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CNES policy about launcher space debris mitigation
ARIANE 5 Application

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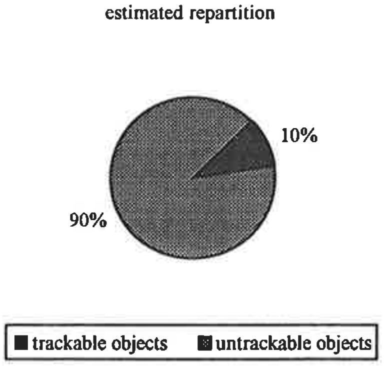
Abstract

Ten years ago, upper stages were left in space without any special precaution at the end of their mission. Due to propellant residuals on board, some of these stages (including an Ariane 1 third stage) exploded and produced an important amount of debris, sometimes in regions where the Space Debris Density was already critical. The problem has been solved for Ariane European launchers : general rules, aiming at launcher debris mitigation, are applied to Ariane 4 and 5 launchers design and operation. The application of these general rules are described in the context of Ariane 5 development in terms of choice of trajectory and modification in the design of stages.

1 INTRODUCTION

Besides about 350 satellites operating today in space, some 6600 other objects can be seen from earth, orbiting without any control. These objects are defunct spacecrafts left after the end of their mission, upper stages of launchers which orbited them, mission related objects such as clamp bands or lens covers, and pieces of hardware coming from in-orbit fragmentation of rocket bodies or defunct spacecraft after the end of their operational mission.
But these 7000 objects trackable by ground means such as US Space Com radars or telescopes are only the tip of the iceberg of space debris (see Figure 1.1), as objects of lower dimensions (less than ten centimeters) are estimated to be ten times more numerous. These smaller objects are mainly fragmentation debris or mission related objects.



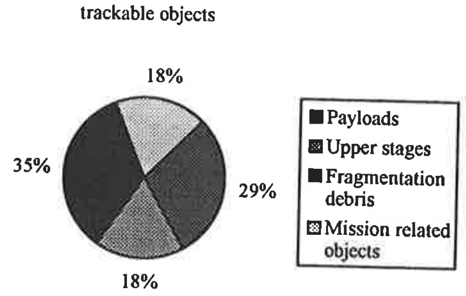


Figure 1.1 : orbital objects as of March 27,1992

This general description of today's space environment shows that only 47 % of objects of more than 10 cm, that is to say less than about 5 % of orbiting objects of all sizes is constituted by spacecraft or upper stages remaining intact after the end of their operational mission. On the contrary, most of the debris are coming from the 100 fragmentation events of satellites or launcher stages which have taken place since the first launch of a satellite in orbit. The twenty most severe in-orbit explosions have produced about 4700 trackable debris.

As far as launchers are concerned, most of them have been affected by this problem : 2 Titan upper stages, 1 Ariane H10, 8 Delta upper stages and 3 Agena rockets have been recorded up to now. Last Delta and Titan explosions took place in 1991 and 1992, and a Long March 4 rocket body exploded in late 1990. During 1991 and 1992, 6 fragmentations concerning PROTON upper stages or other launchers from CEI took place.
This leads nearly all launcher operators to take proper measures to avoid, for launches now being made, the repetition of such events.

2. GENERAL SITUATION

2.1 ARIANE SITUATION

The Ariane launcher flew for the first time on 24th December, 1979 and has now made 50 successful flights, orbiting about 80 satellites. It has left in orbit 50 upper stages (H8 or H10) and 27 Multiple Launch Structures (MLS) SYLDA or SPELDA. Among these objects, 9 third stages and 14 multiple launch structures have already decayed, and one upper stage has exploded in orbit. This fragmentation, which occurred in late 1986 on Sun Synchronous Orbit, produced 499 catalogued debris, among which 61 are still tracked today.

