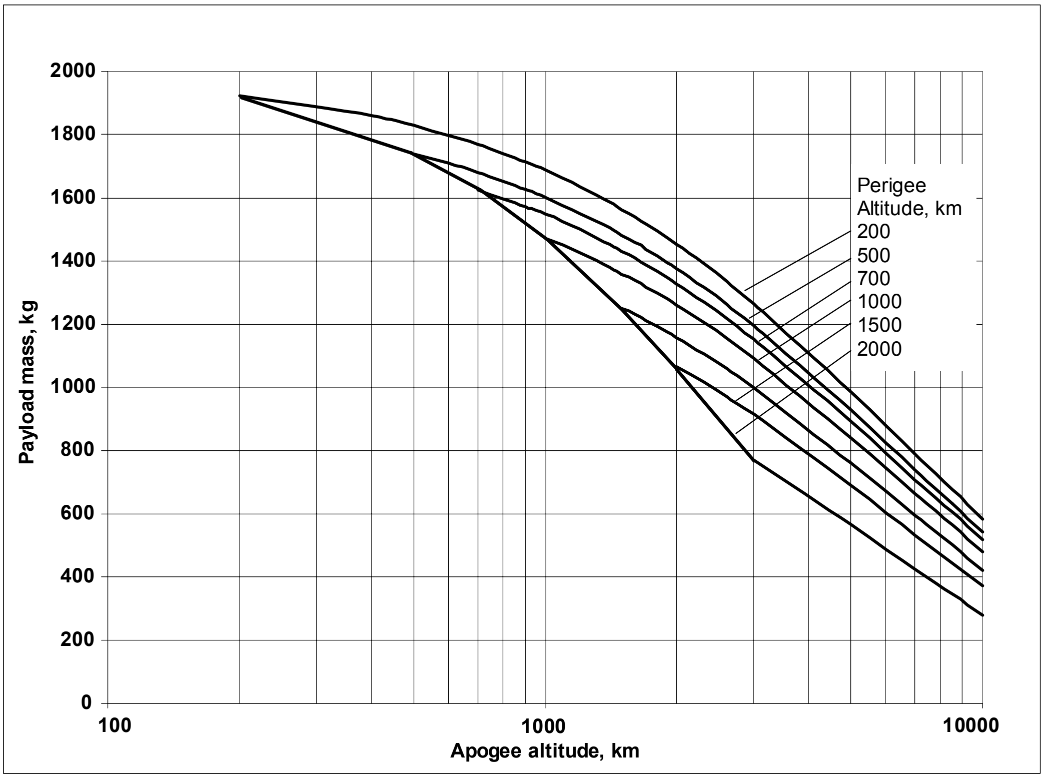

Figure 3-16: Performance for Elliptical Orbits from Baikonur Cosmodrome at i = 51.6°

3.6 Spacecraft Injection and Separation

The *Rockot*-KM, equipped with its *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* launch vehicle control system.

In particular cases by means of analysis of specific trajectory higher values of injection accuracy can be obtained than those provided in Table 3-2.

3.6.2 Separation

Spacecraft separation from *Breeze* 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 separation impulse of the payload, payload mass, moments of inertia and the *Breeze* burn-out mass and the allowable disturbances to the *Breeze* stage. Payloads can either be spun-up along the *Breeze* X-axis (longitudinal axis) or released from a three-axis stabilised upper stage. These two variations are presented below.

3.6.2.1 Spin Stabilised

Spin is performed around the longitudinal axis with in the rate of 10°/min. Higher spin rates may be considered upon Customer's request.

