CHAPTER 3

PERFORMANCE

3.1 Introduction

The LM-3A 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 104°;
- Mass of the payload adapter and the separation system not included in the payload mass;
- The third stage of LM-3A 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-3A is mainly used for conducting GTO mission. The standard GTO is recommended to the User. LM-3A launches Spacecraft (SC) into the standard GTO with following injection parameters from XSLC.

Perigee Altitude	Hp	=200 km
Apogee Altitude	Ha	=35958.2 km
Inclination	i	=28.5°
Perigee Argument	ω	=179.6°

✧ 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-3A is shown in **Table 3-1** and **Figure 3-1**.

Table 3-1 Flight Sequence

Events	Flight Time (s)
Liftoff	0.000
Pitch Over	12.000
Stage-1 Shutdown	146.428
Stage-1/Stage-2 Separation	147.928
Fairing Jettisoning	236.928
Stage-2 Main Engine Shutdown	258.278
Stage-2 Vernier Engine Shutdown	263.278
Stage-2/Stage-3 Separation, and Stage-3 First Start	264.278
Stage-3 First Shutdown	617.299
Coast Phase Beginning	620.799
Coast Phase Ending, and Stage-3 Second Start	1252.513
Stage-3 Second Shutdown, Velocity Adjustment Beginning	1374.440
Velocity Adjustment Ending	1394.440
SC/LV Separation	1474.440