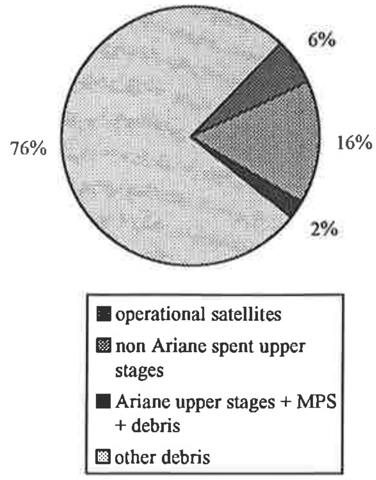


Figure 2.1.1 : Ariane influence on orbital objects

This gives for Ariane (upper stages+MLS+ tracked debris) around 2 % of the tracked objects in orbit (see figure 2.1.1), which is rather low for the 80 satellites launched , most of which being still active. But this prompted CNES , together with ARIANESPACE and ESA, to learn from the experience of the H10 explosion, to adopt proper measures to solve the problem and finally to define a Debris Mitigation Policy.

2.2 CNES GENERAL POLICY CONCERNING LAUNCHER DEBRIS

CNES conducts ARIANE development (by delegation from the European Space Agency), being responsible for the technical and financial coordination of the overall programme. After launcher qualification, it stands as guarantor of launcher qualification and approves any modification made to launcher definition whilst the vehicle is operated by ARIANESPACE. It has responsibility for the safety of the flights (launch pad and range safety, safety on the ground for regions overflown by the launcher).

In this context, CNES, together with ARIANESPACE and ESA, has defined and applied a general policy that ensures, for future flights and development, an adequate behaviour of the launchers with respect to the debris mitigation problem.

This policy can be summed up by saying that the launcher must leave in orbit a maximum of one inert object (or debris) per satellite launched.

To apply this policy, the following requirements are included in Ariane Specifications :

All objects left in orbit have to be fully passivated, whatever the orbit is, to prevent any further explosion of the composite after the end of the mission. In consequence, the last stage and the vehicle equipment bay, which contains active elements such as batteries or tanks with propellant residuals, have to reach a fully inert configuration after having delivered the satellites. In case of a double or multiple launch, Multiple Launch Structures are already (and reliably !) fully inert and do not require any passivation, making multiple launches cleaner than single ones, and showing a greater reason to prefer them.

Separation between Multiple Launch Structures and last stage must be clean. When used for satellite separation (if provided by Ariane), explosive bolts or clamp bands must be trapped to avoid any operational debris.

Solid Propulsion means , such as perigee kick motors that release Aluminium particles, are avoided in orbital operations.

And last but not least, all other stages must naturally reenter the atmosphere or be deorbited.

3 APPLICATION ON ARIANE 5 DEVELOPMENT

The general policy described above has been taken into account from the very beginning of ARIANE 5 development.

3.1 ARIANE 5 configuration

Ariane 5 is a two stage launcher with boosters (figure 3.1.1) capable of carrying into GTO two satellites of a total mass of 5.9 metric tons, this corresponding to a performance in a single launch of 6.8 metric tons. This launcher is in development within the frame of a European Space Agency optional programme managed by CNES. The first flight is scheduled for October 1995.

This completly new launcher is composed of a lower composite, made of a large cryogenic central core (155 tons of LH2 and LOX) with two big strap-on solid boosters (230 tons of solid propellant each), and an upper composite. This upper composite includes the Vehicle Equipment Bay, the 10 tons upper stage EPS (for Etage à Propergols Stockables) and a multiple launch structure, called SPELTRA (for Sructure Porteuse Externe de Lancement Triple) fitted on the external skirt of the VEB. The nose fairing is mounted atop the SPELTRA. The satellites are mounted on the EPS inside the SPELTRA, and on the SPELTRA inside the fairing.

