May 15, 2019

Cyclone-4M SLS ABBREVIATED USER'S GUIDE

Version: 2

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LAUNCH VEHICLE

1.1 ILV Design

The Cyclone-4M ILV is a tandem liquid-propellant medium-lift ILV designed to lift payloads into low and medium circular and elliptic Earth orbits including sun-synchronous orbits.

The Cyclone-4M ILV comprises

- 9.7m,
- Second stage,
- Payload unit.

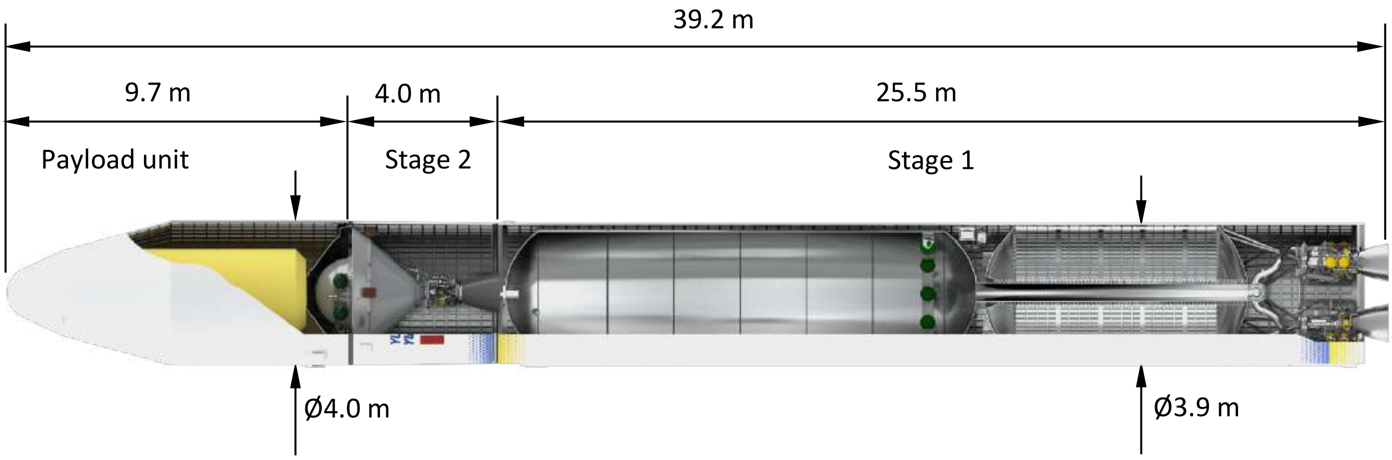

Figure 1.1. Cyclone-4M ILV

1.2 ILV Background

The design of the Cyclone-4M integrated launch vehicle is based on proven engineering solutions that were tried out on other ILVs developed by Yuzhnoye SDO, using primary components developed in Ukraine. The Cyclone-4M Stage 1 is derived from the Zenit and Antares first stages produced at Yuzhmash. Stage 2 is the Cyclone-4's Stage 3, which was modified for autonomous fueling at the FNS and its subsequent ampoulization. The Cyclone-4M payload unit is an upgraded Cyclone-4 PLU.

1.3 Stage 1

1.3.1 Overall Configuration

The Stage 1 basic structure is made of an aluminum alloy and features reinforcement by structural elements made by machining and providing overall reinforcement of the structure. Environmentally friendly kerosene and liquid oxygen are used as propellants.

The oxidizer tank comprises a cylindrical body and two spherical domes. The oxidizer tank body consists of smooth sections. Like the oxidizer tank, the fuel tank comprises a circular-shaped body and two spherical domes. The fuel tank body consists of cylindrical waffle sections.

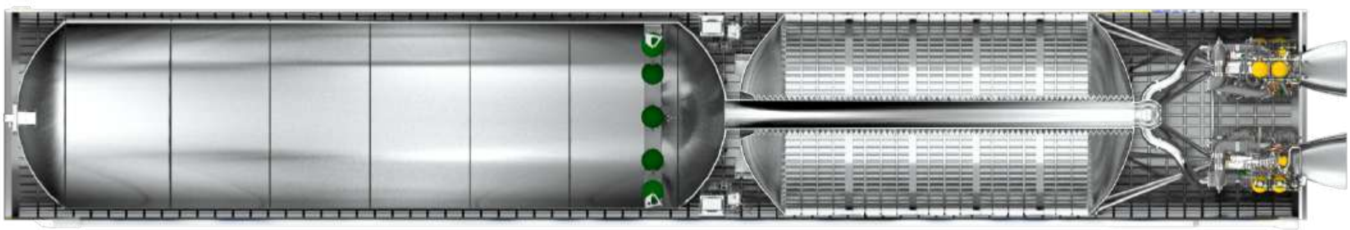

Figure 1.2. Cyclone-4M Stage 1

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Table 1.1 shows the Cyclone-4M ILV Stage 1 basic specifications.

Table 1.1. Cyclone-4M ILV Stage 1 Basic Specifications

Specification	
Propellants	kerosene + LOX
Engine burning time, s	275
Stage wet weight, t	245
Weight of fuel, t	62
Weight of oxidizer, t	166
Length, m	25
Diameter, m	3.9
Engines	RD874 (Four RD870 engine blocks)
Nominal thrust (sea level), tf	317.2
Nominal thrust (vacuum), tf	357.72
Nominal specific impulse (sea level), s	301.5
Nominal specific impulse (vacuum), s	340.0
Attitude control	Two RD870 engine blocks gimbaled at ±6°

1.3.2 Stage 1 Engine

The Stage 1 main engine RD874 (Figure 2.3) burns liquid oxygen and kerosene. It is designed to generate thrust and control thrust vector in all attitude and stabilization axes during Cyclone-4M Stage 1 flight.
The RD874 main engine comprises four RD870 engines (two of which are gimbaled, the other two fixed) mounted on a common frame. Each of the RD870 engine blocks is a single-chamber single-burn liquid-propellant rocket engine with a turbopump propellant-feeding system and an oxidizer-rich preburner. Thrust vectoring is achieved by gimballing each of two swiveling engine blocks in two perpendicular planes.
At the end of their burn, the RD870 engine blocks throttle down to 78% of the nominal full thrust.
The RD874 main engine is designed based on proven Zenit LV engineering solutions.

