Overview of CNES activities related to the compliance of the satellites with FSOA

”Satellite Respectueux de la Loi”

Pierre Omaly

French Space Law conformity verification Bureau for orbital systems

Summary

- Focus of the Modification in the Technical regulation witch have been adopted 11th of July 2017
- SRL is CNES initiative to make satellites compatible with the technical regulation of the French Space Operations Act

  - Synthesis of activities done related to the FSOA
    - Very first actions started in 2010 in the R&T program
    - The activities about compliance with the space operations act and debris represent around 2.5% of the R&D budget
  - Remaining actions

Art. 40. 3 – Space debris limitation

3. The systems must be designed, produced and implemented so that, following the disposal phase:

- all the on-board energy reserves are permanently depleted or placed in such a condition that they entail no risk of generating debris,
- all the means for producing energy on-board are permanently deactivated.
- all the radio-frequency emission capabilities of the platform and the payload are permanently switched off.

The above requirements are not applicable for controlled re-entries.

Art. 40. 4 – Space debris limitation

4. The systems equipped with propulsive elements allowing to modify the orbit must be designed, produced and implemented so that, ~~once~~ the space object is no longer present in the protected region A twenty five years after having ~~has~~ completed its operational phase in an orbit passing through protected region A~~, the space object is deorbited with controlled atmospheric re-entry.~~

~~If the impossibility of meeting this requirement can be duly proven, it must be designed, produced and implemented so that it is no longer present in protected region A twenty-five years after the end of the operational phase.~~ This result is preferably achieved by ~~uncontrolled~~ atmospheric re-entry or, failing that, by placing in a stable orbit for which the perigee remains above protected region A for one hundred years following the end of the operation.

Art. 40. 4 – Space debris limitation

Systems not equipped with propulsive elements allowing to modify the orbit must be designed, produced and implemented so that the space object is no longer present in the protected area twenty-five years after its in-orbit injection.

- If the orbit targeted by the space object after the disposal maneuvers is inside, or passes through, protected region A, and has an eccentricity lower than 0.25, the compliance with the above requirements shall be ensured with a probability of at least 0.5 considering the effect of natural orbital disturbances.

- If the orbit targeted by the space object after the disposal maneuvers has an eccentricity higher than 0.25, the compliance with the above requirements shall be ensured with a probability of at least 0.9 considering the effect of natural orbital disturbances and their associated uncertainties.

Art. 40. 5 – Space debris limitation

5. The space object must be designed, produced and implemented so that, once it has completed its operational phase in an orbit in or passing through protected region B, it is placed in an orbit which does not interfere with this region and located above it. This orbit must be such that, under the effect of natural disturbances, the object does not return to protected region B within one hundred years following the end of the operation.

If the orbit targeted by the space object after the disposal maneuvers has an eccentricity higher than 0.25, the compliance with the above requirements shall be ensured with a probability of at least 0.9 considering the effect of natural orbital disturbances and their associated uncertainties

Art. 40. 6 – Space debris limitation

~~7~~.6. The probability to successfully perform the disposal maneuvers referred to in paragraphs 3, 4 and 5 above must be at least 0.85. ~~The operator must evaluate the probability of being able to successfully carry out the disposal manoeuvres mentioned in paragraphs 3, 4 and 5 above~~. This ~~evaluation,~~ probability which does not include the availability of energy resources, must be calculated before launch ~~made~~ by the operator for the total duration of the ~~operation~~ phase of control for which the system has been qualified and take account of all systems, subsystems and equipments usable for these manoeuvres, their level of redundancy, if any, and their reliability~~, taking account of the effects of the ageing reached at the time they are scheduled to be carried out~~.

Art. 40. 7 – Space debris limitation

~~6~~. 7. The probability of having sufficient consumable energy resources, to successfully carry out the disposal manoeuvres mentioned in paragraphs 3, 4 and 5 above must be at least 0.99 when starting them.

