Analysis of modes and estimation of costs to decrease the level of space contamination during space missions realization

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Sources of space contamination during launch

- Last stages of launch vehicle and separated parts after satellite parameters are reached.
- It means that in two stages launch to Earth satellite orbit (final or intermediate parking) it may be the second stage (example Cosmos-3M, Zenith), in three stage launch it may be the third stage (example Rockot, Soyuz, Proton). With the goal to launch payload on higher orbit some additional stage is used (Fregat, Breez, Breez-M, Block DM). So for launch onto comparatively low orbit one stage (the second or the third occurred on the satellite orbit), after launch onto higher orbit two launcher stages reach near Earth orbit.
- Adapters between last and the previous stages are very often reaching the orbital parameters flying independently after their separation from rocket stages.
- Separable tanks of the upper stage (example Breez-M)

Proton launcher

- Start of Proton

Target orbit and launching scenario influence on space contamination

- The goal is:

  to return consumed rocket stage to the Earth surface allowed area;

  this area is to be sufficiently small, what means that descending trajectory is to be inside small enough corridor;

  last requirement can be satisfied by steep enough descending trajectory, i.e. the ideal perigee height is to be below Earth surface (ideal means calculated without aerodynamic drag);

  preliminary we accept the height of ideal perigee to be minus 100km

Target orbit and launching scenario influence on space contamination. Possible perigee heights.

- What perigee height last stage really has after payload separation?

  Usually without any additional operations needed to keep space clean the last stage has the same perigee height as the payload after its separation from the stage.

  It means that perigee height from 200 km for low Earth orbit to 36000 km for geostationary orbit is to be reached by upper stage at the moment of payload separation.

  It should be mentioned that for high elliptical orbits and even for interplanetary flights the perigee may lie in the mentioned limits.

Target orbit and launching scenario influence on space contamination. Possible perigee heights.

For all these cases the areas of last stage fall is practically unpredictable.

Duration of these stages staying in space is difficult to predict also.

The orbits do exist (for example circular or near circular orbits with mean altitude 1000 - 2000 km and more where stages will fly infinitely long.

How to prevent this accumulation of upper/last stages in space?

The basic idea is to construct launching scenario with comparatively low perigee of last launcher stage on the separation moment, supposing that payload perigee would be raised by its own engine unit. Upper/last stage after apogee maneuver would be transferred onto reentry trajectory.

Contemporary standard optimal launching scenario

- Launch onto orbit with comparatively low perigee height (less than 300 – 700 km, i.e. without apogee impulse)

In limit case the passive part of the launching trajectory is absent. As example the launching scenario of Soyuz launch vehicle may be mentioned with target circular trajectory having 400 km height.

Contemporary standard optimal launching scenario and last stages of rocket fate

- During first part of the trajectory it is possible for spacecraft to reach orbital velocity and perigee height value more than 150 km – then stage enters the atmosphere in unpredictable mode.
- If velocity is suborbital then it enters in atmosphere with possibly acceptable level of predictability.
- After second impulse to raise apogee or to reach orbital parameters the last stage after payload separation will be on the same orbit as payload and it will descend to the Earth surface being uncontrolled (according to now broad accepted approach)

Contemporary standard optimal launching scenario and last stages of rocket fate

- Launch onto orbit with high perigee orbit.
  In this case apogee maneuver is required

As a result the last stage will stay practically on operational orbit of payload for many years

Modified launch scenario to avoid space contamination by rocket stages

- The stage which launches payload together with upper stage (space block) instead of putting space block onto near Earth orbit (so called intermediate orbit or parking orbit) launches it on suborbital trajectory
- After separation from space block the stage enters atmosphere and reaches Earth surface allowed area, but payload is accelerated further by upper stage. Following this additional velocity impulse provided by upper stage engine unit the space block transfers onto intermediate (parking) orbit.

Modified launch scenario to avoid space contamination by rocket stages

upper stage

suborbital stage

- Then upper stage engine is started again raising apogee to the required altitude

Apogee

Raising

payload separation

upper stage perigee height

decreasing maneuver

upper stage trajectory

payload trajectory

Modified launch scenario to avoid space contamination by rocket stages

- In apogee region the engine of upper stage is started again to decrease its perigee altitude. As a result of this maneuver upper stage enters atmosphere in perigee region.
- If necessary the apogee maneuver may be executed not in the first apogee passing but in the following ones. By this way the possibilities to vary the area of stage fall are appeared. But obviously it is preferable to do this maneuver as early as possible in order to keep duration of controllability of stage after separation as short as possible.