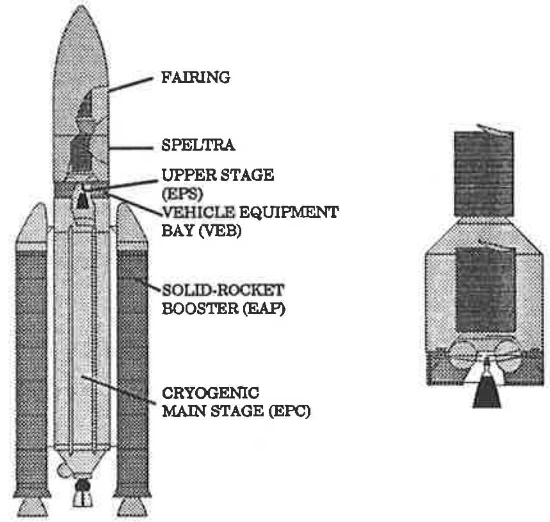


Figure 3.1.1 : ARIANE 5 configuration, at lift-off (left) and arriving in orbit (right)

During the flight, solid boosters and fairing fall down naturally into the Atlantic Ocean.The lower composite being very powerful, the main cryogenic stage is injected in an orbit of 2000 km apogee.

After a balistic flight it falls down natural in ocean (see § 3.1.2.)

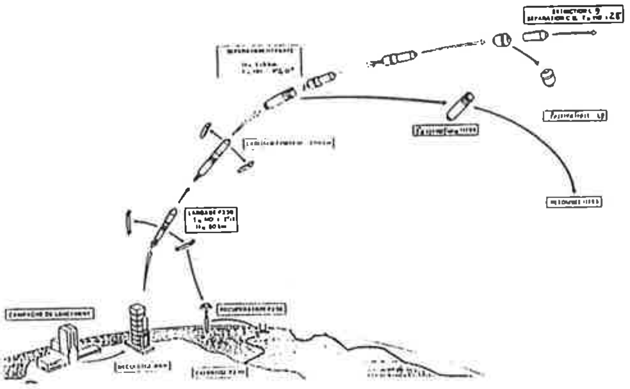


Figure 3.1.2 : Ariane 5 trajectory

The end of Ariane 5 primary mission follows the cut off of the upper stage engine, some 20 minutes after lift-off.
The satellite injection phase then takes place, lasting up to 700 seconds for a standard dual payload launch ; it includes the orientation, spin (when applicable) and separtion of each payloads, as well as the separation in the appropriate direction of the Multiple Payload Carrying Structure (SPELTRA).
All separations are clean, producing no debris : clamp bands, springs, actuators are trapped, pyro cuts are leaktight. The manoeuvres are made by a dedicated Attitude Control System (SCA) mounted on the VEB and using hydrazin thrusters.

The SPELTRA structure is made of carbon fiber sandwich and weighs about 900 kg. Its dimensions are 5.4 m in diameter and 7 m in length. This structure, being fully inert, does not require passivation. Separation of SPELTRA upper parts is made by a linear charge cord device, confined in a pressure-proof expansion tube (figure 3.1.3) which cuts the structure, the lower part remaining bolted with the VEB. Springs attached to the lower part give the necessary relative velocity to avoid any short or long term collision between the two elements or with the satellites.
When provided by the launcher, the satellite separation system uses a clampband, released by the action of a pyrotechnic cutter. Clampband and cutter are trapped with the lower part of the adaptator.

