Low Earth Orbit Kinetic Space Safety Workshop

Keynote: Debris prevention

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Lausanne, Switzerland

CNES – IAA – IAF – ASA – IADC – ISO – ECSS

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Early works, initial standards

First concerns in early 70s', mainly at NASA level :

⇨ Brooks, David R.; Gibson, Gary G.; and Bess, T. Dale: Predicting the Probability That Earth-Orbiting Spacecraft Will Collide With Man-Made Objects in Space. [IAF Paper] A74-34, Sept.-Oct. 1974.

⇨ Brownlee,D.E. ; Tomandl,D.A. ; Hodge,P.W.
The Flux of Meteoroids and Orbital Debris Striking Satellites in Low Earth Orbit
Nature 323, pp 136-138, 1974

⇨ Bess,T.D.
Mass Distribution of Orbiting Man Made Space Debris
NASA TN D-8108 , Dec. 1975

- First collision models
- First debris propagation models
- First orbital density models
- Comparison with micro-meteoroids
- Initial development of "EVOLVE" tool

↳ However, no recommendations yet, just facts!

3700 cataloged debris
900 tons in orbit

Early works, initial standards

Early publications at international level:

Collision Frequency of Artificial Satellites: The Creation of a Debris Belt

DONALD J. KESSLER AND BURTON G. COUR-PALAIS

NASA Johnson Space Center, Houston, Texas 77058

- Early identification of potential problem (1978)
- Potential cascading effect

⇨ **First recommendations!**

. to "deorbit" at end of mission,

. to avoid explosions and collisions

> Various methods to stop or slow the formation of a debris belt should be studied. The model suggests that the most effective way would be to keep the number of large objects as small as practical. This could be accomplished by planning launches so that large objects can be caused to reenter when their usefulness is complete or by using the space shuttle concept to retrieve objects in orbit which no longer serve a useful function. Since it is impractical to retrieve the much larger number of large and small fragments, every effort should be made to prevent their production in space, either by explosion or by collision.

5200 cataloged debris
1400 tons in orbit

[1] Journal of Geophysical Research, June 1st, 1978, Vol 83, No. A6

Early works, initial standards

Dissemination of the information at international level in early 80s':

⇨ Reynolds, R.C., Fischer, N.H., and Edgecombe, D.S.: A Model for the Evolution of the On-Orbit Man-Made Debris Environment. Proceedings of the NASA/JSC Orbital Debris Workshop, NASA Conference Publication 2360, 1982, pp. 102-132.

⇨ Kessler, D.J.: Orbital Debris Environment for Space Station. JSC 20001, 1984.

⇨

Kessler et al, ORBITAL DEBRIS (NASA CP 2360)	GENERAL	1985

⇨

Shin-Yi Su, ORBITAL DEBRIS ENVIRONMENT RESULTING FROM FUTURE ACTIVITIES IN SPACE NASA IAA JOURNAL	GENERAL	30.6.86

⇨ Kessler, D.J., Reynolds, R.C., and Anz-Meador, P.D.: Orbital Debris Environment for Spacecraft Designed to Operate in Low Earth Orbit. NASA TM 100-471, 1988.

⇨

ESA-SP-1109, SPACE DEBRIS The Report of the ESA Space Debris Working Group	GENERAL	Nov. 88

- General description of Space Debris environment
- Modelling
- **First recommendations for Space Station**

6300 cataloged debris in 1982
1600 tons in orbit

Early works, initial standards

First major synthesis in Europe:

SAFE DISPOSAL OF ORBITING SYSTEMS
AND SPACECRAFT -
INCLUDING THE PREVENTION OF
DEBRIS CREATION

- 1987 - 1989
- ESA Contract from Pr. Walter Flury to European Industry
- Study led by MBB-ERNO
- Covering all kinds of satellite and launcher missions

Recommendations, element per element, including Envisat…

Identification of the "classical" mitigation measures:

. Passivation

. Deorbiting of large spacecraft

. No intended release of operational debris

. Long term integrity of systems

. End of Life operations to be performed part of nominal operations

. Debris avoidance (longer term)

