Proton Launch System Mission Planner's Guide

SECTION 2

LV Performance

2. LV PERFORMANCE

2.1 OVERVIEW

This section provides the information needed to make preliminary performance estimates for the Proton M launch vehicle and the Breeze M, into a variety of mission orbits. It is organized so as to provide the user with essential background mission planning information; detailed performance tables and charts follow the text material.

Trajectory profile and operational mission characteristics are provided in the first sections of the chapter. Mission performance data, guidance accuracy data, and Breeze M attitude control capabilities are found in the last half of this section. Performance information is provided in terms of Payload Systems Mass (PSM), which includes the SC mass and the mass of the separation system and payload adapter (PLA).

2.2 PROTON LAUNCH SYSTEM CAPABILITIES

The Proton has been operational since 1970 (pre-1970 launches were considered developmental), and as of 31 July 2009 has carried out more than 323 operational launches. The Proton has achieved a historical success rate of 96.5%. The Proton M and Breeze M are used to conduct all commercial launch missions, as well as a significant number of missions for the Russian government.

The Proton M completed development and was first launched in April 2001. Although identical in outward appearance to the Proton K, it incorporates improvements to the avionics and structures of the first three stages. It also incorporates improved RD-276 first stage engines that have been flying since 2007. The Breeze M storable propellant Upper Stage offers enhanced performance and operational capability, as described in Section 1. As of 31 July 2009, the Breeze M has flown successfully 30 times. Table 2.2-1 summarizes performance for Proton M and Proton M Breeze M to a range of mission orbits.

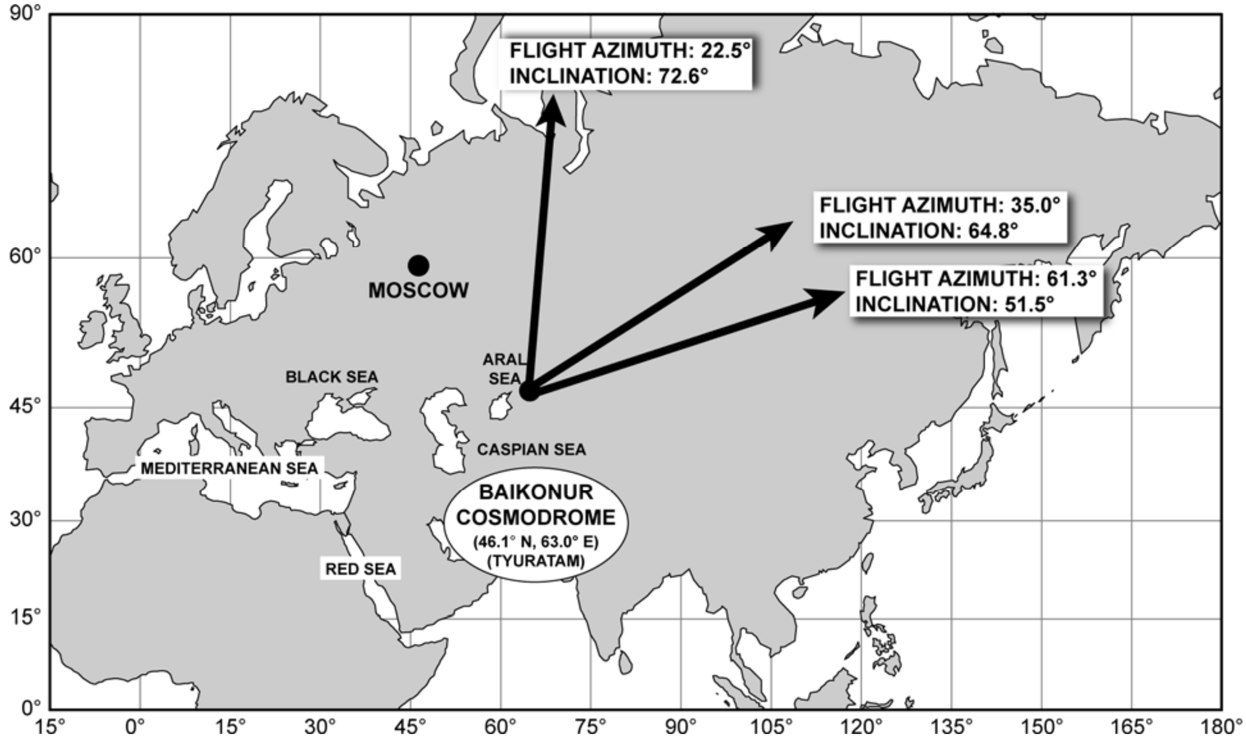
Table 2.2-1: Summary Proton M Performance (PSM) to Reference Orbits

Mission	Proton M (3-Stage)	Proton M/Breeze M (4-Stage)
Circular LEO with altitude H = 180 km • i = 51.5° • i = 64.8° • i = 72.6°	 23.0 MT 22.0 MT 21.0 MT	—
GSO i = 0°, H = 35,786 km circular	N/A	3250 kg
GTO (1500 m/s to GSO) i = 23.2°, Hp = 4120 km, Ha = 35,786 km	N/A	6150 kg
GTO (1800 m/s to GSO) i = 31.1°, Hp = 2175 km, Ha = 35,786 km	N/A	6920 kg

2.2.1 The Baikonur Launch Site

The Proton launch complex, located at the Baikonur Cosmodrome, consists of SC and LV processing and integration facilities and two launch pads available for commercial use. Baikonur, shown in Figure 2.2.1-1, is approximately 2,000 km (1,300 miles) southeast of Moscow in the Republic of Kazakhstan. The Baikonur Cosmodrome measures approximately 90 km east-to-west, and 75 km north-to-south. Proton M LV launch inclinations of 51.5º, 64.8º, and 72.6º are standard inclinations from the Baikonur Cosmodrome.

Figure 2.2.1-1: The Baikonur Launch Site Showing Available Proton M LV Parking Orbit Inclinations



2.2.2 Launch Availability

The Proton launch system is designed to operate under the environmental conditions encountered at Baikonur (Table 2.2.2-1). The Proton can be launched year round, and the time between launches from an individual pad can be as short as 25 days. Proton has demonstrated a launch rate of four per month from multiple launch pads, and a long-term average launch rate of approximately twelve per year. The capability of the Proton system to launch in severe environmental conditions decreases launch delays and ensures that payloads reach orbit as scheduled to begin revenue-generating activities. The short turnaround time between launches can ensure that SC constellations are deployed quickly, minimizing the time required to enter service.

Table 2.2.2-1: Launch Constraints

Temperature	-40°C to 45°C
Maximum Launch Ground Winds (Standard Commercial PLF)	16.5 m/s
Times	Launches available year round
Turn Around Times	25 days per pad
Number of Pads	2 commercial

2.2.3 Breeze M Upper Stage Capabilities

The main engine of the Breeze M can be started up to eight times in flight and allows the stage to offer high precision placement of the SC into orbit. With storable propellant, Breeze M orbital lifetime is limited only by available on-board battery power and is currently 11 hours from LV lift-off to SC separation. The jettisonable Auxiliary Propellant Tank (APT) offers significant mission design flexibility and enables launch services to be offered for low and high energy orbit delivery requirements.

2.3 PROTON ASCENT PROFILE

2.3.1 Proton Booster Ascent

The Proton LV uses a standard ascent trajectory to place the Orbital Unit (OU), which includes the Breeze M, PLA and SC, into a 170 km to 230 km (92 nmi to 124 nmi) low-earth circular parking orbit inclined at 51.5º after the first Breeze M engine firing. A standard ascent trajectory is required to meet jettisoned stage and payload fairing (PLF) impact point constraints. The use of a standard ascent trajectory also simplifies lower ascent mission design and related analysis, thereby increasing system reliability. Once the OU is in the standard parking orbit the SC can be transferred to its target orbit by the Breeze M.

Table 2.3.1-1 lists the time of occurrence for major ascent events for a typical launch. Figure 2.3.1-1 pictorially illustrates a typical Proton ascent into the standard parking orbit and subsequent Breeze M flight to the target orbit.

At approximately T-1.75 s, the six Stage 1 RD-276 engines are commanded to start at 40% of full thrust. Full thrust is commanded at T-0.15 s. Lift-off confirmation is signaled at T+0.5 s. The staged ignition sequence allows verification that all engines are functioning nominally before being committed to launch. The LV executes a roll maneuver beginning at T+10 s to align the flight azimuth to the desired direction.

Stage 2's three RD-0210 and one RD-0211 engines are commanded to ignite at 119 s and are commanded to full thrust when Stage 1 is jettisoned at 123 s. Stage 3's vernier engines are ignited at 332 s followed by Stage 2 shutdown at 334 s.

Stage 2 separation occurs after six small, solid retro-fire motors are ignited at 335 s into flight. Stage 3's single RD-0213 main engine is ignited at 338 s. PLF jettison typically occurs at 348 s into flight, depending on SC heating constraints. The Stage 3 main engine burns until shutdown at 576 s. The four vernier engines burn for an additional 12 s and are shutdown at 588 s.

The Stage 3 retro-fire motors are ignited and Stage 3 is separated from the Breeze M or SC. Figure 2.3.1-2 shows ascent ground track and jettison points, and ground tracking station acquisition times. Figure 2.3.1-3 shows the times and values for the vehicle's inertial velocity, altitude, longitudinal acceleration, and dynamic pressure ($\bar{q}$).