Cost of controllable return of upper/last stages into atmosphere in terms of payload mass

- The basic idea to keep space free from launcher stages used to put spacecraft in Cosmos, discussed above, is to decrease perigee of the stage in order it would enter into atmosphere in some controllable mode, allowed to direct these stages (or their debris in case of destruction of the stages during reentering atmosphere) into allowed areas of the Earth surface.
- For this it is proposed to keep stage controllable even after payload (space block) separation until engine unit of the stage would execute the required deceleration velocity impulse lowering the perigee of stage.

Cost of controllable return of upper/last stages into atmosphere in terms of payload mass and additional functions

- **Controllable** means that the stage is to be capable to fulfill all the operations of attitude and orbital control which it did before separation.
- It should be underlined that practically the contemporary upper stages do possess such capabilities. As example one may mention such stages as Block-DM used as upper stage with Proton and Zenith launchers, Breeze used with Rockot launcher. These their capabilities are used in order to do collision avoiding maneuvers and operations used for multiple launch of several payloads.

Cost of controllable return of upper/last stages into atmosphere in terms of payload mass

- In order to change the altitude of perigee in optimal mode, supposing that optimization criteria is required velocity impulse, one needs to apply this impulse in apogee.
- The value of this impulse divided by perigee height change is decreasing with increasing the semimajor axis of the orbit, or with constant perigee height value – with increasing the apogee height.
- This derivative is the highest for low Earth orbit. For example for raising apogee from initial circular 300 km altitude by one km the velocity impulse equal 0.289 m/s is necessary applied along velocity vector. So if one needs to lower perigee by 400 km it would demand velocity impulse equal 115 m/s.

Cost of controllable return of upper/last stages into atmosphere in terms of payload mass

- If mass of last stage after separation is 800 kg and specific impulse of last stage is 320 s, then mass of propellant to be spent for perigee lowering is 28.8 kg, i.e. 3.6% from stage mass or 1.4% from payload mass. What may be considered perfectly acceptable for keeping space clean.

  To illustrate the case of high elliptical orbit the INTEGRAL project may be considered. INTEGRAL was launched in 2002 by Proton launcher (3 stage) with Block-DM upper stage. Initially Proton has put space block (upper stage + payload) onto low parking orbit with 192 km perigee height and 690 km apogee height.

Cost of controllable return of upper/last stages into atmosphere in terms of payload mass for INTEGRAL type high elliptical orbit

- Then the upper stage has put space block onto high elliptical orbit with perigee, apogee height 685x154000km.
- After that upper stage was separated and collision avoiding maneuver was executed by engine unit of the stage.
- Payload engine unit fulfilled several apogee burns to raise the perigee to the height equal 9028 km.

