**Orbital Debris Activities at CNES with a Focus on Space Debris Environment Impact Evaluation**

Juan-Carlos Dolado-Perez and V. Ruch (CNES)

On this presentation an overview of orbital debris activities at CNES will be given. These activities cover Optical observation, Space surveillance and tracking activities, space environment modelling, re-entry predictions and collision prediction in orbit and at launch. A focus will be given on studies done concerning the evaluation of the long term evolution of the orbital environment. The focus on this subject has been chosen as many exogenous and endogenous uncertainties sources may be still understood in order to define the mitigation and remediation measures to put in place to guarantee the long term sustainability of space activities.

![Graph showing collision risk increase for different missions depending on scenario with two mega-constellations at 1100 and 1200 km.](image)

**Fig. 1.** Collision risk increase for different missions depending on scenario with two mega-constellations at 1100 and 1200 km.

**Biography**

**Juan-Carlos Dolado-Perez**

Juan-Carlos Dolado-Perez is the head of the space debris modelling and risk assessment office at the “Centre National d’Etudes Spatiales” (French Space Agency). Since 2008 he has worked at the system engineering and orbital dynamics sub directorate, where his main research topics concern the long and middle term re-entry prediction, the long term evolution of the space debris population, the on orbit collision risk assessment, the orbit determination from radar and optical measurements and the uncertainty characterization and propagation.

He is a member of the Inter Agencies Space Debris Committee (IADC)’s French Delegation and of the International Academic of Astronautics (IAA)’s Space Debris Committee.
Outline

- Collision Avoidance at Launch
- Optical Space Surveillance
- Data Processing for Cataloguing – Space Surveillance
- Collision Avoidance in – orbit
- Orbital propagation
- Re-Entry Predictions
- Re-Entry Modelling
- Space Debris Environment Modelling – Env. Index
Collision Avoidance at Launch

> Operational Collision Avoidance at Launch since 2010
> Requirement from FSOA (French Law)
> Collision Risk analysis with ISS, Soyuz, ...
> Every launch from Guyana Space Center
> Preliminary joint work in the past between JAXA and CNES

Example Soyuz flight: no risk

Example Ariane 5: risks at 5th and 6th orbit
Optical Space Surveillance

Operations of TAROT network:
- TAROT network covers 70% of GEO belt
  - An additional on-demand site in Australia allows to cover almost 100%
- Catalogue build-up and maintenance of ~500 objects
Observation of GALILEO Constellation Launch

EPS with the 4 GALILEOS on-board

22h04 UTC from Makas Observatory (CNRS 60cm Diameter Telescope)

Observation of GALILEO Constellation Launch

1st Separation between GALILEO Satellites and EPS

Two first GALILEO Satellites moving away from the EPS

22h27 UTC from Makes Observatory (CNRS 60cm Diameter Telescope)
Observation of GALILEO Constellation launch

22h47 UTC from Maolos Observatory

Observation of GALILEO Constellation launch

22h56 UTC from Maolos Observatory
Progress on the development of techniques for the enhancement of the covariance realism:

- Maintaining the Gaussianity of Covariance matrices

Use of a reference frame where $T \ [m]$ is replaced by $t \ [sec]$
Data Processing for Cataloguing

Progress on the development of advanced techniques for correlation and cataloguing:

- Bayesian data association techniques
  - Joint Probabilistic Data Association
  - Multi Hypothesis Tracking
  - Multi-Bernoulli – Finite Sets Statistics

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Log-likelihood vs Mahalanobis

\[
d^2_L = K \ln(2\pi) + \ln(|\Sigma|) + (x - \mu)^T \Sigma^{-1} (x - \mu)
\]

Additional studies to improve our capability to

- Task and Schedule sensors
- Evaluate information gain coming from observations and optimize observation strategies
- Analysis of ionosphere correction models
- Development of IOD methods
- ...
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On-Orbit Collision Avoidance

