CHAPTER 3

PERFORMANCE

3.1 Introduction

The LM-3B performance figures given in this chapter are based on the following assumptions:

- Launching from XSLC (Xichang Satellite Launch Center, Sichuan Province, China), taking into account the relevant range safety limitations and ground tracking requirements;
- Initial launch azimuth being 97.5°;
- Mass of the payload adapter and the separation system not included in the payload mass;
- The third stage of LM-3B launch vehicle carrying sufficient propellant to reach the intended orbit with a probability of no less than 99.73%;
- At fairing jettisoning, the aerodynamic flux being less than 1135 W/m^2;
- Orbital altitude values given with respect to a spherical earth with a radius of 6378 km.

3.2 Mission Description

3.2.1 Standard Geo-synchronous Transfer Orbit (GTO)

LM-3B is mainly used for conducting GTO mission. The standard GTO is recommended to the User. LM-3B launches Spacecraft (SC) into the standard GTO with following injection parameters from XSLC.

Perigee Altitude	Hp	=200 km
Apogee Altitude	Ha	=35954 km
Inclination	i	=28.5°
Perigee Argument	ω	=178°

✧ The above data are the parameters of the instant orbit that SC runs on when SC/LV separation takes place. *Ha* is equivalent to true altitude of 35786 km at first apogee, due to perturbation caused by Earth oblateness.

3.2.2 Flight Sequence

The typical flight sequence of LM-3B is shown in **Table 3-1** and **Figure 3-1**.

Table 3-1 Flight Sequence

Events	Flight Time (s)
Liftoff	0.000
Pitch Over	10.000
Boosters Shutdown	127.211
Boosters Separation	128.711
Stage-1 Shutdown	144.680
Stage-1/Stage-2 Separation	146.180
Fairing Jettisoning	215.180
Stage-2 Main Engine Shutdown	325.450
Stage-2 Vernier Engine Shutdown	330.450
Stage-2/Stage-3 Separation, and Stage-3 First Start	331.450
Stage-3 First Shutdown	615.677
Coast Phase Beginning	619.177
Coast Phase Ending, and Stage-3 Second Start	1258.424
Stage-3 Second Shutdown, Velocity Adjustment Beginning	1437.673
Velocity Adjustment Ending	1457.673
SC/LV Separation	1537.673

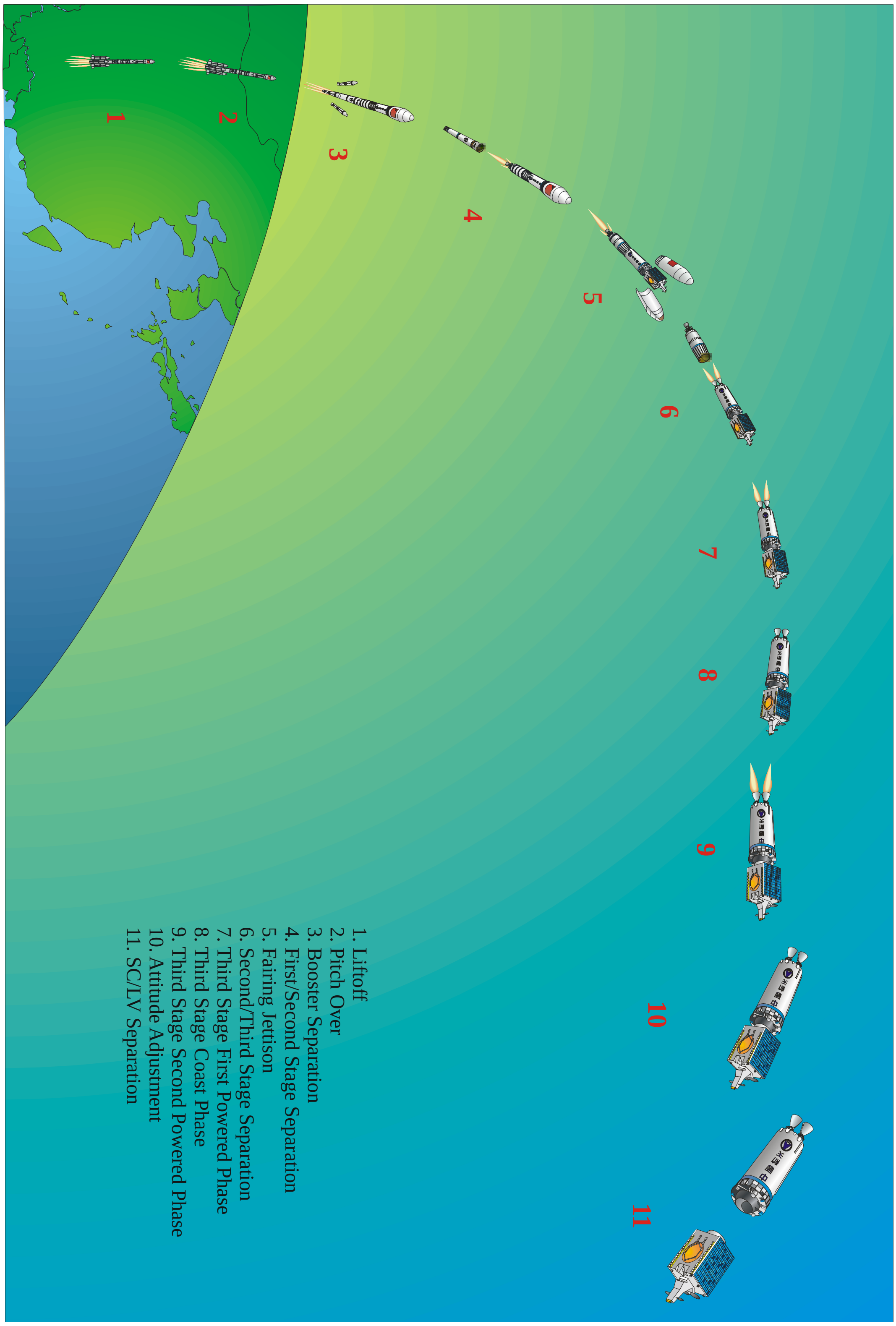


Figure 3-1 LM-3B Flight Sequence

3-3

3.2.3 Characteristic Parameters of Typical Trajectory

The characteristic parameters of typical trajectory are shown in **Table 3-2**.The flight acceleration, velocity, Mach numbers and altitude vs. time are shown in **Figure 3-2a** and **Figure 3-2b**.

