Consiglio Nazionale delle Ricerche

THE PAST ON-ORBIT SATELLITES AND ROCKET BODIES FRAGMENTATIONS

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CNUCE C97-020
1 Dicembre 1997

CNUCE

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Technical Report C97- 020

1 December 1997

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1. PREFACE

Since the launch of Sputnik on October 4, 1957, more than 3800 successful rocket launches have taken place. Today, more than 8500 earth orbiting objects are tracked with radar and telescopes of the U.S. Space Surveillance Network, but those account for less than 10 percent of the centimeter-sized objects and, furthermore, they are supposed to be complete up to 90-99 percent for sizes larger than 20 cm in Low Earth Orbit (LEO). Investigations of space debris, made either by ground based observatories (radar and optical facilities) or the examination of returned spacecraft surfaces, dramatically enlarged the knowledge of the space environment: millions of particles larger than 1 mm were estimated, while the number of the 1 cm size objects, or larger, might be between 70,000 and 150,000.

While at microscopic sizes the natural meteoroid population still dominates the particle flux near the earth, above 1 mm in diameter the particles are mainly man-made debris, originating from a conspicuous number of **sources**. Among the major ones there are:

⇒ Rocket bodies and payloads that no longer perform their intended mission
⇒ Breakup fragments
⇒ Solid rocket motor ejecta
⇒ Nuclear power plants coolant
⇒ Debris produced by surface degradation under the harsh space conditions, including thermal stress, cosmic electromagnetic radiation and atomic oxygen erosion

Breakup fragments can be originated by three types of events categorized as:

1. ***Operational events*** (intentional separation of objects from a payload, rocket body or structure)
2. ***Anomalous events*** (unplanned separation of one or more detectable objects from a payload, or rocket stage, due to the effects of environmental stress)
3. ***Past fragmentations of orbiting bodies*** (accidental or deliberate destructive disruption of an orbital payload, rocket body or structure)

On-orbit fragmentations may result from either explosions or collisions. Following the first of such events, the explosion of the *Transit 4A* rocket body of June 29, 1961, a total of 143 breakups have been recorded by the U.S. orbital tracking facilities until August 31, 1997. These account for over forty percent of the catalogued population and the majority of the undetectable small size fragments.

In order to understand the origin and distribution of the artificial debris in the 0.1-10 cm size range, we carried out a massive effort to estimate the contribution of the historical on-orbit fragmentation events.

Our research involved an extensive work to:

1. **characterize each breakup object in terms of :**

- ⇒ Name
- ⇒ USSPACECOM number
- ⇒ COSPAR Identifier
- ⇒ Mass
- ⇒ Pre-event osculating orbital elements
- ⇒ Nationality
- ⇒ Epoch of the launch
- ⇒ Epoch of the fragmentation event
- ⇒ Breakup point
- ⇒ Number of catalogued debris upon breakup
- ⇒ Number of catalogued debris in orbit on 1st January 1997
- ⇒ Explosion intensity
- ⇒ Probable cause for breakup
- ⇒ Classification of the event in terms of the breakup energy

2. **Carry out a statistical investigation to classify the events in terms of:**

- ⇒ Breakup probable cause (deliberate, propulsion-related, unknown, battery, collision)
- ⇒ Number of fragmentations by year
- ⇒ Breakup object nationality
- ⇒ Breakup object type (i.e., satellite, rocket body)
- ⇒ Breakup energy
- ⇒ Type of breakup orbit (i.e., Low Earth, Geostationary, Geosynchronous and Glonass Tansfer, Molniya, etc.)
- ⇒ Contribution to the catalogued population

3. **Independently simulate all the past fragmentation events and propagate the fragments orbits to a common reference epoch.**

For the events characterization, several external sources were used (Refs. 1, 2, 3, 4, 5 and 6), together with our original and extensive analysis for all cases. Each of the 140 on-orbit breakups (recorded in the period 1961 - January 1997) was simulated, and the resulting debris cloud propagated (until January 1, 1997), using a dedicated software system (CLDSIM, Ref. 7).

