Fragmentation Data Message

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Agenda

1. Need for a Fragmentation Data Message
2. Example of fragmentation data gathering – March 2019 ASAT test
3. FDM content
4. Why it could be interesting for NAV WG
5. Summary, conclusions and future steps

Fragmentation Data Message

INTRODUCTION

Introduction

- original concept developed together with RDM in mid-2015
- concept paper drafted at the same time as the RDM concept paper (found on my computer thanks to Spotlight; not sure if shared with WG)
- contents were based on the output of the prototype ESA SST Fragmentation Analysis System (FAS)
- no significant development since, all resourced dedicated to RDM
- since 2015:
    - different perspective on fragmentation events from ESA Space Debris Office activities
    - NDM progress, including RDM, OCM, and OCM (in development)
    - RDM development and contents led to some doubts about the original FDM content

Need for a

FRAGMENTATION DATA MESSAGE

all data from the ESA Space Environment Report available at:

https://www.sdo.esoc.esa.int/environment_report/Space_Environment_Report_latest.pdf

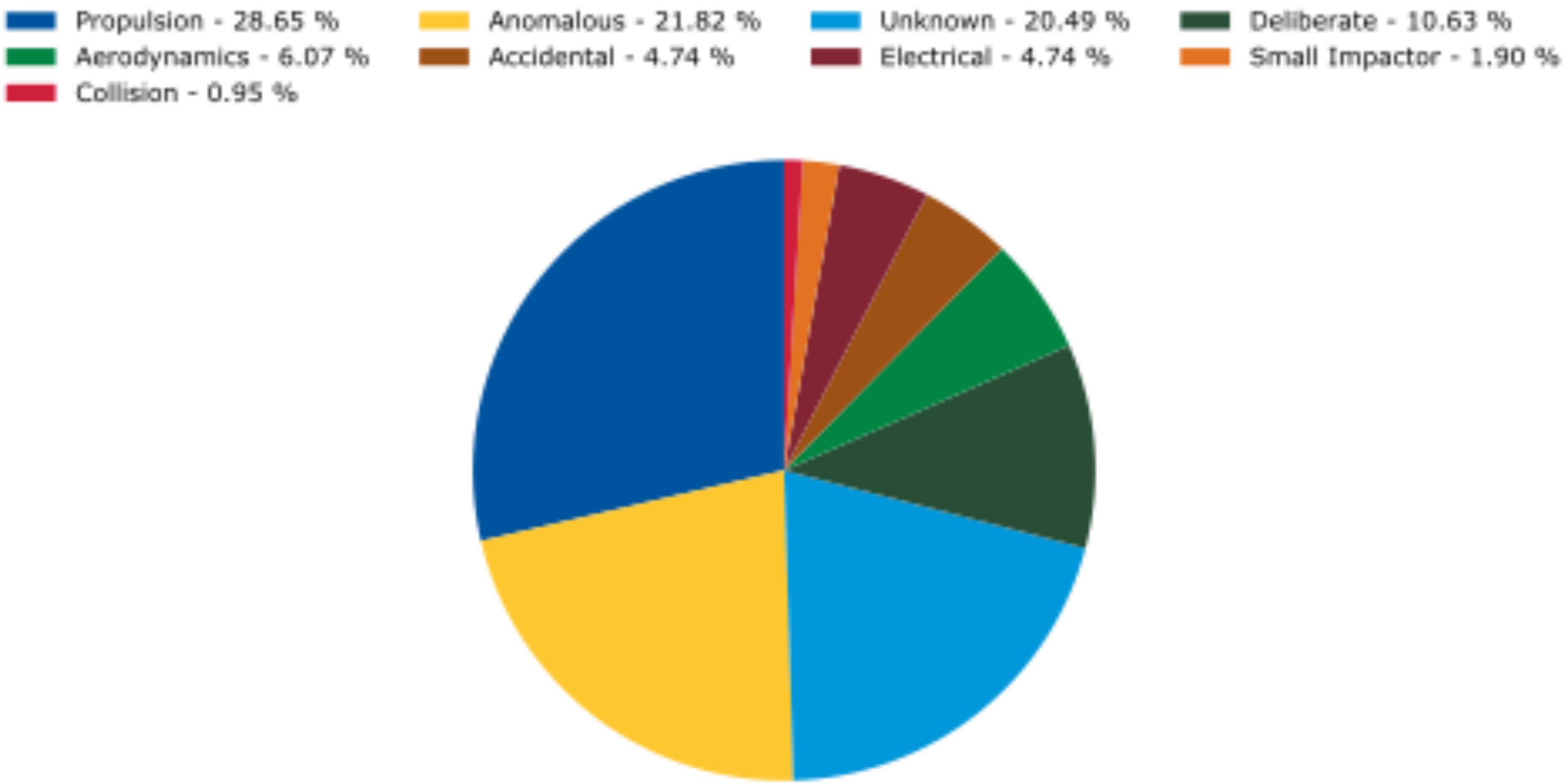
Event epoch	Mass [kg]	Catalogued objects	Asserted objects	Orbit	Event cause
2018-02-12	360.0	0	90	LMO	Propulsion
2018-02-28	1486.62	58	100	EGO	Propulsion
2018-05-22	56.0	4	60	LMO	Propulsion
2018-08-17	1000.0	4	6	LEO	Propulsion
2018-08-24	56.0	1	20	UFO	Propulsion
2018-08-30	2020.0	453	491	MGO	Propulsion
2018-12-22	42.0	12	12	LEO	Unknown
Total	5020.62	532	779		

