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 and drop zones. 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 third stage Breeze can serve a wide range of both circular and elliptical orbits in the range from 200 km 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 3.2-1.

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 3.2-1: Approved 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 early on in its ascent so that inclinations that lie between these allowable launch azimuths can be reached. Sometimes the dog-leg manoeuvres may result in a decrease of payload performance.

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, quick in-orbit deployment of payload 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 cruise engine ignition in 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 the cruise engine ignition in 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:

- If the required orbital altitude is lower or equal to 400 km, a so-called "direct injection" into the orbit is achieved via a single burn of *Breeze*.
- For target orbits higher than 400 km altitude, *Breeze* is fired at least twice, the first time directly after stage two separation and - after a coast phase - the stage is circularised into the target orbit altitude. For SSO injection a third burn would be used for a plane change manoeuvre, if necessary.
- All payload performances are calculated for the standard *Rockot*-KM (Commercial Modified) 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 heatflow has dropped below 1135 W/m^2.
- The performance values are based on the four *Rockot* flights as well as the over 140 SS-19 flights.

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 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 *Payload 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 orbit 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 second stage's flight allow the second stage's drop zone to be precisely positioned outside of any country's territorial waters.

The upper composite comprised of *Breeze* and the payload is then injected into a 96.1° inclined parking orbit. Finally, the target orbit inclination is reached upon a plane change manoeuvre carried out by *Breeze* main engine during 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 typical 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 engine occurs shortly before Stage 1 burn-out.

After shut down of stage 1 engine, stage 1 is separated using its retro rocket system. 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 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 cruise 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 coast phase, *Breeze* follows a Sun-oriented flight program. This cycle contains the sections, after main engine shut down: 1 hour the +X axis is oriented towards Sun and then 0.5 hour the -X axis. During the +X orientation phase, the angle between the +X axis and the direction of the Sun shall be not greater than 100 deg. During the -X orientation phase, the angle between the -X axis and the direction of 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 depending on 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).

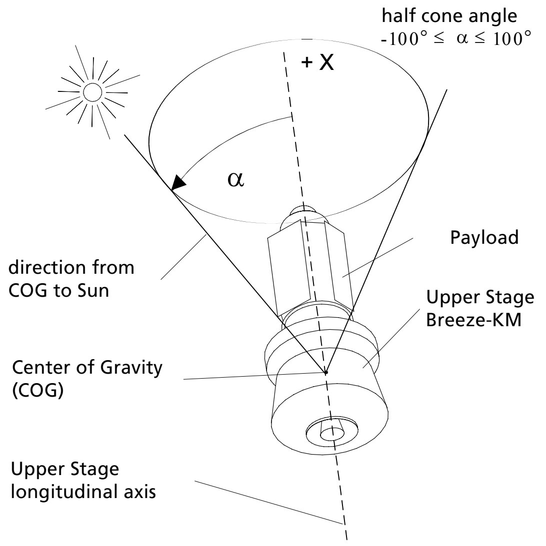

Figure 3-1 (1) : *Breeze*-KM Sun orientation during drift phase

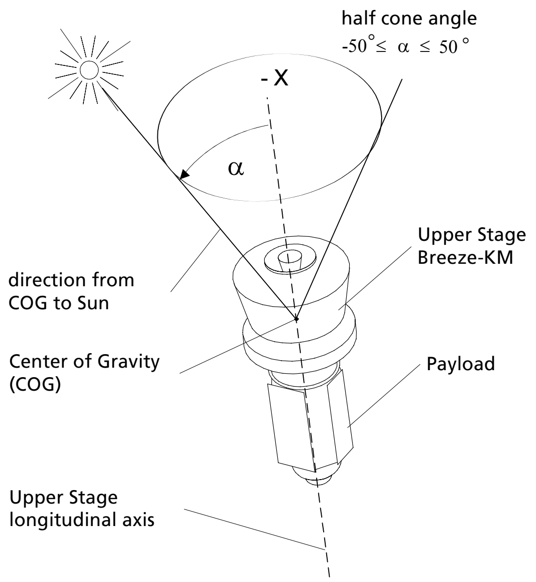

Figure 3-1 (2) : *Breeze*-KM Sun orientation during drift phase

Examples of Trajectories

Typical trajectories that achieve a 300 km circular orbit with an inclination of 63° and a 700 km circular orbit with an inclination of 63° are shown below in Figures 3-6 to 3-9 respectively. The trajectory in Figures 3-6 and 3-7 corresponds to a one-impulse injection scheme whereas the trajectory in Figures 3-8 and 3-9 corresponds to a two-impulse injection scheme. Shown in the figures are the major ignition, separation and burn-out events and the main trajectory characteristics, such as:

- time counted from launch (t, sec.)
- relative velocity (v, m/sec.)
- relative flight path angle (Q, deg)
- total pressure (q, Pa)
- altitude (h, km)

Figures 3-6 to 3-11 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 activities of the various stages.

Figures 3-10, 3-11 and 3-12 show a trajectory and flight sequence that achieves a Sun-Synchronous Orbit (SSO). Note the use of the restartable *Breeze* engine to reach the final orbital parameters.