Table 3-2 Characteristic Parameters of Typical Trajectory

Event	**Relative Velocity (m/s)**	**Flight Altitude (km)**	**Ground Distance (km)**	**Ballistic Inclination (°)**	**SC projection Latitude (°)**	**SC projection Longitude(°)**
Liftoff	0.000	1.825	0.000	90.000	28.246	102.027
Booster Shutdown	2242.964	53.944	68.716	24.804	28.161	102.720
Boosters Separation	2282.754	55.360	71.777	24.509	28.157	102.751
Stage-1 Shutdown	2735.779	70.955	108.172	21.711	28.110	103.117
Stage-1/Stage-2 Separation	2740.492	72.466	111.953	21.480	28.105	103.155
Fairing Jettisoning	3317.843	131.512	307.187	12.479	17.829	105.115
Stage-2 Main Engine Shutdown	5148.022	190.261	744.771	4.334	27.090	109.464
Stage-2 Vernier Engine Shutdown	5164.813	192.145	769.756	4.096	27.043	109.711
Stage-2/Stage-3 Separation	5164.493	192.509	774.756	4.047	27.034	109.760
Stage-3 First Shutdown	7358.010	204.340	2466.220	-0.003	22.800	125.868
Coast Phase Beginning	7362.949	204.322	2491.177	0.006	22.724	126.096
Stage-3 Second Start	7373.724	200.109	7061.323	-0.033	4.363	164.098
Stage-3 Second Shutdown	9792.292	219.913	8531.117	3.025	-2.348	175.503
Terminal Velocity Adjustment Ending	9791.531	231.622	8719.973	3.806	-3.195	176.979
SC/LV Separation	9724.207	304.579	9466.105	6.879	-6.514	182.839

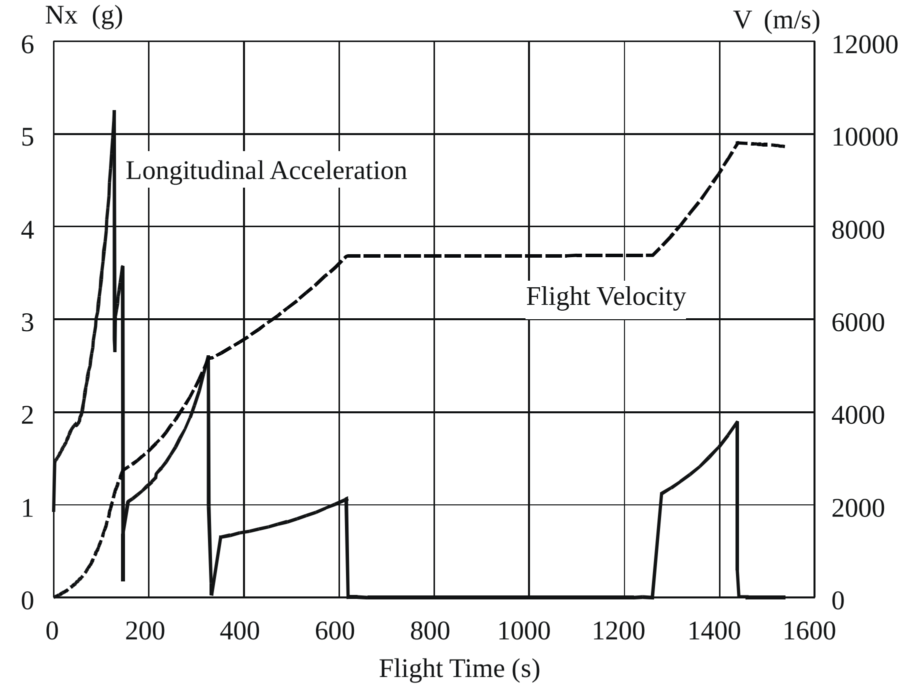


Figure 3-2a LV Flight Acceleration and Flight Velocity vs. Flight Time

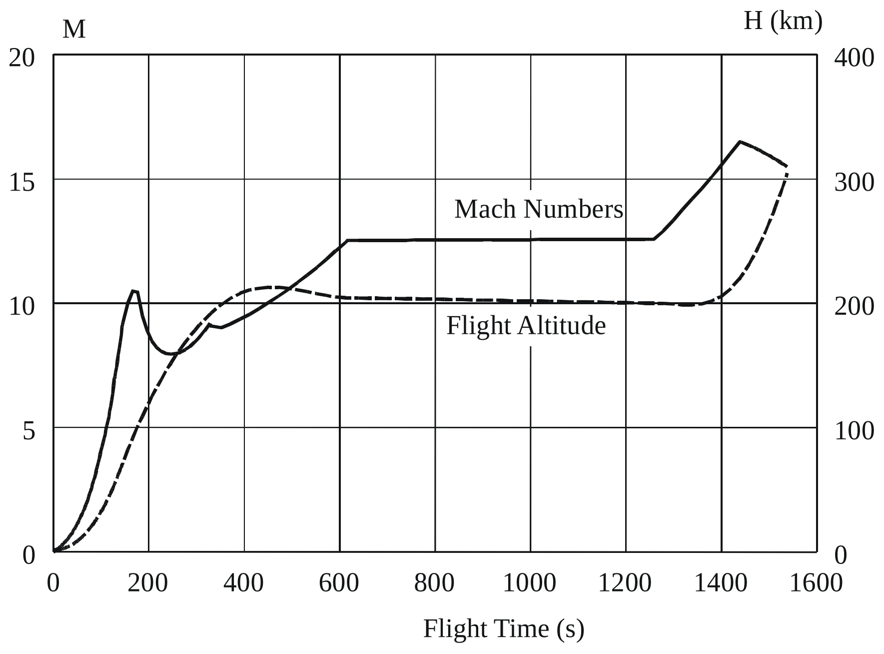


Figure 3-2b LV Flight Altitude and Mach Numbers vs. Flight Time

3.3 Standard Launch Capacities

3.3.1 Basic Information on XSLC

LM-3B launch vehicle conducts GTO mission from Xichang Satellite Launch Center (XSLC), which is located in Sichuan Province, China. LM-3B uses Launch Pad #2 of XSLC. The geographic coordinates are listed as follows:

Latitude:	28.2 °N
Longitude:	102.02 °E
Elevation:	1826 m

Launch Direction is shown in **Figure 3-3**.