Fragmentation events in 2018

Over 500 catalogued objects generated; at least 250 sub-catalogue objects generated

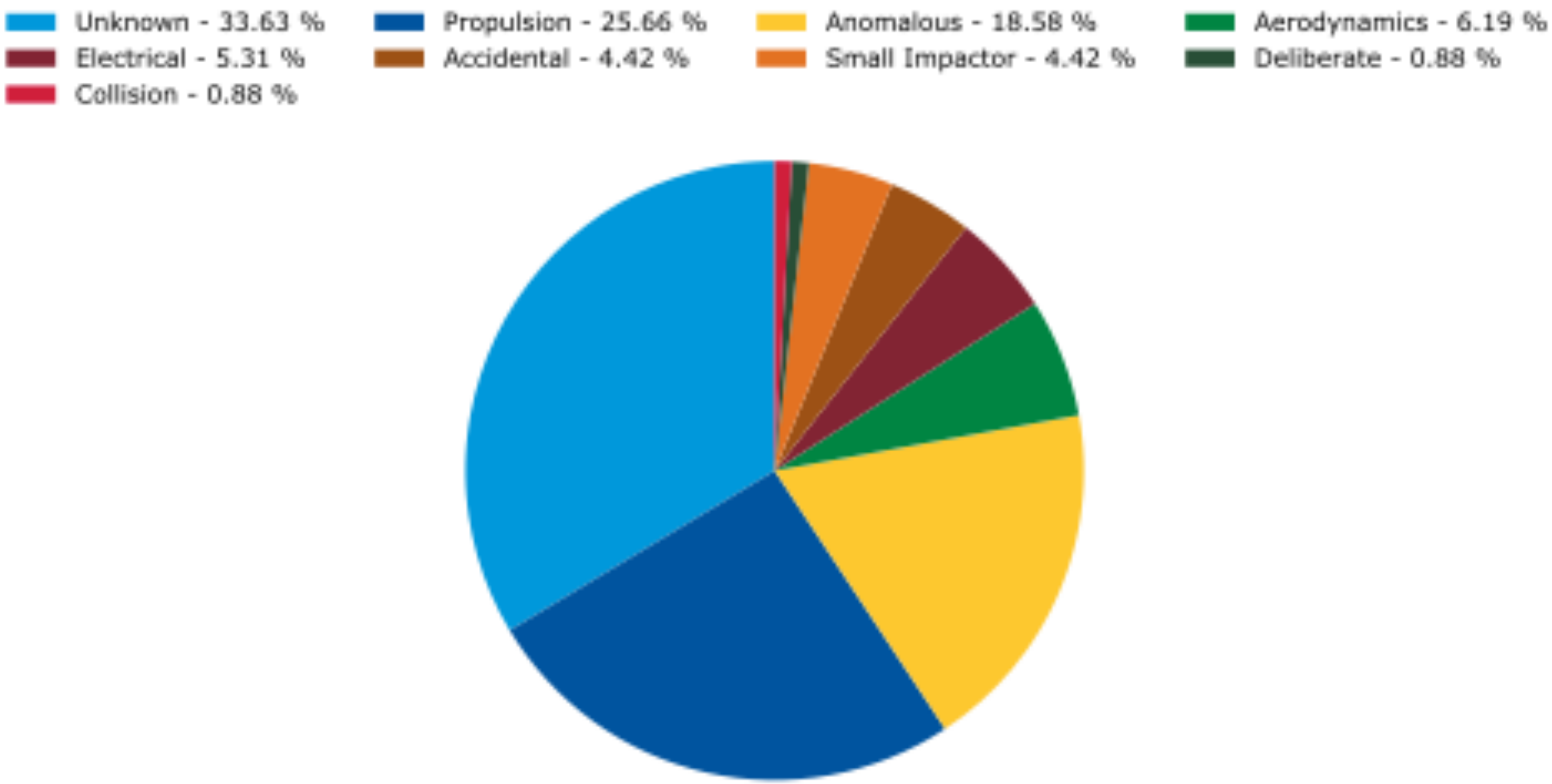
	All history	Last 20 years
Number of events	532	248
Non-deliberate events per year	8.0	11.6
Events where 50% of the generated fragments have a lifetime of greater than 10 years	2.7	3.0
Events where 50% of the generated fragments have a lifetime of greater than 25 years	2.0	2.3
Mean time (years) between launch and fragmentation	5.8	9.8
Median time (years) between launch and fragmentation	1.3	7.2