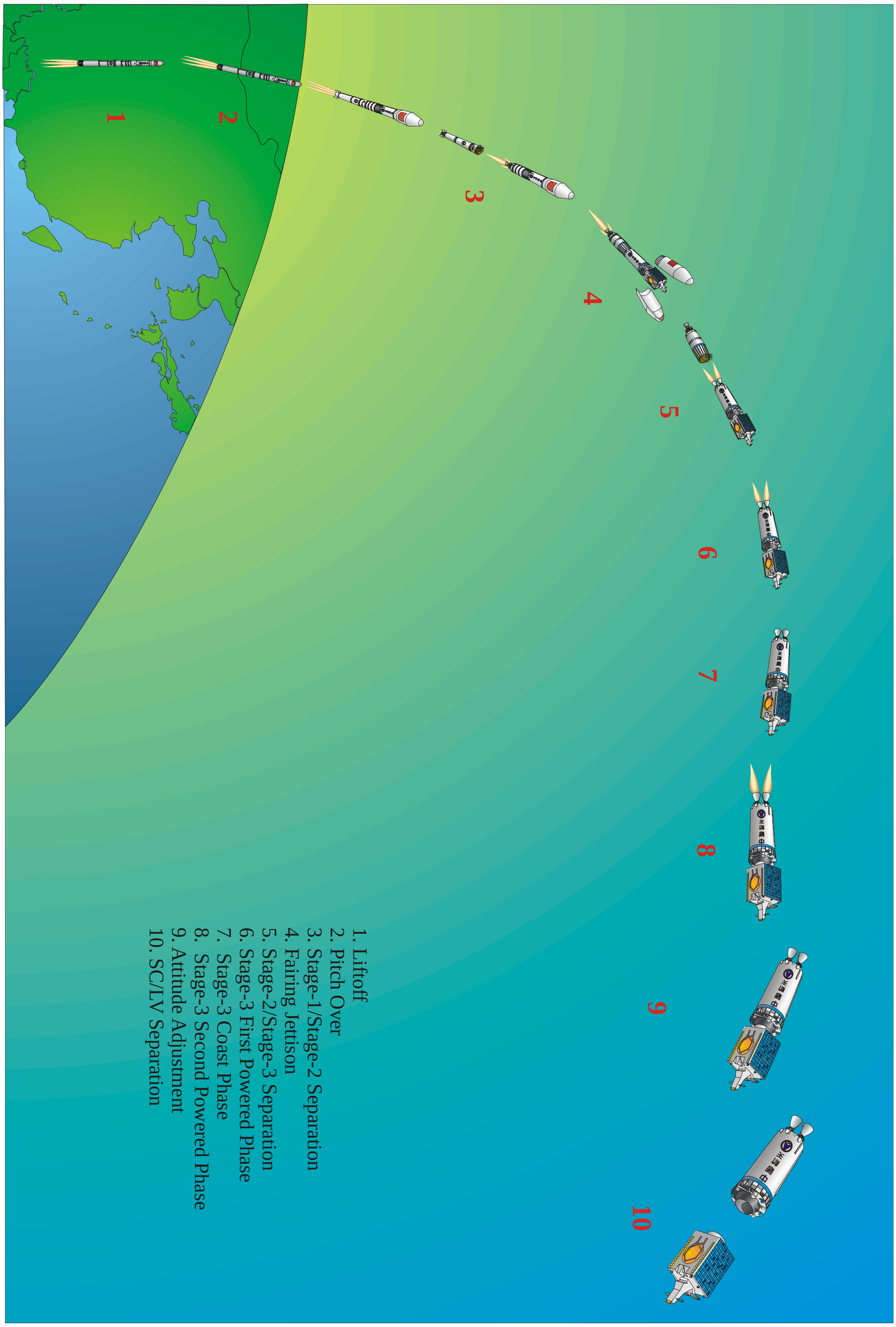


Figure 3-1 LM-3A Flight Sequence

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
Stage-1 Shutdown	2274.922	55.626	79.065	19.5535	27.908	102.806
Stage-1/Stage-2 Separation	2284.654	56.804	82.252	19.2233	27.901	102.838
Fairing Jettisoning	3576.273	118.971	324.879	9.9956	27.317	105.211
Stage-2 Main Engine Shutdown	4075.408	134.172	403.340	9.6121	27.118	105.972
Stage-2 Vernier Engine Shutdown	4088.837	137.844	423.014	9.2738	27.067	106.162
Stage-2/Stage-3 Separation	4087.556	138.561	426.951	9.1953	27.057	106.200
Stage-3 First Shutdown	7392.039	195.265	2291.528	-0.1240	21.416	123.541
Coast Phase Beginning	7399.471	195.188	2316.632	-0.1135	21.330	123.765
Stage-3 Second Start	7407.512	194.859	6853.729	0.1726	2.136	160.766
Stage-3 Second Shutdown	9796.206	212.941	7855.140	2.3461	-2.448	168.520
Terminal Velocity Adjustment Ending	9802.071	222.677	8044.293	3.0934	-3.291	170.000
SC/LV Separation	9741.457	287.952	8792.918	6.0489	-6.599	175.888