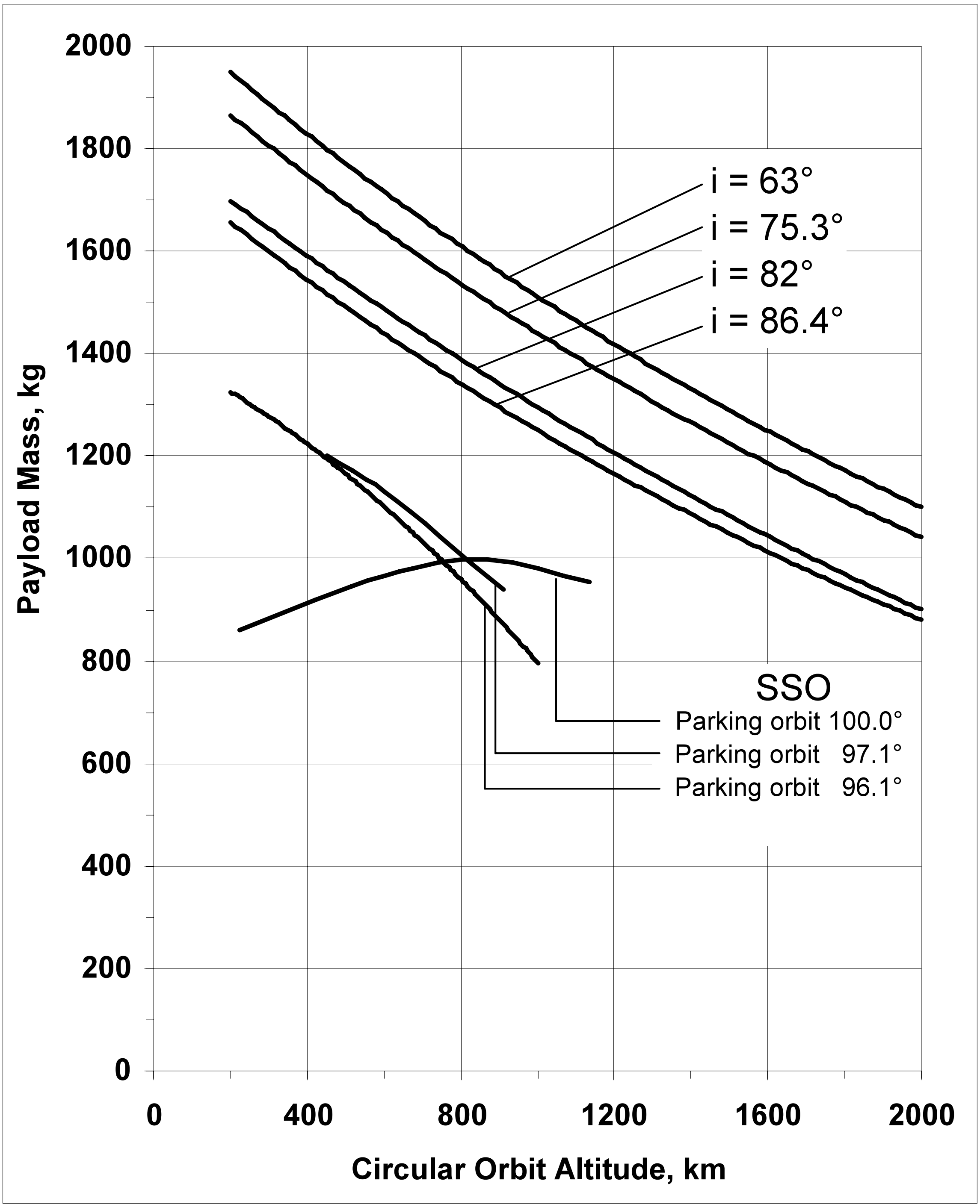

Figure 3-2: Performance Capabilities for Circular Orbits

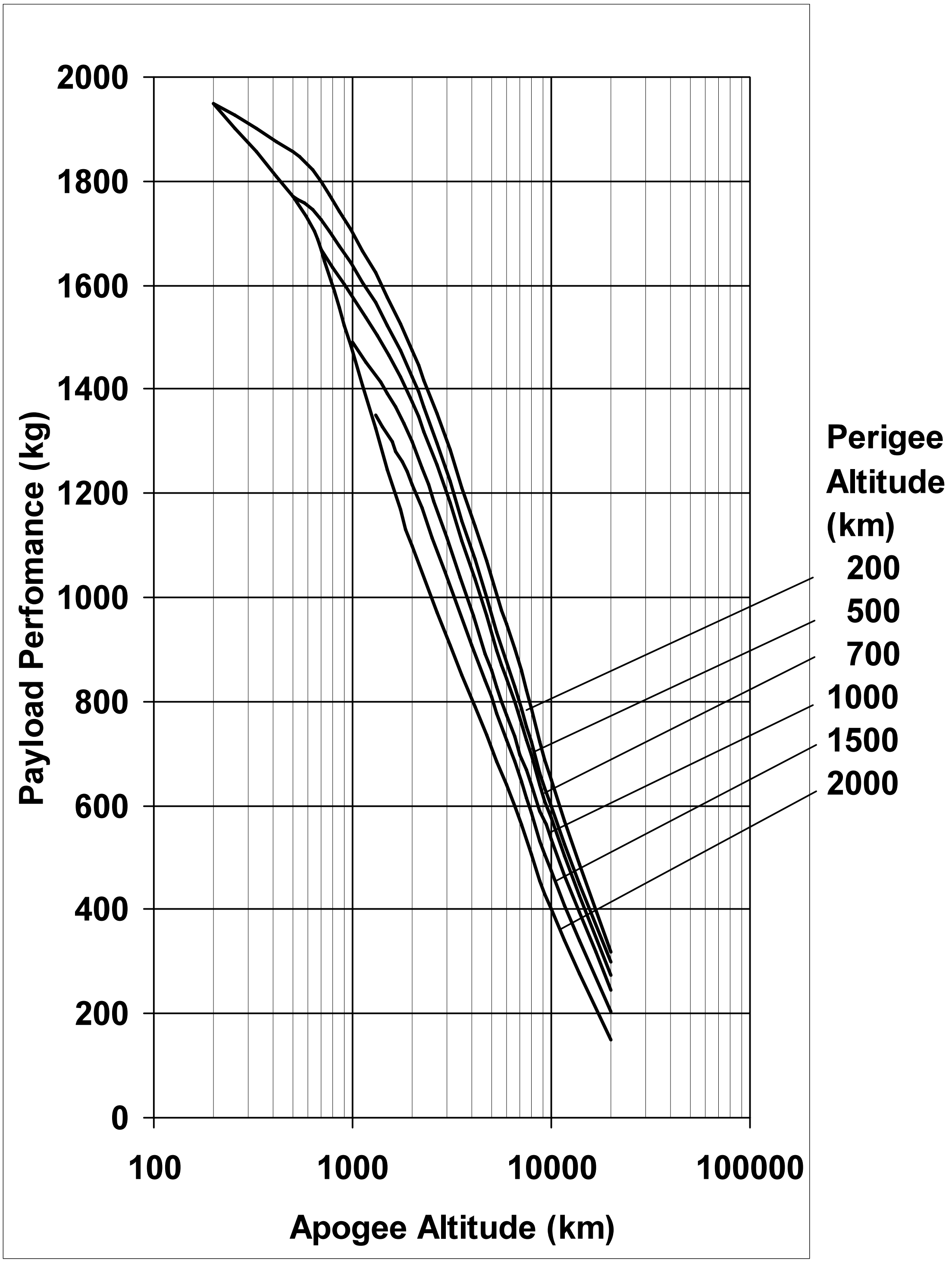

Figure 3-3: Performance for Elliptical Orbits at i = 63°

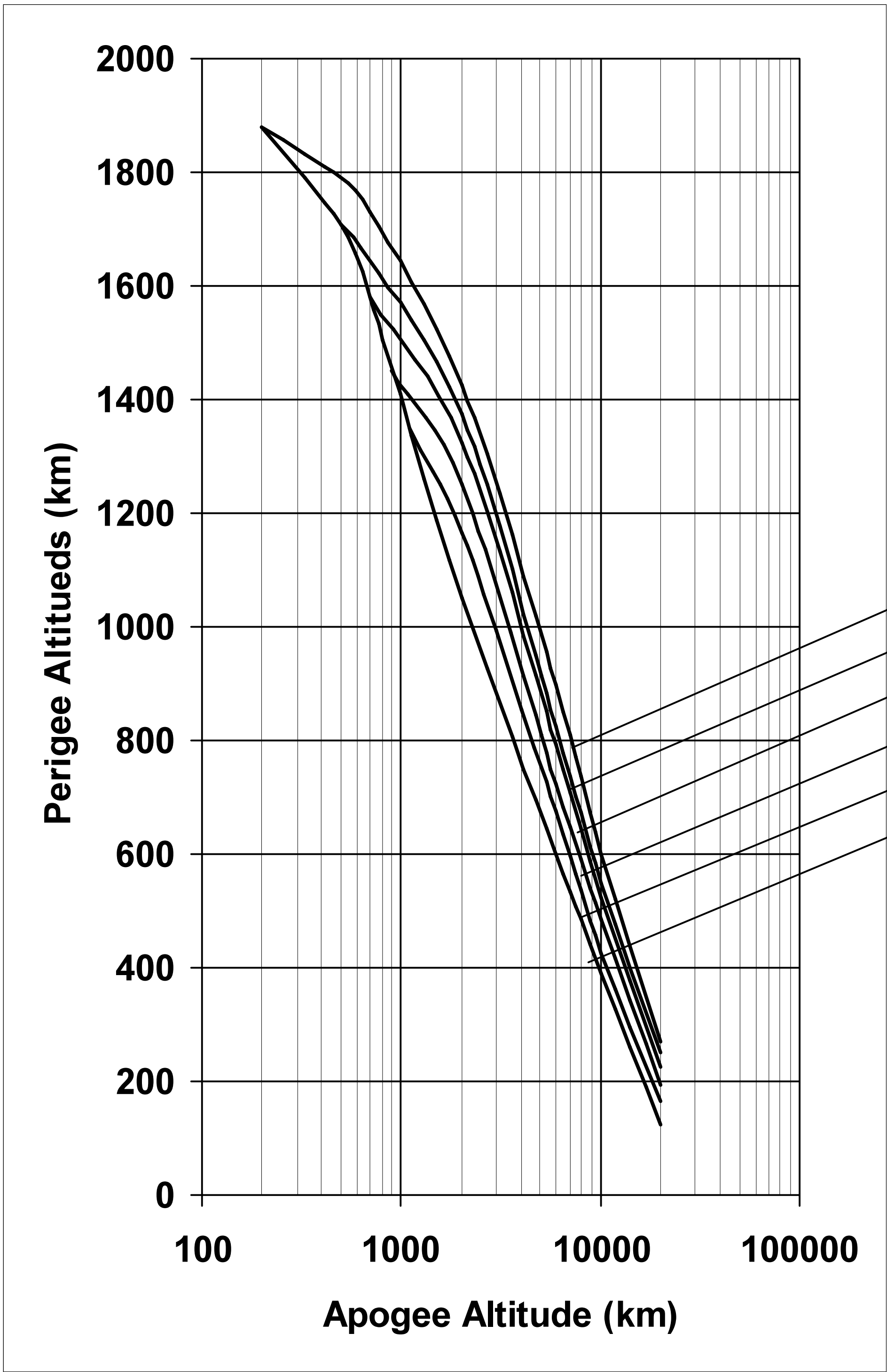