Art. 44-1– Quantitative human safety objectives for return of a space object to Earth

1. With regard to the return of a space object, the quantitative safety objectives, expressed as the maximum probability of causing at least one casualty (collective risk) ~~are defined as follows:~~ is 10^{-4}

~~· 2*10-5 for return of an integral object;~~

~~· 2*10-5 for controlled atmospheric re-entry with destruction of the space object;~~

~~· If it can be duly proven that controlled atmospheric re-entry with destruction of the space object as mentioned above is impossible, the operator must do its best efforts to meet a quantitative objective of 10-4 for uncontrolled re-entry with destruction of the space object.~~

Art 55.2 – Interim provisions

b) For space objects launched between 10th December 2010 and 31st December 2020:

· the provisions of paragraphs 1 to 2 of article 40 and those of article 45 do not apply;

· with regard to the provisions of paragraph 3 to 7 ~~6~~ of article 40 and those of article 41, the operator must implement the best possible strategy considering the space object definition;

· with regard to the provisions of article 44, the operator must implement the best possible strategy considering the space object definition and must perform a risk estimate.

SRL objectives

It is necessary to implement actions allowing CNES (and French operators) satellites to meet the LOS requirements.

The SRL study enabled the identification :

- of tools,
- architectural principles
- equipment / technologies

that will have to be improved in order to be used in developments targeting launches after 01/01/2021.

This leads to a "roadmap", initiated at the system level and impacting sub-systems and technologies

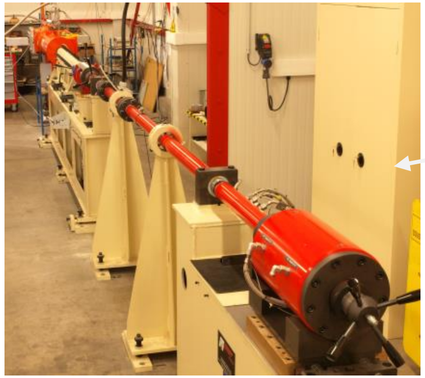
Few activities directly financed by SRL but mostly is coordination between the different existent source of activity

OVERVIEW

- **Art.40-1 : no generation of debris during the nominal operations**
- **Art.40-3 : passivation of energy reserves and deactivation of means of energy production at end of mission**
- **Art.40-4 : to leave the protected area in less than 25 years**
- **Art.40-6 : probability of success > 0,85 to perform the disposal maneuvers**
- **Art.44-1 : casualty risk < 10-4**

Art.40-1 : no generation of debris during the nominal operations

In priority the tanks, the batteries and the pannels bahavior relatively to a debris impact

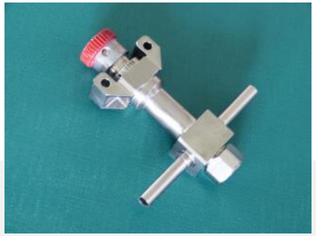


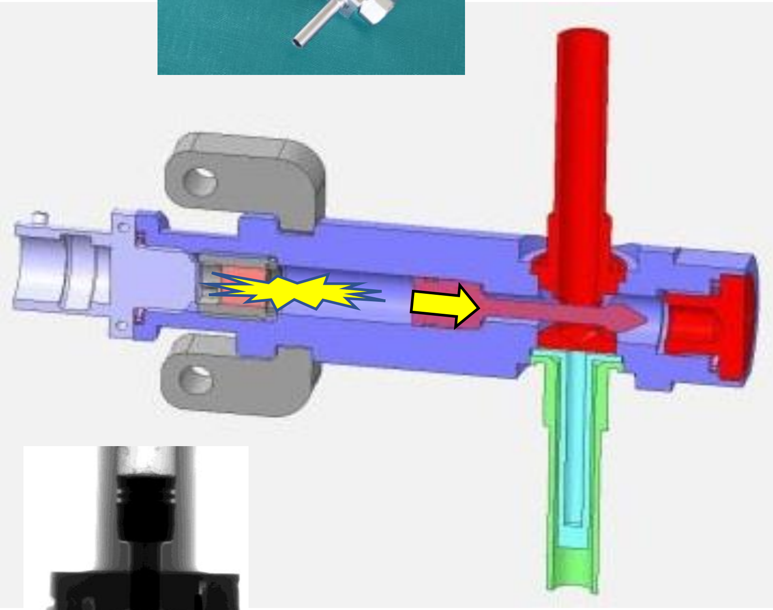
- **Pressurized tanks :**The objective is twofold : to analyze the explosive character, to analyze the generation of debris
  - Modeling hypervelocity impacts on a pressure vessel(R-S12/PF-0002-044) and with reactive fluid (R-S17/PF-0005-099)
  - Improvement of the THIOT Ingénierie test facility (R-S14/MT-0003-147) objectif :12 km/s
  - Fixed high impact ballistic equations (R-S17/PF-0005-098) – expérimental