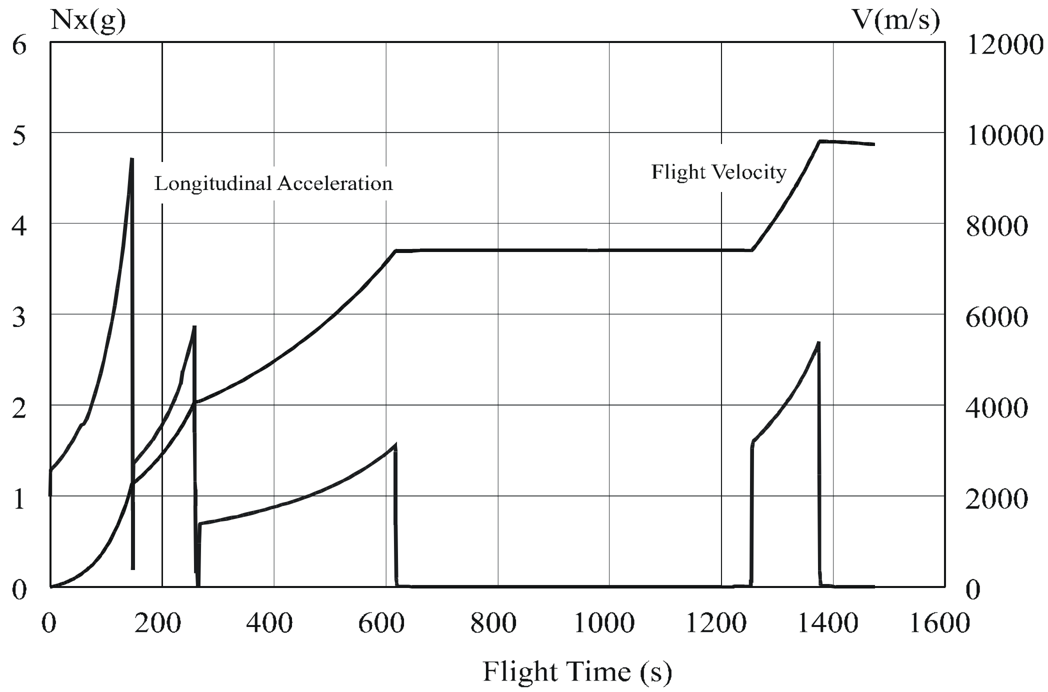


Figure 3-2a LV Flight Acceleration and Flight Velocity vs. Flight Time

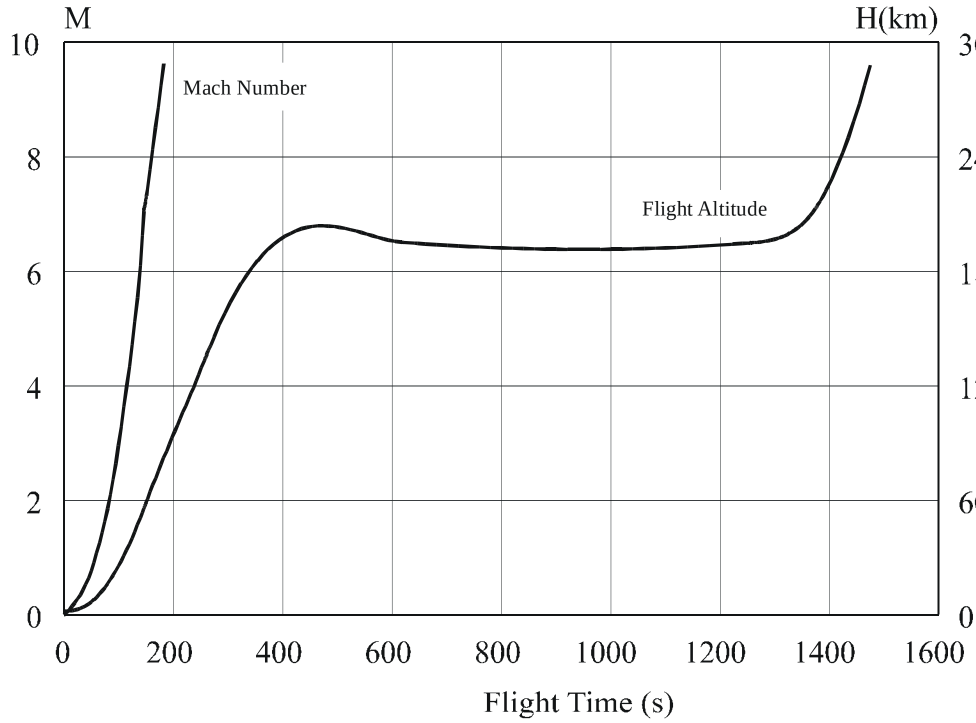


Figure 3-2b LV Flight Altitude and Mach Numbers vs. Flight Time

3.3 Standard Launch Capacities

3.3.1 Basic Information on XSLC

LM-3A launch vehicle conducts GTO mission from Xichang Satellite Launch Center (XSLC), which is located in Sichuan Province, China. LM-3A 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**.