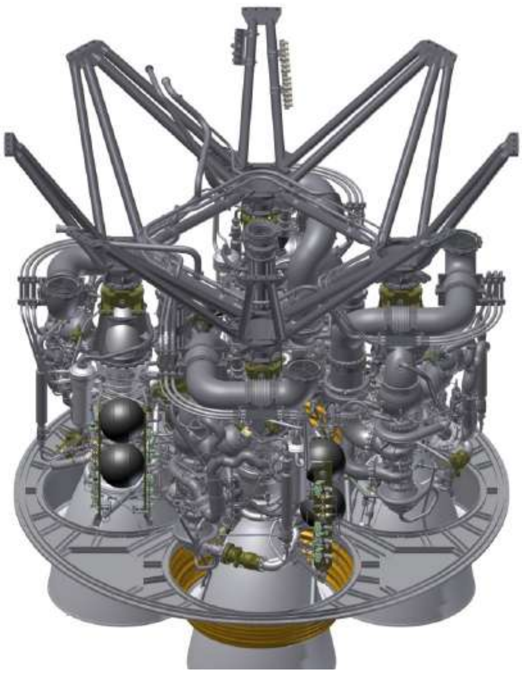

Figure 1.3 Stage 1 Main Engine

1.4 Stage 2

1.4.1 Overall Configuration

The Stage 2 basic structure comprises a joint propellant compartment accommodating and securing the main engine, liquid jet system, PHS elements, avionics, and the thermal control system. In addition, the propellant compartment provides a mechanical interface between Stage 2 and the interstage and the payload unit.
The propellant compartment is an -all-welded leak-proof sphero-conical tank comprising two reservoirs: a sphero-cylindrical oxidizer reservoir and a conical fuel reservoir.
Stage 2 flight control is achieved by gimballing the main engine and by the operation of the liquid jet system.

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Passive thermal control devices – heat pipes – average and level the temperature field along a thermal radiator, which is provided in the upper section of the skirt, during prelaunch operations and in flight.
The interstage is mated to Stage 2 using eight explosive bolts and gets detached together with Stage 1 at stage separation.

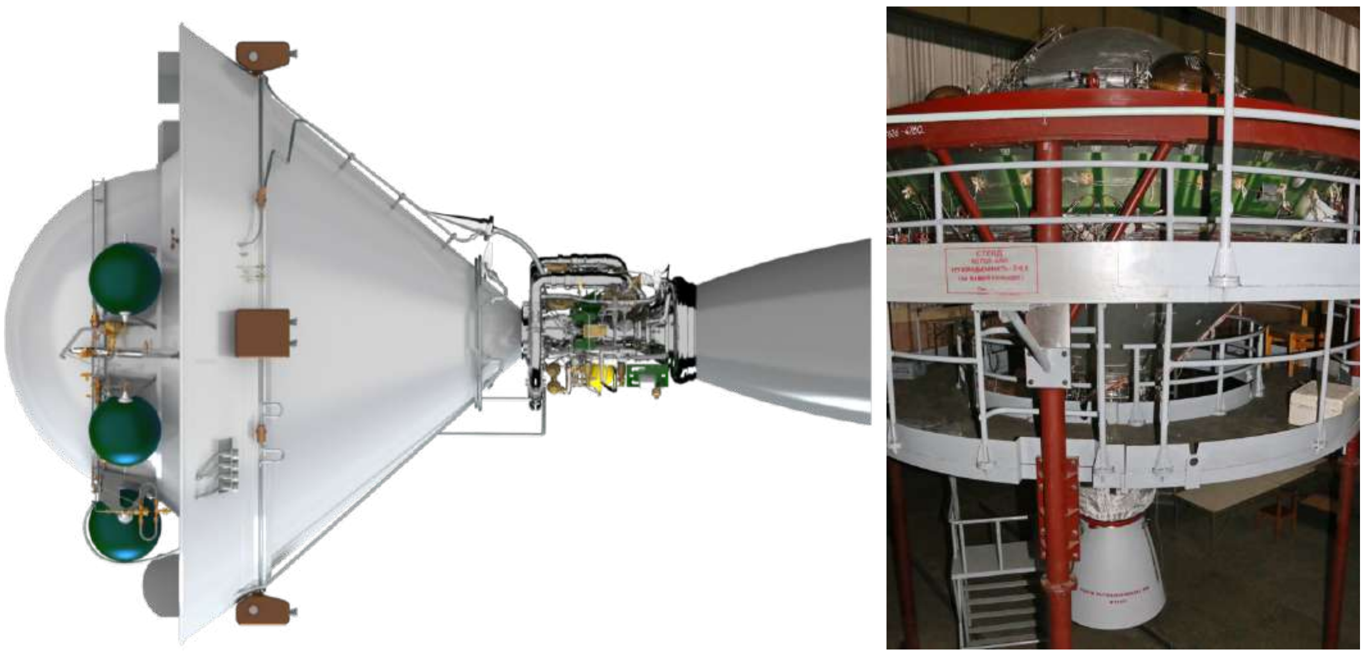

Figure 1.4. Cyclone-4M Stage 2

Table 1.2. Cyclone-4M Stage 2 Basic Specifications

Specification	
Propellants	NT+UDMH
Engine burn time, s	481
Stage wet weight, t	12.9
Weight of fuel, t	3.2
Weight of oxidizer, t	7.7
Length, m	4
Diameter, m	3.9
Engine	RD861K
Nominal thrust in vacuum, tf	7.916
Nominal specific impulse in vacuum, s	330
Attitude control	gimballing at ±5°

1.4.2 Stage 2 Engine

The Stage 2 main engine RD861K (Figure 1.5) burns hypergolic propellants: nitrogen tetroxide and unsymmetrical dimethylhydrazine. The engine is designed to generate thrust and provide pitch and yaw thrust vectoring during powered flight of the Cyclone-4M Stage 2.
The RD861K main engine is a single-chamber five-burn open-cycle engine with a turbopump feeding system and injection of a producer gas into the supersonic nozzle section. Thrust vectoring is provided by gimballing the engine in two perpendicular planes.
Yuzhnoye SDO has developed the RD861K main engine for the Cyclone-4 launch vehicle; this engine is an upgraded version of the RD861 engine installed in the Cyclone-3, Stage 3.

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Figure 1.5. Stage 2 Main Engine

1.5 Payload Unit

The payload unit is designed to accommodate spacecraft inside the ILV and protect them from exposure to the environment during ILV ground operations at the LS and in flight.

1.5.1 Components and Assembly

The payload unit is an individual engineering assembly unit. The PLU comprises a payload fairing, spacecraft, SC adapter (or dispenser in case of a cluster mission), and a payload adapter (Figure 1.6). All the PLU sections meet the cleanliness requirements and are suited for use in the environment defined as ISO 14644-1 Class 8. To maintain required temperature and humidity for SC between the PLU integration and the launch, a ground-based system supplies the air with controlled temperature, humidity, and cleanliness inside the PLU.