Table 2.3.1-1: Standard LV Ascent Event Times

Event Description	Event Time (sec)
Command ignition sequence start	-3.10
Stage 1 ignition to 40% (initial) thrust	-1.75
Command Stage 1 to full thrust	-0.15
Lift-off (lift-off contact signal)	0.00
Maximum dynamic pressure	65.5
Stage 2 ignition	119.0
Stage 1 / 2 separation	123.4
Stage 3 vernier engine ignition	332.1
Stage 2 engine shutdown	334.5
Stage 2 / 3 separation	335.2
Stage 3 main engine ignition	337.6
PLF jettison	348.2
Stage 3 main engine shutdown	576.4
Stage 3 vernier engine shutdown	588.3
Stage 3 / OU separation	588.4

Figure 2.3.1-1: Typical Proton M LV Ascent Plus Breeze M Main Engine Burns

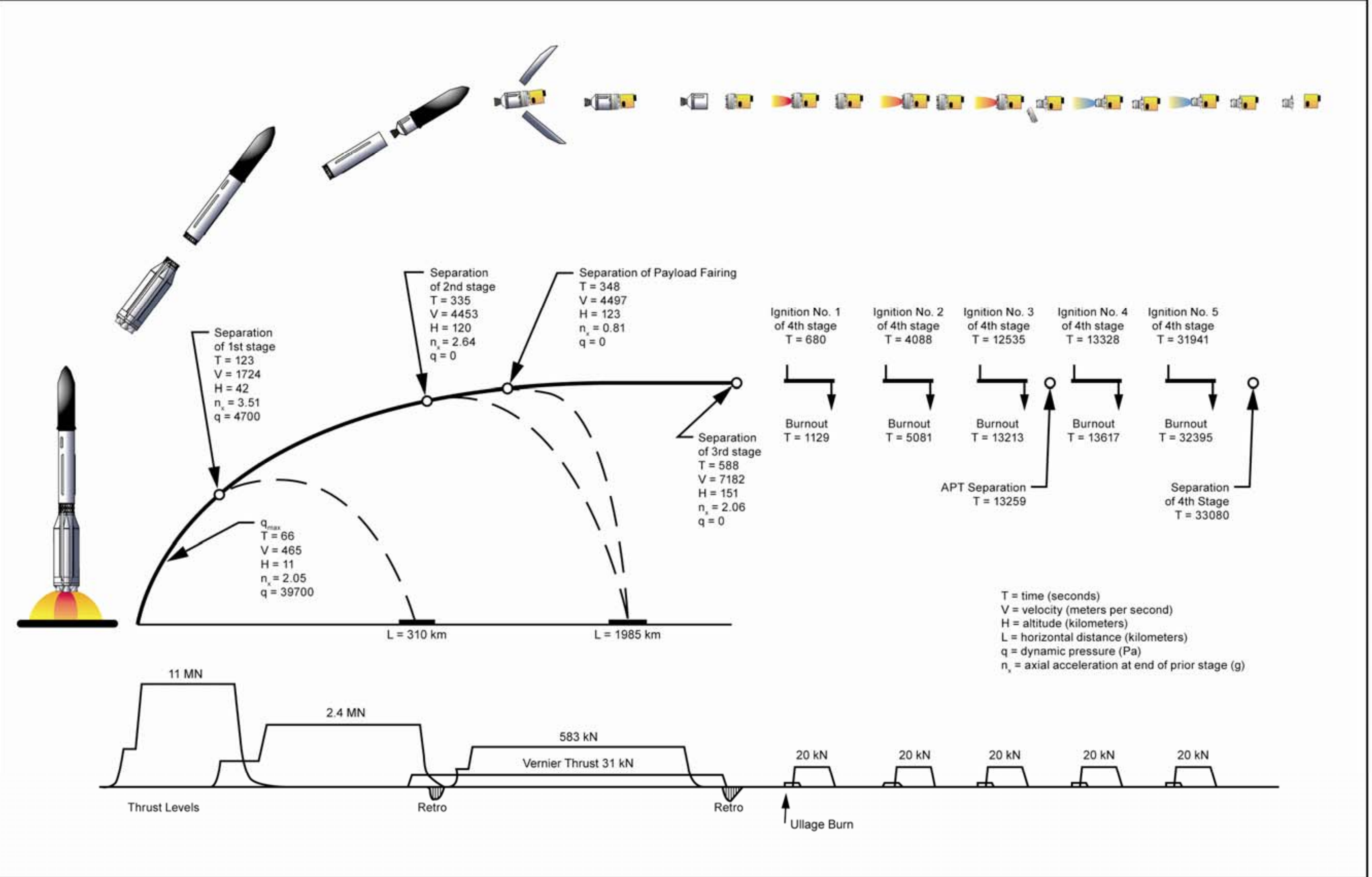
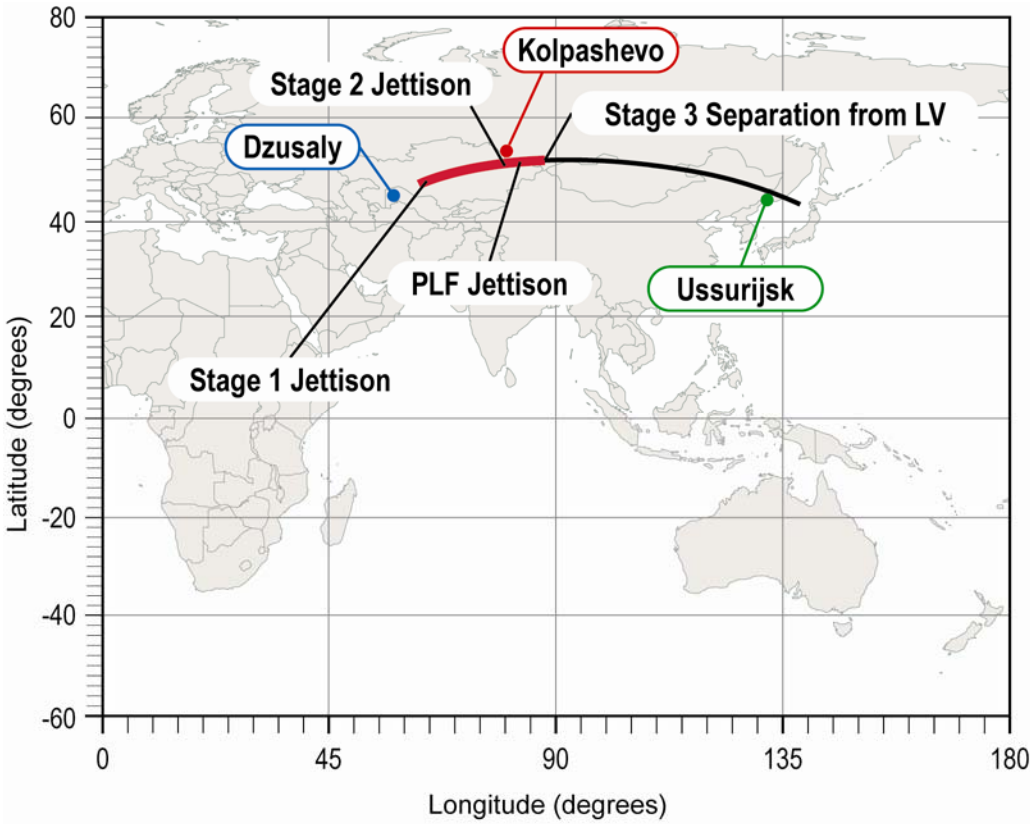


Figure 2.3.1-2: Standard Proton M LV Ascent Ground Track and Jettison Points, and Ground Tracking Station Acquisition Times for Proton M Ascent



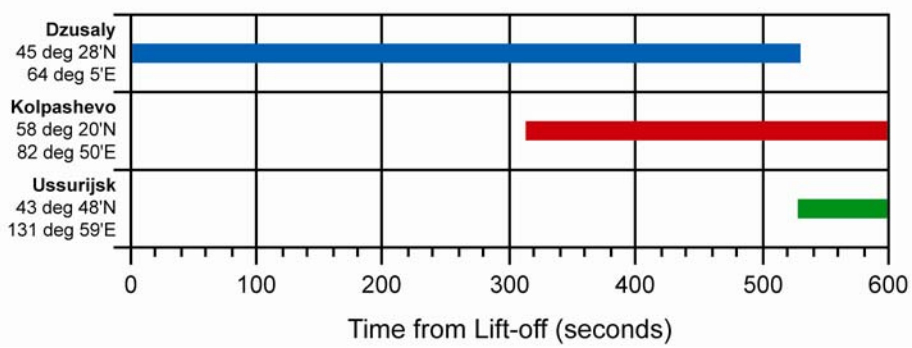
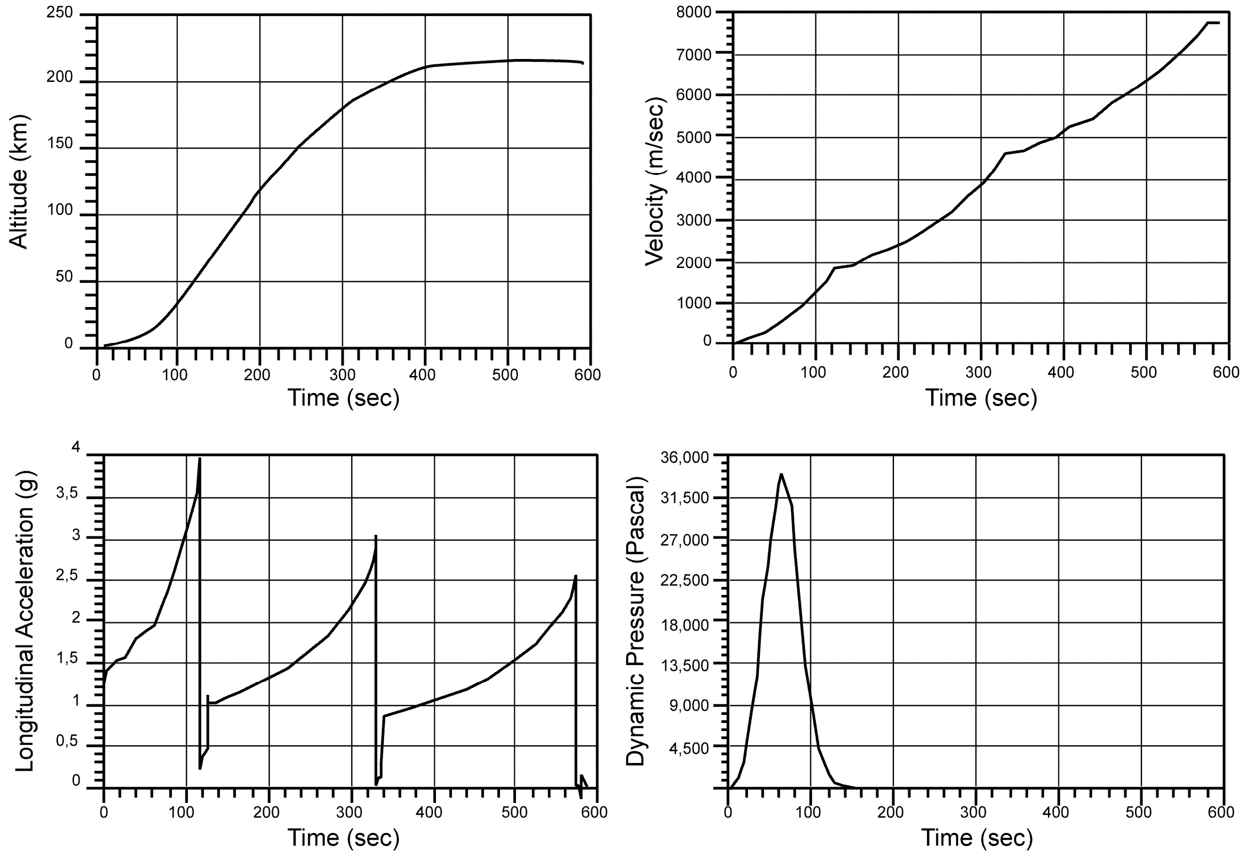


Figure 2.3.1-3: Typical Proton M Lower Ascent Altitude, Inertial Velocity, Longitudinal Acceleration, and Dynamic Pressure



2.3.2 Breeze M Standard Mission Profile

The first three stages of the Proton LV inject the Breeze M/SC into a sub-orbital trajectory. After the Proton third stage separation, Breeze M performs the first of five main engine burns that inject the Breeze M/SC into a standard low earth parking orbit. After coasting in the parking orbit for about 50 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 to 7000 km. 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 complete depletion of the propellant in the APT. When the propellant in this tank is depleted, the main engine shuts down for two minutes while 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 a Geosynchronous Orbit (GEO). 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 coast along the parking, 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 either to periodically roll 180 degrees about the Breeze M longitudinal X-axis or pitch about its transverse Z-axis, or to roll continuously about the Breeze M longitudinal X-axis with an angular rate of up to 3 deg/s.