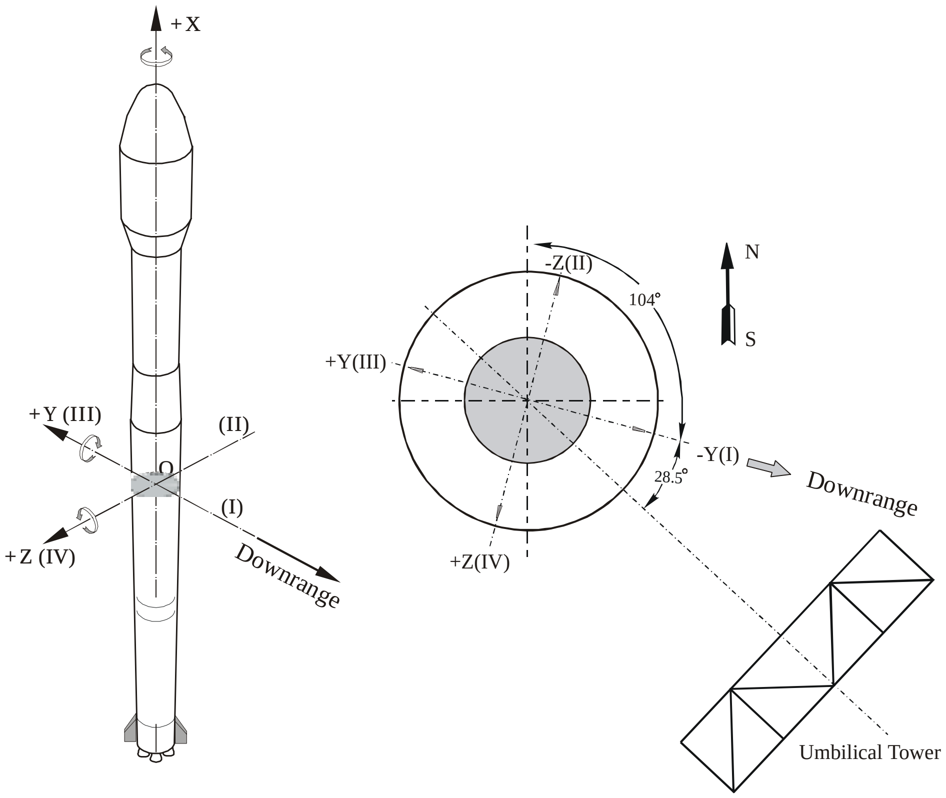


Figure 3-3 Launch Direction

3.3.2 Launch Capacity to Standard GTO

The LM-3A Standard GTO is defined in **Paragraph 3.2.1**, and see also **Figure 2-11** of **Chapter 2**. There are two kinds of engine shutdown methods that can be adopted by the LV Stage-3, Commanded Shutdown (CS) and Minimum Residual Shutdown (MRS).

Commanded Shutdown (CS) means, the third stage of LM-3A 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-3A adopts.

Minimum Residual Shutdown (MRS) means, the propellants of the third stage is burned to minimum residuals for a significant increase in nominal performance capability. However, the injection accuracy in case of MRS will be lower.

The standard GTO performances of LM-3A corresponding to the two shutdown methods are as follows:

Commanded Shutdown (CS): 2600 kg
Minimum Residual Shutdown (MRS): 2700 kg

If there is no special explanation, the launch capacities stated in this User's Manual is corresponding to Commanded Shutdown (CS) method.

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

3.3.3 Mission Performance

LM-3A 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-3A for standard GTO mission is 2600 kg. The different GTO launch capabilities vs. different inclinations and apogee altitudes are shown in **Figure 3-4.**

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

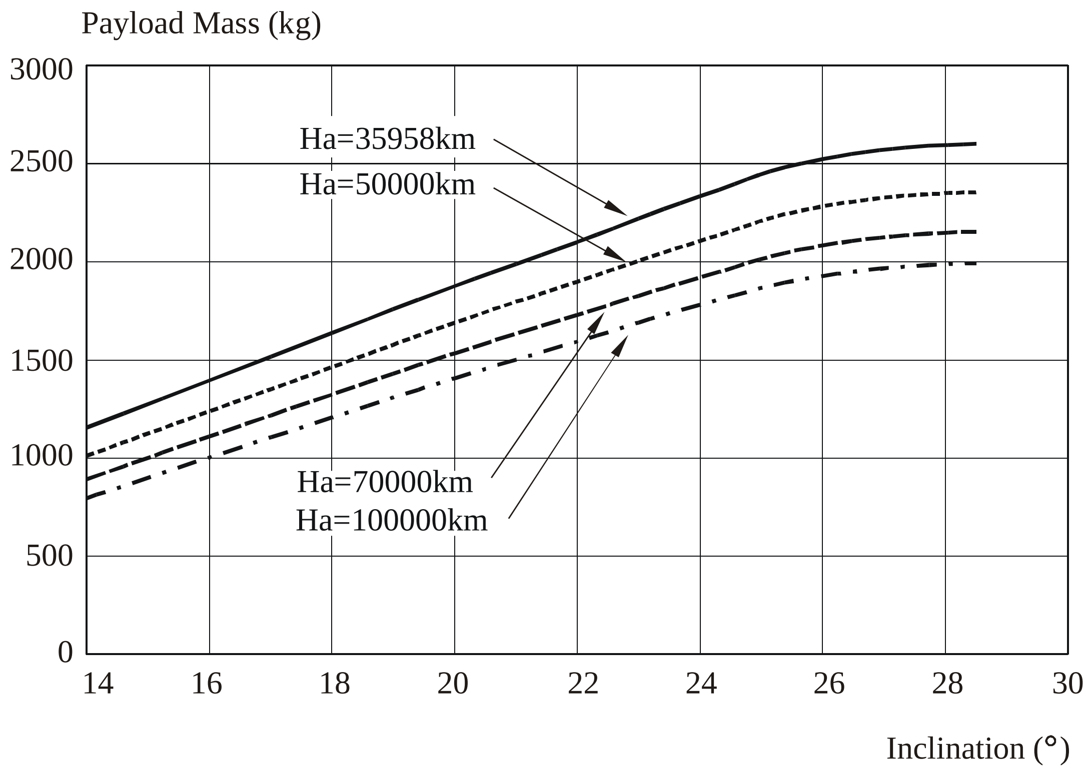
The Launch Capacity of LM-3A for LEO Mission (h=200 km, i=28.5°) is 6000 kg.