Figure 3-4: Performance for Elliptical Orbits at i = 75.3°

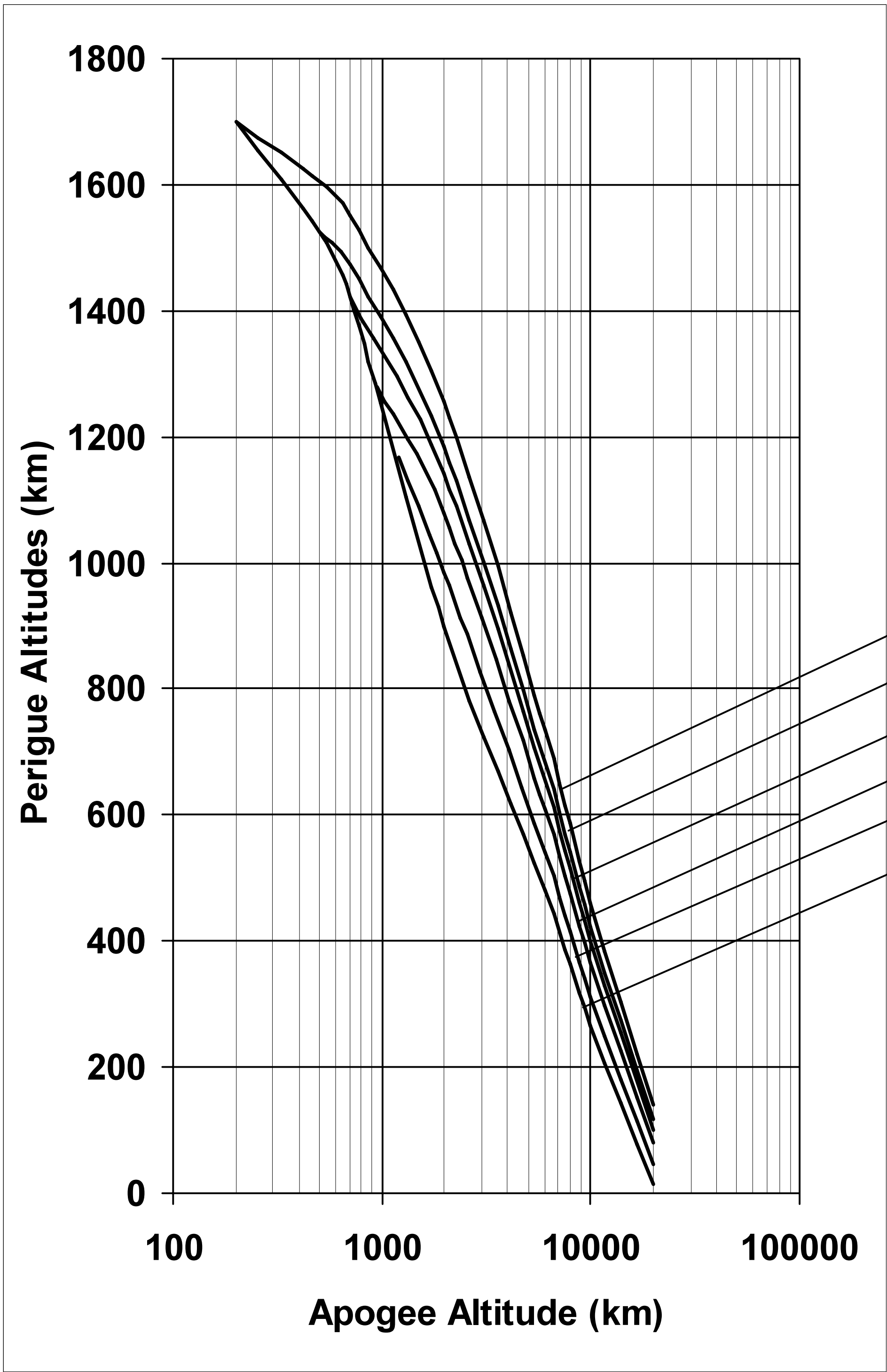

Figure 3-5: Performance for Elliptical Orbits at i = 82°

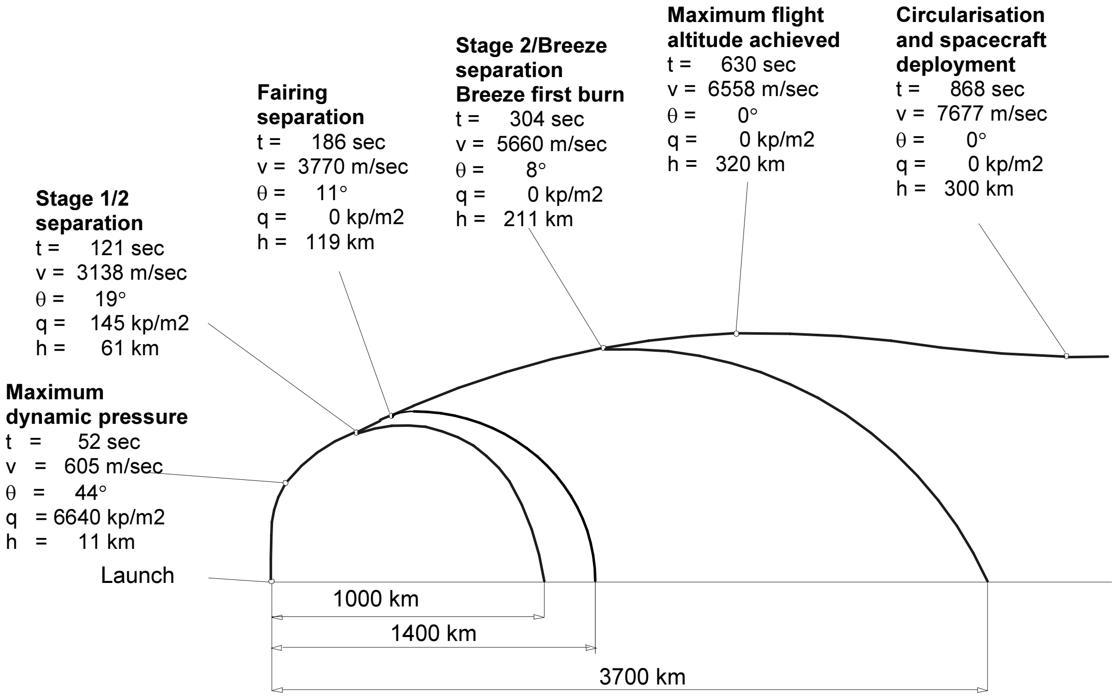

Figure 3-6 Ascent trajectory for LEO 300 km

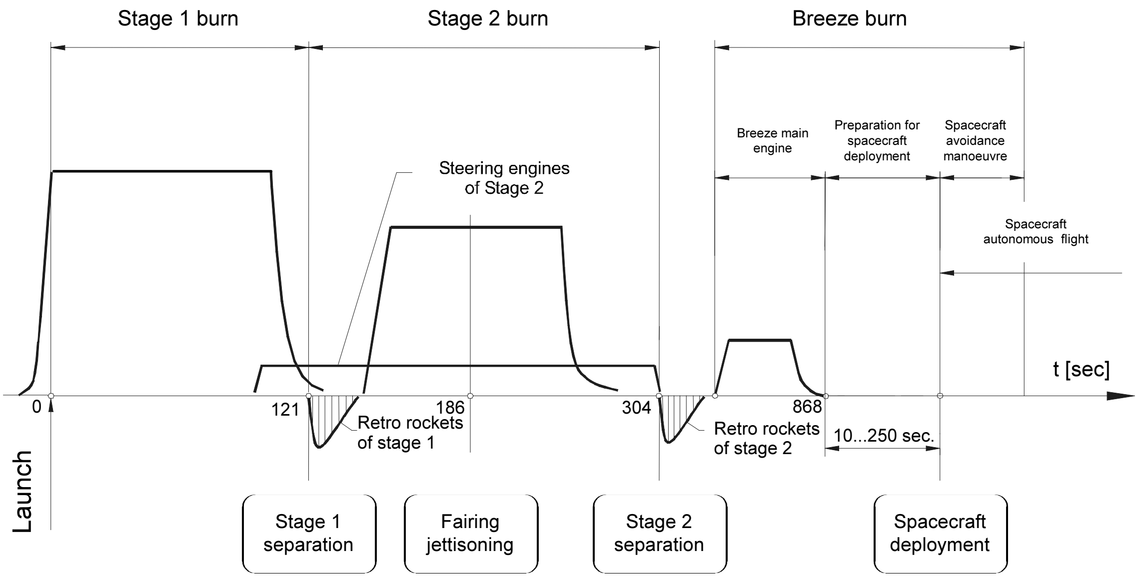