After approximately 5.2 hours in the transfer orbit, the Breeze M performs a fifth burn, which raises perigee and lowers inclination into a Geosynchronous Transfer Orbit (GTO) with the desired target orbit parameters. When this burn is completed, the Breeze M performs a maneuver to orient the SC for separation, which takes place within 12 - 40 minutes of the end of the final burn. The total time of the Breeze M standard mission profile from LV lift-off to SC separation is approximately 9.3 hours.

In the standard "9-hour" Breeze M mission profile described above, the SC is injected into the target orbit from the ascending node of the parking orbit, and SC separation occurs at 52 degrees East longitude. If, however, the Customer requires a longitude at separation other than 52 degrees East, then Breeze M can either remain in the parking orbit or in the intermediate orbit for a longer period of time. Each additional revolution in the parking orbit will change the separation point longitude by 22.5 degrees to the west. Similarly, each additional revolution in the intermediate orbit (with 5,000 km apogee) will move the separation point longitude by approximately 35 degrees to the west. Other values of separation longitude can be achieved by choosing different intermediate orbit apogees. In general, the number of revolutions that the Breeze M remains in the parking orbit or the intermediate orbit will be determined in the course of the mission design optimization process during the mission integration phase.

The Proton M LV main orbital characteristics for a geosynchronous transfer mission design involving SC injection using a 9-hour mission profile from the first ascending node of the parking orbit at an inclination of 51.5° are shown in Figure 2.3.2-1.

Figure 2.3.2-2 shows a typical ground track of the entire Proton M/Breeze M flight from LV lift-off to SC injection into GTO using a 9-hour mission profile from the first ascending node of the parking orbit at an inclination of 51.5°.

When launching a SC into GTO, besides the 9-hour Breeze M mission profile, a 7-hour mission profile is possible. In this case, the transfer orbit apogee is raised entirely via a velocity impulse at the first ascending node of the parking orbit. This eliminates another revolution of the orbital unit with an intermediate orbit having an apogee of ~5000 km. In this 7-hour mission, the SC is injected at a point with a longitude of ~87° East.

The main orbital characteristics for a geosynchronous transfer mission design involving SC injection using the Proton M LV and Breeze M with a 7-hour mission profile from the first ascending node of the parking orbit at an inclination of 51.5° are shown in Figure 2.3.2-3. Figure 2.3.2-4 shows a typical ground track of the entire Proton M/Breeze M flight from LV lift-off to SC injection into GTO using a 7-hour mission profile from the first ascending node of the parking orbit at an inclination of 51.5°.

For each primary injection alternative using the Breeze M (the "9-hour" mission with 5 main engine burns, and the "7-hour" mission with 4 main engine burns), there is a special case, where the velocity impulse required to raise the apogee of the transfer orbit to the GSO altitude is performed at the first ascending node of the parking orbit with a single burn of the Breeze M main engine. The jettison of the APT occurs after the Breeze M main engine has shut down. In both of these cases, the mission duration remains unchanged while the number of main engine burns is reduced by one, which results in a "9-hour" injection profile with 4 burns or a "7-hour" profile with 3 main engine burns.

2.3.3 Collision and Contamination Avoidance Maneuver

Per the mission timeline, the Breeze M performs specific maneuvers to minimize the possibility of recontact with or contamination of a Customer’s SC. The separation event provides a typical relative velocity between the SC and the Breeze M of at least 0.3 m/s.

Approximately two hours after SC separation, the Breeze M performs an attitude change maneuver to re-orient itself. Four 392-N thrusters are fired to increase relative velocity between the Breeze M and the SC. After completion of this maneuver, the Breeze M propellant tanks are depressurized and the stage is made inert. Final relative velocity between the SC and Breeze M is typically at least 5 m/s.

2.4 PERFORMANCE GROUND RULES

A number of standard mission ground rules have been used to develop the reference Proton M/Breeze M performance capabilities identified in this document. They are described in this section.

2.4.1 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 mission unique mass delivered to the target orbit, including the separated SC, the SC-to-LV adapter, and all other mission-specific hardware required on the LV to support the payload (e.g., harnessing, purge hardware etc.). Table 4.1.4-1 provides masses for the available Proton M adapter systems.

Figure 2.3.2-1: Typical 9-Hour Breeze M Mission Profile for SC Injection into GTO from the First Ascending Node of the Parking Orbit with an Inclination of 51.5°

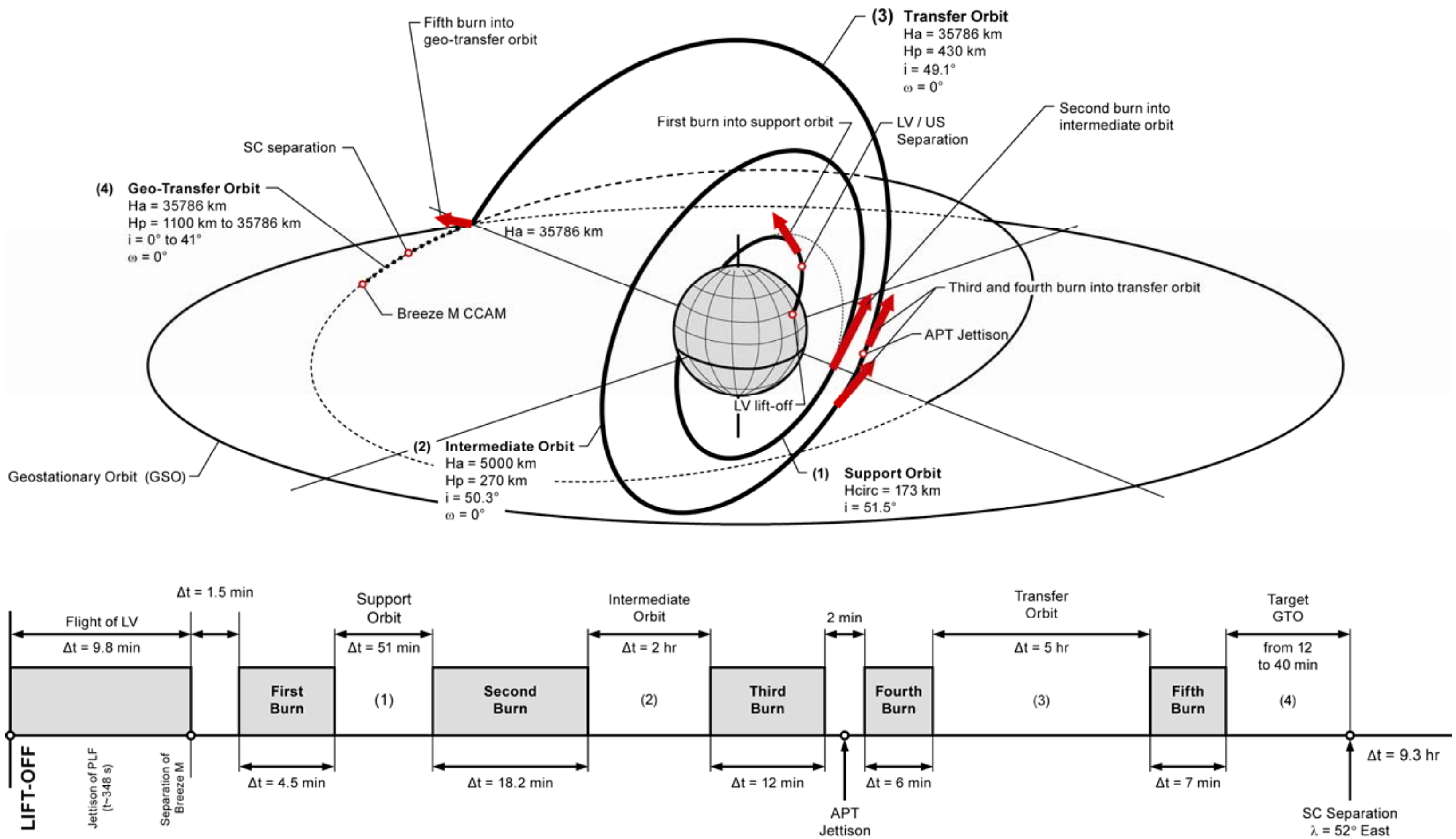
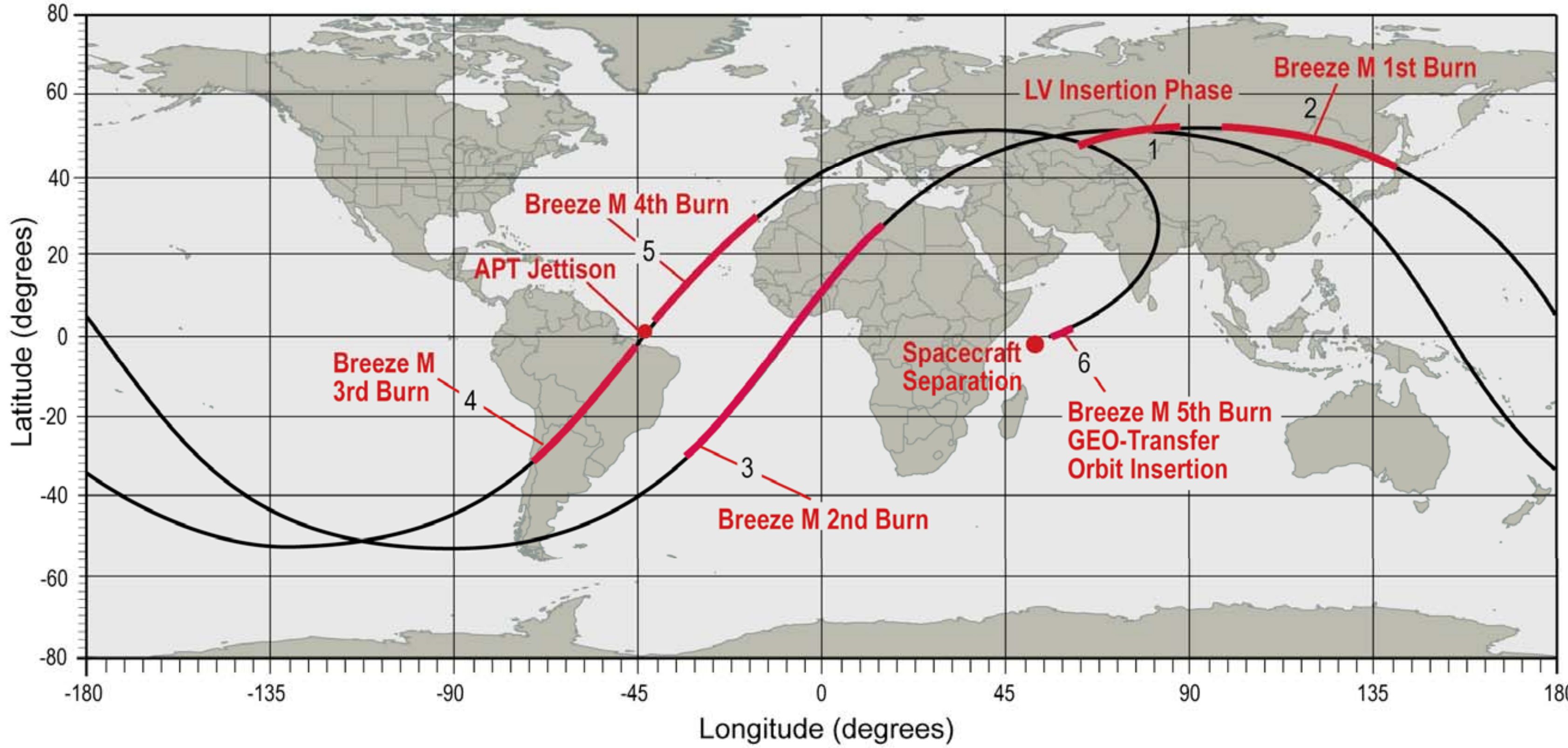