Operational Collision Risk assessment of 99 satellites
- 24 LEO
- 26 MEO
- 49 GEO
On-Orbit Collision Avoidance

Collision Risk 3-D Probability Computation

Fig. 2 Comparison of the 2D and 3D-probability of collision for the generated cases. High-velocity encounters (> 50 m s⁻¹) are plotted in orange and low-velocity encounters (≤ 50 m s⁻¹) in blue.
**Orbital Debris Propagation**

**Improvement of STELA semi-analytic propagator**

- Use of recurrence formulation for zonal perturbation: maximum degree of development is no more limited to 15
- Development of third body perturbation up to order 8
  - Ability to propagate INTEGRAL orbits (sma = 87941 km, ecc = 0.856)
  - Ability to propagate for a decade SIMBOL-X orbit (sma = 106247 km, ecc = 0.75)
- Work ongoing on the inclusion of short periods of non-conservative forces
  - PRS
  - Drag

Work initiated on the propagation of space debris using density model approaches
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Reentry Predictions

Tiangong-1 Reentry

- On-ground risk evaluation > a week prior to reentry
Reentry Predictions

Tiangong-1 Reentry

- Refinement of the reentry epoch and location with radar observations

Reentry prediction 1 day prior to real reentry

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Reentry Modeling

- EXPERIMENTAL DATA
  - From ground tests
  - From flight experiments

- VALIDATION OF THE REENTRY MODELING TOOLS
  - CNES tools: DEBRISK, PAMPERO
  - Existing JAXA – CNES cooperation

Simulation chain: Physical analysis, validation, model reduction, prediction and certification

- High fidelity code
  - Accuracy
  - Validation

- Spacecraft oriented code
  - Cost

- Object oriented code
  - Sensitivity analysis
  - Research of Meta models
  - Fragmentation assessment
  - UQ associated with the results

DEBRISK
  - Official certification tool
Space Debris Environment Modelling

- Long term evolution of space debris environment, shows a unstable behavior in the LEO regime, if efforts are not made to reduce the number of objects on the environment.

N.B.: PMD Compliance refers to objects non compliant with the 25-Years rule that we have voluntarily de-orbited
Space Debris Environment Modelling

- SATELLITES Compliance to LEO EOL guidelines

- Global S/C compliance lying on natural effects
  - ~17% of OCC satellites compliant thanks to a maneuver

- Reality is 17%!!

N.B.: PMD Compliance refers to objects non compliant with the 25-Years rule that we have voluntarily de-orbited
Space Debris Environment Modelling

- Mitigation and Remediation Complementarity

Mitigation is needed whichever the Remediation Scenario

- Large Constellation Effect and Environmental Index
Space Debris Environment Modelling

- Large Constellation / small sats Effect and Environmental Index

### Scenario 1 vs. Baseline

**[Relative increase of flux vs. time]**

**GENERAL**
- Objects > 10 cm

**BACKGROUND**
- 1 cm < Debris < 10 cm, generated by NASA BU
- PMD 90% X
- PMD 20%, max lifetime 25 years
- PMD 20% in 2013, rising linearly and stabilizing at 90% in 2050, max lifetime 25 years

**EXPLOSIONS**
- Explosions:
  - random number of explosions per year (between 5 and 12)
  - 5 < nb debris < 250
  - Explosing objects were launched before 2020

**CONSTELLATIONS**
- Constellation Altitude (km) 1100
- Injection Altitude (km) direct
- Electric orbiting duration (days) 50
- Collision avoidance effectiveness rate (%) 100
- PMD rate (%) 90
- PMD deorbitation orbit type eccentric
- PMD target lifetime (years) 25
- Launch stages: none (direct reentry) X
- Launch stages: PMD 90%, target lifetime = 25 years

**CUBESATS**
- Cubesats launches: from 200 in 2013 to 600 in 2050 and later, <600km
- Cubesats launches: from 20 in 2013 to 60 in 2050 and later, >600km
Thank You for your Attention