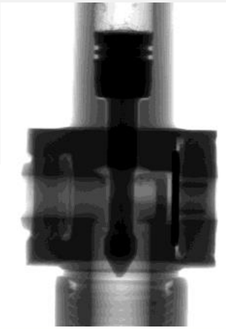
- **Batteries :**
  - Batteries Behavior vis-a-vis LOS requirements (R-S17/PF-0005-103) :complementary work with TRP and GSTP ESA : mechanical test

- **Structural Pannels :**The objective is twofold : to analyze how they protect the equipment and to analyze the generation of debris
  - R-S12/MT-0003-103 - Reinforcement of NIDA panels against debris
  - R-S04, R-S14/MT-0003-018 – Ballistic equations Honeycomb NIDA

Art.40-3 : passivation of energy reserves and deactivation of means of energy production at end of mission



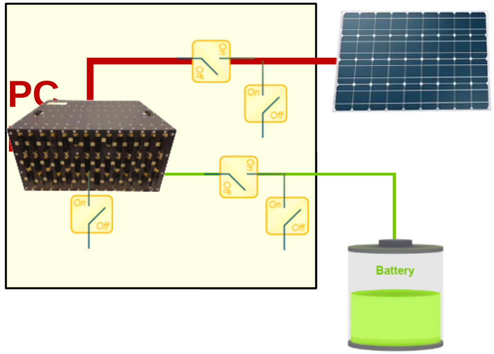


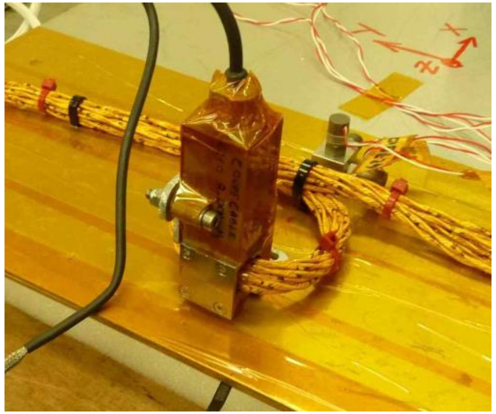


Depletion of the fluids

- **R-S11/PF-0001-024 – Telecom propulsion passivation**
  - several solutions have been identified by the manufacturers, complementing the "usual" propellant depletion through the thrusters at end of mission
  - Operational activities with TELECOM 2 / SPOT family
- **CNES has developed the microperforator, the more feasible and cheapest system in short terms**
  - it punches the tubing with a projectile and releases the pressurization gaz
  - R-S11, R-S13, R-S15/PF-0002-041, Y-TSO-14-61 (Démonstrateurs)
  - It is CNES qualified and will be tested with propellant and vapors
- **An initiator with a long life duration has been studied** (R-S12/TG-0002-010, R-S12/TG-0002-070)
- **To be done : long term behavior of the fluids within the tanks and other capacities** (fluid loops, …)**, depending of the thermal environment**

Art.40-3 : passivation of energy reserves and deactivation of means of energy production at end of mission





TRL5 demonstrated :
Verification of the performances on a harness of 12 twisted pairs of AWG 18.