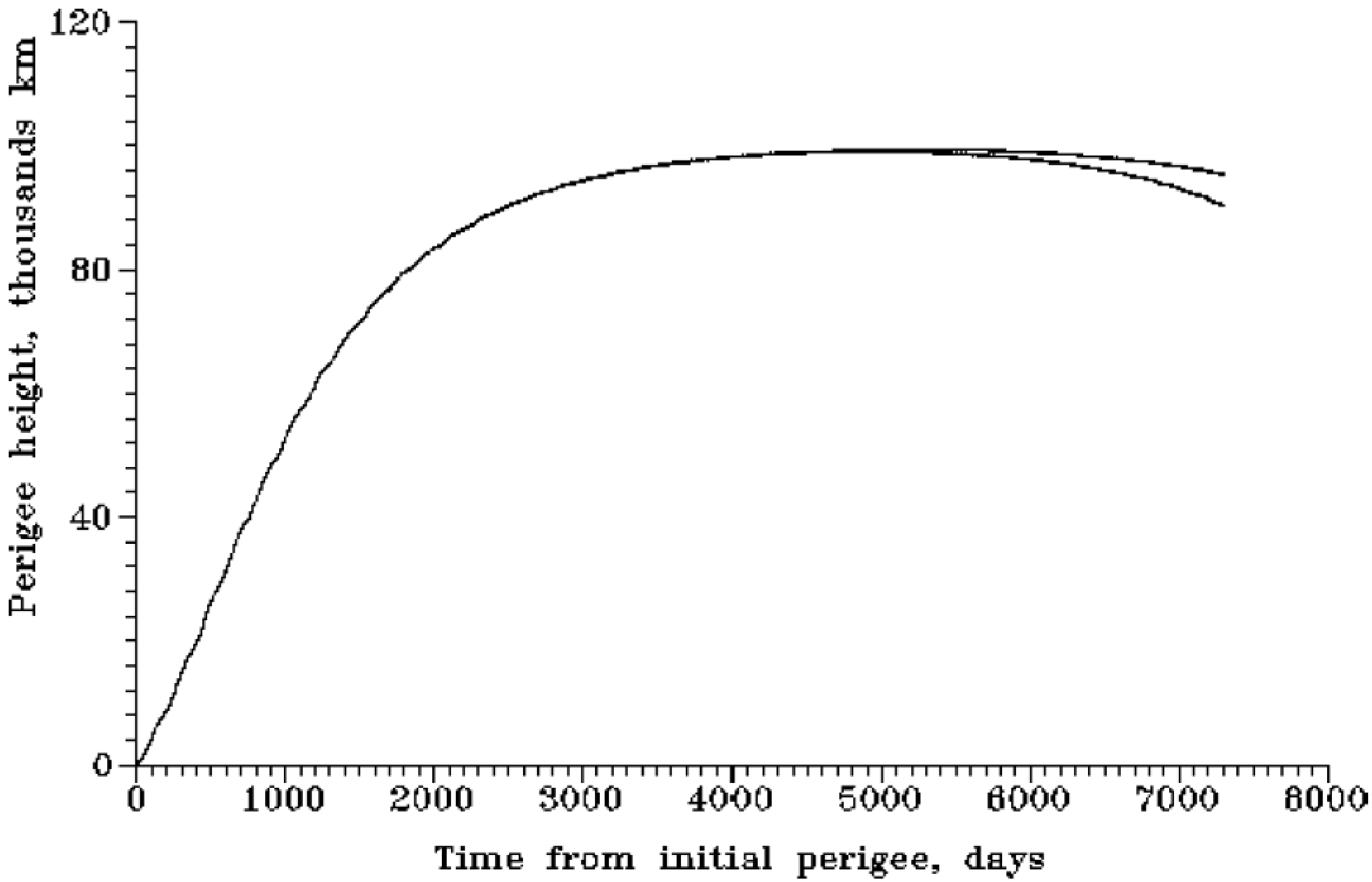
Cost of controllable return of upper/last stages into atmosphere in terms of payload mass for INTEGRAL type high elliptical orbit

- Suppose we are to remove upper stage from the orbit after payload separation by applying deceleration velocity impulse in apogee in order to decrease perigee height to minus 100 km (i.e. to decrease by 800 km). For this apogee impulse is required to be equal 25.2 m/s. If auxiliary engines of the stage with specific impulse equal 220 s would be used for this purpose then the propellant consumption is estimated to be 1.16% of the stage mass, i.e. about 23.2 kg (upper stage mass after payload separation is about 2000 kg) what is 0.58% of the payload 4000 kg mass – perfectly acceptable.
- It is clear that the same approach can be applied for other cases of launch to high elliptical orbits.