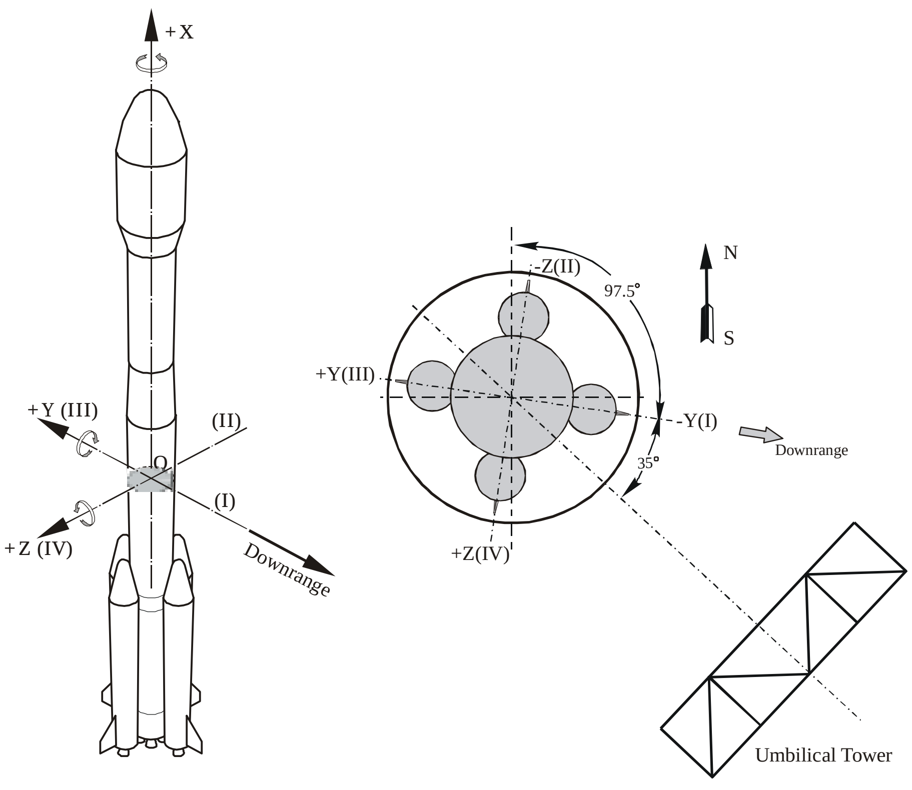


Figure 3-3 Launch Direction

3.3.2 Launch Capacity to Standard GTO

The LM-3B Standard GTO is defined in **Paragraph 3.2.1**, and see also **Figure 2-12** of **Chapter 2**.

LM-3B provides two kinds of fairing encapsulation methods: Encapsulation-on-pad and Encapsulation-in-BS3. Refer to **Chapter 8**. Therefore, LM-3B has different launch capacities corresponding to different encapsulation methods.

The launch capabilities corresponding to different Encapsulation Methods are listed as follows:

Encapsulation-on-pad:	5100 kg (recommended)
Encapsulation-in-BS3:	5000 kg

LM-3B provides 4 different types of fairings with different diameters (Φ4m and Φ4.2m) and different encapsulation methods. Refer to **Chapter 4**. For same encapsulation methods, the launch capacities will remain unchanged, because the structure mass difference between the Φ4m fairing and Φ4.2m fairing can be ignored.

If there is no special explanation, the standard GTO launch capacity (5100kg) stated in this User's Manual is corresponding to the LV with Encapsulation-on-pad method.

3.3.3 Mission Performance

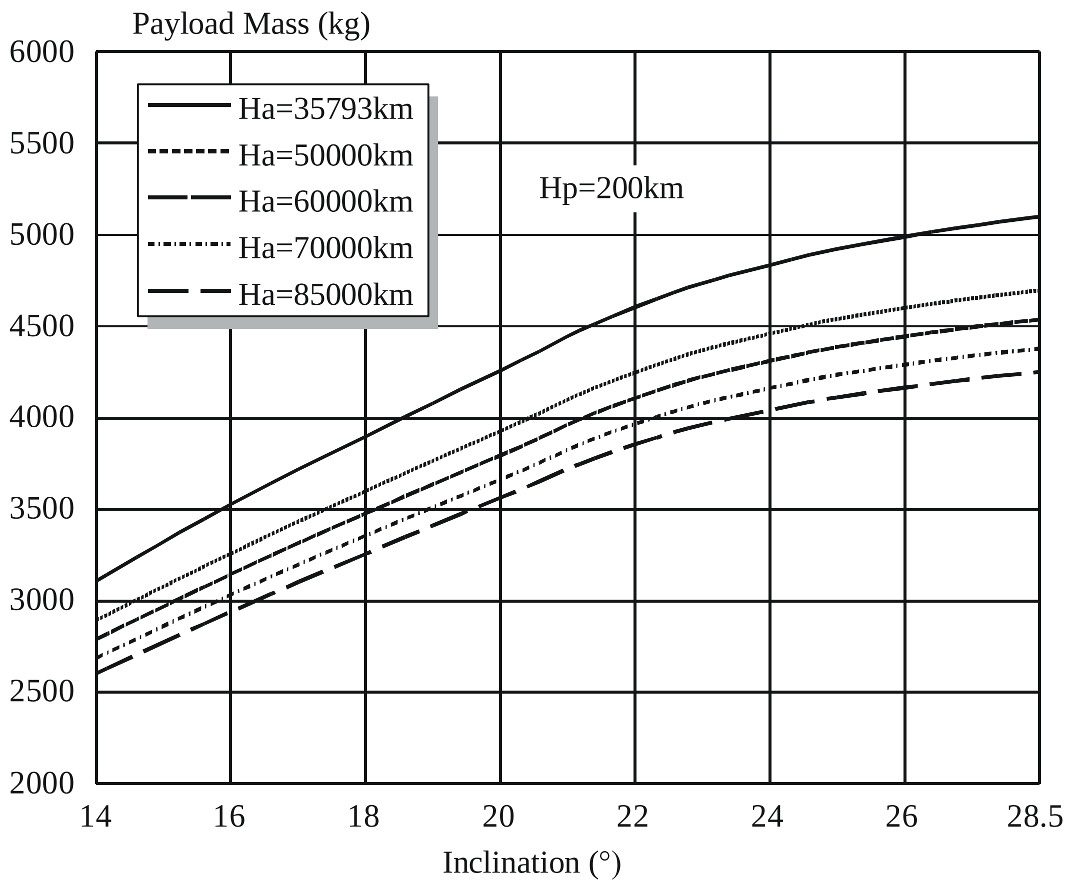
LM-3B can conduct various missions. The launch capacities for the four typical missions are introduced as follows, in which GTO mission is the prime mission.

- **GTO Mission**

The launch capacity of LM-3B for standard GTO mission is 5100kg (by Encapsulation-on-pad) and 5000kg (by Encapsulation-in-BS3). The different GTO launch capabilities vs. different inclinations and apogee altitudes are shown in **Figure 3-4** and **Figure 3-5**.