- **Sun-Synchronous Orbit (SSO) Mission**

LM-3A is capable of sending SC to SSO directly. The launch performance of LM-3A for SSO Mission is shown in **Figure 3-5**.

- **Earth-Escape Mission**

The Earth-Escape Performance of LM-3A is shown in **Figure 3-6**. C3 is the square of the velocity at unlimited distance with unit of km^2/s^2.



Inclination (°)	Apogee Altitude			
i	Ha=35958km	Ha=50000km	Ha=70000km	Ha=100000km
14	1154	1011	892	795
16	1395	1238	1110	1003
18	1637	1463	1323	1206
20	1877	1689	1534	1407
22	2101	1899	1729	1593
24	2334	2106	1920	1780
26	2523	2282	2083	1928
28.5	2600	2354	2153	1993

Figure 3-4 LM-3A GTO Launch Performance

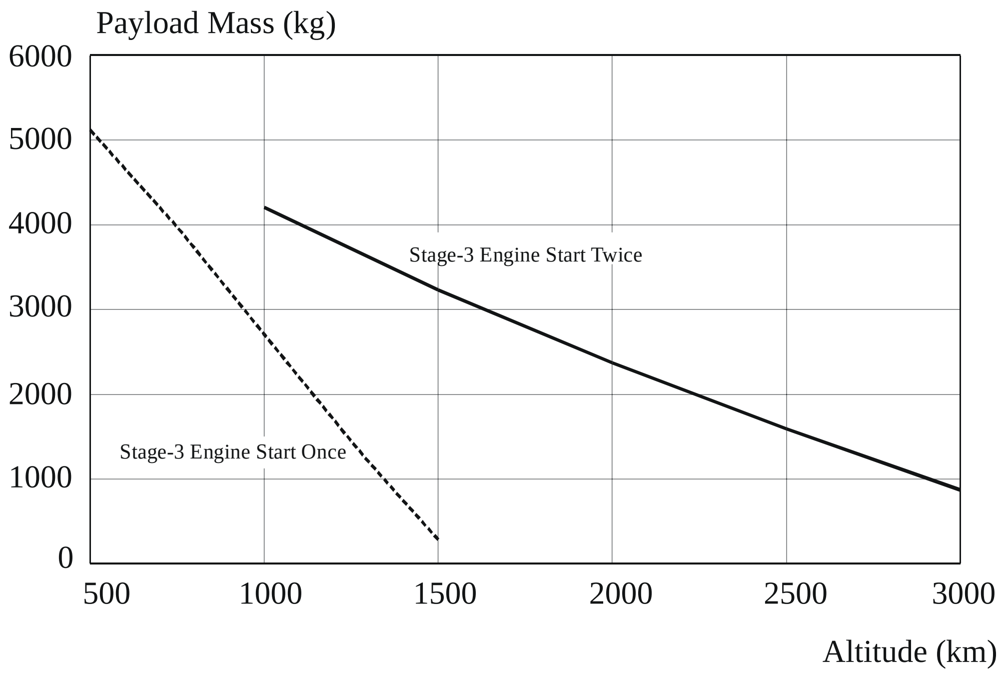


Figure 3-5 LM-3A SSO Launch Performance

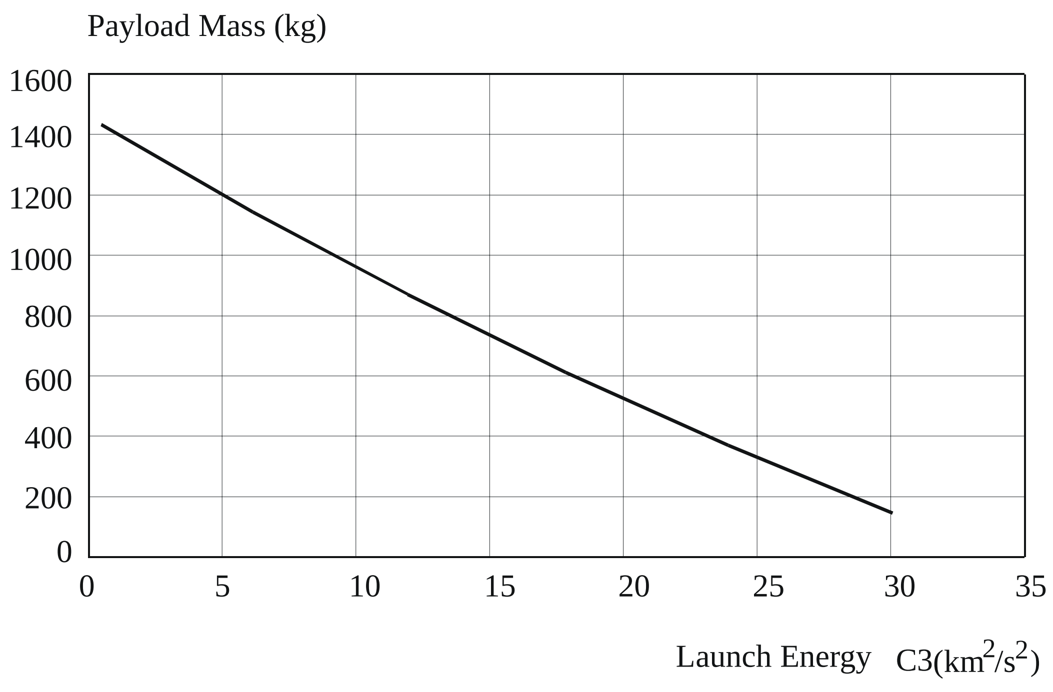


Figure 3-6 LM-3A Earth-Escape Mission Performance

3.4 Optimization Analysis on Special Missions

3.4.1 Ways to Enhance Mission Performance

3.4.1.1 Minimum Residual Shutdown (MRS)

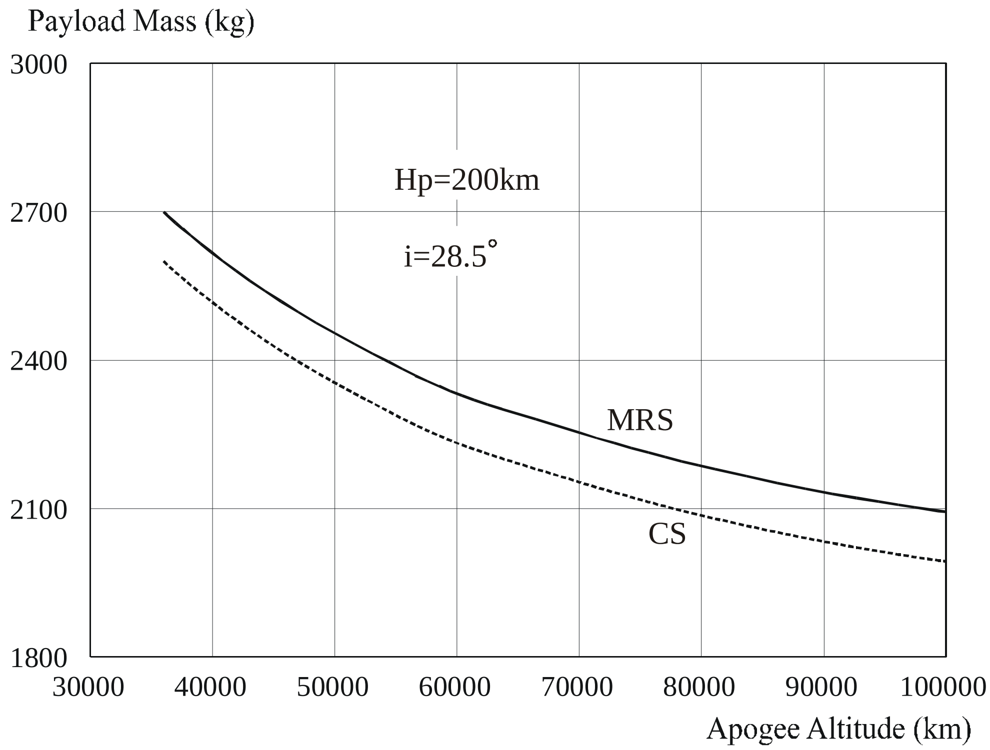
The launch capacities given in **Paragraph 3.3** are gotten under condition of Commanded Shutdown (CS).