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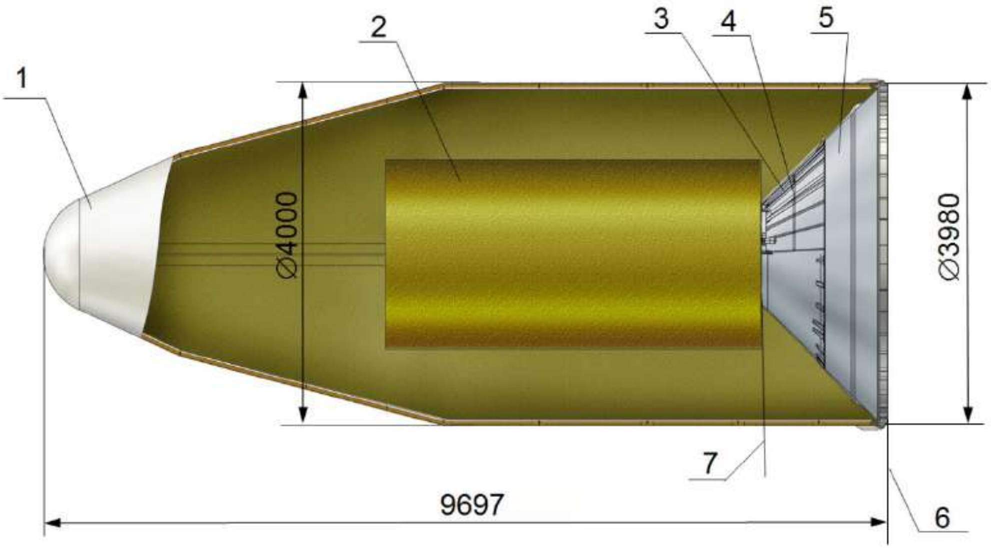

1 – payload fairing; 2 – spacecraft; 3 – spacecraft adapter; 4 – isolating diaphragm;
5 – payload adapter; 6 – PLU/Stage 2 interface plane; 7 – SC interface plane

Figure 1.6. Cyclone-4M Payload Unit

The payload adapter mated to the payload fairing and the SC adapter forms a dust- and moisture-proof volume where an environment required for the SC is maintained.

The payload adapter structure is made of aluminum alloys.

The payload adapter is 725 mm high, and its upper ring is 2660 mm in diameter. The adapter can accommodate the following payloads:

- SC with an adapter developed by Yuzhnoye ,
- Dispenser developed by Yuzhnoye with a spacecraft cluster.

In addition, the payload adapter allows the launch services Customer (SC developer) to use their own adapter (dispenser).

The SC adapter is designed to accommodate a spacecraft with an 1194-mm interface inside the ILV and ensure its separation with specified parameters on reaching the target orbit. The SC adapter is mounted on the payload adapter.

1.5.2 Payload Fairing

The payload fairing is designed to protect spacecraft against thermal and aerodynamic loads at liftoff and in atmospheric flight, and against exposure to the environment during ground operations with the

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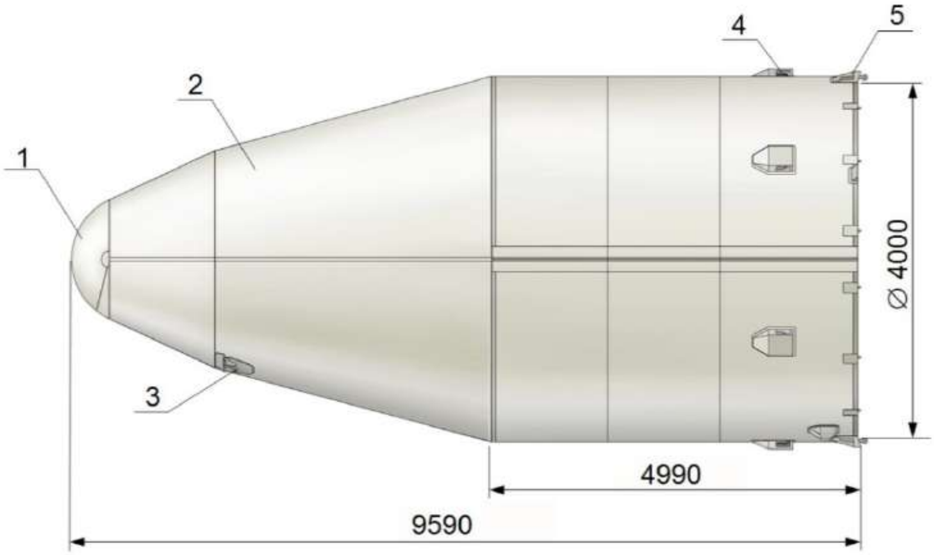
spacecraft integrated with the LV and the PLU. The PLF consists of two halves fastened with locks (Figure 1.7).



1 – nose; 2 – body; 3 – thermal conditioning air inlet; 4 – thermal conditioning air outlet (6 pcs.); 5- curtain

Figure 1.7. Payload Fairing

The PLF comprises a metal body, vertical separation system, elements of a horizontal separation system, PLF jettison pneumatic system, internal thermal insulation, elements of the PLU internal thermal conditioning, cable harness, and general assembly units.
The PLF structure determines maximum payload size (accounting for manufacturing tolerances and dynamic vibrations of a spacecraft during prelaunch operations and in flight).
The PLF in horizontal position is rolled onto the PLU during the PLU integration at the LS.

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2 ILV SPECIFICATIONS AND CAPABILITIES

2.1 Summary

The Cyclone-4 M ILV lifts spacecraft into low and medium circular and elliptic orbits including sun-synchronous. This Section presents the data allowing a potential launch services Customer to get a preliminary understanding of the ILV payload capability and weight parameters. Please contact MLS for details about the ILV payload capability depending on your specific mission requirements.

2.2 Launch Point Parameters

The Cyclone-4M ILV is launched from the Canso launch site, Nova Scotia, Canada.
The launch pad coordinates are 45.3° North and 61.0° West.

2.3 Permissible Orbits

The launch site allows launching into orbits inclined at 45.1° up to inclinations of sun-synchronous orbits. Figure 2.1 shows the ground tracks and drop zones of the Cyclone-4M separated parts for SC injection into orbits inclined at 51.6°, 87.9°, and 98.1°.

Figure 2.1. Ground tracks and drop zones of Cyclone-4M ILV separated parts for SC injection into orbits inclined at 51.6°, 87.9°, and 98.1°

For launches into orbits with inclination less than 45.1°, the Cyclone-4M can perform a lateral maneuver at the equator. The ILV payload capability into such orbits can be available to the Customer upon an individual request.

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2.4 Standard Injection Trajectory into 200-km Orbit Inclined at 51.6°

2.4.1 Ascent Profile

The launch azimuth A_l = 118.5° and a single burn of the Stage 2 main engine are used for SC injection into a 200-km orbit inclined at 51.6° (Figure 2.2).