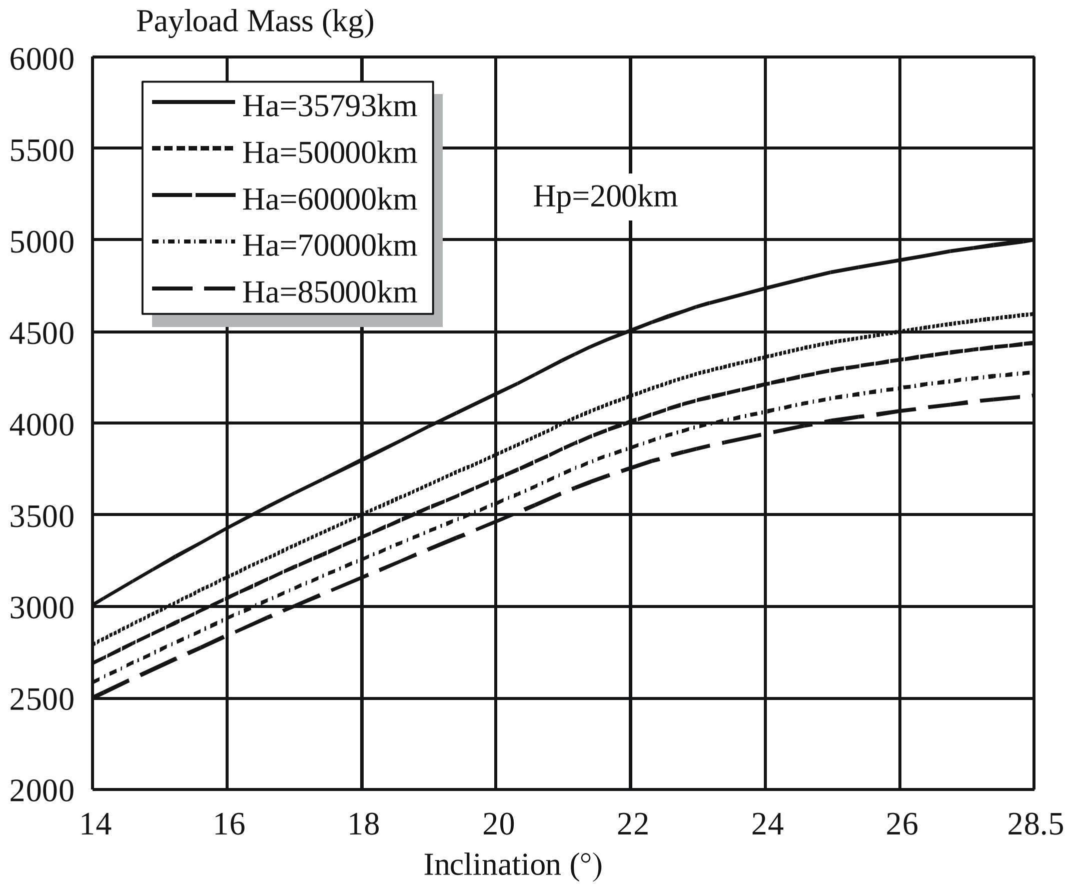
- **Low-Earth Orbit (LEO) Mission**

The Launch Capacity of LM-3B for LEO Mission (h=200 km, i=28.5°) is 11,200 kg.



Inclination (°)	Apogee Altitude (km)				
i	Ha=35793	Ha=50000	Ha=60000	Ha=70000	Ha=85000
14	3109	2893	2790	2687	2603
16	3527	3259	3146	3034	2941
18	3899	3600	3478	3357	3257
20	4259	3928	3795	3663	3564
22	4605	4248	4108	3967	3855
24	4835	4460	4311	4162	4042
26	4990	4600	4445	4291	4165
28.5	5100	4696	4537	4378	4251

Figure 3-4 LM-3B GTO Launch Performance (Encapsulation-on-Pad)



Inclination (°)	Apogee Altitude (km)				
i	Ha=35793	Ha=50000	Ha=60000	Ha=70000	Ha=85000
14	3009	2793	2690	2587	2503
16	3427	3159	3046	2934	2841
18	3799	3500	3378	3257	3157
20	4159	3828	3695	3563	3464
22	4505	4148	4008	3867	3755
24	4735	4360	4211	4062	3942
26	4890	4500	4345	4191	4065
28.5	5000	4596	4437	4278	4151

Figure 3-5 LM-3B GTO Launch Performance
(Encapsulation-in-BS3)

Sun-Synchronous Orbit (SSO) Mission

LM-3B is capable of sending SC to SSO directly. The launch performance of LM-3B for SSO Mission is shown in **Figure 3-6**.

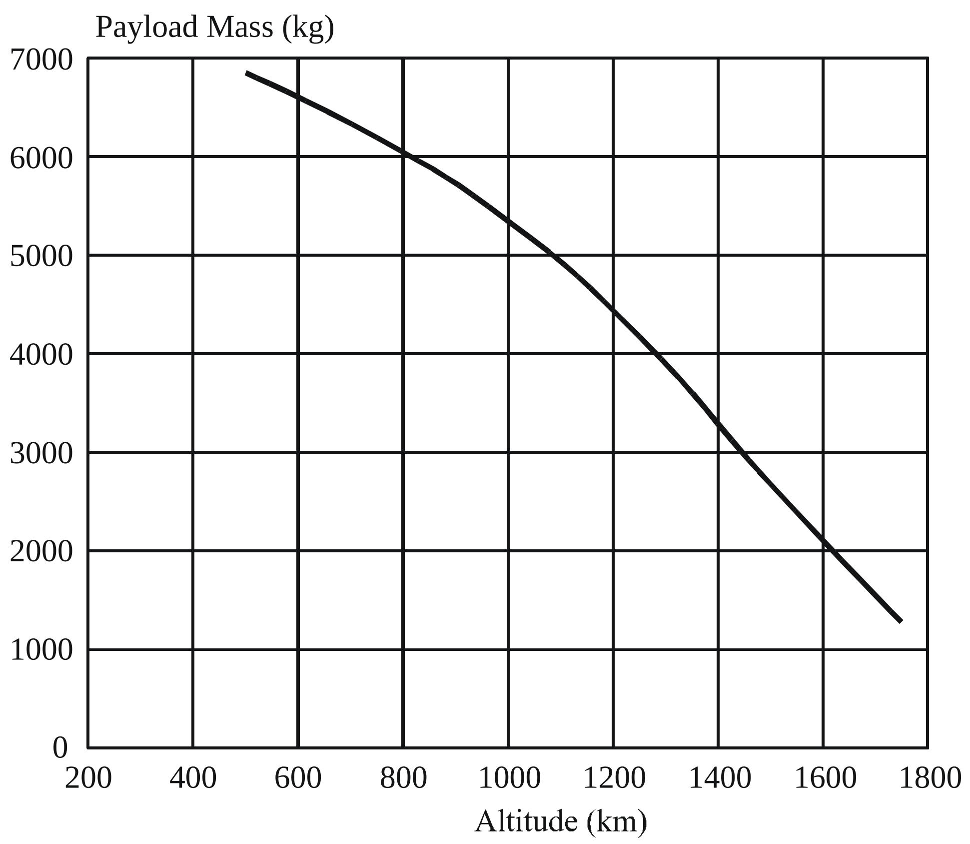


Figure 3-6 LM-3B SSO Launch Performance

- **Earth-Escape Mission**

The Earth-Escape Performance of LM-3B is shown in **Figure 3-7**. C3 is the square of the velocity at unlimited distance with unit of km^2/s^2.