Electrical passivation

- **R-S11/PF-0005-034 – End of life passivation of power system**
  - several solutions have been identified by the manufacturers at the SA level or PCDU or batteries and implemented on the myriade
- **R-S17/PF-0005-103 – "Passive" battery behavior with respect to LOS constraints**
  - to analyze the behavior of a passivated battery regarding short-circuit, thermal run-away, overcharge
- **Demonstration of the performances of an Off the Shelf cable cutter :**
  - Key characteristics
    - Reliability >0,995 @95% confidence
    - Lifetime of explosive components demonstrated >20 years at 30°C
    - Qualified for a French Air Force programme
    - REACH Free energetic materials

Art.40-4 : to leave the protected area in less than 25 years

oom in folded configuration

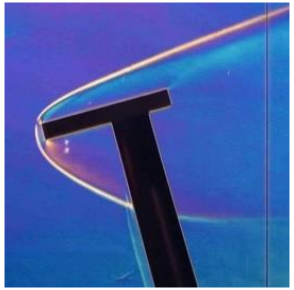
- **Operational**
  - R-S10/PF-0002-031 – Desorbitation from end-of-life survival mode of satellites in low orbit (feasibility and recommendations)
  - R-S12/BS-0004-004 - LEO autonomous De-orbiting , in case of loss of ground control (feasability)
  - Gossamer technology development in the frame on Microscope to deploy the drag sail (March–April 2018)
- **Space mechanics**
  - R-S11/TG-0004-014 - De-orbiting strategies leading to a controlled re-entry (preliminary studies)
  - R-S13/BS-0005-012 - De-orbiting of satellites in electric propulsion
- **AOCS**
  - R-S15/PF-0002-067 - Attitude control for very low-altitude satellites (interest for controlled reentry)
  - R-S17/PF-0002-088 – Definition of AOCS mode for post mission disposal (minimal configuration necessary, interest in case of mission extension)

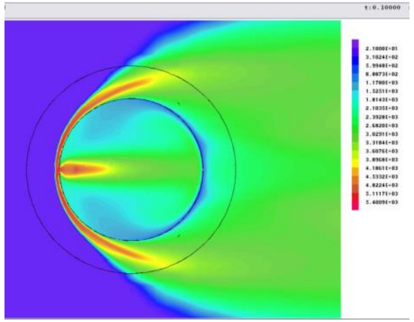
Satellite with IDEAS in deployed configuration

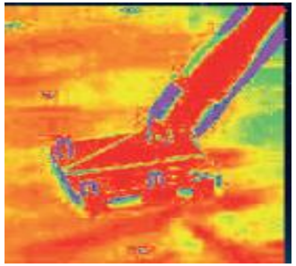
Art.40-6 : probability of success > 0,85 to perform the disposal maneuvers

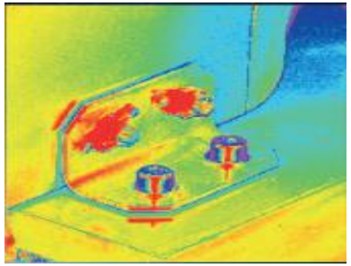
- **Bubble-type transient nozzle failure management from *AOCS* information**
  - R-S14/PF-0005-062 et Y-TSO-15-64 (Demonstrators)
  - algorithms development and ground simulations
  - not only for the passivation phase but also for the nominal operations
- **Health Monitoring**
  - R-S14/BS-0004-029 - Modeling the degradation of satellite equipment or subsystems
    - interest for mission extension
    - to be continued

Art.44-1 : casualty risk < 10-4









- **Models (DEBRISK – PAMPERO)**
  - R-S12/PF-0002-047 – Aerothermodynamics formulation for debris (rarefied, transitional and continue)
  - R-S15/PF-0002-065 - Evaluation of margins in DEBRISK models
  - R-S12/PF-0002-048 - Wind tunnel testing of flate plate
  - R-S14/PF-0002-056 -Aerothermal effect of a hole in a tank during reentry
  - R-S14/PF-0002-060 - Study of the effect of wake on atmospheric reentry
- **Materials :**
  - R-S14, R-S16/PF-0002-058 - Oxydation & emissivity of materials at hight T° (dont céramiques)
  - R-S15/TG-0003-036 - Resistance of satellite structures at high temperature (fragmentation)