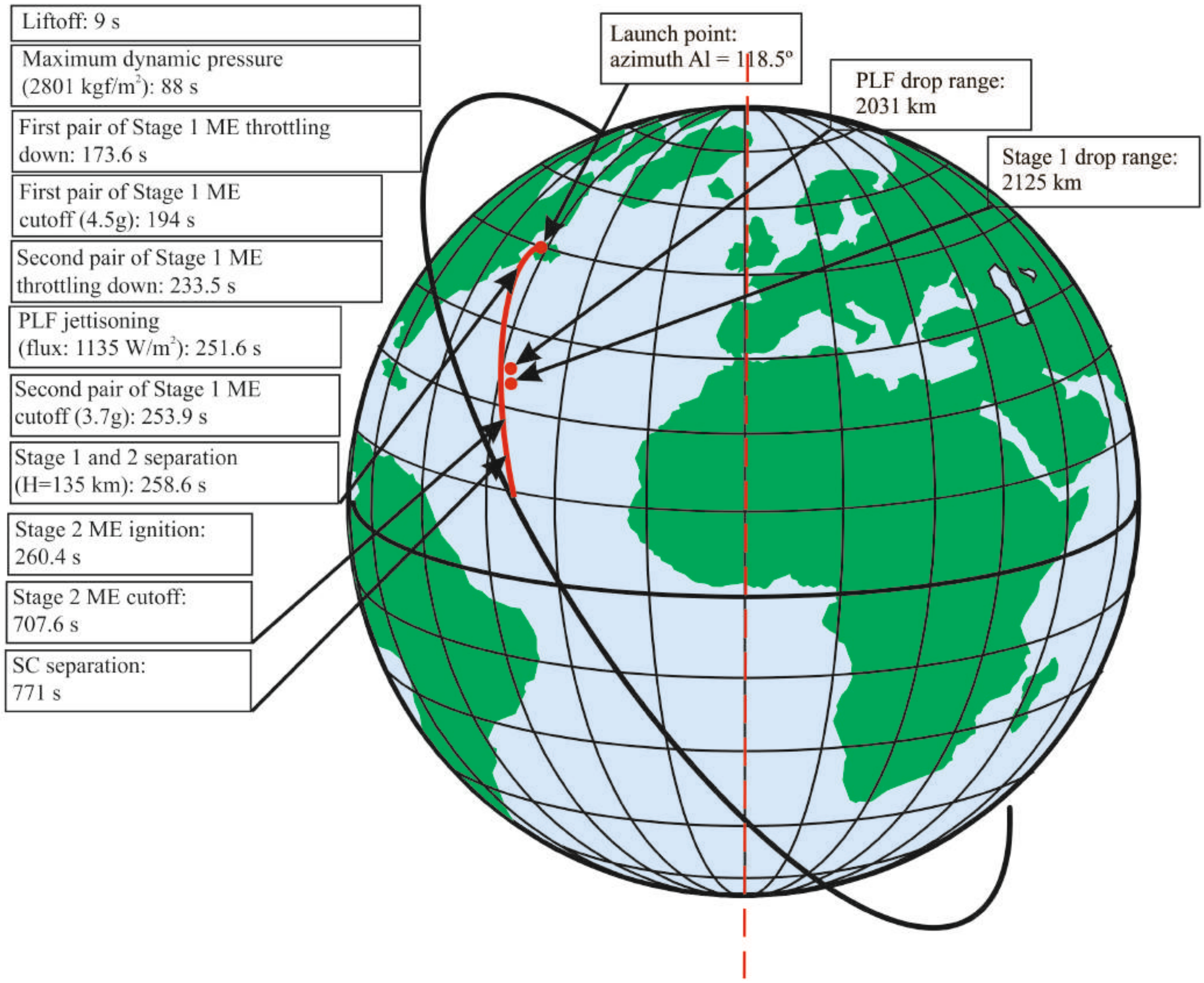

Figure 2.2. SC Injection into 200-km Circular Orbit

The Cyclone-4M Stage 1 generates thrust during the first 254 seconds of the flight. Pitch and roll maneuvers start 12 seconds after ILV liftoff from the launch pad. The maximum axial acceleration limitation is applied 174 seconds into flight by throttling the first pair of the engine blocks sequentially, cutting off the first pair of the engine blocks, and throttling the second pair of the engine blocks.
Starting from 72 seconds into flight and until the end of the Stage 1 flight (259 s into flight), the pitch maneuver is performed by monitoring gravitational turn of the velocity vector.

The PLF is jettisoned at about 252 seconds after liftoff at a free-molecular heat flux of ≤ 1135 W/m^2. The maximum axial acceleration is 4.9 g_0, where g_0 is a typical value of gravitational acceleration at the earth's surface. When the stage separation command is issued 260 seconds into flight, the Stage 2 main engine ignites. The nominal main engine burn time is 447.24 s. The Stage 2 main engine cuts off with a delta velocity of about 1 m/s to that required for a target spacecraft orbit. The LJS thrusters ignite at the main engine cutoff and operate for about 59 seconds to gain the velocity required for the target orbit.
The SC is then separated, and Stage 2 is passivated.

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2.4.2 Flight Timeline

Table 2.1 shows a typical sequence of events for payload delivery onboard the Cyclone-4M into a 200-km circular orbit inclined at 51.6°.

Table 2.1. Cyclone-4M ILV Flight Timeline for a 200 km Orbit

Time, s	Event
0	Go-inertial
8	Engine ignition command
9	Liftoff
12	Pitch and roll maneuvers to reach launch azimuth
88	Maximum dynamic pressure
174 to 194	Throttling of the first pair of Stage 1 engine blocks
194	Maximum axial acceleration
233.5 to 254	Throttling of the second pair of Stage 1 engine blocks
252	PLF jettison
259	Stage 1 separation. Stage 2 LJS thrusters ignition
261	Stage 2 ME ignition
708	Stage 2 ME cutoff. LJS thruster ignition
767	LJS thruster cutoff
TBD, mission specific	SC separation. Stage 2 passivation

2.4.3 Ground Track

Figure 2.3 shows the Cyclone-4M ILV ground track for spacecraft injection into a 51.6° inclined orbit.