Fragmentation event statistics



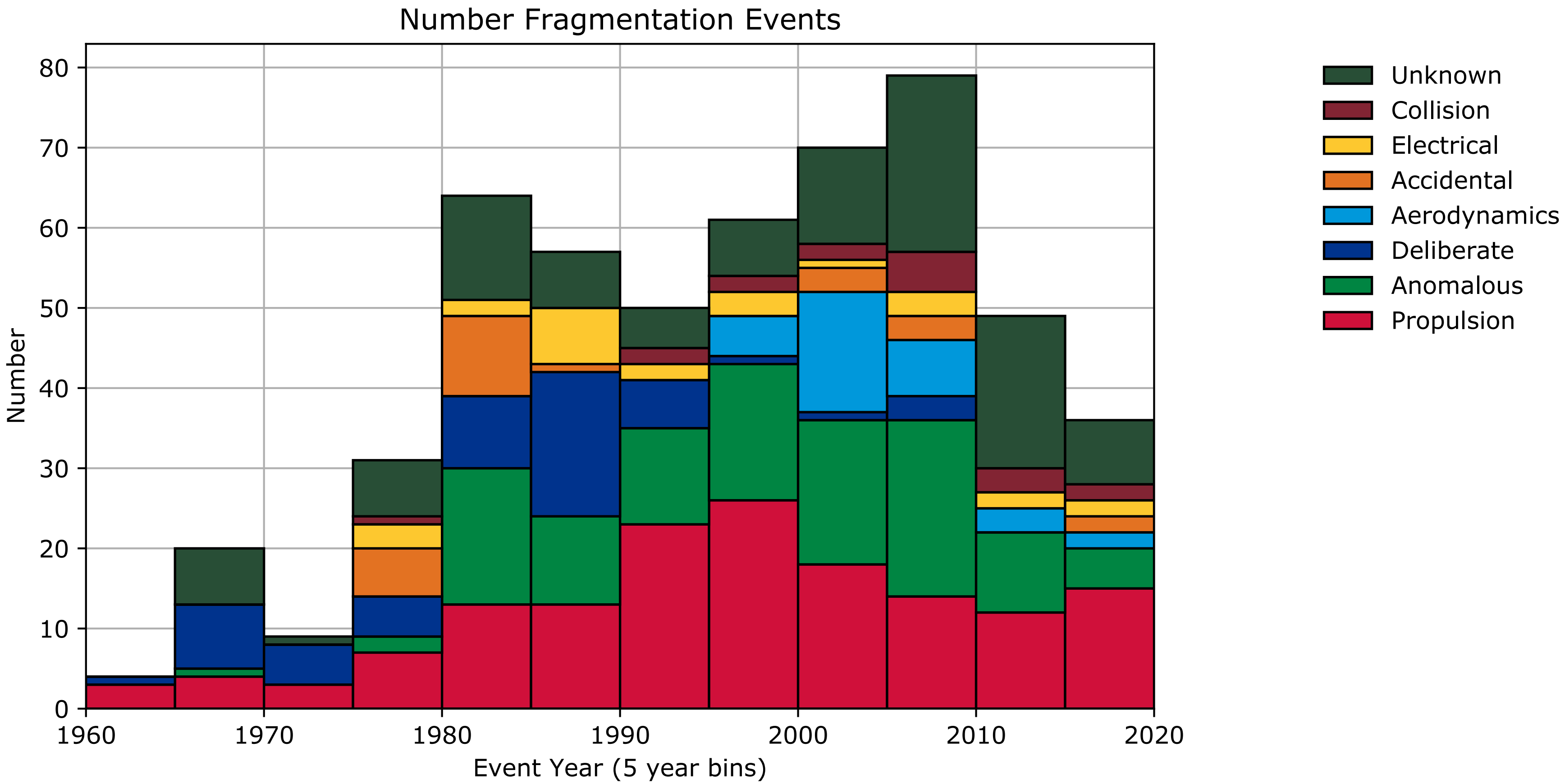
Fragmentation event cause – entire time history