Art.44-1 : casualty risk < 10-4

❖ Design for demise

- Destruction of LEO satellite structures R-S11, R-S14, R-S16/PF-0002-036
  - Exothermal materials in order to initiate and favor the burning of the structures
- Compatible tanks with LOS
  - R-S16/PF-0002-071 - LOS Compatible Reservoir for Lower Earth Orbit Electric Satellites
  - R-S17/PF-0002-084 - Development of "demisable" tanks made of composite materials

Much of work is still to be done : understanding, margins reduction, …

Active Debris Removal, Servicing

- **To develop GNC algorithms for space rendez-vous**
  - R-S11/TG-0004-012 : Vision-based relative navigation
  - R-S11/TG-0004-013 : Optimal multi-target rendezvous
  - R-S12/BS-0005-006 : Orbital Transfer for Active Debris Removal missions (low thrust)
  - R-S13/BS-0005-014 : Guidance / Control methods for the near and strongly constrained orbital rendezvous
  - R-S16/BS-0005-026 : Study of the near autonomous rendezvous in electric propulsion

Timetable

	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
Art.40-1 : no generation of debris during the nominal operations										
Equation balistique liée au NIDA	<<									
IHV : Pressurized tanks										
Modélisation des impacts hyper vitesse										
Amélioration du moyen d’essais THIOT Ingénierie										
Correction des équations balistiques à grande vitesse d'impact										
Renforcement de panneaux NIDA										
Art.40-3 : passivation of energy reserves and deactivation of means of energy production at end of mission										
Pasivation GEO										
Microperforator										
initiator with a long life										
Power system passivation										
Battery stress test										
Art.40-4 : to leave the protected area in less than 25 years										
Desorbitation from end-of-life survival mode of satellites in low orbit										
LEO autonomous desorption, in case of loss of ground control										
De-orbiting strategies leading to a controlled re-entry										
Desorbitation of satellites in electric propulsion										
Attitude control for very low-altitude satellites										
Defining an AOCS Mode for PMD										C

Timetable

	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
Art.40-6 : probability of success > 0,85 to perform the disposal maneuvers										
Gestion de panne tuyère transitoire de type bulle à partir d'informations du SCAO					■					
Health Monitoring					■	■				
Art.44-1 : casualty risk < 10-4										
Aerothermal model for Debrisk reentry			■							
Wind tunnel			■	■	■	■				
Aerothermal effect of a hole in a tank during reentry					■					
Study of the effect of wake on atmospheric reentry							■	■		
Oxidation & emissivity of materials at high T °					■	■	■	■		
Evaluation of margins in DEBRISK models							■			
Resistance of satellite structures at high temperature						■	■	■		
Destruction of LEO satellite structures		■	■	■	■	■	■	■	■	
LOS Compatible Reservoir for Lower Earth Orbit Electric Satellites							■	■	■	
Development of "demisable" tanks made of composite materials							■	■	■	
Active Debris Removal, servicing										
Optimal multi-target rendezvous		■	■	■						
Vision-based relative navigation		■								
Guidance / Control methods for the near and strongly constrained orbital rendezvous				■	■	■				
Study of the near autonomous rendezvous in electric propulsion							■	■		

Some topics are still need to be addressed more deeply:

Lack of knowledge

- 10^{-4} risk for more than 500kg spacecraft (tools improvements)
- Debris generation during small debris impacts on solar panels
- The behavior of green propellants and end-of-life risks associated with their passivation (MP103S)
- Uncertainty of thermal conditions at the end of satellite life and therefore need to consolidate temperature ranges for simulations of fluidic and electrical passivation (battery)
- Difficulty with reliability prediction methods to replicate actual situations. Current methods show lower reliabilities than those observed in flight.

To conclude

1. Tools for the reentry study (margin, breakup improvement, material database..)
2. Passivation (batteries ,pressurized tanks, green propellant..)
3. Probability to succeed the end of life activities
4. Keep direct discussion with French prime