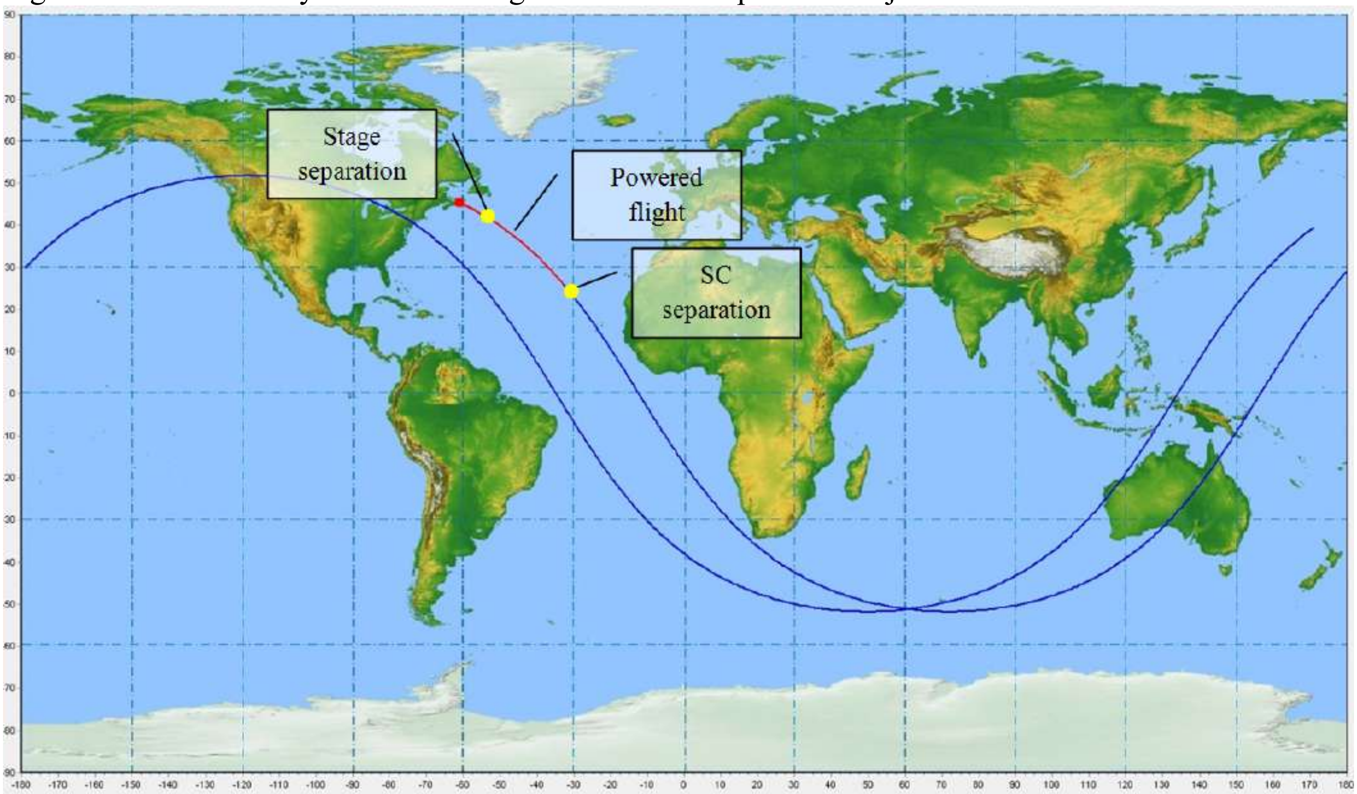

Figure 2.3. Cyclone-4M ILV Ground Track for Spacecraft Injection into 51.6° Inclined Orbit

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2.5 Standard Trajectory into Sun-Synchronous Orbit

2.5.1 Injection Scenario

SC injection into a sun-synchronous orbit with an altitude of 700 km and inclination of 98.1° is achieved through two burns of the second stage main engine (figure 2.4).

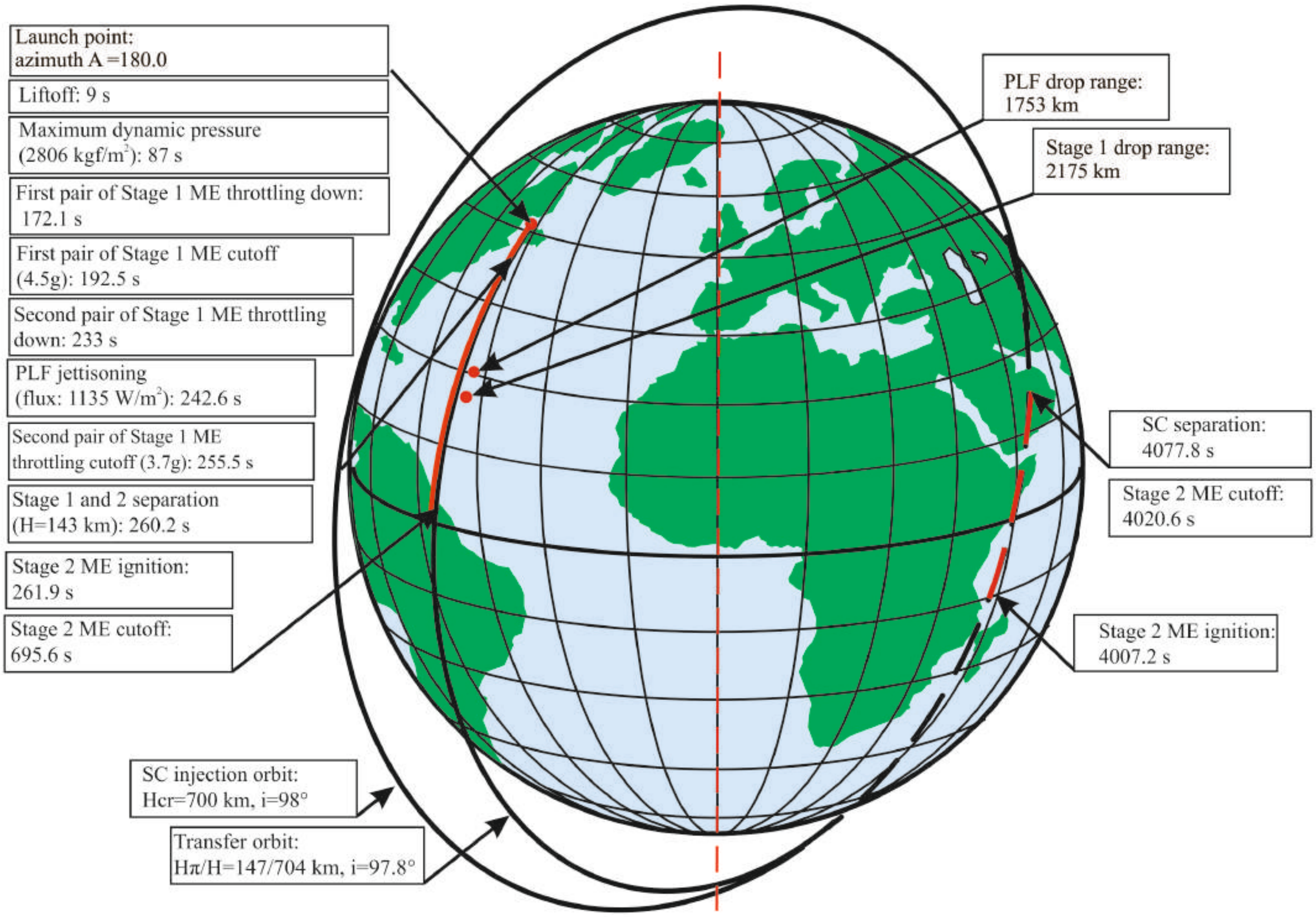

Figure 2.4. SC injection into a standard 700-km sun-synchronous orbit

For injection into the SSO, the ILV launch azimuth is 180°; 75^{h} seconds into flight, the vehicle performs a cross range maneuver to the right in the direction of flight. Such a combination of the launch azimuth and the cross range ensures that the ILV flight path bypasses the town of Little Dover and achieves the required orbit inclination.

The Cyclone-4M Stage 1 generates thrust during the first 256 seconds of the flight. The maximum axial acceleration limitation is applied 172 seconds into flight by throttling the first pair of the engine blocks sequentially, cutting off the first pair of the engine blocks, and throttling of the second pair of the engine blocks. Starting from 72 seconds into flight and until the end of the Stage 1 flight, the pitch maneuver is performed by monitoring gravitational turn of the velocity vector. Starting from 75 seconds into flight, Stage 1 performs the cross-range maneuver by slowly turning in yaw at an angular velocity of minus 0.08 deg/s. During subsequent flight, Stage 1 slowly increases the yaw angle, which equals minus 14.8 degrees by the end of Stage 1 flight segment. The PLF is jettisoned about 243 seconds into flight at a free-molecular heat flux of ≤1135W/m². The maximum axial acceleration is 4.9g. When the stage separation command is issued 262 seconds into flight, the Stage 2 main engine ignites. The nominal main engine burn #1 time is 434 s. The main engine cuts off with a delta velocity of about 1 m/s to that required for a target spacecraft orbit.