Propulsion, anomaly and unknown most common causes of fragmentation



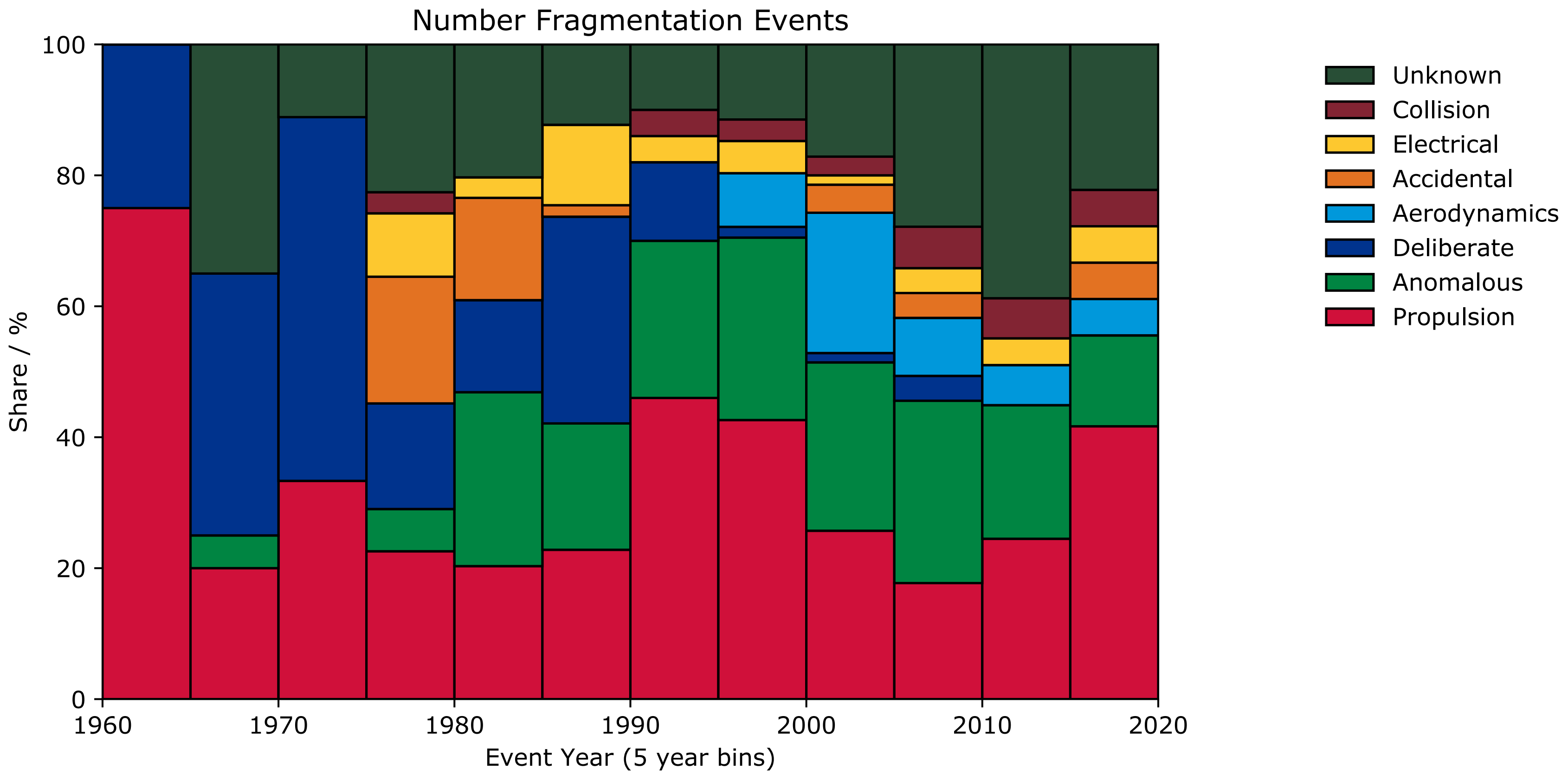
Fragmentation event cause – last 10 years