Figure 3-7 : Flight sequence for LEO 300 km

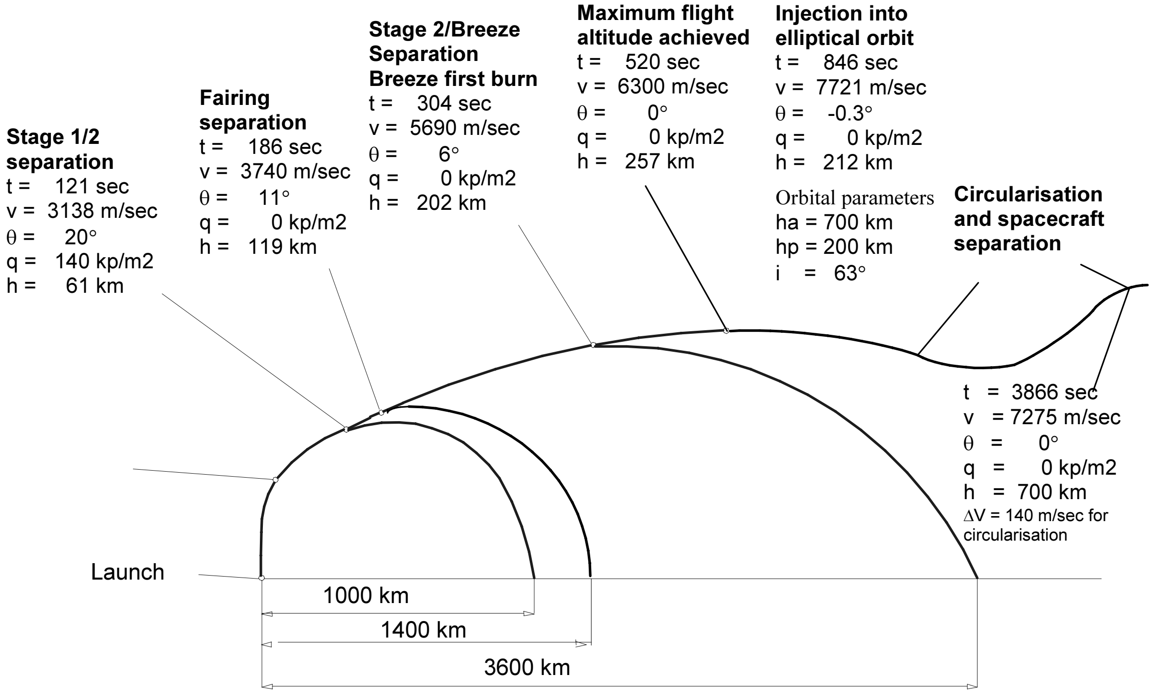

Figure 3-8 : Ascent trajectory for LEO 700 km

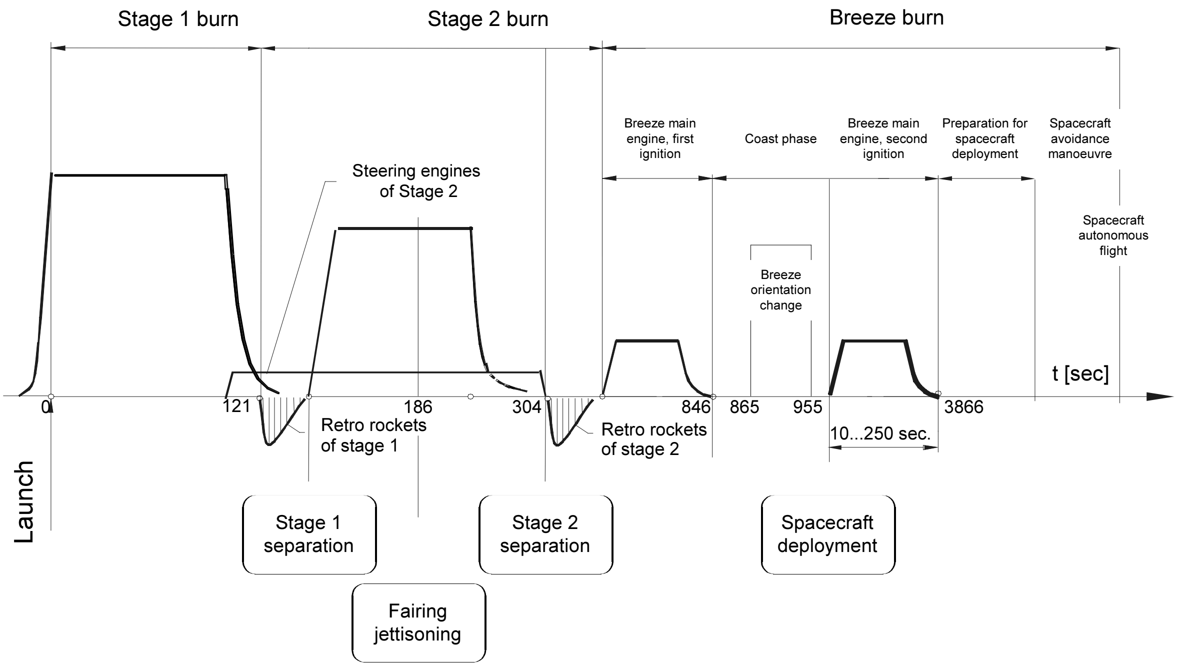

Figure 3-9 : Flight sequence for LEO 700 km

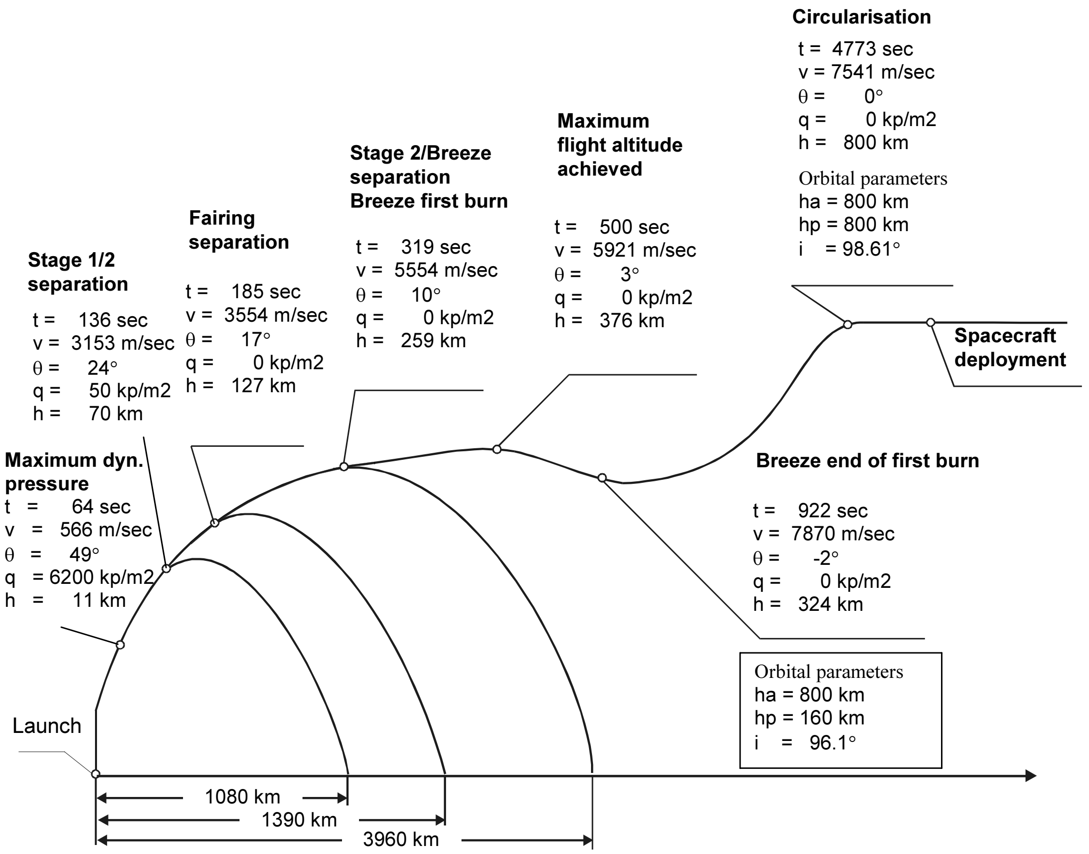