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The LJS thrusters ignite at the main engine cutoff and operate for about 59 seconds to gain the velocity required for the target orbit. The vehicle then coasts for 2712 seconds. 3464 seconds into flight, the LJS thrusters ignite to generate axial acceleration for 543 seconds. The Stage 2 main engine restarts 4008 seconds into flight. The main engine burn #2 lasts 13 seconds. When the RD861K engine cuts off, the LJS thrusters ignite to gain a required speed; the thrusters operate for 42 seconds. The SC is then separated, and Stage 2 is passivated.

2.5.2 Flight Timeline

Table 2.2 shows a typical sequence of events for payload delivery by the Cyclone-4M into a typical 700-km sun-synchronous orbit inclined at 98.1°.

Table 2.2. Cyclone-4M Flight Timeline for a Typical 700-km Sun-Synchronous Orbit

Time, seconds	Event
0	Go-inertial
8	Engine ignition command issue
9	Liftoff
12	Pitch and roll maneuvers to reach launch azimuth
75	Cross range maneuver
87	Maximum dynamic pressure
173 to 193	Throttling of the first pair of the Stage 1 engine blocks
193	Maximum axial acceleration
236 to 256	Throttling of the second pair of the Stage 1 engine blocks
243	PLF jettison
261	Stage 1 separation. Stage 2 LJS thrusters ignition
262	Stage 2 ME first ignition
696	Stage 2 ME first cutoff
3464	Ignition of Stage 2 LJS thrusters to generate axial acceleration
4008	Stage 2 ME second ignition
4021	Stage 2 ME second cutoff
TBD, mission specific	SC separation. Stage 2 passivation

2.5.3 Ground Track

Figure 2.5 shows the Cyclone-4M ILV ground track for spacecraft injection into a 98.1° inclined orbit.

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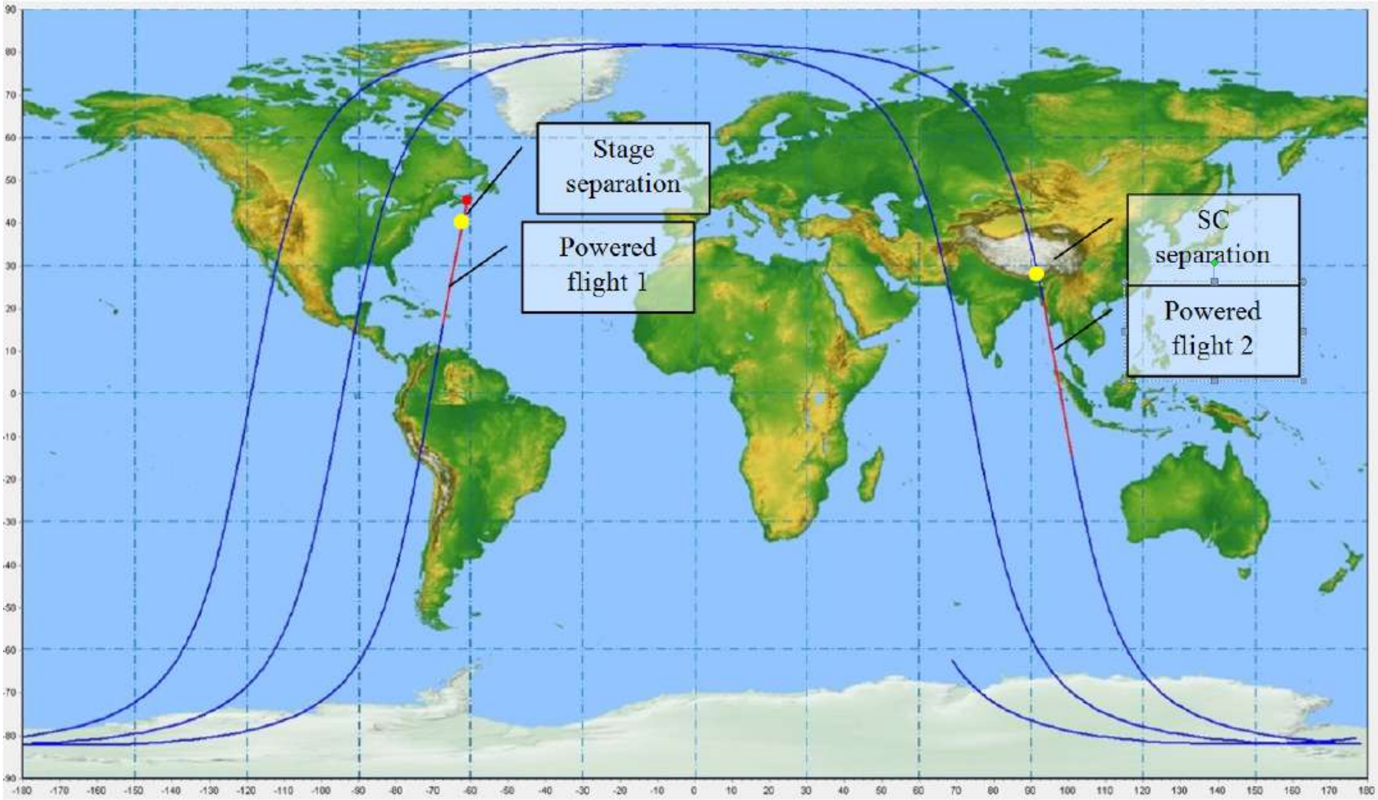

Figure 2.5. Cyclone-4M ILV Ground Track for Spacecraft Injection into 98.1° Inclined Orbit

2.6 Payload Capabilities

2.6.1 Circular Orbits

Table 2.3 and Figure 2.6 show the maximum SC mass delivered into circular orbits with altitudes (H_c) of 200 to 10 000 km and inclinations of 45.1°, 51.6°, and 88°.

Table 2.3. Cyclone-4M ILV Payload Capability into Circular Orbits

H_c, km	SC mass, kg		
	i = 45.1°	i = 51.6°	i = 88°
200	4980	4930	4030
400	4390	4310	3590
500	4380	4250	3560
600	4240	4160	3480
800	4030	3950	3370
1000	3870	3790	3170
1200	3660	3590	3000
2000	2960	2900	2400
4000	1900	1850	1410
6000	1260	1220	880
8000	860	820	530
8800	730	690	
10000	590	550	