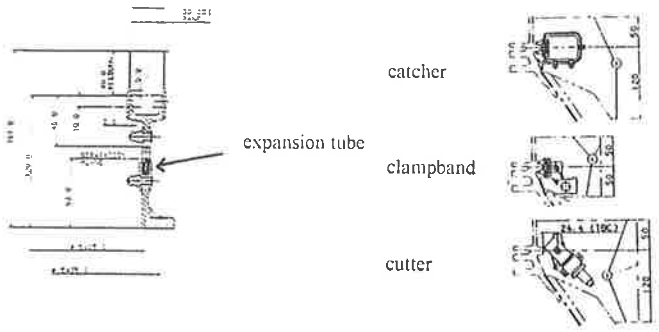


Figure 3.1.3 : SPELTRA (left) and satellite (right) separation systems

3.2. EPC REENTRY

An example of the difficulties met in designing a stage for a commanded reentry. From a performance point of view, the optimal Ariane 5 trajectory is Zperigee = 135 km, Z apogee = 3625km. Such a trajectory is not of long duration and should lead to a reentry of EPC in a rather short time (less than 10 orbits). A completly uncontroled reentry means two types of unacceptable risks : First is a risk explosion of the stage before reentry, which would mean pollution of this low earth orbit. The second is a risk of a hazardous reentry on Earth and possible of important damage caused by the undestroyed part of the stage (part of the engine for instance).

To avoid these risks the stage was first designed to be completely controlled and commanded on reentry :

- After separation between EPC and the upper composite, the mission of the stage was as follows :
  For a duration of about three hours (one and half orbits) the stage was controlled : the pressure inside the two tanks was regulated, the attitude of the stage was commanded. At the second apogee a boost initiated the reentry of the stage in the Pacific Ocean (see figure 3.2.1).

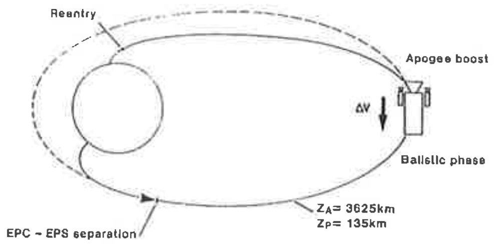


Fig. 3.2.1 - EPC commanded deorbitation

This long specific mission led to many modifications on the stage (see figure 3.2.2.);
A computer had to be installed in the stage. The stage had to be equipped with an inertial mesurement unit and with a dedicaded attitude control system.
Due to the very high reliability specification of such a mission (failure tolerance), all this equipment had to be duplicated.
To create the apogee boost, solid propellant rockets were necessary. Their installation on the stage was not a easy problem to solve.
All these modifications make the mission of the stage long and difficult. They involed extra costs for the stage and so for the global mission.

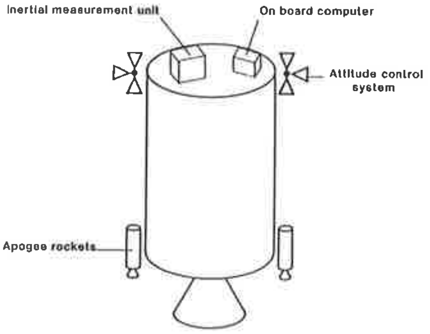


Fig. 3.2.2 - EPC modifications

- After a first phase of preliminary studies, it was decided to abandon this configuration of mission.
- A natural reentry of the stage was decided and to avoid the loss of performance (≈ 500 kg in GTO) due to a non-optimal trajectory, the capabilities of the upper stage were increased from 7 to nearly 10 tonnes of propellant.
  The mission of the stage is now more simple (see figure 3.2.3). At separation the EPC is left on a 50 km x 1800 km trajectory, the stage is passivated to avoid explosion before reentry and a tumbling movement is created.
  The stage falls back naturally into the Pacific Ocean for GTO and LEO missions, and into the Artic for SSO missions after a one and half hours of balistic flight.
  Our experience clearly shows the difficulties encountered in designing a stage for a commanded reentry.

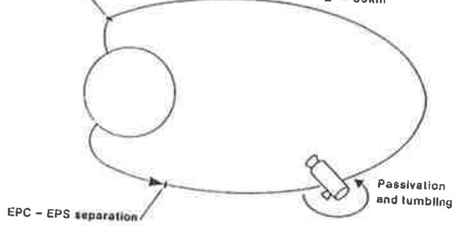


Fig. 3.2.3 - EPC natural reentry

3.3. ARIANE 5 - UPPER COMPOSITE PASSIVATION

Following the satellite injection into orbit, the Upper Composite of Ariane 5 is passivated ; it should be underlined here that passivation is not technically compulsory : indeed, a simple expulsion of the residual hydrazine of the Attitude Control System together with a global spin movement of the Composite would lead to a very low probability of explosion.
However, considering the potential energy remaining in the Composite, it was decided to passivate the Composite, i.e. to perform a programmed sequence of actions ensuring that no explosion can occur in orbit due to internal reasons (chemical blend or over-pressure) ; after passivation, the Composite is considered an inert orbiting object.