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

a) Payload mass distribution (MoI) and centre of mass ((CoM) constraints see Section 6.3.2) and spacecraft dynamic properties

b) 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 deployment
- other payload requirements for the *Breeze*-KM upper stage

c) Necessity to continue flight control of the upper stage after payload deployment

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

Orbital parameters error type	3-Sigma errors
Average orbital altitude	±1.5%
Inclination	±0.05°
Eccentricity	0.0025
Right Ascension of Ascending Node	±0.05°
Argument of Perigee (for elliptical orbits)	±1.0°

Table 3-2: Orbital Injection Errors

3.6.2.2 Three-Axis Stabilised

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

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

The 3-sigma attitude error along each spacecraft geometrical axis will not exceed 1.5°- 3°. The maximum angular velocities of the *Breeze*-KM / spacecraft combination prior to the payload deployment are:

ω_x = ± 1 °/sec
ω_y = ± 0.5 °/sec
ω_z = ± 0.5 °/sec

The SC separation scheme system design including the number of pushers, their allocation and energy is developed in accordance with the requirements for ensuring the SC normal operations as well as with available restrictions. The schemes are selected by the LV Contractor and agreed with the Customer.

As a possible way to reduce potential disturbances obtained by SC during separation, the following actions can be used:

- selection of pushers optimum characteristics including their energy;
- control of pusher position for compensation of side shift of SC center of mass

Besides, electrical connectors can be selected in accordance with their separation forces characteristics, and separation energy can be compensated with the help of the spring compensators mounted on the connectors.

Analysis shows that even for light SCs (having a weight of not more than 500 kg and moments of inertia of not more than 50 kg.m^2) separation, their total angular velocities ω_y and ω_z will not exceed 2.5°/sec and the longitudinal component of ω_x will not exceed 1.5°/sec, if the above methods are combined. For larger and more inertial SC the disturbance values will be less.

Note:

These values shall be considered as average ones. The actual parameters can differ from this level depending on the properties of the specific spacecraft.

The separation method can be chosen by the Customer based on available constraints and separation system requirements from the upper stage side.

3.6.2.3 Typical Multiple Satellite Deployment Scenarios

Breeze 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 3-17 shows the separation of three spacecraft sequentially, with delta-v added to each spacecraft to aid in-orbit plane phasing.

Figure 3-18 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 co-operation with the payload subcontractor and is agreed with the Customer.

Transducers to indicate the separation can be provided, as well.