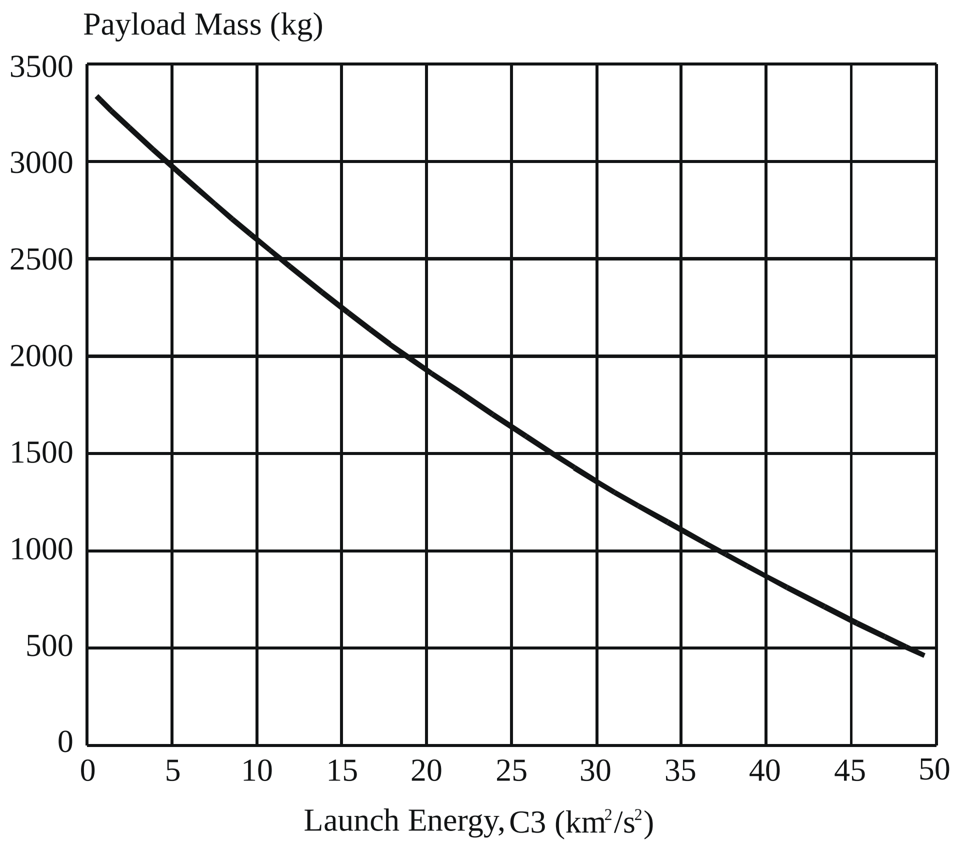


Figure 3-7 LM-3B Earth-Escape Mission Performance

3.4 Optimization Analysis on Special Missions

3.4.1 Ways to Enhance Mission Performance

3.4.1.1 Minimum Residual Shutdown (MRS)

The launch capacities given in **Paragraph 3.3** are gotten under condition of Commanded Shutdown (CS). Commanded Shutdown means, the third stage of LM-3B launch vehicle carries sufficient propellant allowing the payload to enter the predetermined orbit with probability no less than 99.73%. Commanded Shutdown is the main shutdown method that LM-3B adopts.

If the reserved propellants are reduced, the propellants will be used adequately, and the launch capability will be increased. However, the commanded shutdown probability will also be lower. The relationship between commanded shutdown probability and corresponding increased launch capability are shown in the following table.

Table 3-3 Relationship between Shutdown Probability and Launch Capability

Commanded Shutdown Probability	Increased Launch Capability (kg)
99.7%	0
95.5%	33
68.3%	67
50%	78

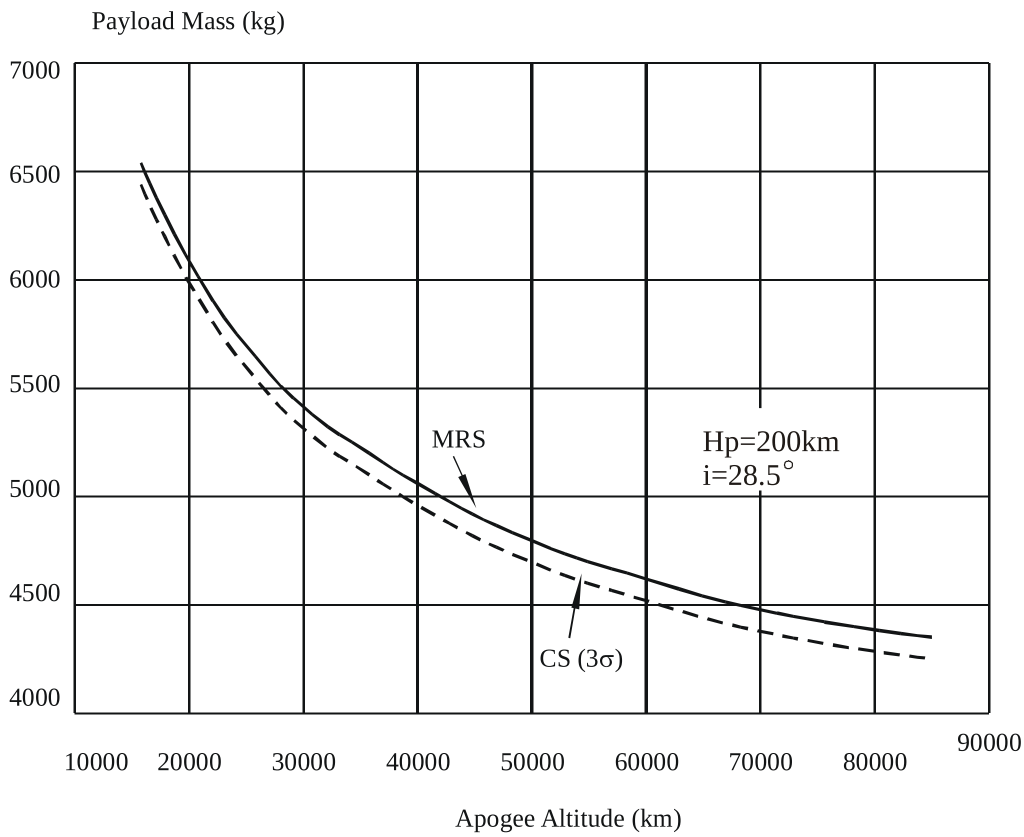
Minimum Residual Shutdown (MRS) means, the propellants of third stage is burned to minimum residuals for a significant increase in nominal performance capability. MRS is the designed capability of LM-3B. It is applicable and qualified though the LM-3B/Mabuhay mission.