Propulsion, anomaly and unknown (the three leading causes) account for over 75 %

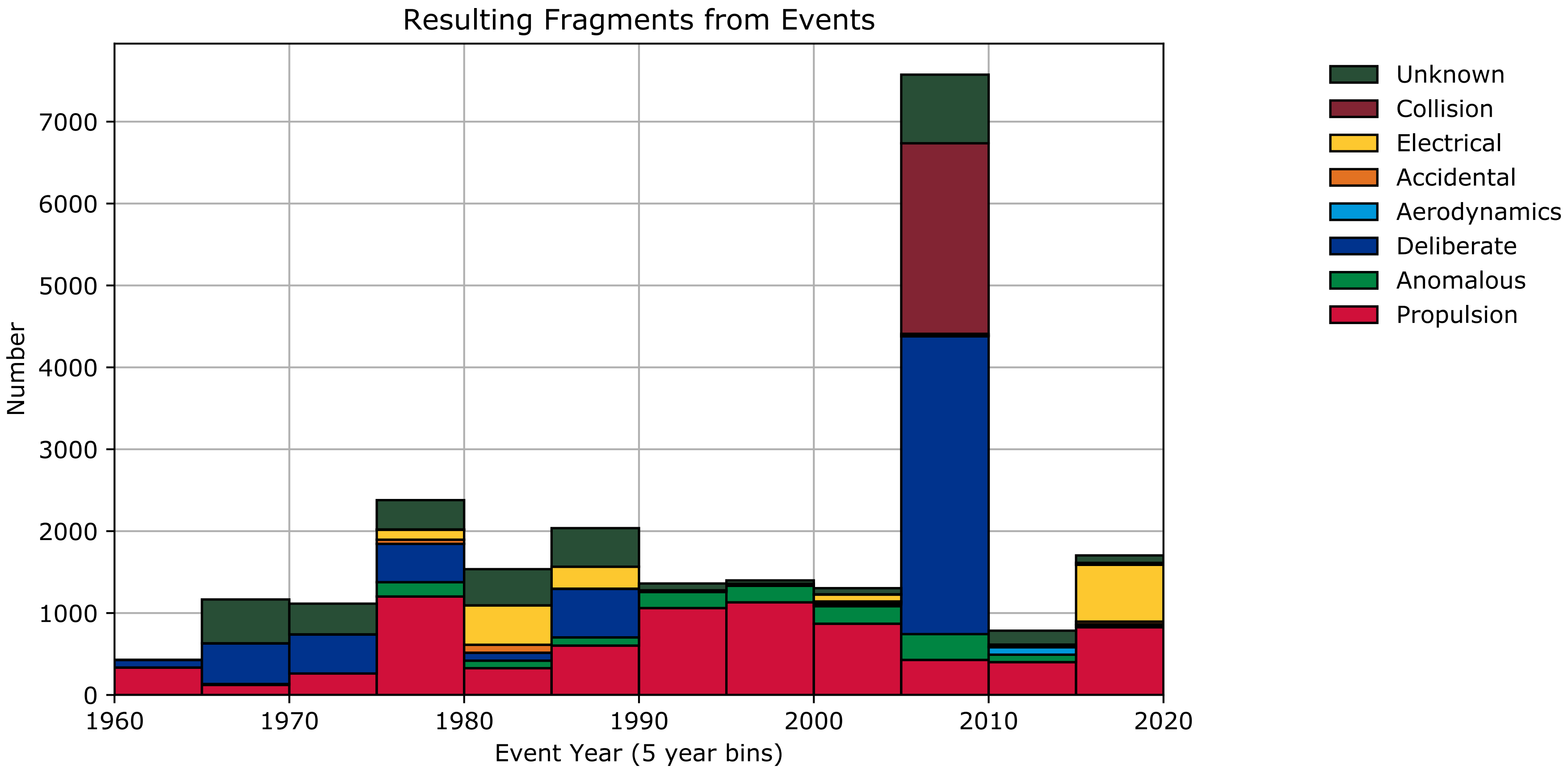


Absolute number of fragmentation events per event cause

The last 5 year bin (2015-2020) is still ongoing, no decrease in total event numbers from 2010-2015 likely.