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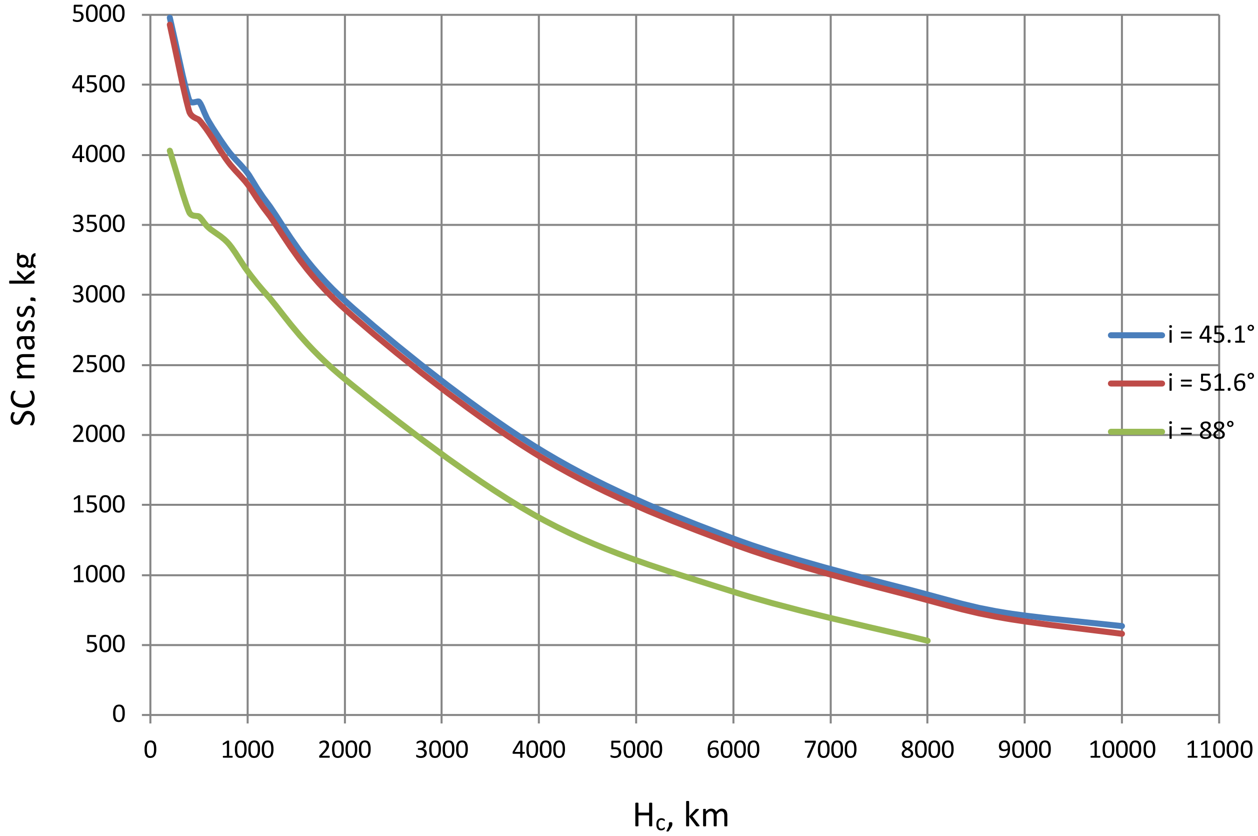

Figure 2.6. Cyclone-4M ILV Payload Capability into Circular Orbits

2.6.2 Elliptic Orbits

Table 2.4 and Figure 2.7 show the maximum SC mass delivered into elliptic orbits with a perigee altitude of 200 km, apogee altitude (H_α) of 200 to 43000 km, and inclinations of 45.1°, 51.6°, and 88°.

Table 2.4. Cyclone-4M ILV Payload Capability into Elliptic Orbits

H_α, km	SC mass, kg		
	i = 45.1°	i = 51.6°	i = 88°
200	4980	4930	4030
400	4800	4690	3900
1000	4420	4310	3610
2000	3880	3810	3150
5000	2840	2780	2280
7000	2400	2370	1920
10000	1980	1950	1530
25000	1100	1070	750
43000	760	730	

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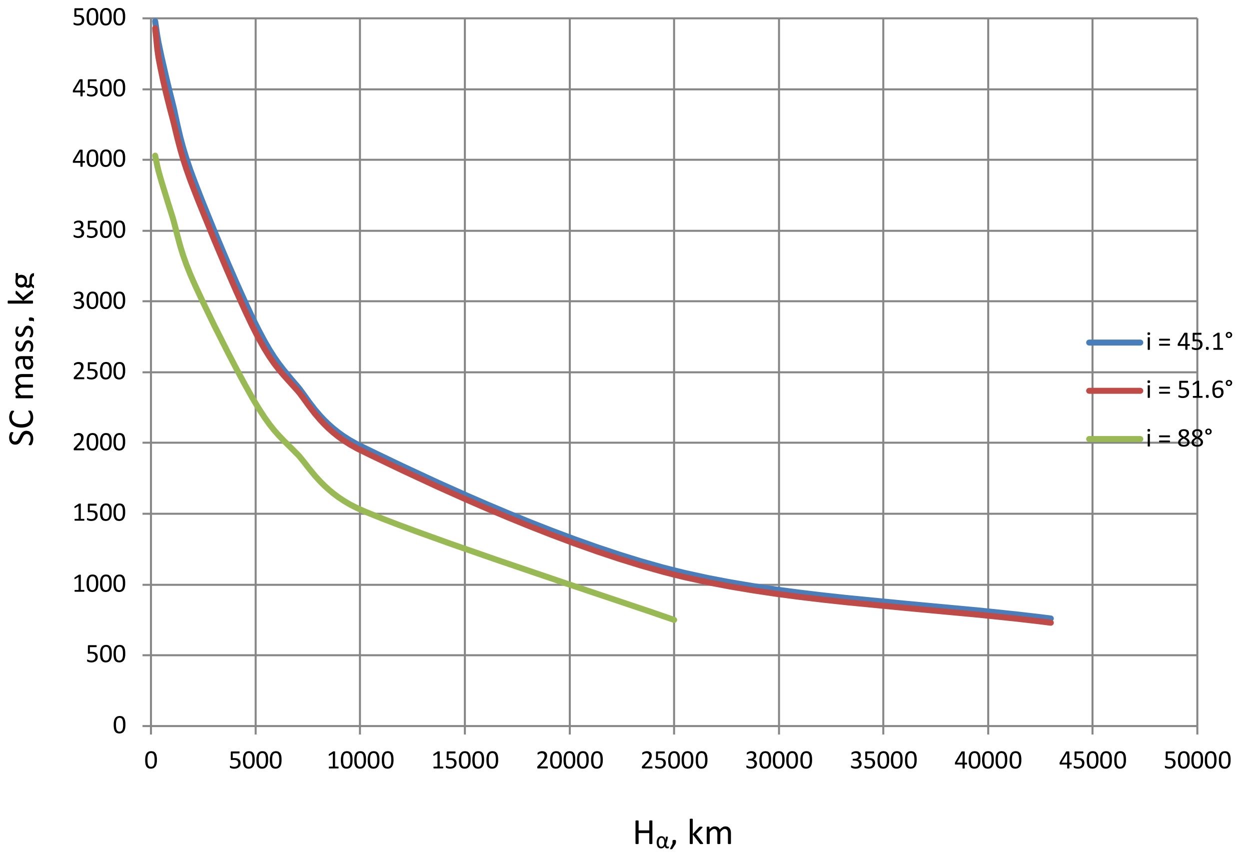

Figure 2.7. Cyclone-4M ILV Payload Capability into Elliptic Orbits (perigee = 200 km)

2.6.3 Sun-Synchronous Orbits

Table 2.5 and Figure 2.8 show the SC mass injected into 400- to 1000-km sun-synchronous orbits.