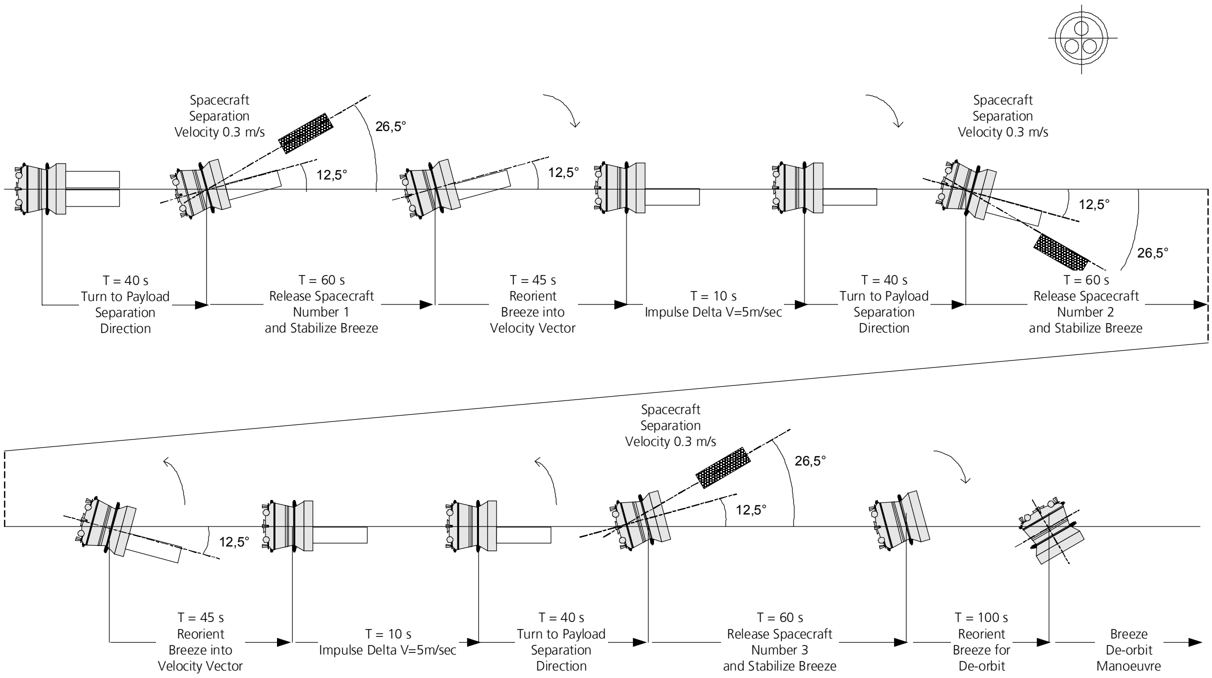

Figure 3-17:Multiple Payload Deployment Scheme

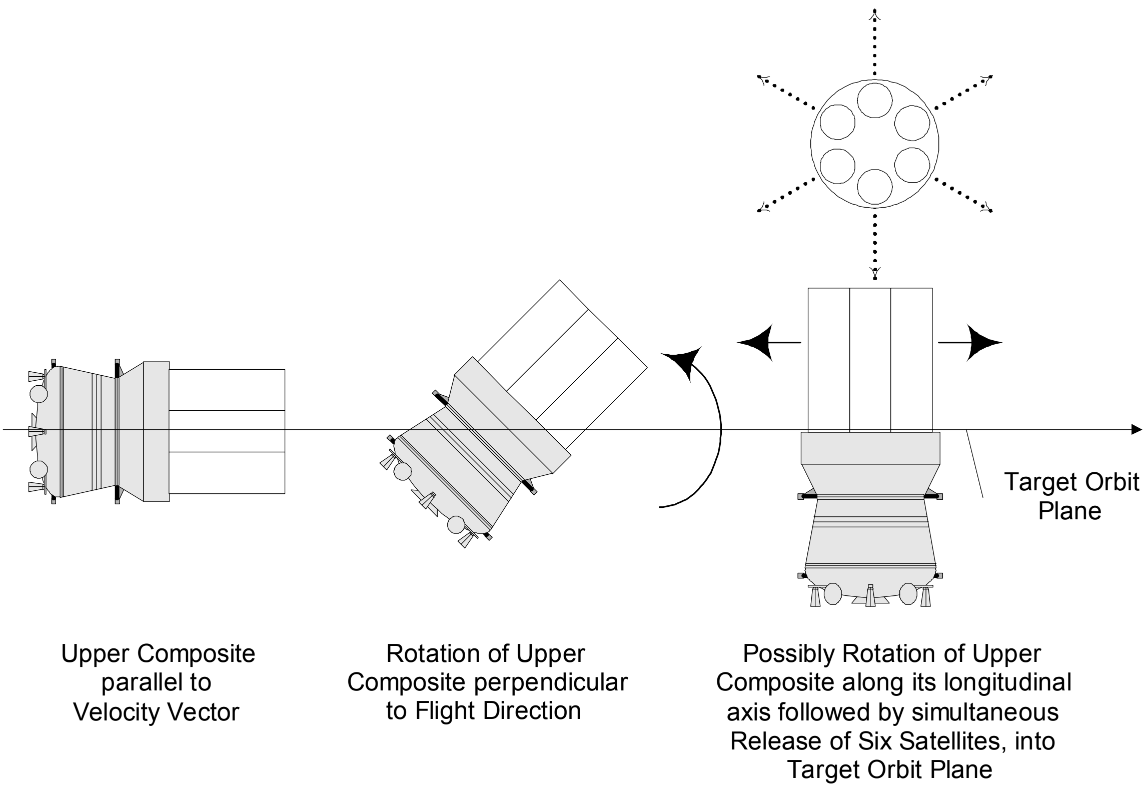

Figure 3-18: Simultaneous Deployment of Six Spacecraft