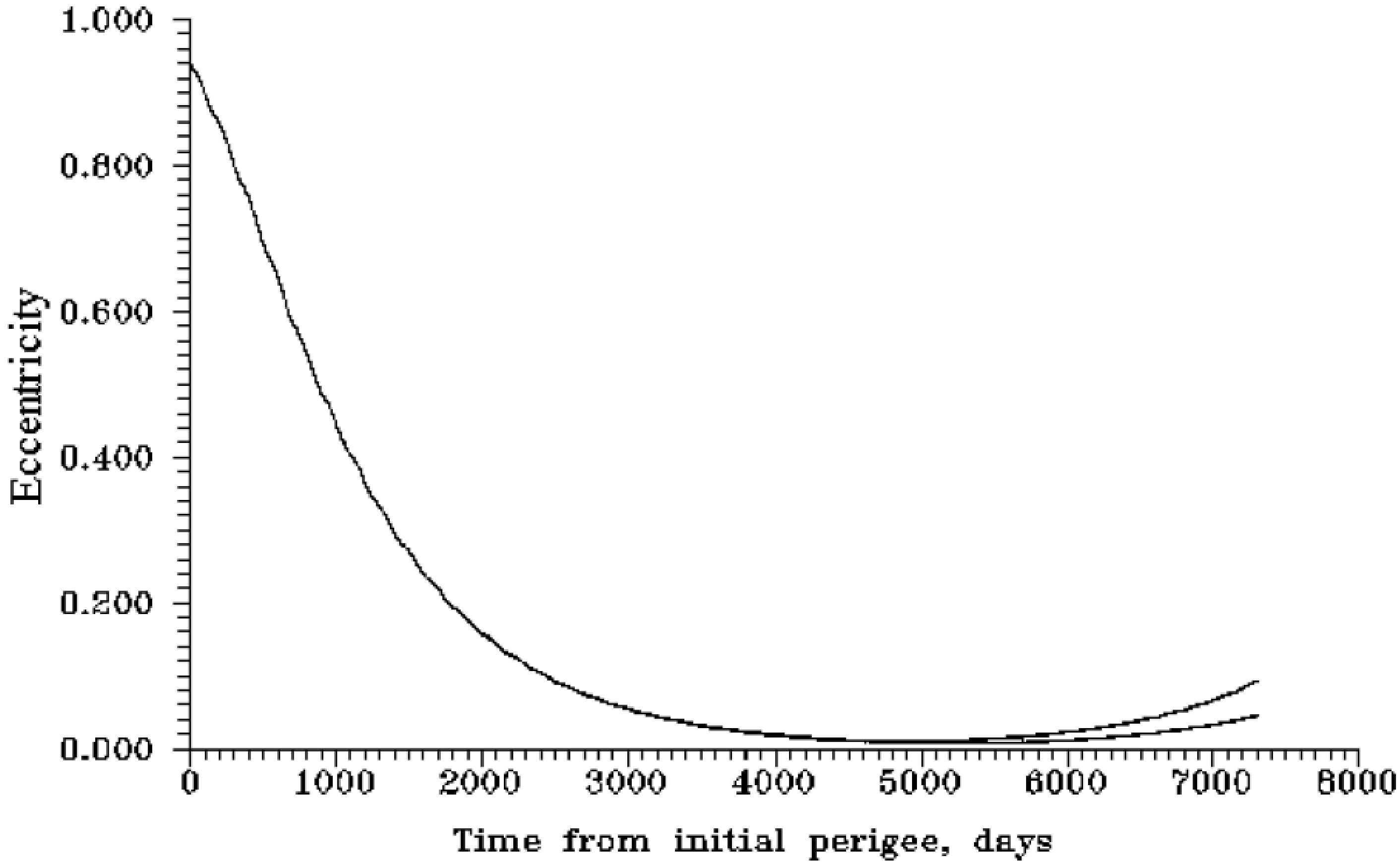
Cost of controllable return of upper/last stages into atmosphere in terms of payload mass for INTEGRAL type high elliptical orbit

- But condition is to be kept: the required perigee height of the upper stage is to be acceptably low.
- If payload demands higher value of perigee altitude it is preferable for this purpose to raise apogee by payload engine unit as it was done in INTEGRAL case. Usually it does not lead to unacceptable if any payload mass losses even in case when specific impulse of payload engine unit is less than the one of upper stage.
- It should be mentioned that there is the method to raise perigee of payload without use of any engine velocity impulses. With appropriate choose of initial parameters of the orbit it is possible to use gravitational influence of the Moon and the Sun to raise the perigee. It takes some time, but in some cases it is tolerable.