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Early works, initial standards

First standard in Europe:

System safety requirements
for ESA space systems

- ESA-PSS-01-40 Issue 2, September **1988**
- Not devoted to Space Debris, but includes numerous associated requirements
  - . Controlled reentry for hazardous space systems, deorbiting
  - . Proper mastering of collision risks, passivation
- Probably too theoretical and not applicable

8600 cataloged debris
2700 tons in orbit

II – 1.6.2 Means shall be provided to prevent the hazardous descent of debris as the result of a launch vehicle launch abort, or the uncontrolled de-orbiting or orbital decay of spacecraft, or space system elements that are likely to survive re-entry.

II – 1.6.4 The creation of space debris in orbits that repeatedly intersect orbital paths used by space systems shall be avoided.

II – 3.1.1.3 Orbiting spent stages shall have the capability of being safely de-orbited.

II – 3.1.2.5 Residual propellants contained in spent or aborted stages shall be safely dispersed.

Early national standards

NASA Standard (1995):

Guidelines and Assessment Procedures for Limiting Orbital Debris

9000 cataloged debris
3800 tons in orbit

- Every "classical" mitigation rules

- Depleting on-board energy sources after completion of mission
- Limiting orbit lifetime after mission completion to 25 years or maneuvering to a disposal orbit
- Limiting the generation of debris associated with normal space operations
- Limiting the consequences of impact with existing orbital debris or meteoroids
- Limiting the risk from space system components surviving reentry as a result of postmission disposal

NASDA Standard (1996) NASDA-STD-18:

(1) Preventing the space systems after the end of its mission from on-orbit breakup which generates a large amount of debris

(2) Transferring a post-mission spacecraft that has been operated on geostationary earth orbit (GEO) into higher orbit in order to preserve GEO environment

(3) Reducing the time during which the upper stage left on geostationary transfer orbit (GTO) would interfere with GEO to preserve GEO environment

(4) Minimizing objects released on orbit during operation of a space system

(5) Reducing the time during which a post-mission space system would interfere with useful orbit region

Early national standards

ECSS-Q-40-A

Not dedicated to Debris

Evolution of the PSS-01-40 applicable to ESA (April 1996)

CNES RNC-Q-40-512:

Dedicated to Debris

Applicable by decision of DG 18 June **1999**

Structured into 3 parts:

- Management
  - . Space Debris Mitigation Plan, aimed at checking compliance
- Design
  - . Prevention *(Limitation of number of debris – ASAT forbidden – Probability of accidental explosion – Material selection)*
  - . Safety rules wrt ground – Casualty risk
- Operations
  - . Passivation
  - . End of Life Maneuvers *(25-year rule, GEO rule, probability of successful EOL > 99%)*
  - . Collision avoidance *(General recommendation "if possible")*

11000 cataloged debris
4500 tons in orbit

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IADC – UNCOPUOS

IADC (Inter-Agency Space Debris Coordination Committee):

- Initial meetings starting in 1987 between NASA and ESA
- Officially 1st IADC meeting in Moscow 1993
- 13 agencies today - 4 Working Groups + Steering Group
  - ↳ IADC Space Debris Mitigation Guidelines + Support Document
    - 5 years convergence
    - Unanimously approved in 2002, revised in 2007
- Numerous other documents
    - IADC Protection Manual,
    - IADC Statement on Large Constellations in LEO (2015-2017, revised in 2019)…

11000 cataloged debris

4900 tons in orbit

UN Guidelines:

- Elaborated by UNCOPUOS on the basis of IADC Guidelines
- Published in 2007
- No mention of 25-year rule

The making of ISO 24113

European Space Debris Mitigation Standard EDMS (1998):

- 5 years work to prepare EDMS
- Derived from the CNES standard
- Vol.1 = Standard
- Vol.2 = Explanations and Guidelines for implementation
- Edition 1.7 ready for approval on July 1st, **2002**

↳ but, not allowed to write standards!