Figure 3-10: Ascent Trajectory for a 800 km/98.6 deg inclined SSO

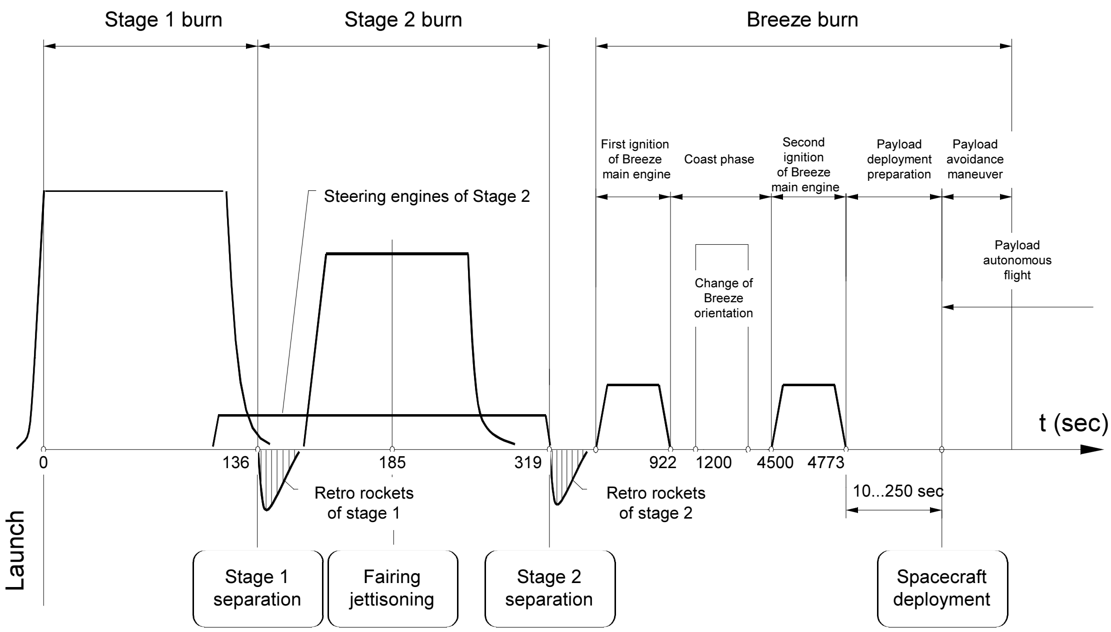

Figure 3-11: Flight Sequence for a 800 km/98.6 deg inclined SSO

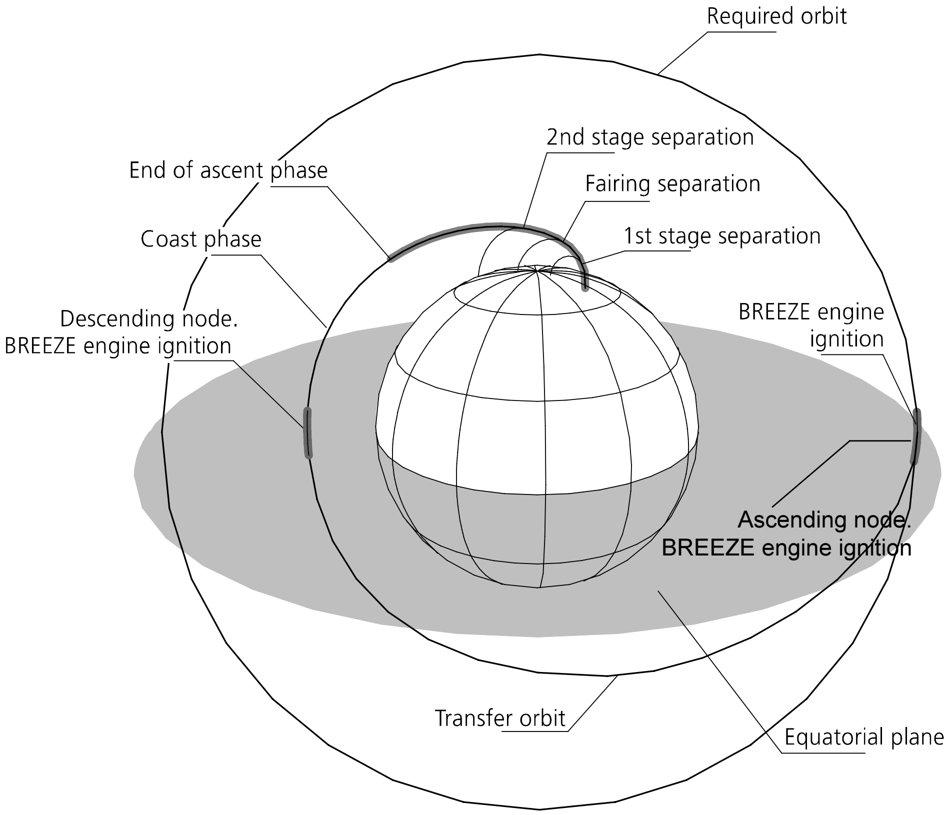

Figure 3-12 : Sun-synchronous Injection Scheme

3.5 *Baikonur Performance*

The following section provides performance curves for Rockot launches from Baikonur Cosmodrome in Kazachstan. 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/m^2 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.