Figure 2.3.2-2: Typical Ground Track of the Proton M Breeze M Flight for SC Injection into GTO Using a 9-Hour Mission Profile from the First Ascending Node of the Parking Orbit with an Inclination of 51.5°



1 - LV insertion phase
2 - Breeze M main engine first firing - parking orbit insertion
3 - Breeze M main engine second firing - intermediate orbit insertion
4, 5 - Breeze M main engine third and fourth firings - transfer orbit insertion
6 - Breeze M main engine fifth firing - geo-transfer orbit insertion

Figure 2.3.2-3: Typical 7-Hour Breeze M Mission Profile for SC Injection into GTO from the First Ascending Node of the Parking Orbit with an Inclination of 51.5°

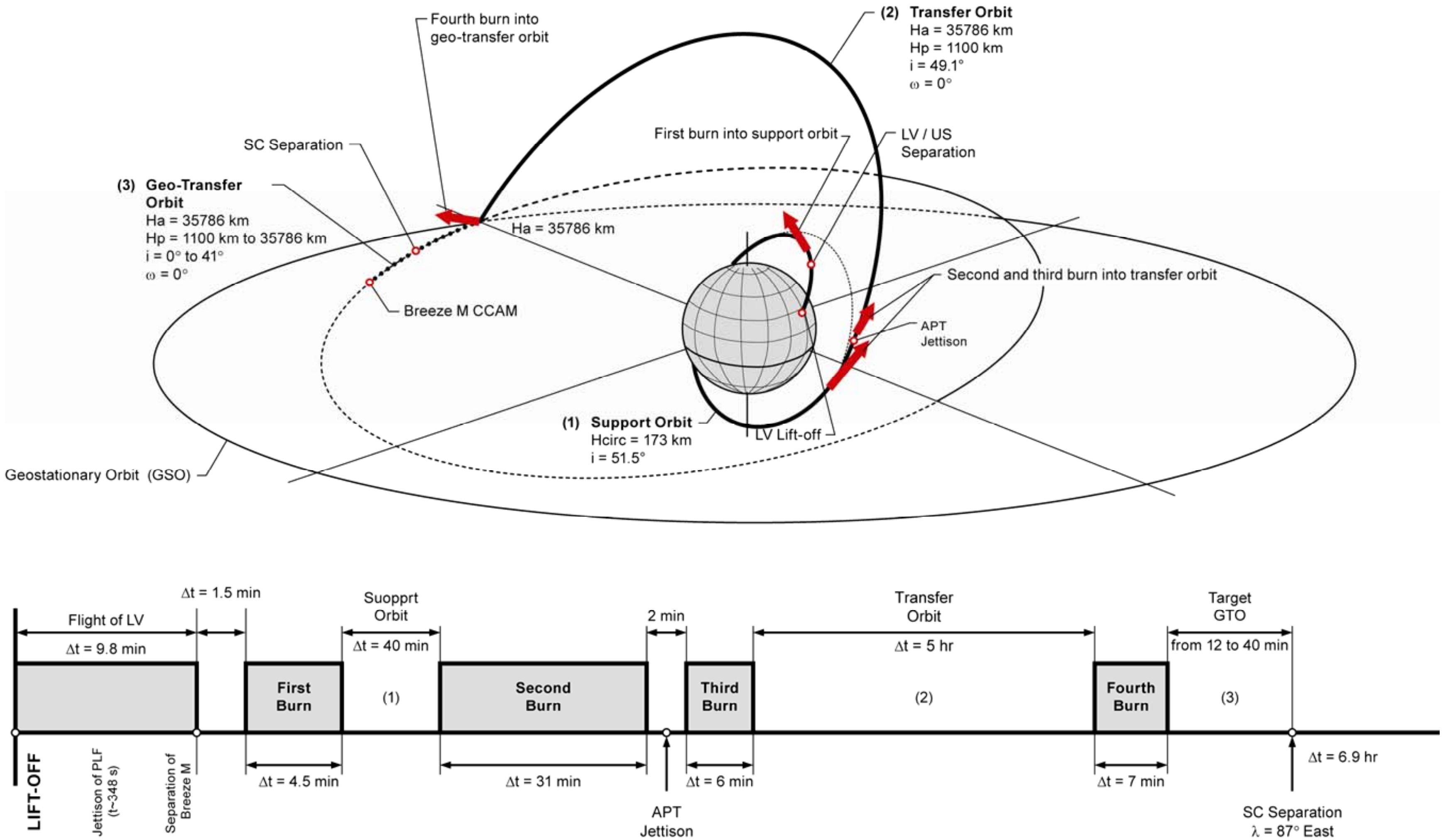
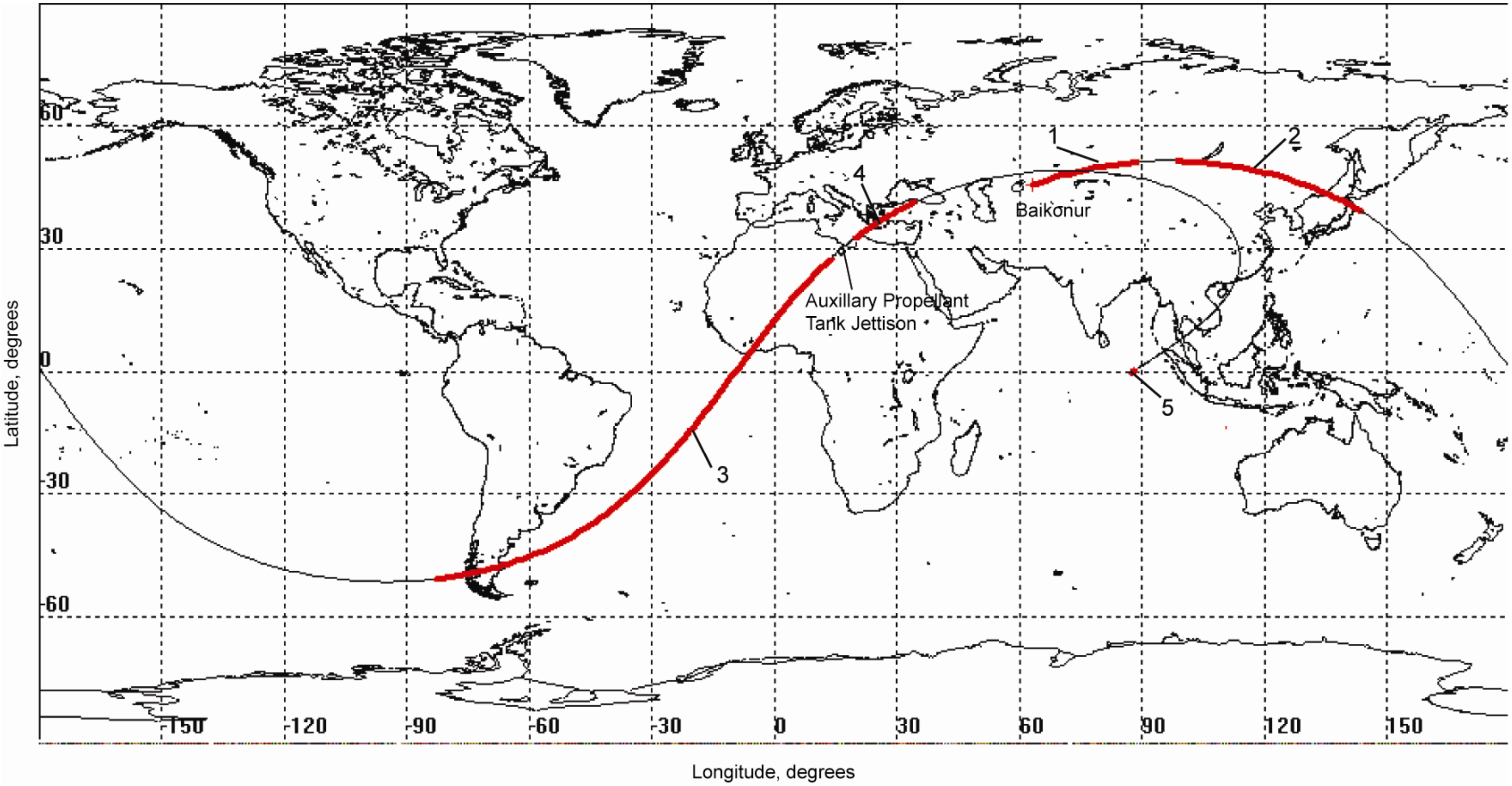