The third stage of LM-3B is equipped with Propellant Utilization System (PUS). The deviation of LOX/LH2 mixture ratio can be compensated by PUS. The propellants can be consumed adequately, and the LV is under control and reliable. In this case, if the SC carries liquid propellants, it can flexibly execute orbit maneuver according to ground tracking data after SC/LV separation. Therefore, the third stage of LM-3B may be burned to minimum residuals to provide more LV energy to SC and to reduce the maneuver velocity of SC from GTO to GEO.

By using MRS and CS method, the different launch capacities of LM-3B with Encapsulation-on-pad configuration for GTO (i=28.5°) mission are shown in **Figure 3-8**.

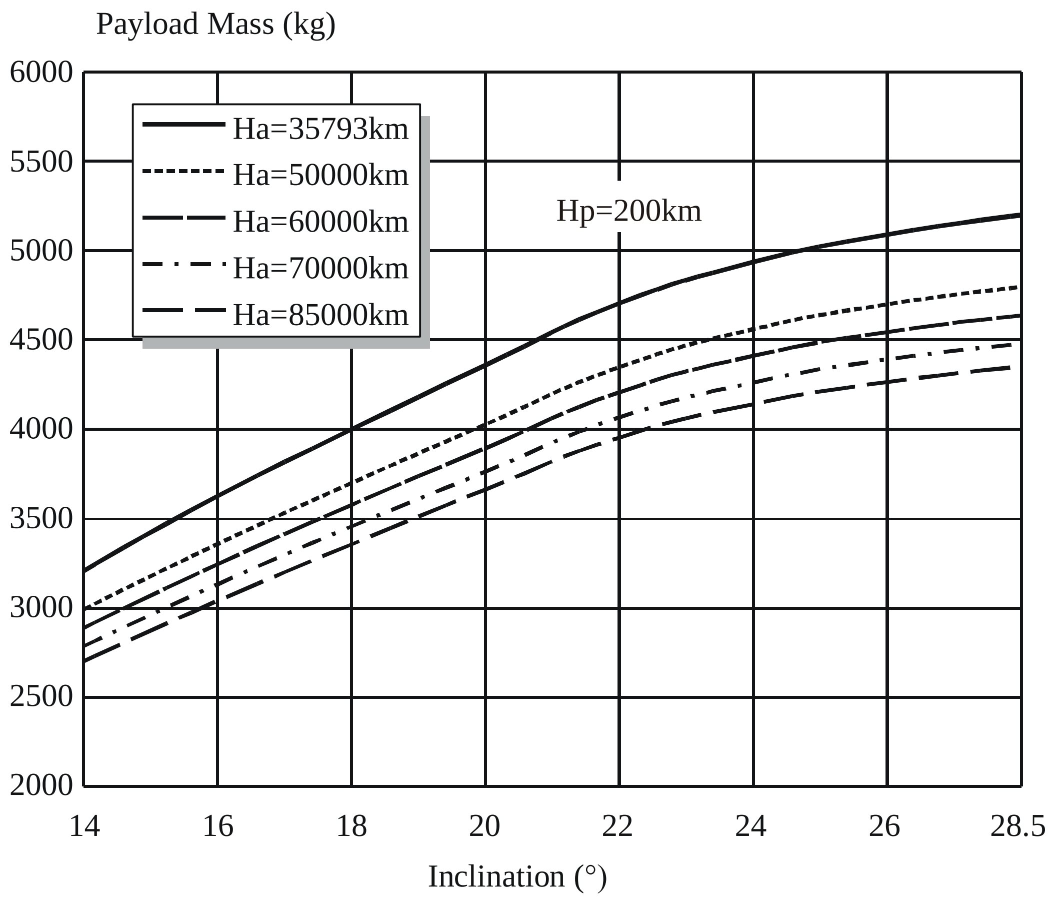
Under the condition of adopting MRS method, the launch capacity of LM-3B with Encapsulation-on-pad configuration for standard GTO mission is 5200kg, see **Figure 3-9**, and the launch capacity of LM-3B with Encapsulation-in-BS3 configuration is 5100kg, see **Figure 3-10**.

Under the condition of adopting MRS method, LM-3B provides users with more LV launch capacity. However, the orbital injection accuracy should be tolerated. If user is interested in this shutdown method, please contact CALT.