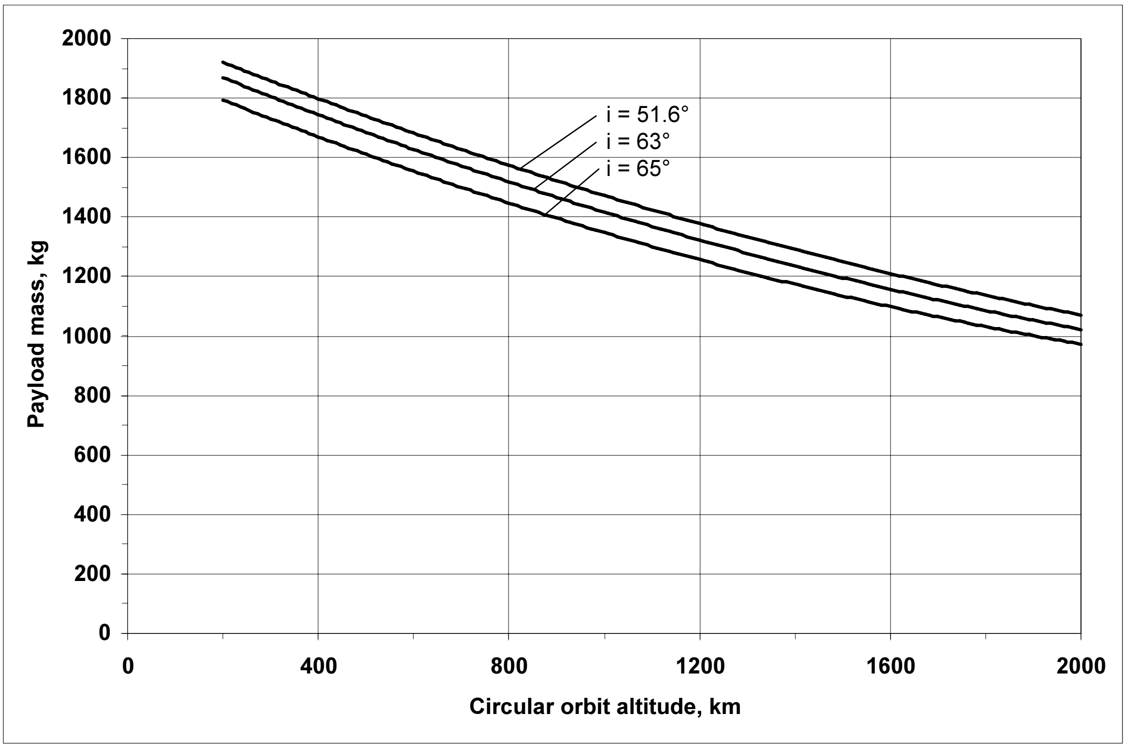

Figure 3-13: Payload Performance for Circular Orbits from Baikonur Cosmodrome

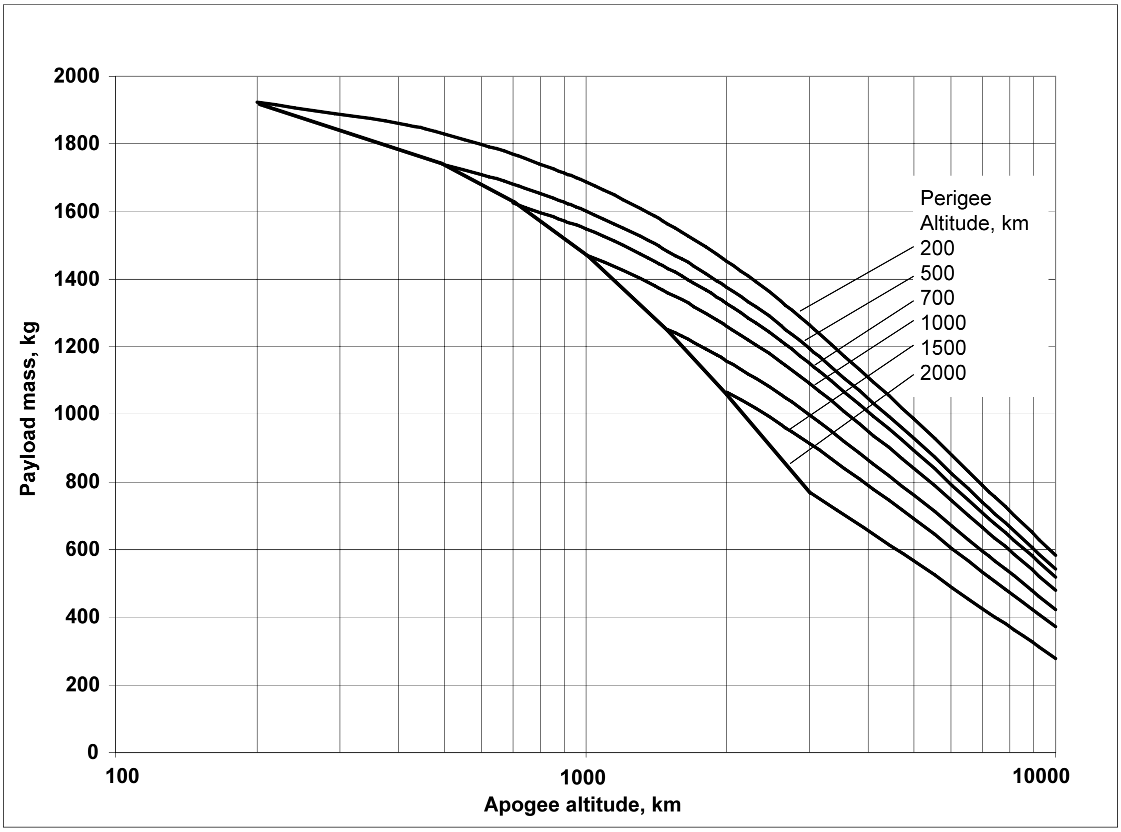

Figure 3-14: Payload Performance for Elliptical Orbits from Baikonur Cosmodrome

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 3.6-1 provides 3-sigma orbital injection errors for two reference circular orbits:

Orbit 1: 300 km orbital altitude single-impulse injection scheme (direct injection)

Orbit 2: 700 km orbital altitude two-impulse injection scheme (injection with coast phase)

Injection accuracy for SSO orbits are typically within the values quoted for the orbit 2 case. It should be noted that these values are generic in nature; in specific cases dedicated mission analysis should reveal accuracies lower than those quoted here. Typically the error for the injection accuracy of the longitude of the ascending node (all orbits) is less than 4 arc minutes.