Perigee height evolution under Sun and Moon influence



Eccentricity evolution under Sun and Moon influence



Cost of controllable return of upper/last stages into atmosphere in terms of payload mass for geostationary orbit

- Thus to keep upper stage perigee low enough one needs to reload part of functions of upper stage to payload engine unit, what may lead to requirement to spend quite visible amount of propellant by payload engine itself and consequently to have big enough tanks for propellant.
- For example in order to transfer from geotransfer orbit to geostationary orbit (flat case, i.e. without orbit rotation, supposing perigee height of geotransfer orbit is 200 km and apogee height 42241km) it is required to apply velocity impulse equal 1447 m/s. It means that 38.3% of payload initial mass is to spend as propellant to transfer it from geotransfer orbit to geostationary one if specific impulse is equal 306 s.

Cost of controllable return of upper/last stages into atmosphere in terms of payload mass for geostationary orbit

- But it does not means any losses of payload mass on operational orbit. Even more: some gains are possible.
- To return upper stage on Earth surface apogee impulse is necessary to apply. Supposing that ideal perigee minus 100 km is required the value of this impulse is 32 m/s, what for 220 s specific impulse of the stage auxiliary engines means 1.5% of the upper stage final mass or only 0.75% of the payload mass.
- It should be reminded that scenario assuming suborbital velocity of the stage which preceding the upper stage leads not to losses but to gains in payload mass.

Cost of controllable return of upper/last stages into atmosphere in terms of payload mass for 20000km and 1000 km circular orbits

- Earth satellites which are the constituents of Global Positioning Systems are flying on the circular orbit with 20000km height. In the predictable future it is expected regular launches of spacecraft on such orbits. If apply the same concept as discussed above in removing upper stage from the orbit, the apogee impulse 77 m/s is needed what means 3.5% of upper stage mass is to be spent as additional propellant (for 220 c specific impulse).
- The most expensive return to the Earth surface is the one when orbit is near circular and comparatively low, for example its height is equal 1000 km. To launch payload on such orbit the passive part trajectory is necessary.

Cost of controllable return of upper/last stages into atmosphere in terms of payload mass for 1000 km circular orbit

- The scenario in this case assumes that initially last stage puts payload on some low (200 km height) circular orbit, then impulse is applied to raise apogee up to the height of the target circular orbit, the in apogee the last impulse is applied to reach circular orbit. After this last stage is separated and to return it to the Earth surface the velocity impulse is required equal 126 m/s, what means that 4.19% of last stage mass is to be spent as propellant (300 s specific impulse) to decrease perigee height to minus 100 km (decreasing by 1100 km). The increasing of expenditures for stage return will continue with circular orbit height until payload its own engine unit will be used.

Expended spacecraft removing from the orbit

- According contemporary concepts the expended spacecraft, i.e. spacecraft finished their operational life are to be removed from orbit in safe mode.
- If operational orbit was with comparatively low perigee height the approach can be used similar to described above one for last/upper stages of launcher.
- For high elliptical orbit with high enough perigee the solution of the problem may be based on the choose of initial parameters of the orbit in such a way which determines the ballistic life of the spacecraft. In other words after some prescribed duration of spacecraft functioning it enters atmosphere under influence of Sun and Moon. To guarantee controllable reentry of the spacecraft into atmosphere the possibility to apply small final deceleration apogee impulse (about 10-20 m/s) is to be taken in account.

Expended spacecraft removing from the orbit

- But for transfer from geostationary orbit (or from GPS orbit) onto reentry trajectory high enough velocity impulse is required (about 1500 m/s).
- With the use of chemical rocket engine to apply necessary impulse the maneuver looks too costly: about half of payload mass is to be spent for this.
- In case of geostationary spacecraft the use of solar electric power engine for this purpose seems to be promising. There are two reasons for that: Russian geostationary spacecraft are equipped by such engines for correction maneuvers purposes and they have enough electrical power to feed such engines. Supposing that specific impulse of engine is 2000 s and required impulse to be 2000 m/s (due to some gravitational loses for low thrust engine) the mass of propellant is to be about 10% of payload mass

Expended spacecraft removing from the orbit

- It should be mentioned that to put s/c onto solar satellite orbit is cheaper than to transfer it on reentry orbit: for this about 1600 m/s is required what means 8% of payload mass to be spent as propellant (xenon).
- Unfortunately for GPS orbits such technology seems to be not applicable because in this case spacecraft are not equipped by solar electric propulsion engines.