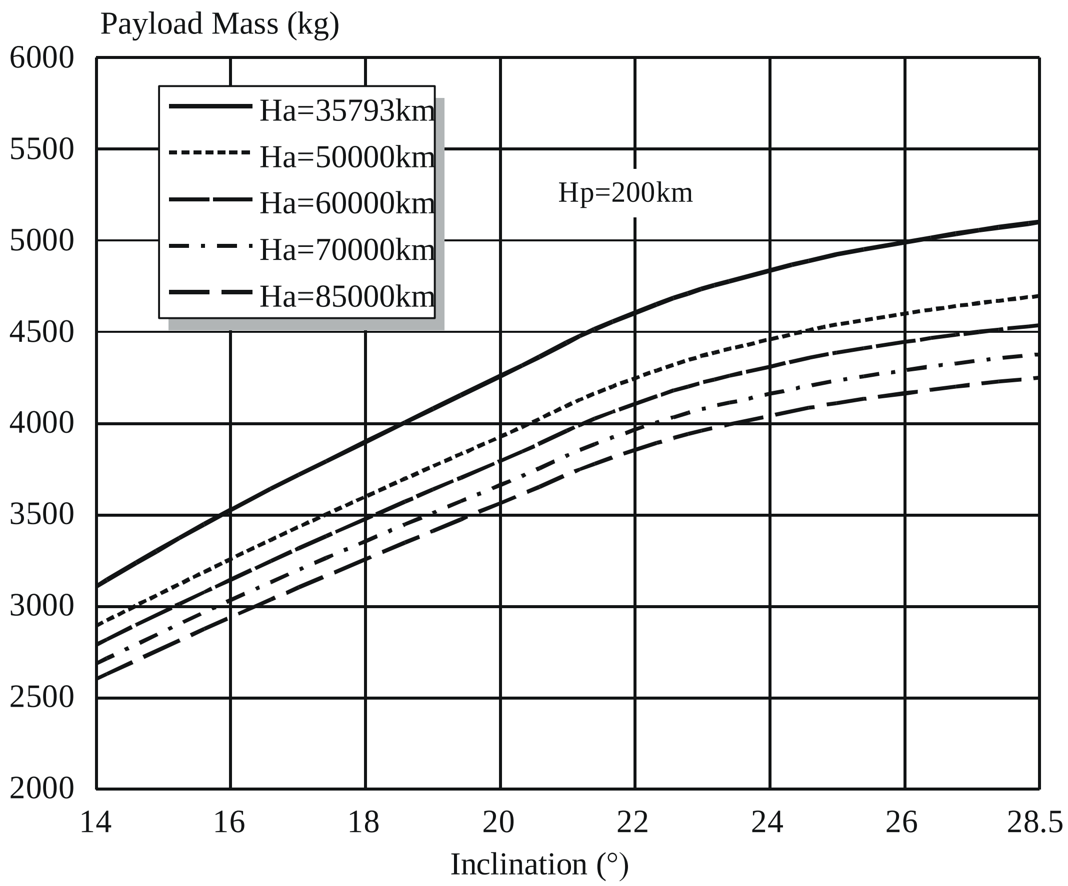
Apogee Altitude (km)	SC Mass (kg)	
Ha	CS (3σ)	MRS
15786	6440	6540
20786	5917	6017
25786	5547	5647
30786	5280	5380
35786	5100	5200
40000	4960	5060
50000	4696	4796
60000	4520	4620
70000	4378	4478
85000	4251	4351

Figure 3-8 Launch Capacities under Different Shutdown Method (Encapsulation-on-pad)



Inclination (°)	Apogee (km)				
i	Ha=35793	Ha=50000	Ha=60000	Ha=70000	Ha=85000
14	3209	2993	2890	2787	2703
16	3627	3359	3246	3134	3041
18	3999	3700	3578	3457	3357
20	4359	4028	3895	3763	3664
22	4705	4348	4208	4067	3955
24	4935	4560	4411	4262	4142
26	5090	4700	4545	4391	4265
28.5	5200	4796	4637	4478	4351

Figure 3-9 LM-3B GTO Mission Launch Capacity Under the Condition of MRS (Encapsulation-on-pad)



Inclination (°)	Apogee Altitude (km)				
i	Ha=35793	Ha=50000	Ha=60000	Ha=70000	Ha=85000
14	3109	2893	2790	2687	2603
16	3527	3259	3146	3034	2941
18	3899	3600	3478	3357	3257
20	4259	3928	3795	3663	3564
22	4605	4248	4108	3967	3855
24	4835	4460	4311	4162	4042
26	4990	4600	4445	4291	4165
28.5	5100	4696	4537	4378	4251

Figure 3-10 LM-3B GTO Mission Launch Capacity Under the Condition of MRS (Encapsulation-in-BS3)

3.4.1.2 Super GTO Performance

For the same launch mission, different launch trajectories can be selected. For example, one method is to decrease the inclination by keeping apogee altitude unchanged, and the other method is to increase the apogee altitude i.e. "Super GTO launching method".

Because the velocity of SC is relative low when the SC travels to the apogee of Super GTO, it is easier for SC to maneuver to 0°-inclination orbit. In this case, the propellants in SC are consumed less, and the lifetime of SC is longer. LM-3B has successfully launched Mabuhay, Apstar-IIR, ChinaStar-1 satellites to Super GTO.

When the SC mass is relative light, the remaining launch capacity of LM-3B can be used either for increasing apogee altitude or for reducing inclination. The injection accuracy for such a mission is different from that of Standard GTO mission.

The LM-3B launch capacities for Super GTO mission are shown in **Figure 3-4**, **Figure 3-5, Figure 3- 9 and Figure 3-10**.

3.4.2 Special Mission Requirements

The prime task of LM-3B is to perform standard GTO mission. However, LM-3B can be also used for special missions according to user's requirement, such as Super GTO mission, SSO mission, LEO mission or lunar mission, Martian mission etc.

LM-3B is capable of Dual-launch and piggyback for GTO mission and multiple-launch for LEO mission.

3.5 Injection Accuracy

The injection accuracy for Standard GTO mission is shown in **Table 3-4a**.

Table 3-4a Injection Accuracy for Standard GTO Mission (1σ)

Symbol	Parameters	Deviation
Δa	Semi-major Axis	40 km
Δi	Inclination	0.07°
Δω	Perigee Argument	0.20°
ΔΩ	Right Ascension of Ascending Node	0.20°*
ΔHp	Perigee Altitude	10 km

Note: * the error of launch time is not considered in determining ΔΩ.

The covariance matrix of injection for Injection Accuracy of Standard GTO mission is shown **Table 3-4b**:

Table 3-4b covariance matrix of injection for Standard GTO mission

	a (Semi-major axis)	e (eccentricity)	i (inclination)	ω (argument of perigee)	Ω (ascending node)
a	1524	0.02492	0.5266	3.2344	-0.09688
e		0.52706E-6	0.8615E-5	0.6146E-4	0.5314E-8
i			0.4752E-2	0.1237E-3	-0.4212E-2
ω				0.03897	-0.01780
Ω					0.03927

The injection accuracy of two Super GTO missions conducted by LM-3B are introduced as example:

Super GTO Mission 1: *i*=24.5°, *hp*=200km, *ha*=47924km.

Table 3-5a Injection Accuracy for Super GTO Mission (*ha*=47924km) (1σ)

Symbol	Parameters	Deviation
Δa	Semi-major Axis	63 km
Δi	Inclination	0.071°
Δω	Perigee Argument	0.085°
ΔΩ	Right Ascension of Ascending Node	0.19°*
ΔHp	Perigee Altitude	10 km

Note: * the error of launch time is not considered in determining ΔΩ.

Table 3-5b Covariance Matrix of injection for Super GTO Mission (*ha*=47924km)

	a	e	i	ω	Ω
a	3969	0.0281	3.067	3.13	-1.06
e		0.383E-6	-0.603	0.21241E-4	0.2667E-4
i			0.00504	0.230E-2	-0.24602E-2
ω				0.723E-2	0.46666E-2
Ω					0.361E-1

Super GTO Mission 2: i=24.5°, hp=200km, ha=85000km.