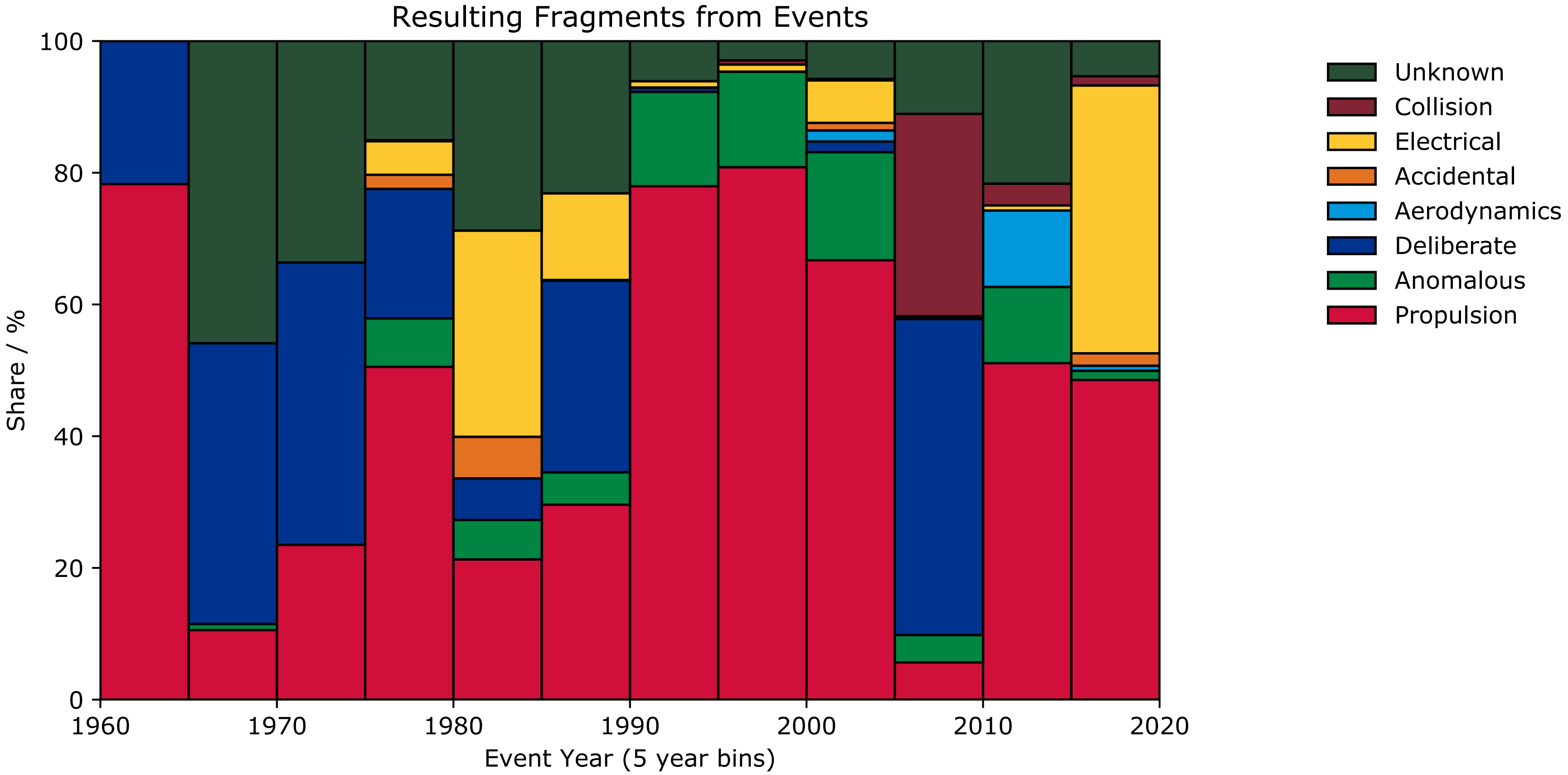


Relative number of fragmentation events per event cause



Absolute number of fragments generated per event cause

Large number of deliberate fragments in the 2005-2010 bin



Relative number of resulting fragments per event cause

Fragmentation data gathering and exchange scenarios

ASAT TEST (MARCH 2019)

Data gathering steps (informal)

intended to show use case scenarios for an FDM

1. identify target
    1. look at orbits matching expected target
    2. look at passes over launch of ASAT missile
2. estimate epoch of collision
3. preliminary analysis of consequences + risk to ESA missions
4. tracking/identifying fragments

Fragmentation Data Message

CONTENT

Original proposal in draft concept paper from 2015

A prototype Fragmentation Analysis System has already been developed for ESA's SSA system. Examples of data from its output are:

- *identification of the progenitor object (name, International designator ID)*
- *spatial coordinates of the fragmentation event*
- *the spread (in terms of Keplerian elements) of the fragments*
- *in case the fragmentation was the result of a collision, properties of the second colliding spacecraft (name, mass; details covered by the CDM)*
- *the data lines contain the fragment number, detection epoch and catalogue ID, if one has been issued*
- *optional lines at the end holding analysis results, such as the spatial density increase information (both real/measured and simulated)*

Example from 2015 draft concept paper

```
CCSDS_FDM_VERS              = 0.4
COMMENT This is a comment.
CREATION_DATE               = 2015-04-22T11:17:33
ORIGINATOR                  = ESA SSA
MESSAGE_ID                  = SSA-20150422-332
META_START
COMMENT This is a comment
FRAGMENTATION_ID            = ESA-2020-132
FRAGMENTATION_STATUS        = DETECTED
TYPE_OF_EVENT               = COLLISION
TIME_OF_EVENT               = 2020-01-17T02:14:00
CATALOG_NAME                = SSA
OBJECT1_DESIGNATOR          = 7219
OBJECT1_NAME                = SPACESAT-1
OBJECT1_INTERNATIONAL_DESIGNATOR      = 2018-015B
OBJECT1_OWNER               = SATOPERATIONS PLC
OBJECT2_DESIGNATOR          = 26207
OBJECT2_NAME                = SPACESAT-2 DEBRIS
OBJECT2_INTERNATIONAL DESIGNATOR      = 2019-057CV
OBJECT2_OWNER               = SATOPERATIONS PLC
OBJECT2_TYPE                = DEBRIS
REF_FRAME                   = GCRF
POSITON_X                   = 4578.324    [km]
POSITON_Y                   = 4578.324    [km]
POSITON_Z                   = 4578.324    [km]
NUMBER_OF_FRAGMENTS         = 5
COLLISION_ID                = 123456
RELATIVE_SPEED              = 15.3        [km/s]
META_STOP
1 56789 2020-01-17T02:14:00 2014-016C
2 56790 2020-01-17T02:14:00 2014-016D
3 56791 2020-01-17T02:14:00 2014-016F
4 56792 2020-01-17T02:14:00 2014-016G
5 56793 2020-01-17T02:14:00 2014-016H

SPATIAL_DENSITY_START

7000 0.00000482
7200 0.00000482
7300 0.00000482
7400 0.00000482
7500 0.00000482

SPATIAL_DENSITY_STOP
```