Figure 2.3.2-4: Typical Ground Track of the Proton M Breeze M Flight for SC Injection into GTO Using a 7-Hour Mission Profile from the First Ascending Node of the Parking Orbit with an Inclination of 51.5°



1 - LV Insertion Phase
2 - US "Breeze M" main engine first burn and flight to support orbit
3, 4 - US "Breeze M" main engine second and third burn and flight to transfer orbit
5 - US "Breeze M" main engine fourth burn and flight to geotransfer orbit

2.4.2 Payload Fairings

Currently, two PLFs are offered for Proton M Breeze M missions. These PLFs are described in Section 4. All performance tables for GTO missions described in this section assume the use of the 15255 mm long PLF (PLF-BR-15255). For GTO missions using the lighter 13305 mm long PLF (PLF-BR-13305) design, a performance increase of 15 kg to GTO can be assumed.

PLF jettison times are constrained to occur so that fairing hardware will impact in designated areas. For Proton M/Breeze M flights, fairing jettison occurs at approximately 340 to 350 seconds into the flight at an altitude of 121 to 125 kilometers or more. Maximum Free Molecular Heat Flux (FMHF) after PLF jettison does not exceed 1135 W/m^2.

2.4.3 Mission Analysis Ground Rules

All Proton M mission estimates provided in this document assume launch from the Baikonur Cosmodrome. Launch Pads 24 and 39 at Baikonur are located at 46.1 degrees North geodetic latitude and 63.0 degrees East longitude. All identified altitudes are based on a spherical Earth radius of 6378 km for GTO missions.

Caution must be exercised in deriving performance estimates for missions whose inclinations differ from those presented. The first three stages of the Proton M launch system can only deliver payloads directly into, or near, the standard low earth orbit at an inclination of 51.5, 64.8, or 72.6 degrees. All other inclinations can be reached only through an orbital plane change maneuver. Performance estimates should not be made based on interpolation between performance values derived from different parking orbit inclinations.

2.4.4 Performance Confidence Levels

Proton M missions are targeted to meet the requirements of each user. Most Proton M missions are targeted based on a conservative 2.33σ confidence level that the mission objectives will be achieved. All Proton M/Breeze M performance information contained in this document assumes adequate propellant margin to meet a 2.33σ confidence level. Proton M LEO performance assumes a 3σ propellant margin.

For Customers desiring information about 3σ propellant margins for standard GTO Proton M missions, it can be assumed that standard 9-hour (five-burn) Breeze M mission performance is reduced by 40 kg from the values in Table 2.5.2-2, and 7-hour (four-burn) Breeze M mission performance is reduced by 45 kg from the values in Table 2.5.2-1.

2.5 GEOSYNCHRONOUS TRANSFER MISSIONS

2.5.1 Launch to GTO/GSO

The elliptical GTO transfer mission is the standard mission profile for most commercial Proton launches. Variable mass SC are delivered to a GTO with a 35,786 km apogee altitude, a 0° argument of perigee, and a variable orbit perigee and inclination consistent with the lift-off mass of the SC and the delivered LV performance. From this point, the SC will perform the remaining perigee raising and inclination reduction to reach GSO.

For the purpose of establishing a baseline, ILS uses a reference geosynchronous transfer mission performance quotation based on an injection orbit where the SC Δ-velocity to GSO equals 1,500 m/s. This reference mission is indicative of the geosynchronous transfer missions used by vehicles launched from low inclination launch sites. The reference orbit assumes a 4,120 km perigee altitude, a 35,786 km apogee altitude, a 23.2° orbit inclination, and a 0° argument of perigee.

A SC with a PSM of 3250 kg or less can be injected by the Breeze M directly into GSO. This is made possible by the mission design flexibility and orbital lifetime capability of the Breeze M, and can offer substantial advantages to the SC manufacturer and operator through the elimination of the mass, complexity and cost of the SC apogee propulsion system.

2.5.2 Proton M Breeze M Performance

The Proton M/Breeze M performance to GTO with a GSO apogee is shown in Figures 2.5.2-1 and 2.5.2-2. Data is shown that represents LV performance in terms of PSM versus residual SC Δ-velocity from GTO to GSO. Analyses have been conducted to determine the optimum orbit that can be achieved with Proton M for a given PSM. Given a payload mass and launch from the Baikonur Cosmodrome, the Breeze M delivers the SC to a GTO that results in minimum spacecraft Δ-velocity remaining to reach GSO.

Two major variations of the Breeze M injection to GTO/GSO, described in Section 2.3.2, have been demonstrated with successful missions. As of 31 July 2009, the 9-hour mission has been flown 19 times to GTO using 5 burns of the main engine and five times to GSO using 4 burns. The 7-hour mission has been flown successfully two times to GTO (one 4-burn and one 3-burn) and one time to GSO (3-burn).

As shown in Tables 2.5.2-1 and 2.5.2-2, performance to GTO for the 7-hour mission is considerably lower than for the 9-hour mission due to increased gravity losses (increased propellant consumption) during burns at the first ascending node to raise the apogee of the transfer orbit.

Figure 2.5.2-1: Mass of the Payload System for an Optimum GTO Using a Standard 7-Hour Injection from the First Ascending Node of the Parking Orbit with an Inclination of 51.5° (4 Breeze M Main Engine Burns)

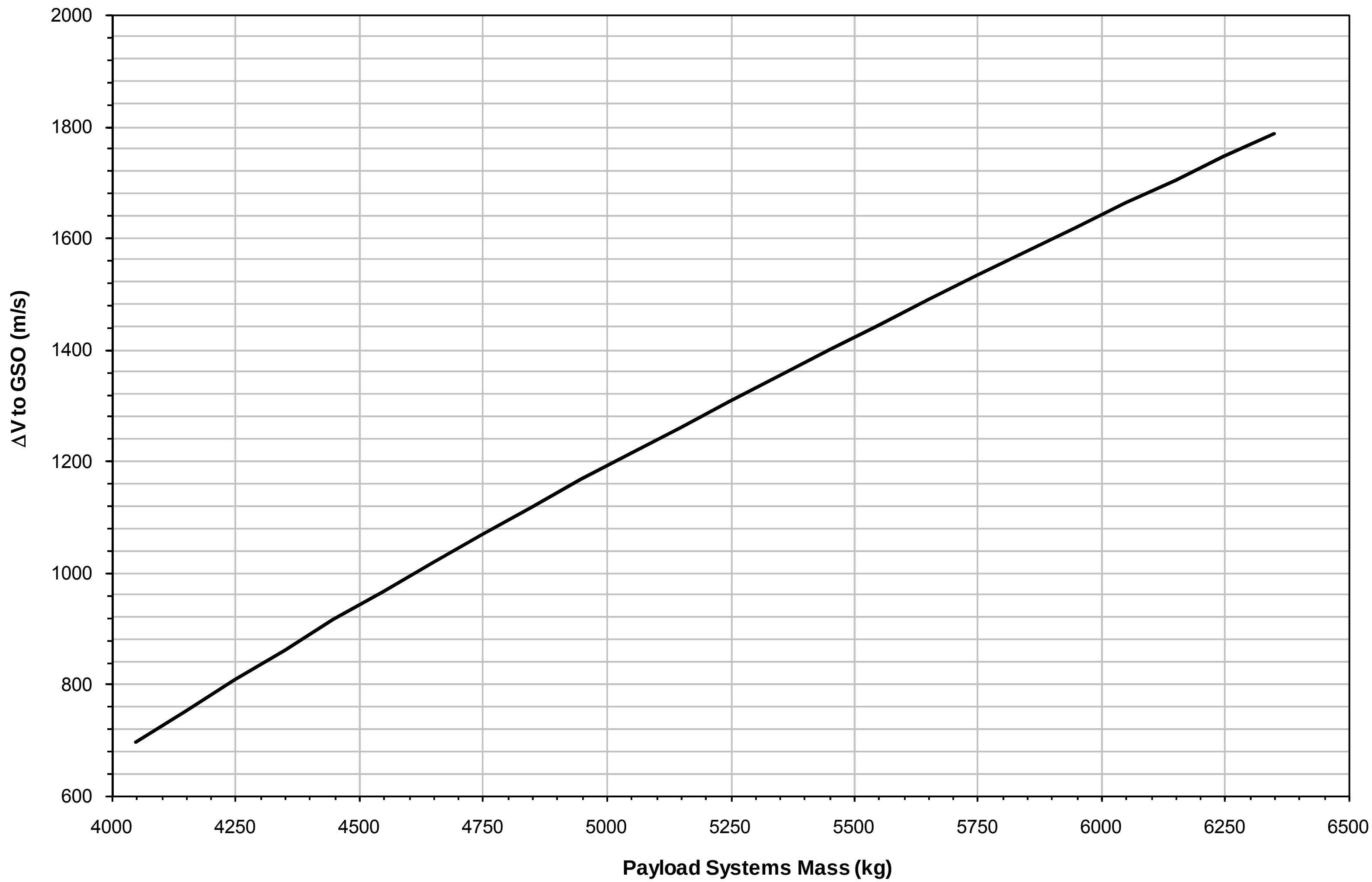
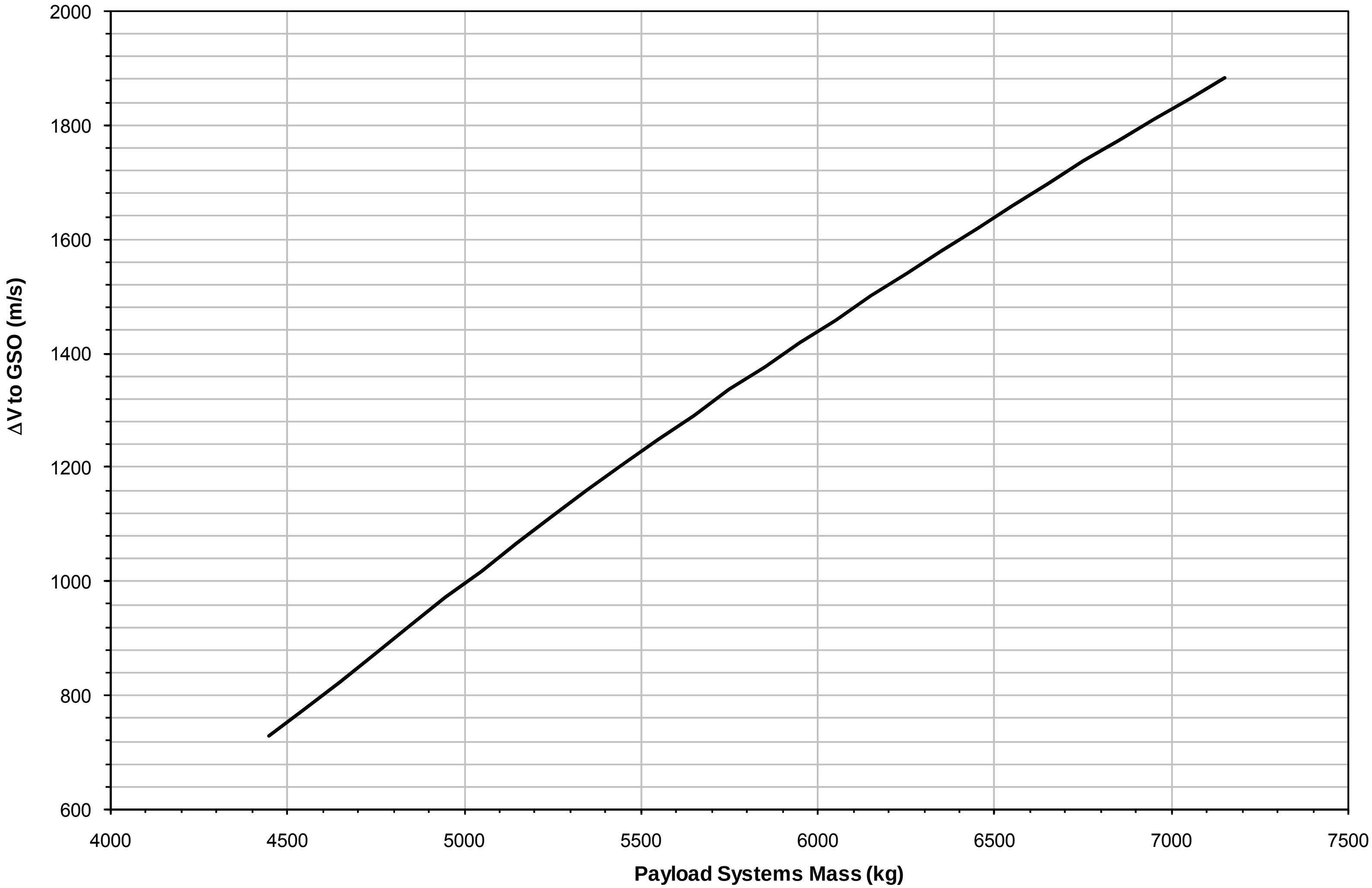