10000 cataloged debris

4200 tons in orbit

European Code of Conduct ECoC (2003) :

- From Sept. 2003 to June 2004
- Replacement of all “shall” by “should”
- Approval ASI - BNSC – CNES - DLR - ESA on 26 July **2004**
- Issue 2 in August 2005 ⇨ Non binding
- Volume 2 “Support to Implementation of ECoC”

11000 cataloged debris

4800 tons in orbit

↳ **Used as initial text for ISO 24113**

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ISO 24113 and second level standards

ISO-24113 = Highest level standard:

- Lengthy process from 2005 to formal issue in February **2010**
- Family of "second level" standards
- Revised 2017 and under revision 2022

↳ Major evolution to include all "second level" standards

- ISO 23312 devoted to Spacecraft & ISO 20893 devoted to Launchers
  = Detailed requirements in addition to ISO 24113
- ISO 27852 Orbit Lifetime Estimation, …

- Preparatory work at European level through ECSS SDWG – "Mirror" Working Group

17500 cataloged debris

6000 tons in orbit

Adopted by ESA through:

- ESA/ADMIN/IPOL(2008)2 dated 1 April 2008 - Space Debris Mitigation for Agency Projects
- Updated as ESA/ADMIN/IPOL(2014)2 dated 28 March 2014
- ECSS-U-AS-10C 10 February 2012 Adoption Notice of ISO 24113
- SEBB-ST-U-004 (2017) Dedicated to ESA Re-entry Safety Requirements

↳ Constraining document: same status as a Law

17200 cataloged debris

6700 tons in orbit

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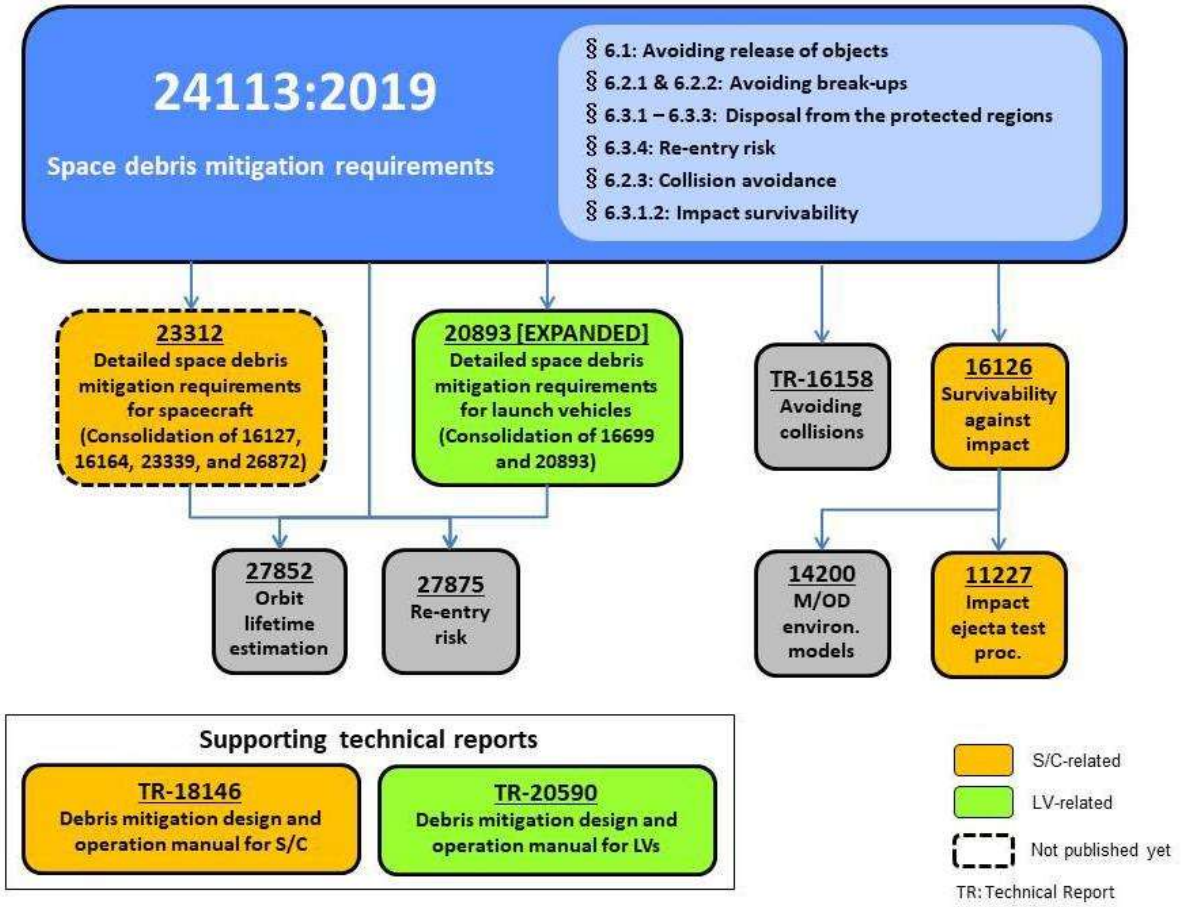
ISO 24113 and second level standards