Identify event type and spacecraft

use-case and content analysis still ongoing – type of information exchanged might change!

- **event cause**: deliberate, collision, electrical, anomaly, propulsion, etc (terminology TBD)
- **object(s) fragmenting**: standard CDM/RDM (object name, COSPAR ID, catalogue name, catalogue designator) for up to 2 objects (to cover the collision case; also maybe for deliberate/ASAT case)
- **epoch of the fragmentation**: estimate + fragmentation window(s)
- some information on risk increase, affected orbital regimes (?)
- **actual fragments generated**:
    - **total numbers**: predicted/estimated, observed/detected, tracked, etc
    - **total mass**
    - **spread in orbital elements** (?) at estimated fragmentation epoch

Actual fragments

- information for each fragment actually observed
- orbit and physical properties information (OPM-like):
    - some kind of fragment ID (OPM name & designator might be enough)
    - status (observed, catalogued, etc – terminology TBD)
    - state vector
    - physical properties: mass, cross-section
    - delta-v from original spacecraft (?)
- tracking data (TDM-like): for a tracked object, actual tracking data might be desirable
- OD information (CDM/RDM-like)
- predicted conjunctions (?)

Fragmentation Data Message

WHY IT COULD BE INTERESTING FOR NAV WG

FDM and CDM, RDM, NHM (?)

- natural extension of current/soon-to-be SSA/SST NDMs (CDM and RDM)
- meet the needs of SSA/SST data producers (institutional and commercial)
- avoid the proliferation of proprietary formats from data producers

- a lot of overlap in content with existing messages (even more than RDM):
  - orbit-related information: OPM, OEM(?), OCM
  - tracking data: TDM
  - fragment physical properties: OPM and OCM

- it could be either a bridge to the planned Navigation Hybrid Message, or even a first implementation

Fragmentation Data Message

SUMMARY, CONCLUSIONS AND FUTURE STEPS

Summary and conclusions

- need from existing users (both institutional and commercial) for an FDM
- natural extension of existing SSA/SST NDMs (CDM and RDM)
- large overlap with existing NDMs (various flavours of the ODM, potentially with the TDM as well)
- potential to mesh well with whatever plans the NAV WG has for a future Navigation Hybrid Message:
    - bridge between existing NDMs and the NHM
    - first ‘instantiation’ or ‘flavour’ of the NHM
    - potential extension/enhancement of the NDM XML to cover FDM functionality (?)

Future steps

- user analysis to try to understand the need from non-ESA users
- find second prototyping agency
- prepare mock-up messages showing various implementation paths
- requirements analysis
- prepare new Concept Paper (if WG decides to pursue it + 2nd prototype)

Fragmentation Data Message

BACK-UP SLIDES

Orbit	Description	Definition		
GEO	Geostationary Orbit	$i \in [0, 25]$	$h_p \in [35586, 35986]$	$h_a \in [35586, 35986]$
IGO	Inclined Geosynchronous Orbit	$a \in [37948, 46380]$	$e \in [0.00, 0.25]$	$i \in [25, 180]$
EGO	Extended Geostationary Orbit	$a \in [37948, 46380]$	$e \in [0.00, 0.25]$	$i \in [0, 25]$
NSO	Navigation Satellites Orbit	$i \in [50, 70]$	$h_p \in [18100, 24300]$	$h_a \in [18100, 24300]$
GTO	GEO Transfer Orbit	$i \in [0, 90]$	$h_p \in [0, 2000]$	$h_a \in [31570, 40002]$
MEO	Medium Earth Orbit	$h_p \in [2000, 31570]$	$h_a \in [2000, 31570]$	
GHO	GEO-superGEO Crossing Orbits	$h_p \in [31570, 40002]$	$h_a > 40002$	
LEO	Low Earth Orbit	$h_p \in [0, 2000]$	$h_a \in [0, 2000]$	
HAO	High Altitude Earth Orbit	$h_p > 40002$	$h_a > 40002$	
MGO	MEO-GEO Crossing Orbits	$h_p \in [2000, 31570]$	$h_a \in [31570, 40002]$	
HEO	Highly Eccentric Earth Orbit	$h_p \in [0, 31570]$	$h_a > 40002$	
LMO	LEO-MEO Crossing Orbits	$h_p \in [0, 2000]$	$h_a \in [2000, 31570]$	
UFO	Undefined Orbit			
ESO	Escape Orbits			