The third stage of LM-3A 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-3A 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. (Refer to **Paragraph 3.3**)

By using MRS and CS method, the different launch capacities of LM-3A for GTO (i=28.5°) mission are shown in **Figure 3-7**.

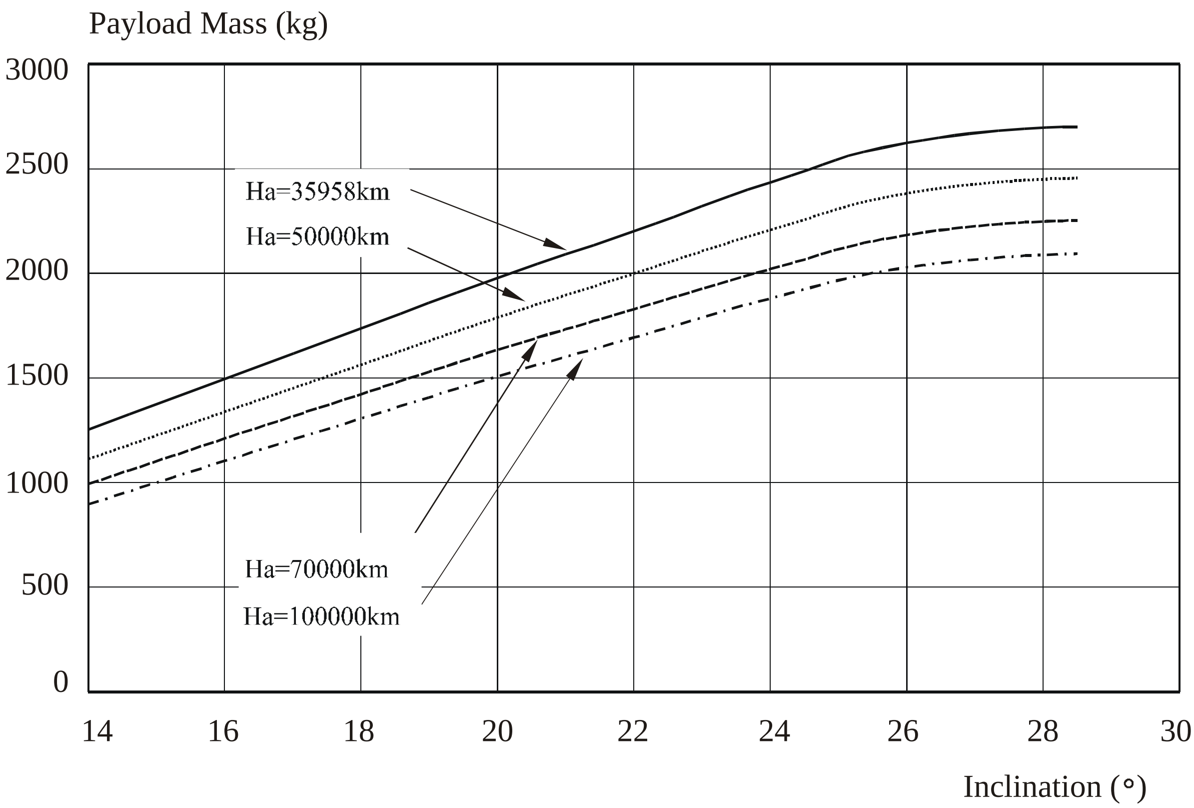
Under the condition of adopting MRS method, the different launch capabilities vs. different inclinations and apogee altitudes are shown in **Figure 3-8.**