UN Long Term Sustainability Standards

Remarkable achievement – Non binding

UN COPUOS Guidelines on Long-term Sustainability of Outer Space Activities

A. Policy and regulatory framework for space activities

- Guideline A.1 Adopt, revise and amend, as necessary, national regulatory frameworks for outer space activities
- Guideline A.2 Consider a number of elements when developing, revising or amending, as necessary, national regulatory frameworks for outer space activities
- Guideline A.3 Supervise national space activities
- Guideline A.4 Ensure the equitable, rational and efficient use of the radio frequency spectrum and the various orbital regions used by satellites
- Guideline A.5 Enhance the practice of registering space objects

B. Safety of space operations

- Guideline B.1 Provide updated contact information and share information on space objects and orbital events
- Guideline B.2 Improve accuracy of orbital data on space objects and enhance the practice and utility of sharing orbital information on space objects
- Guideline B.3 Promote the collection, sharing and dissemination of space debris monitoring information
- Guideline B.4 Perform conjunction assessment during all orbital phases of controlled flight
- Guideline B.5 Develop practical approaches for pre-launch conjunction assessment
- Guideline B.6 Share operational space weather data and forecasts
- Guideline B.7 Develop space weather models and tools and collect established practices on the mitigation of space weather effects
- Guideline B.8 Design and operation of space objects regardless of their physical and operational characteristics
- Guideline B.9 Take measures to address risks associated with the uncontrolled re-entry of space objects
- Guideline B.10 Observe measures of precaution when using sources of laser beams passing through outer space

C. International cooperation, capacity-building and awareness

- Guideline C.1 Promote and facilitate international cooperation in support of the long-term sustainability of outer space activities
- Guideline C.2 Share experience related to the long-term sustainability of outer space activities and develop new procedures, as appropriate, for information exchange
- Guideline C.3 Promote and support capacity-building
- Guideline C.4 Raise awareness of space activities

D. Scientific and technical research and development

- Guideline D.1 Promote and support research into and the development of ways to support sustainable exploration and use of outer space
- Guideline D.2 Investigate and consider new measures to manage the space debris population in the long term