Figure 2.5.2-2: Mass of the Payload System for an Optimum GTO Using Standard 9-Hour Injection from the First Ascending Node of the Parking Orbit with an Inclination of 51.5° (5 Breeze M Main Engine Burns)



The derived orbit parameters are provided in Table 2.5.2-1 for a 7-hour/4-burn Breeze M mission, and Table 2.5.2-2 for a 9-hour/5-burn Breeze M mission. Parametric performance to non-optimized GTOs using the 9-hour/five-burn Breeze M mission design is provided in Table 2.5.2-3.

Argument of Perigee can be varied as a design parameter of the GTO target orbit. Baseline Proton performance in Tables 2.5.2-1 through 2.5.2-3 assumes an argument of perigee of 0 degree. Argument of perigee can be adjusted to ± 5 degrees at a performance penalty of 10 kg, and adjusted to ± 10 degrees at a performance penalty of 27 kg.

The Breeze M's capability for up to eight main engine restarts and up to an 11-hour mission duration allow great flexibility for customized mission designs. Customers with unique mission requirements are encouraged to contact ILS to obtain more information about how the Breeze M can meet their specific needs.

Table 2.5.2-1: Proton M/Breeze M Performance for an Optimum GTO Using a Standard 7-Hour Injection from the First Ascending Node of the Parking Orbit with an Inclination of 51.5° (4 Breeze M Main Engine Burns)

PSM (kg)	GTO Parameters				Minimum SC Velocity for Transfer to GSO, ΔVsc (m/s)
	Inclination (deg)	Perigee Altitude (km)	Apogee Altitude (km)	Argument of Perigee (deg)	
4050	8.20	14480	35,786	0	697
4150	9.00	13410	35,786	0	753
4250	9.80	12412	35,786	0	808
4350	10.70	11557	35,786	0	862
4450	11.60	10728	35,786	0	916
4550	12.40	9931	35,786	0	967
4650	13.30	9230	35,786	0	1018
4750	14.20	8571	35,786	0	1068
4850	15.20	7996	35,786	0	1118
4950	16.10	7414	35,786	0	1166
5050	17.10	6910	35,786	0	1214
5150	18.00	6395	35,786	0	1260
5250	18.90	5887	35,786	0	1306
5350	19.90	5449	35,786	0	1352
5450	20.87	4997	35,786	0	1398
5550	21.90	4609	35,786	0	1443
5650	22.90	4228	35,786	0	1487
5750	24.00	3908	35,786	0	1531
5850	25.10	3614	35,786	0	1574
5950	26.20	3318	35,786	0	1617
6050	27.30	3021	35,786	0	1660
6150	28.40	2744	35,786	0	1702
6250	29.54	2489	35,786	0	1744
6350	30.70	2271	35,786	0	1785

SC separation occurs at a geographic longitude of 87° E.
Performance is based on the use of a standard PLF-BR-15255.
FMHF at fairing jettison shall not exceed 1135 W/m^2.
The PSM includes LV adapter system mass.
The PSM is calculated based on a 2.33σ confidence level Breeze M propellant margin.

Table 2.5.2-2: Proton M/Breeze M Performance for an Optimum GTO Using a Standard 9-Hour Injection from the First Ascending Node of the Parking Orbit with an Inclination of 51.5° (5 Breeze M Main Engine Burns)

PSM (kg)	GTO Parameters				Minimum SC Velocity for Transfer to GSO, ΔVsc (m/s)
	Inclination (deg)	Perigee Altitude (km)	Apogee Altitude (km)	Argument of Perigee (deg)	
4450	8.60	13,814	35,786	0	729
4550	9.30	13,020	35,786	0	774
4650	10.10	12,211	35,786	0	823
4750	10.90	11,400	35,786	0	873
4850	11.70	10,610	35,786	0	923
4950	12.50	9898	35,786	0	971
5050	13.30	9204	35,786	0	1019
5150	14.20	8597	35,786	0	1067
5250	15.10	8028	35,786	0	1114
5350	16.00	7495	35,786	0	1160
5450	16.90	6995	35,786	0	1205
5550	17.80	6527	35,786	0	1249
5650	18.60	6025	35,786	0	1292
5750	19.50	5591	35,786	0	1335
5850	20.40	5186	35,786	0	1377
5950	21.30	4807	35,786	0	1418
6050	22.20	4432	35,786	0	1459
6150	23.20	4120	35,786	0	1500
6250	24.20	3830	35,786	0	1540
6350	25.20	3540	35,786	0	1580
6450	26.20	3250	35,786	0	1620
6550	27.20	2981	35,786	0	1659
6650	28.25	2742	35,786	0	1698
6750	29.30	2529	35,786	0	1736
6850	30.35	2329	35,786	0	1773
6950	31.40	2135	35,786	0	1810
7050	32.50	1970	35,786	0	1847
7150	33.60	1816	35,786	0	1883

SC separation occurs at a geographic longitude of 52° E.
Performance is based on the use of a standard PLF-BR-15255.
FMHF at fairing jettison shall not exceed 1135 W/m^2.
The PSM includes LV adapter system mass.
The PSM is calculated based on a 2.33σ confidence level Breeze M propellant margin.

Table 2.5.2-3: Proton M/Breeze M Parametric Performance for a Non-Optimum GTO Using a Standard 9-Hour Injection from the First Ascending Node of the Parking Orbit with an Inclination of 51.5° (5 Breeze M Main Engine Burns)

PSM (kg)	GTO Parameters				SC Velocity for Transfer to GSO, ΔV_{SC} (m/s)
	Inclination (deg)	Perigee Altitude (km)	Apogee Altitude (km)	Argument of Perigee (deg)	
4450	8.0	13,283	35,786	0	731
	7.1	12,508	35,786	0	738
	6.1	11,680	35,786	0	751
4550	8.6	12,429	35,786	0	776
	7.6	11,600	35,786	0	784
	6.6	10,786	35,786	0	798
4650	9.4	11,632	35,786	0	825
	8.3	10,736	35,786	0	834
	7.2	9882	35,786	0	849
4750	10.2	10,834	35,786	0	875
	9.6	10,355	35,786	0	879
	9.0	9906	35,786	0	884
	8.5	9505	35,786	0	891
	7.8	8975	35,786	0	902
4850	11.0	10,062	35,786	0	925
	10.4	9595	35,786	0	929
	9.8	9134	35,786	0	935
	9.2	8698	35,786	0	942
	8.5	8173	35,786	0	954
4950	11.8	9364	35,786	0	973
	11.1	8829	35,786	0	978
	10.5	8385	35,786	0	984
	9.9	7943	35,786	0	992
	9.1	7375	35,786	0	1005
5050	12.6	8685	35,786	0	1021
	11.9	8163	35,786	0	1026
	11.2	7662	35,786	0	1033
	10.6	7217	35,786	0	1042
	9.8	6650	35,786	0	1056