Type	Description
PL	Payload
PF	Payload Fragmentation Debris
PD	Payload Debris
PM	Payload Mission Related Object
RB	Rocket Body
RF	Rocket Fragmentation Debris
RD	Rocket Debris
RM	Rocket Mission Related Object
UI	Unidentified

Assumed Introduced for the MASTER model [8]. Currently the only assumed events are in the GEO region, backed by information obtained during survey campaigns.

Fragmentation causes

Accidental: Subsystems that showed design flaws ultimately leading to breakups in some cases. This includes, for example, the breakup of Hitomi (Astro-H) in 2016 or the sub-class of Oko satellites:

Cosmos 862 class The Oko missile early warning satellites were launched into Molniya orbits. Each satellite carried an explosive charge in order to destroy it in case of a malfunction. Reportedly, the control of this mechanism was unreliable.

Aerodynamics: A breakup most often caused by an overpressure due to atmospheric drag.

Collision: There have been several collisions observed between objects. A sub-class are so-called small impactors:

Small impactor Caused by a collision, but without explicit evidence for an impactor. Changes in the angular momentum, attitude and subsystem failures are, however, indirect indications of an impact.

Deliberate: all intentional breakup events.

ASAT Anti-satellite tests.

Payload recovery failure Some satellites were designed such that they exploded as soon as a non-nominal re-entry was detected.

Cosmos 2031 class The Orlets reconnaissance satellites were introduced in 1989 and employed detonation as a standard procedure after the nominal mission.

Electrical: Most of the events in this category occurred due to an overcharging and subsequent explosion of batteries. A sub-class is defined based on the satellite bus.

DMSP/NOAA class Based on the Television and InfraRed Observation Satellite (TIROS-N) satellite bus, some of the satellites in this series suffered from battery explosions.

Propulsion: Stored energy for non-passivated propulsion-related subsystems might lead to an explosion, for example due to thermal stress. Several sub-classes are defined for rocket stages that showed repeated breakup events.

Delta upper stage There were several events for Delta second stages due to residual propellants until depletion burns were introduced in 1981.

SL-12 ullage motor The Blok D/DM upper stages of the Proton rocket used two ullage motors to support the main engine. They were released as the main engine performed its final burn.

Titan Transtage The upper stage of the Titan 3A rocket used a hypergolic fuel oxidizer combination.

Briz-M The fourth stage of the Proton rocket which is used to insert satellites into higher orbits.

Ariane upper stage Breakups for the H8 and H10 cryogenic stages were observed, most likely due to overpressure and subsequent bulkhead rupture. Passivation was introduced in 1990.

Tsyklon upper stage The third stage of the Tsyklon-3 launcher used a hypergolic fuel oxidizer combination.

Zenit-2 upper stage The second stage of the Zenit 2 launcher used an RP-1/Liquid oxygen propellant.

Anomalous: Defined as the unplanned separation, usually at low velocity, of one or more detectable objects from a satellite that remains essentially intact. This may include debris shedding due to material deterioration, which includes insulation material or solar panels all of which have been observed from ground in the past. Events with sufficient evidence for an impact of debris or micrometeroids are classified under Small Impactor. Sub-classes for anomalous events are defined, as soon as events occur multiple times for the same spacecraft or bus type.

Transit class satellites of the U.S. Navy's first satellite navigation system operational between 1964 and 1996.

Scout class refers to the Altair upper stage of the Scout rocket family.

Meteor class Russian meteorological satellite family.

Vostok class refers to the upper stage of the Vostok rocket (Blok E)

ERS/SPOT class both the ERS-1 and -2 satellites, as well as the SPOT-4 satellite had confirmed anomalies and fragments were catalogued.

Assumed Introduced for the MASTER model [8]. Currently the only assumed events are in the GEO region, backed by information obtained during survey campaigns.

Unconfirmed A provisional status until an event is confirmed and classified accordingly.

Unknown Is assigned whenever there is lacking evidence to support a more specific classification.

Cosmos 699 class For many of the ELINT Ocean Reconnaissance Satellites (EORSAT) a breakup was observed during the orbital decay.

Delta 4 class events with several catalogued objects for the Delta Cryogenic Second Stages (DCSS).

L-14B class The third stage of the Long March 4B (CZ-4B) launcher used a hypergolic propellant.

H-IIA class The second stage of the H-IIA launcher used a cryogenic propellant.