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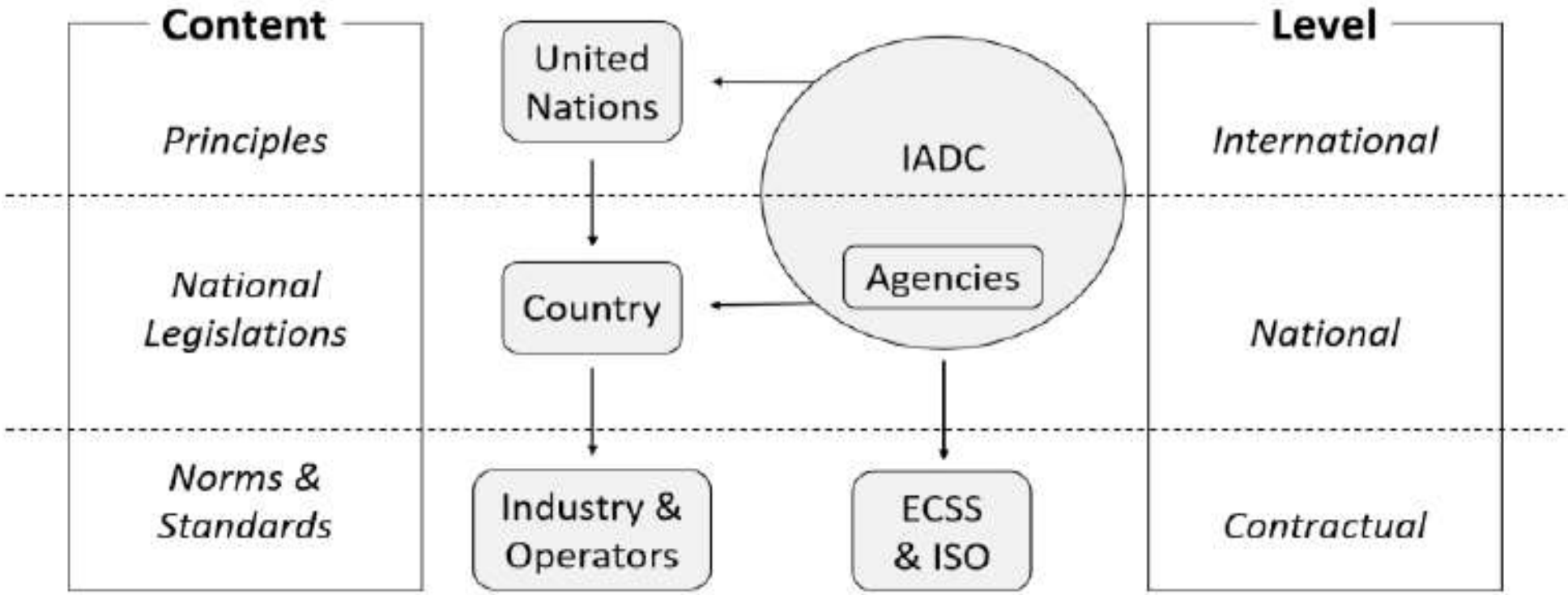
Regulatory framework at international level



Space Safety Coalition

Best practices for the Sustainability of the Space Operations:

- Interesting initiative at operator level (led by Dan Oltrogge)
- Endorsed by 31 space industry stakeholders - September 2019. Now endorsed by 57 !

A=Association/Foundation	C=Consulting/Analytical Serv.	D=Disposal services
F=Flight safety/SSA/STM	G=Govt Operator	I=Insurer
L=Launch provider	M=Manufacturer of spacecraft	O=Operator (commercial)
P=Part/comp manufacturer	R=RPO/OOS services	T=Systems/Tools supplier

- Non binding
- Preamble: “respecting IADC, UNCOPUOS and ISO…”
- Numerous additional points (not exhaustive):
  - Exchange of information among operators
  - Specific rules for constellations
  - Spacecraft above 400 km shall have some collision avoidance capacity
  - Probability of successful disposal shall be better than 95%
  - Specific points on Passivation
  - Atmospheric reentry shall take place within 5 years for spacecraft equipped with a propulsion system
  - Numerous qualitative requirements…

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Laws

Numerous National Regulations related to Licensing [1] (not exhaustive…):

- US Commercial Space Launch Act: 1984
- UK Outer Space Act: Initial regulation in 1986
- South Africa Space Affairs Act in 1993
- Argentina: Establishment of the National Registry of objects launched into outer space" in 1995
- Russia: Decree and statute on licensing space operations in 1996
- Australia: Space Activities Act in 1998
- Brazil: Space Agency Administrative Edict in 2001.