PSM (kg)	GTO Parameters				SC Velocity for Transfer to GSO, ΔV_{SC} (m/s)
	Inclination (deg)	Perigee Altitude (km)	Apogee Altitude (km)	Argument of Perigee (deg)	
5150	13.5	8085	35,786	0	1069
	12.7	7496	35,786	0	1075
	12.0	7008	35,786	0	1082
	11.4	6575	35,786	0	1091
	10.5	5936	35,786	0	1108
5250	14.4	7523	35,786	0	1116
	13.6	6963	35,786	0	1121
	12.8	6395	35,786	0	1130
	12.1	5898	35,786	0	1141
	11.2	5267	35,786	0	1159
5350	15.3	6997	35,786	0	1162
	14.4	6371	35,786	0	1168
	13.6	5819	35,786	0	1177
	12.9	5317	35,786	0	1189
	11.9	4640	35,786	0	1209
5450	16.1	6445	35,786	0	1207
	15.2	5815	35,786	0	1214
	14.4	5260	35,786	0	1224
	13.7	4771	35,786	0	1236
	12.7	4080	35,786	0	1258
5550	17.1	6041	35,786	0	1251
	16.1	5360	35,786	0	1258
	15.2	4733	35,786	0	1270
	14.5	4258	35,786	0	1282
	13.5	3555	35,786	0	1306
5650	17.9	5550	35,786	0	1294
	16.9	4866	35,786	0	1302
	16.0	4238	35,786	0	1315
	15.3	3742	35,786	0	1329
	14.3	3060	35,786	0	1353
5750	18.9	5180	35,786	0	1337
	17.8	4429	35,786	0	1346
	16.9	3810	35,786	0	1359
	16.2	3323	35,786	0	1373
	15.2	2607	35,786	0	1400

PSM (kg)	GTO Parameters				SC Velocity for Transfer to GSO, ΔV_{SC} (m/s)
	Inclination (deg)	Perigee Altitude (km)	Apogee Altitude (km)	Argument of Perigee (deg)	
5850	19.8	4780	35,786	0	1379
	18.7	4018	35,786	0	1389
	17.8	3391	35,786	0	1403
	17.1	2896	35,786	0	1418
	16.1	2167	35,786	0	1447
5950	20.7	4404	35,786	0	1420
	19.6	3631	35,786	0	1431
	18.8	3068	35,786	0	1444
	18.1	2574	35,786	0	1459
	17.0	1738	35,786	0	1494
6050	21.7	4089	35,786	0	1461
	20.6	3314	35,786	0	1472
	19.8	2750	35,786	0	1485
	19.0	2164	35,786	0	1504
	18.0	1360	35,786	0	1540

SC separation occurs at a geographic longitude of 52° E.
Performance is based on the use of a standard PLF-BR-15255.
FMHF at fairing jettison shall not exceed 1135 W/m^2.
The PSM includes LV adapter system mass.
The PSM is calculated based on a 2.33σ confidence level Breeze M propellant margin.

2.6 ORBIT INJECTION ACCURACY

Table 2.6-1 shows Breeze M 3σ orbit injection accuracy predictions for various missions. The accuracy predictions are enveloping values and mission-specific analysis will be performed to verify that payload accuracy requirements are satisfied.

Table 2.6-1: Breeze M Upper Stage 3σ Orbit Injection Accuracies

	Perigee	Apogee	Inclination	Argument of Perigee	Period
200 km Circular Parking Orbit	± 4.0 km	± 4.0 km	± 0.03 deg	-	± 3 sec
10000 km Circular Orbit	± 20 km	± 20 km	± 0.1 deg	-	± 100 sec
4120 km x 35786 km @ 23.2 degrees GTO	± 360 km	± 150 km	± 0.3 deg	± 0.8 deg	-

	Eccentricity	Longitude	Inclination	Period
Geostationary	0.0075	± 0.7 deg	± 0.3 deg	± 950.0 sec

Note: For injection into other orbits, the injection accuracy will be determined for that orbit.

2.7 SPACECRAFT ORIENTATION AND SEPARATION

The Breeze M Upper Stage is capable of aligning the SC and separating in one of three modes; 3-axis stabilized, longitudinal spinup, or transverse spinup. The longitudinal spinup can be performed by using the Breeze M capability. The transverse spinup can be performed by either using separation springs of different length or by rotation of the Breeze M. Tables 2.7-1 through 2.7-3 show approximate SC movement requirements after separation for each of the three options. The selected payload separation mechanism will affect separation rates. The orientation and separation conditions are typical values, and a mission unique analysis will be performed to verify that payload requirements are satisfied. Figure 2.7-1 illustrates rotation axes.

Table 2.7-1: SC Separation Accuracies, Longitudinal Spin

Reference	Value
SC spin rate about spin axis	6 deg/s ± 1 deg/s
SC tip-off rate about perpendicular spin axes	± 1.1 deg/s
Relative separation velocity	≥ 0.35 m/s
Error of spin axis orientation	± 5 deg

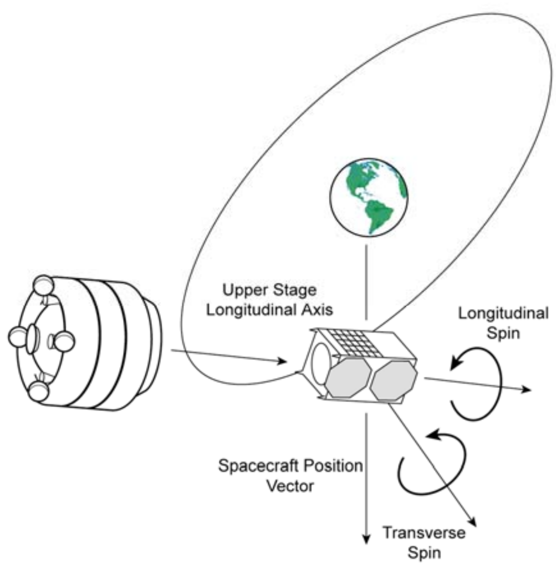
Table 2.7-2: SC Separation Accuracies, Transverse Spin

Reference	Value
SC spin rate about spin axis	2 deg/s ± 1 deg/s
SC tip-off rate about perpendicular spin axes	± 0.7 deg/s
Relative separation velocity	≥ 0.5 m/s
Error of spin axis orientation	± 5 deg

Table 2.7-3: SC Separation Accuracies, Three-Axis Stabilized

Reference	Value
Relative separation velocity	≥ 0.3 m/s
SC tip-off rate about any of SC axes	± 1.0 deg/s
SC separation attitude error	± 5 deg

Figure 2.7-1: Separation Axes Definition



NOTE: SC axes defined by SC Customer

2.8 LAUNCH VEHICLE TELEMETRY DATA

ILS has adopted standard formats regarding orbital state vector data that are provided to the launch services Customer during and after the launch mission. These standard formats enable the satellite operator to properly determine orbital conditions at various times during the mission. The standard data is transmitted to the SC Mission Control Center at relevant times.

The data formats are:

Format I - Preliminary injection orbit parameters (Table 2.8-1) 30 minutes after SC separation

Format II - Breeze M attitude parameters prior to SC separation (Table 2.8-2) 60 minutes after SC separation

Format III - Final target orbit data (Table 2.8-3) no later than 180 minutes after SC separation

ILS will provide in Formats I - III, Tables 2.8-1 through 2.8-3, respectively, US state vector data at SC separation and Breeze M attitude data prior to SC separation. Format I is normally provided only for the target orbit, but may be provided for the transfer orbit on Customer request. Submittal times for the additional Format I data will be established during the mission integration phase.

The formatted telemetered data is submitted to the Customer by ILS at Baikonur via fax or voice to the SC Mission Control Center.

Table 2.8-1: Format I - Preliminary Orbit Parameters

No.	Item	Units of Measurement	Design Values	Measured Values
1.	Epoch	Date (DD/MM/YY) and time (hr, min, sec) (GMT)		
2.	Semi-major axis, a	km		
3.	Eccentricity, e	N/A		
4.	Inclination, i	degrees		
5.	Right Ascension of the Ascending Node, Ω	degrees		
6.	Argument of Perigee, ω	degrees		
7.	True Anomaly, ν	degrees		
8.	Perigee altitude, H_p	km		
9.	Apogee altitude, H_a	km		

Notes:

a) Line Item 1 date and time will be GMT (Greenwich Mean Time).

b) The data in rows 2 - 9 are osculating data.

Osculation time: For the transfer orbit, this is the time of the shutoff of the Breeze M engine at the fourth firing, which occurs upon injection into transfer orbit. For the target orbit, this is the time of SC separation from Breeze M.

c) The osculating values of the altitude at perigee and apogee are determined on the basis of the perigee and apogee radii with consideration for the radius of the spherical model of Earth of 6378 km.

d) The data in rows 4 - 7 were determined in the absolute inertial frame of the current epoch (Figure 2.8-2). The following are taken as the current epoch:

- Upon the first presentation of data (transfer orbit), this is the time of the shutoff of the Breeze M engine at the fourth firing, which occurs upon injection into transfer orbit.
- Upon the second presentation of data (target orbit), this is the time of separation of the SC from the Breeze M.

e) The measured values are determined on the basis of telemetry data.

Table 2.8-2: Format II - Breeze M Attitude Data at Separation

No.	Item	Units of Measurement	Design Values	Measured Values
1.	Epoch	Date (DD/MM/YY) and time (hr, min, sec) (GMT)		
2.	Roll angular rate, ω_x of Breeze M	degrees/sec		
3.	Yaw angular rate, ω_y of Breeze M	degrees/sec		
4.	Pitch angular rate, ω_z of Breeze M	degrees/sec		
5.	Right ascension of $+X_{US}$ axis, α (See Figure 2.8-1)	degrees		
6.	Declination of $+X_{US}$ axis, δ (See Figure 2.8-1)	degrees		

Notes:

a) Line Item 1 date and time will be GMT (Greenwich Mean Time).

b) The data in rows 2 - 4 were determined relative to the fixed coordinate system of the Breeze M US.

c) The data in rows 5 and 6 were determined in the absolute inertial frame of the current epoch (Figure 2.8-1). The current epoch is the time of SC separation from the US.

d) The measured values are determined on the basis of telemetry data.