Table 3-6a Injection Accuracy for Super GTO Mission (*ha*=85000 km) (1σ)

Symbol	Parameters	Deviation
Δa	Semi-major Axis	252 km
Δi	Inclination	0.12°
Δω	Perigee Argument	0.13°
ΔΩ	Right Ascension of Ascending Node	0.20°*
ΔHp	Perigee Altitude	10 km

Note: * the error of launch time is not considered in determining ΔΩ.

Table 3-6b Covariance Matrix of injection for Super GTO Mission (ha=85000km)

	a	e	i	ω	Ω
a	63504	0.179	21.3	8.60	-3.94
e		8.02E-7	3.33E-5	4.03E-5	-0.591E-5
i			0.0144	5.07E-3	-4.96E-3
ω				0.0169	-0.92126E-2
Ω					0.04

3.6 Pointing Accuracy

3.6.1 Perigee Coordinate System Definition

During the period from 20 seconds after the third stage shutdown to SC/LV separation, the attitude control system on the third stage adjusts the pointing direction of the SC/LV stack to the pre-determined direction. It takes about 80 seconds to complete the attitude-adjustment operation. The pointing requirements are defined by the perigee coordinate system (U, V, and W). The user shall propose the pointing requirements. Before SC/LV separation, the attitude control system can maintain attitude errors of SC/LV stack less than 1°.

The perigee coordinate system (OUVW) is defined as follows:

- The origin of the perigee coordinate system (O) is at the center of the earth,
- OU is a radial vector with the origin at the earth center, pointing to the intended perigee.
- OV is perpendicular to OU in the intended orbit plane and points to the intended direction of the perigee velocity.
- OW is perpendicular to OV and OU and OUVW forms a right-handed orthogonal system.

See **Figure 3-11**.

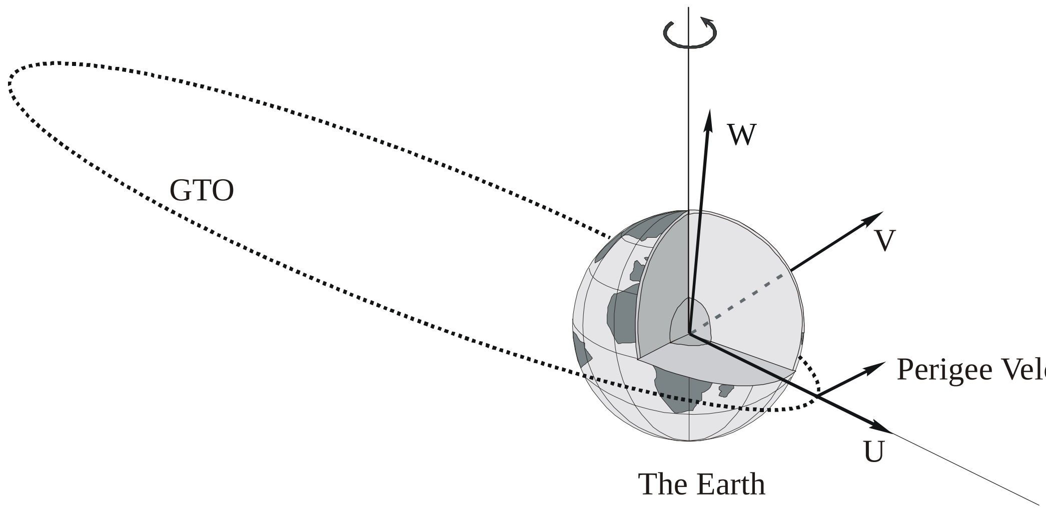


Figure 3-11 Perigee Coordinate System (OUVW)

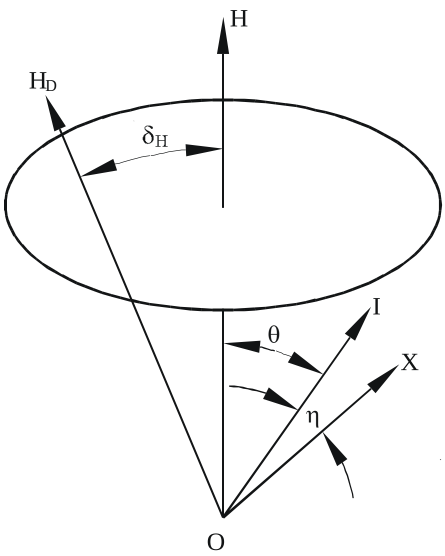
3.6.2 Separation Accuracy

- For the SC needs spin-up rate along LV longitude axis (the spin-up rate from 5 rpm to 10 rpm), the post-separation pointing parameters are as follows:
  If: lateral angular rate: ω<2.5°/s
  Angular momentum pointing direction deviation: δ**H**<8°

- For the SC needs spin-up rate along SC lateral axis (the spin-up rate less than 3°/s), the post-separation pointing parameters are as follows:
  If: lateral angular rate: ω<0.7°/s
  Angular momentum pointing direction deviation: δ**H**<15°

- For the SC doesn't need spin-up, the post-separation pointing parameters are as follows:
  If: lateral angular rate: ω <1°/s (Combined in two lateral main inertial axes)
  Instant deviation at geometry axis: δx<3°

See **Figure 3-12**.



H: Actual Angular Momentum;
H_D: Required Angular Momentum;
I: SC Primary Inertial Axis;
δ_H: Deviation of Angular Momentum;
X: SC Geometric Axis;
θ: Nutation Angle;
η: Dynamic Balance Angle;
O: Center of Gravity

Figure 3-12 Separation Accuracy Definition

3.7 Spin-up Accuracy

3.7.1 Longitudinal Spin-up Accuracy

The attitude-control system of the third stage can provide the SC with spin-up rate of up to 10 rpm along LV longitude axis.

For the SC with longitudinal spin-up rate of 10rpm, the spin-up accuracy can be controlled in the range of 0~0.6rpm.

3.7.2 Lateral Spin-up Accuracy

By using of separation springs, the SC/LV separation system can provide SC with lateral spin-up rate of up to 3°/s along later axis of the SC.

For the SC with lateral spin-up rate of 3°/s, the spin-up accuracy can be controlled in the range of 2.2±0.8 °/s.

3.8 Launch Windows

Because the third stage of LM-3B uses cryogenic LH_2 and LOX as propellants and the launch preparation is relative complicated, the SC is expected to have at least one launch window within each day of the launch. In general, each launch window should be longer than 45 min. If the requirements are not complied by the payload, the user can consult with CALT.