↳ **In general, indirectly related to Space Debris**

[1] *Addressing Orbital Debris Through National Regulation R. Crowther*

French Space Operations Act (FSOA):

- First Law directly related to Space Debris (2008) – Revised in 2011 and 2017
- Cancels and Replaces the French Standard RNC-CNES-Q-40-512
- Declined into two "Application" documents:
  - Technical Regulation RT ("Flying" segment = Launchers and Satellites)
  - Operations of the Guiana Space Center Installations REI = Ground segment
- All Space Debris Mitigation rules included in RT
- Partial waiver regime up to 2020 for transitory phase
- Currently under heavy revision

Current status

Relatively coherent set of Requirements at international level thanks to extensive exchanges at international level, IADC, ISO, IAF-STM, IAA-SDC

However, a lot of work ongoing at National and International levels (not exhaustive)

- **No intentional generation of space debris in nominal operations**
  - . Different approaches:
    - - Limitation of number per space operations
    - - Requirement of a maximal Number x Lifetime
  - . Limitation of the use of Solids and Pyros in orbit

- **No voluntary destruction of space objects**
  - . Explicit in most of the standards (including Russian GOST)
  - . Not forbidden in some others, but with associated constraints

- **No accidental fragmentation in orbit**
  - . Passivation, generalized to internal sources, including probability of successful passivation
  - . Probability of collision with small debris over operational life preventing End of Life Maneuvers
  - . Probability of collision with small debris over orbital lifetime generating new debris (quantified)

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Current status

Ctd…

- **Limitation of lifetime in orbit after end of operations**
  - . Question of Mission Extension
  - . 25-year rule under revision, proportional to the operational lifetime
  - ⇨ Studies are necessary at both efficiency level and impact on spacecraft before inventing strongly reduced value
- **Collision avoidance**
  - . Maneuvering capability compulsory in GEO and above a TBD altitude in LEO
  - . Proposal to define a Protected Zone for Human missions (370-430 km?)
  - . COLA Collision Avoidance at Launch
  - . Need for shared methodology and thresholds, at requirement level
  - . Initial checkout at low altitude
- **Limitation of Casualty Risk on Ground**
  - . Good coherence on the methodology and threshold, but lack of benchmark
  - . D4D – Design For Demise
- **Dedicated rules for New Space Operations, IOS, RPO, ADR, …** but more Operations than Debris Mitigation

↳Whatever we propose, we must be sure to reach a consensus at international level (inc. Russia, China…) otherwise it will never be applied, except for some voluntary cases, as already today…

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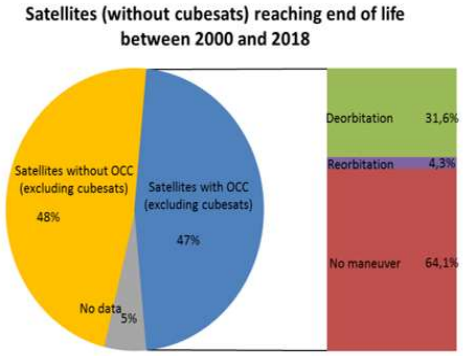
Priorities

Very poor compliance today globally

- Still a lot of Mission Related Objects released in orbit knowingly
- Mean PMD compliance in LEO over 20 years ≅ 25% in 2021 *(V. Ruch – CNES under publication)*
- Still numerous fragmentations in orbit ≅ 1 per month
- Poor compliance to casualty risk at reentry



[OCC = Orbital Change Capacity]

Compliancy with regulation

- **36 %** of Maneuverable S/C **tried to be compliant**
- **26%** of Maneuverable S/C **were compliant**
- **12% of all non cubesats were compliant**

J-C. Dolado Perez et al. CNES presentation to IADC WG2 - 2019

- ⇨ **Do what has been decided since 1995 - Understand why the score is so low**
- ⇨ **Very high reactivity is necessary to update the existing standards**
- ⇨ **It is fundamental to be coordinated at international level to share the same set of rules**

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THANK YOU

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