Table 2.8-3: Format III - Final SC Target Orbit Data

No.	Item	Units of Measurement	Design Values	Measured Values
1.	Lift-off time	Date (DD/MM/YY) and time (hr, min, sec) (GMT)		
2.	Epoch	Date (DD/MM/YY) and time (hr, min, sec) (GMT)		
3.	Semi-major axis, a	km		
4.	Eccentricity, e	N/A		
5.	Inclination, i	degrees		
6.	Right Ascension of the Ascending Node, Ω	degrees		
7.	Argument of Perigee, ω	degrees		
8.	True Anomaly, ν	degrees		
9.	Perigee altitude, H_p	km		
10.	Apogee altitude, H_a	km		
11.	Separation longitude	degrees		
12.	Separation latitude	degrees		

Notes:

a) The date and time in Line Items 1 and 2 will be GMT (Greenwich Mean Time).

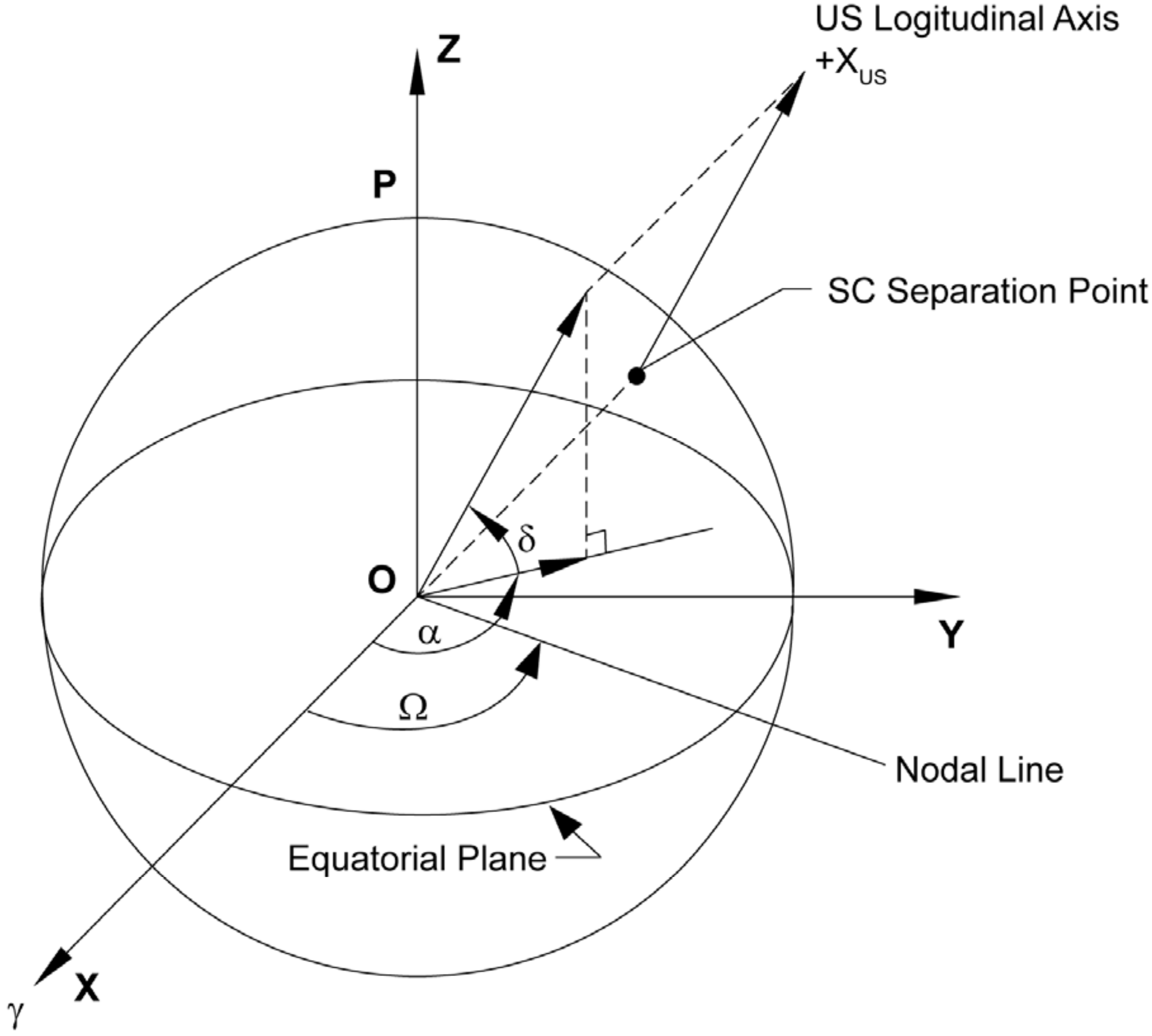
b) Osculating data will be provided in Line Items 3 - 10. The osculating time is the time of separation of the SC and Breeze M Upper Stage.

c) The osculating values of the altitude at perigee and apogee are determined on the basis of the perigee and apogee radius with consideration for the radius of the spherical model of Earth of 6378 km.

d) Data in rows 5 - 8 are defined in absolute inertial coordinate system of a current epoch (Figure 2.8-2). The current epoch is the time of SC separation from the US.

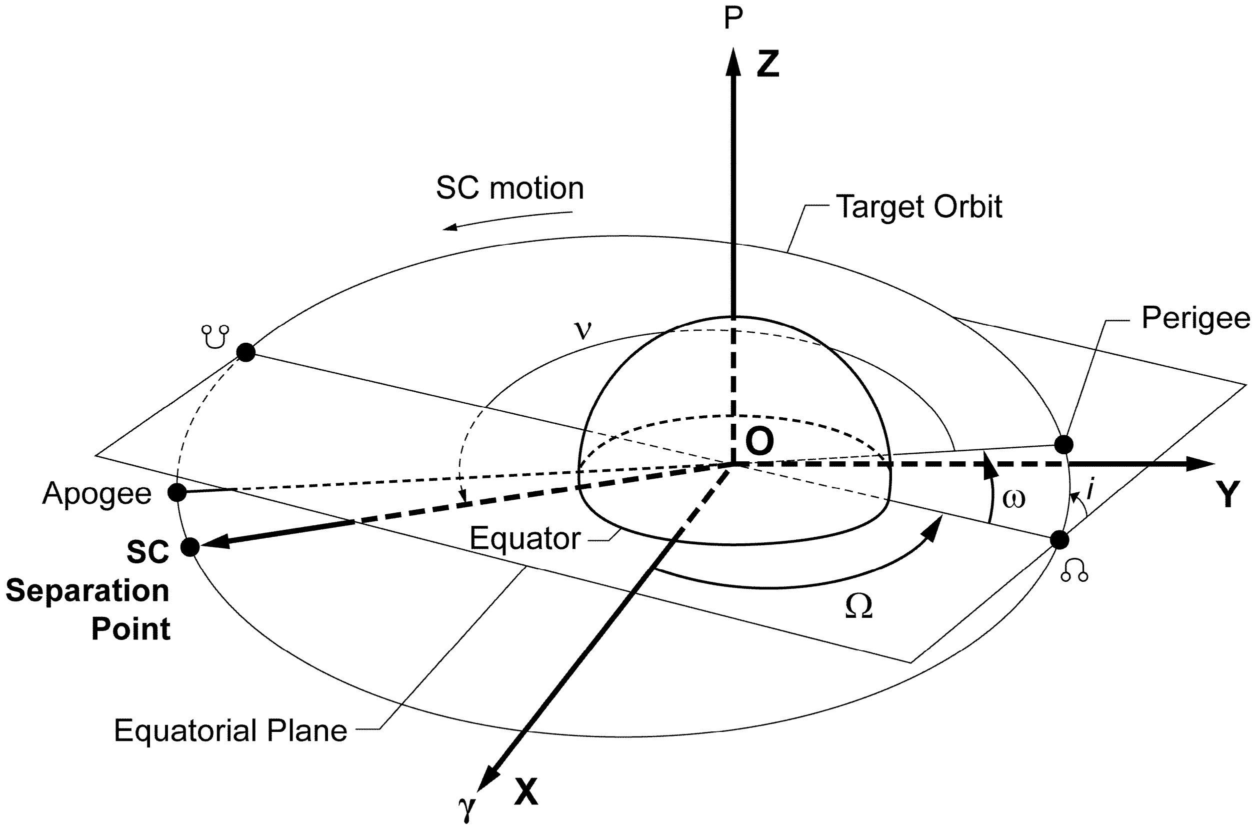
e) The measured values are determined on the basis of telemetry data.

Figure 2.8-1: Right Ascension and Declination of the $+X_{US}$ Axis in the Earth-Centered Absolute Inertial Frame



α — right ascension of $+X_{US}$ axis
δ — declination of $+X_{US}$ axis
Ω — right ascension of the ascending node
The origin of the Earth-Centered inertial frame is located at Earth's center.
The X axis lies in the plane of the equator and is directed toward the point of the vernal equinox γ.
The Z axis coincides with Earth's axis of rotation and is directed toward Earth's North Pole P.
The Y axis completes a right-handed coordinate system.

Figure 2.8-2: Orbit Parameters Definition in Absolute OXYZ Inertial Reference Frame



i - Inclination
Ω - RAAN
ν - True Anomaly
ω - Argument of Perigee
☊ - Ascending Node
☋ - Descending Node
P - North Pole
γ - Vernal Equinox

Within two days following separation, the SC contractor will provide SC derived state vector data to ILS, as shown in Table 2.8-4.

The SC contractor will provide SC rotation data about the SC X, Y and Z axes immediately after separation.

Table 2.8-4: Spacecraft-Supplied Post-Separation Data

	Parameter	Units
1	Epoch	Date (DD/MM/YY) and time (hr, min, sec) (GMT)
2	Semi-major axis, a	km
3	Eccentricity, e	--
4	Inclination, i	deg
5	Right Ascension of the Ascending Node, Ω	deg
6	True Anomaly, ν	deg
7	Perigee altitude, H_p	km
8	Apogee altitude, H_a	km
9	Argument of Perigee, ω	deg
10	SC spin axis relative right ascension	deg
11	SC spin axis declination	deg
12	SC angular rate about Z_{SC} immediately after separation	deg/sec
13	SC angular rate about Y_{SC} immediately after separation	deg/sec
14	SC angular rate about X_{SC} immediately after separation	deg/sec

Notes:

a) Line Item 1 date and time will be GMT (Greenwich Mean Time).

b) SC separation spin axis right ascension and declination are specified in Earth-centered coordinate system, as defined in Figure 2.8-1.

c) Data in rows 4 - 6 and in 10 are defined in absolute inertial coordinate system of a current epoch (Figure 2.8-2). The current epoch is the time of SC separation from the Breeze M Upper Stage.

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