Under the condition of adopting MRS method, LM-3A 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	**Payload Mass (kg)**	
Ha	CS	MRS
35958	2600	2700
50000	2354	2454
70000	2153	2253
100000	1993	2093

Figure 3-7 Launch Capacities under Different Shutdown Method



Inclination (°)	Apogee Altitude (km)			
i	ha=35958km	ha=50000km	ha=70000km	ha=100000km
14	1254	1111	992	895
16	1495	1338	1210	1103
18	1737	1563	1423	1306
20	1977	1789	1634	1507
22	2201	1999	1829	1693
24	2434	2206	2020	1880
26	2623	2382	2183	2028
28.5	2700	2454	2253	2093

Figure 3-8 LM-3A GTO Mission Launch Capacity Under the Condition of MRS

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. When the SC mass is less than 2600 kg, the remaining launch capacity of LM-3A can be used for increasing apogee altitude to make the lifetime of SC longer.

The LM-3A launch capacities for Super GTO mission are shown in **Figure 3-4**, **Figure 3- 7 and Figure 3-8**.

3.4.2 Special Mission Requirements

The prime task of LM-3A is to perform standard GTO mission. However, LM-3A 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-3A 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

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 3-9**.

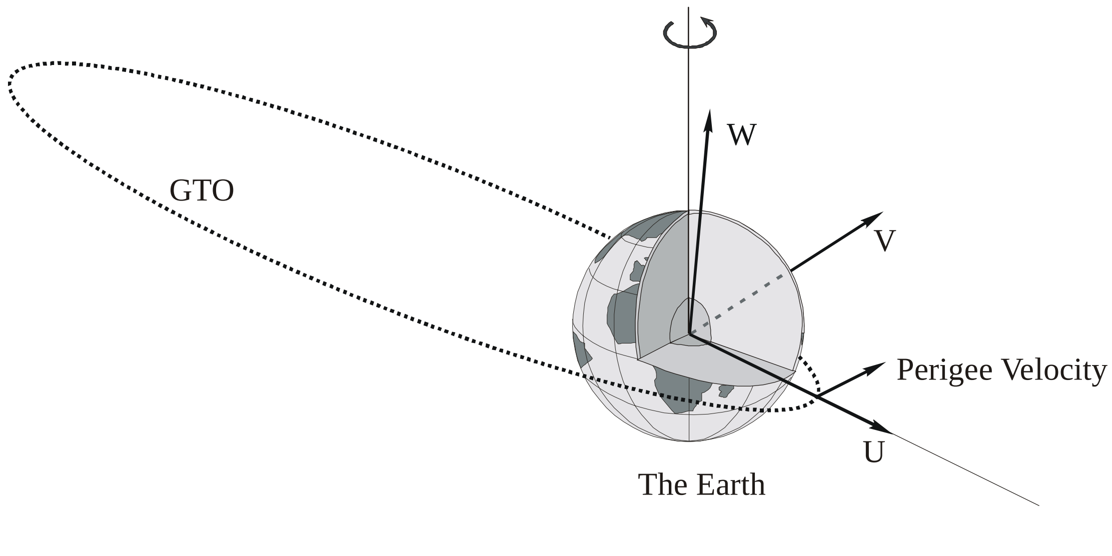


Figure 3-9 Perigee Coordinate System (OUVW)

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

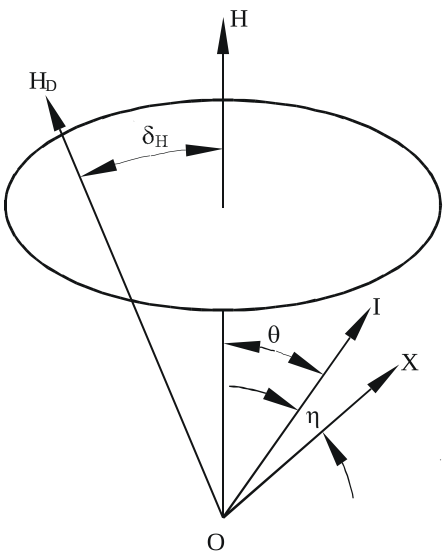
  Angular momentum pointing direction deviation: δ**H**<15°

- 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 3-10**.



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 3-10 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-3A 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.