3.3.1. Upper Composite description :

The Upper Composite of Ariane 5 includes the Upper Stage EPS and the Vehicle Equipemnt Bay.

The EPS, conceived by DASA-ERNO, is mounted inside the VEB.
Its main propulsion system uses a single 27.5 kN pressure fed engine (flow diagram in Fig.3.3.1.1.)
Four cylindro spherical tanks, pressurized in flight at 20 bars, contain 9.7 tons hypergolic propellant (3.2 tons MMH and 6.5 tons N_2O_4).
Pressurisation is achieved with 30 kg Hélium, stored in two 400 bars spherical tanks ; the two staged pressure regulator operates at input pressures higher than 30 bars.

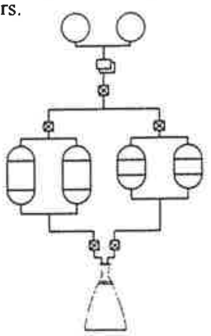


fig. 3.3.1.1 - EPS Flow diagram

The Attitude Control System (flow diagram Fig.3.3.1.2.) is located in the Vehicle Equipment Bay ; two cylindrical tanks contain 60 kg Hydrazine, separated from the Nitrogen pressurant by bladders (blow down mode).
Attitude Control is performed using six identical 300N thrusters, two for longitudinal axis, four for roll control.

When the passivation manoeuvres begin, the status of these two propulsion systems is the following :
The high pressure vessels have expelled most of their Hélium in the main tanks ; residuals can be estimated to be 7 kg at 60 bars.
The propellant tanks still contain the performance reserve propellant and the geometrical residuals which together represent 150 kg N_2O_4 and 100 kg MMH, pressurized at 20 bar by Hélium.
The residual hydrazine in the ACS may reach 20 kg at 15 bars under worst conditions and the amount of Nitrogen in the ACS tanks is very low (4 kg).

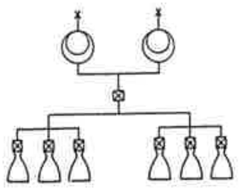


Fig. 3.3.1.2 - SCA Flow diagram

3.3.2. Constraints applicable to passivation definition

Four major constraints shall be taken into account during passivation :

- The non-collision requirement is obvious.
  Quantitatively, the first apogee altitude difference between non-payloads and payloads shall be greater than 10 km, as between payloads it shall be greater than 25 km. Depending on the missions specifications, the separation ΔV provided by the payloads separation system (springs or actuators) may not be enough to ensure such Composite withdrawal ; a specific manoeuvre is then necessary potentially complex to realise due to an unfavourable location of the Center Of Gravity of the Composite without payloads.
- The pollution level on the satellites shall remain below the specified level (organic deposit lower than 2 mg/m^2).
  Such a constraint imposes a suitable combination of distance and respective angular aspect between the Composite during passivation and the two payloads ; it also imposes a time lag before passivation is performed fig. 3.3.2.1 displays an example of the density map (here NO_2 volumic distribution around the Composite) ; the relative trajectory of payloads within this volume are time-integrated and compared to the specification.

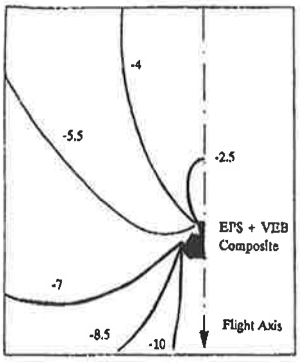


Fig. 3.3.2.1 - Pollution level (Log) g/cm2/s)

- Mission duration shall be minimised in order to cope with the telemetry constraints.
  During the first flights, in order to acquire a good confidence in the passivation, the process will be followed by ground stations. Taking into account the standard network considered for the primary mission, the passivation has to be performed in roughly 1000 seconds.
- Last, the passivation manoeuvres shall be compatible with the power supply dimensionning of the Vehicle Equipment Bay. As an example, a 1000 seconds extension of the mission duration keeping all equipment active (On Board Computer, Sequential Electronics, Inertial Reference Unit and Telemetry subsystem) would require roughly 10% of the global on board electrical energy.