Table 2.5. Cyclone-4M ILV Payload Capability into SSO

H_c, km	SC mass, kg	Inclination, degrees
400	3380	97
500	3350	97.35
600	3320	97.7
700	3270	98.1
800	3170	98.5
900	3060	98.9
1000	2940	99.4

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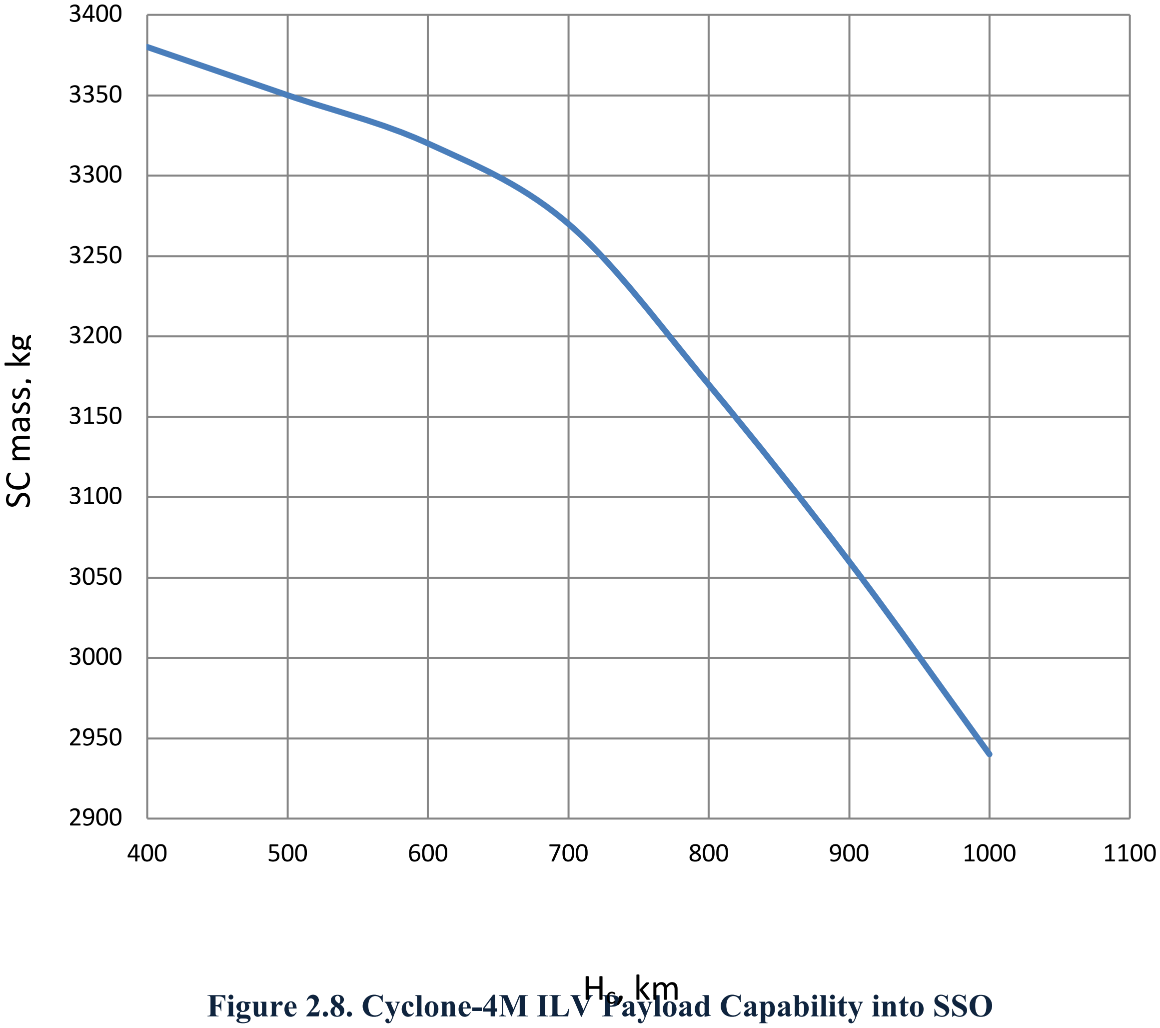

Figure 2.8. Cyclone-4M ILV Payload Capability into SSO

2.7 Injection Accuracy

The worst-case deviations of SC orbit parameters (±3σ) at Stage 2 separation, with the Cyclone-4M ILV control system operating, do not exceed the following values:

- For a circular orbit (H_c = 200 km, i = 51.6º)
  - Altitude ± 5.0 km
  - Inclination ±(0.05-0.08) degrees
- For a sun-synchronous orbit (H_c = 700 km, i = 98.1º)
  - Altitude ± 5.0 km
  - Inclination ±(0.05-0.08) degrees
  - Perigee argument ± 10 degrees (e ≥ 0.00115).

The SC orbit parameters to be controlled are agreed upon with the launch services Customer on a mission specific basis.

The Cyclone-4M ILV accuracy for the agreed upon controlled orbit parameters are determined during the SC integration with the ILV.

2.8 SC Attitude in ILV Flight

During the ILV powered flight phases, the SC attitude is defined by the ILV thrust vector direction required for SC delivery into the target orbit.

During the ILV coast, the ILV control system can provide any required SC attitude in pitch, roll, and yaw, as well as longitudinal spin at 3 °/s, except for the following phases:

- Telemetry data transmission phase (as a rule, each coast includes one such phase),
- Stage maneuvering into an attitude required for the Stage 2 main engine ignition.

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2.9 SC Separation

Spacecraft separation can take place either right after (15 seconds after) the SC delivery into the target orbit or after the Stage 2 maneuver with the SC to achieve the required attitude. The maneuver can take up to 4 minutes.

The SC separation command (command to break the mechanical interface between the SC and the SCA) is sent no less than 10 seconds after the end of the Stage 2 angular maneuver.

The Stage 2 angular stabilization and angular velocity errors at SC separation command issue do not exceed the following values:

- For pitch, yaw, and roll angles: ±1°,
- For pitch, yaw, and roll angular velocities: ±0.2 °/s.

The SC is separated from Stage 2 by push-off springs. The number and characteristics of the push-off springs are determined during integration of a specific SC into the LV, taking into account Customer's requirements for the separation process.

An estimated increment of the SC linear velocity relative to Stage 2 during separation is about 1 m/s.

SC disturbances due to separation do not exceed the following values:

- About the longitudinal axis of rotation: ±1°/s,
- About the lateral axes of rotation: ±1.35 °/s to ±3.0 °/s.

The SC disturbances due to separation depend on the inertial properties of the spacecraft and the separated part of Stage 2, as well as on the type, number, position, and breaking behavior of the mechanical, electrical, and other interfaces between the SC and the LV.

2.10 Stage 2 Deorbiting

The Stage 2 separated part can be removed from the spacecraft orbit by using

- LJS thrusters, or
- Main engine.

Using only the LJS thrusters, the separated part of Stage 2 is transferred from the SC orbit into a different orbit, which prevents any collision with the SC in future.

Using the main engine, the separated part of Stage 2 can be transferred either to a different closed orbit or to an open orbit, which will ensure atmospheric reentry of the separated part.

When the deorbiting is complete, Stage 2 passivation is performed.

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