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 spacecraft separation system (e.g. spring constants of spring pushers, type of release mechanism), the direction of separation impulse on the payload, payload mass, mass distribution and the *Breeze* burnout 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 *Breeze* stage. These two variations are presented below.

3.6.2.1 Spin Stabilised

Spin is performed around the longitudinal axis within 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 depending on:

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

Error Type	**Orbit 1**	**Orbit 2**
Orbital altitude	± 1%	± 2%
Inclination	± 0.03°	± 0.05°

Table 3.6-1: Orbital injection errors

b) Customer requirements for the spin regime:

- 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. The *Breeze*-KM finally vents all its tanks to end the mission.

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° for orbit 1, 3° for orbit 2. 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 including the pushers number, allocation and energy are 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 uesd:

- selection of pushers per their characteristics including controlled power intensity
- 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 force characteristics, and separation energy can be compensated with the help of the spring compensators on the connectors.

Analysis shows that even for light SC's (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 a middle level. The actual parameters can differ from this level for each specific SC. They can be more or less than this level.

The spacecraft separation method will be chosen by the Customer based on available constraints and separation system requirements.

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. Depicted in the figures below are two typical payload deployment schemes.

Figure 3-15 shows the separation of three spacecraft sequentially, with delta-v added to each spacecraft to aid in-orbit plane phasing.

Figure 3-16 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 measure the separation forces can be provided, as well.

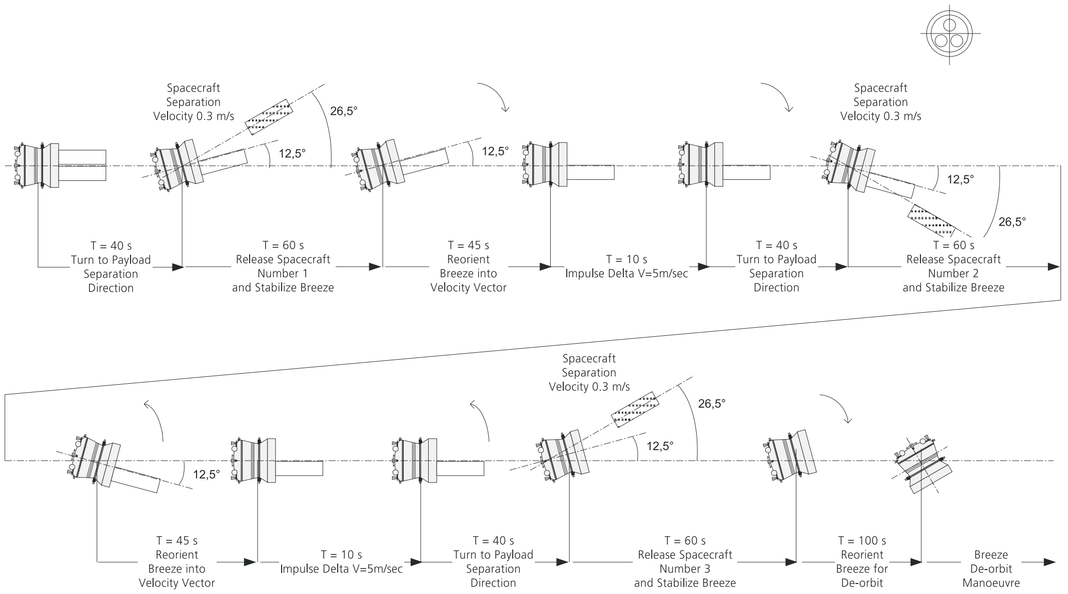

Figure 3-15 : Multiple Payload Deployment Scheme

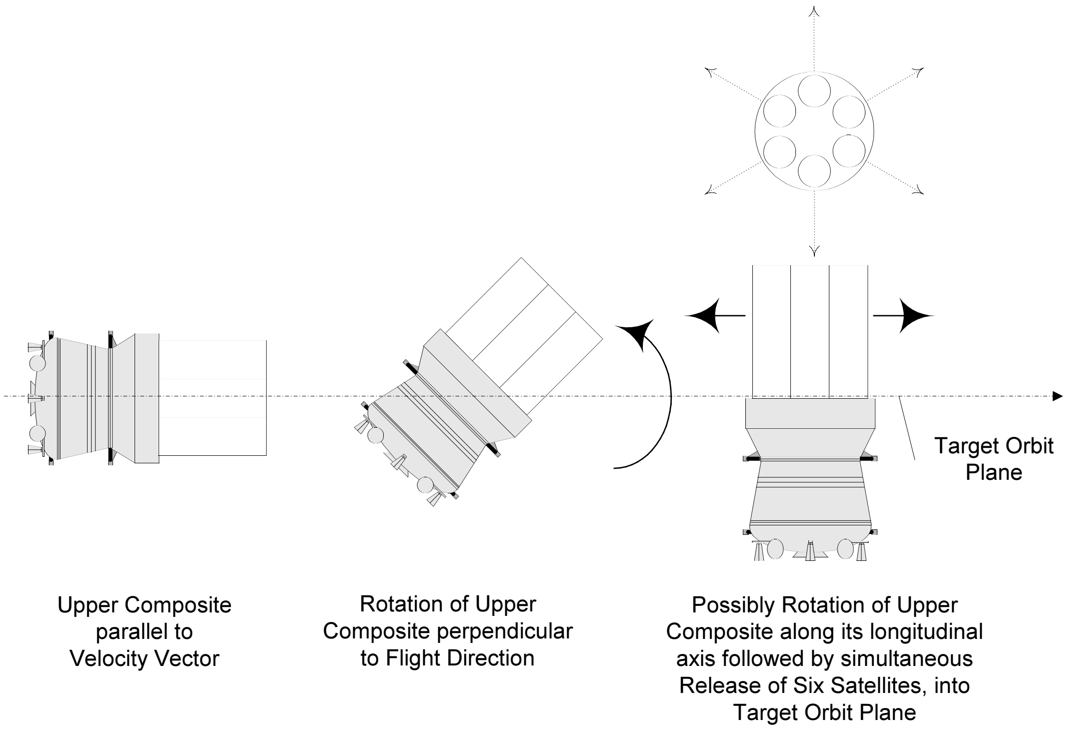

Figure 3-16 : Simultaneous Deployment of Six Spacecraft