3.3.3. Reference solution

The solution that was finally chosen by DASA-ERNO for the main propulsion system consists in two additional pyrotechnical valves, both located on the low pressure circuit at the common inlet of propellant tanks, one on the N_2O_4 side, one on the MMH side, connected to reaction less exhauts, T shaped, located on top of the EPS (Fig. 3.3.3.1).
On the ACS side, tanks have to be covered with Multi Layer Insulation.

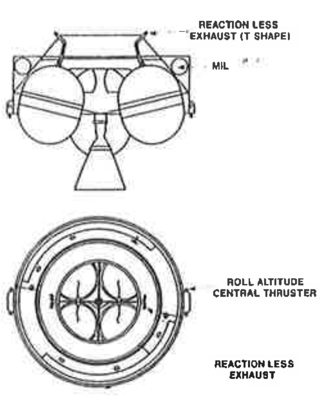


Fig. 3.3.3.1 - EPS Passivation System

The passivation sequence starts a short time after the last satellite placement :

- The Composite is spinne at a low level in order to guarantee its controlability during the manoeuvres even under the worst case.
- The Composite is tilted towards a mission dependant direction, optimizing the attitude with respect to thermal constraints and micrometeoroïds and debris impact risk (under study) ; a small ΔV is provided by ACS to ensure proper separation with the payloads.
- The Composite then acquires a higher spin, roughly 45°/second to settle the remaining propellant on the lateral sides of the tanks ; in this configuration, the pressurant inlet of the tanks is always free of liquid.
- After a coast phase lasting several hundreds of seconds, the two pyro valves are fired simultaneously ; the global torque applied to the Composite during tank depressurisation is very low, resulting forces being lower than the Newton ; simulations have shown that the Attitude Control of the Composite is not affected by the expulsion.
- The four roll thrusters of the ACS are then fired simultaneously, kept open until total consumption of Hydrazine, here again providing a torque free passivation.

Passivation of the both propulsion systems is effective after roughly 600 seconds.
After this time lag, thermodynamical conditions inside the propellant tanks are such that no pressure can build up again ; the remaining propellant is slowly evaporated and tanks are finally totally emptied.

The High Pressure tanks are depressurized down to the pressure of the first stage of the regulator, 30 bars. This value is acceptable, being 25 times lower than the rupture pressure of the tanks, which anyhow are designed to leak before burst.

The final blow-down pressure inside the SCA tanks is close to 6 bars whereas limit pressure is more than 40 bars ; Matra demonstrated that even under worst conditions pressure build up due to unburnable Hydrazine remains low compared to ACS operating pressure.

4 CONCLUSION

This effort made on ARIANE 5 shows the involvment of European participants in the Ariane programme towards a cleaner use of outer space. Effective measures were taken on Ariane launchers to limit debris production, whereas in some cases debris mitigation requirements are not in conflict with fulfilling launch mission requirements or may even be helpful, in most cases they are and do have a great impact on launcher conception and operation .

Passivation is a constraining requirement for Ariane 5 : additional hardware has to be implemented and specific manoeuvres are required.

It complexifies the development effort of the stages, since these new procedures and hardware have to be defined, tested, qualified and validated though extensive simulations.
However, this effort was felt compulsory to design a "cleaner" launcher by reducing drastically the risks of orbiting debris creation.

These measures are, in our view, the most efficient and realistic policy to be applied in the present commercial launch service environment, where the competition is very hard.

5 ACKNOWLEDGMENTS

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