In this paper, the results of the characterization of each fragmentation event, together with some statistical investigations, will be presented.

2. INTRODUCTION

After nearly forty years of intentional space operations, almost 25,000 objects have been officially catalogued, with more than approximately one-third of them still in orbit around the earth. The detectable debris environment population (up to more than 8500 objects with a limiting diameter of roughly 10 cm in LEO and about 1 m in High Earth Orbit) is continuously monitored by the space surveillance systems of the United States and Russia.

The **detectable satellite population** is neither sampled nor estimated, but measured directly, and the sources for almost all of these objects are very well known. Only about 6 percent of the catalogued objects in earth orbit are operational satellites, about one-sixth are derelict rocket bodies discarded after their use, while over one-fifth are non-operational payloads. Pieces of hardware usually released during the payload deployment process or as part of subsequent payload operations (i.e. lens caps, separation devices, spin-up mechanisms, empty propellant tanks, payload shrouds and a few objects thrown away or dropped during manned activities) are considered operational debris, and constitute about 11 percent of the catalogued population. The remnants of the 143 satellites and rocket stages that fragmented in orbit (from 1961 to August 1997) account for over forty percent of the population by number. The anomalous events (unplanned, non-destructive breakups producing only a few objects in orbit long after the parent spacecraft has been launched) contribute with a 3 percent to the catalogued population.

In addition to take advantage of the common products of the US Space Surveillance Network (SSN), NASA has expanded the orbital debris database by special applications or data reductions of specific space surveillance sensors.

A few **dedicated observation campaigns** were carried out, **using ground based optical telescopes and radars**. Since 1986, NASA has worked closely with the U.S. Space Command to its Ground Electro-Optical Deep Space Sensors (GEODSS). The recent processing of the optical tracking data from GEODSS, with a resolution of 1 cm in LEO and 10 cm in Geostationary Orbit (GEO), indicates that the NORAD catalogue underestimates the population in LEO and higher orbits.
A significant amount of ground radar data has been obtained using the Arecibo, Goldstone and Haystack sensors. The major source of cm-sized object measurement is the Haystack campaign which has been carried out for over six years since 1990 (Ref. 8). More than 3000 hours of observations, with over 9000 detections, equated to an estimated population of 1-10 cm debris on the order of ten times greater than the detectable population across a wide band of low-earth orbits.

During the last dozen years a few **spacecraft surfaces exposed to the circumterrestrial space** were returned to earth for analysis (e.g. Solar Max, Palapa, Long Duration Exposure Facility, EURECA, Hubble Space Telescope solar panel). The search of pits or holes from hypervelocity impacts with meteoroids and orbital debris improved the knowledge of the sub-millimetric particulate environment around 500 km of altitude.

The examination of returned spacecraft surfaces, together with an effective search work made by the Haystack Auxiliary Radar, the Goldstone and Arecibo radio telescopes , the NASA's Liquid Mirror Telescope and the NASA's CCD Debris Telescope, have extended the range of orbital debris measurements from 10 cm diameter objects to particles as small as one micron (Ref. 9).
Besides the U.S. radar and optical facilities, the German Tracking and Imaging Radar system (TIRA) of the Research Establishment for Applied Science (FGAN) has been used in recent years to establish an independent European data source (Ref. 10).

The main outcome of all the collected measurements was to show the very large number of millimetric and centimetric particles present in space, much more than expected: tens of thousands of fragments measuring more than 1 cm and hundreds of thousands still smaller space debris.

As well as the space debris accumulation is in progress, the technological pollution becomes a serious threat to further space exploration. **Especially dangerous are debris in the 1-10 m size range**. They, though too small to be tracked by operational systems, are large enough to cause catastrophic damage to many satellites, and also to threaten the structural integrity of spent Russian and American spacecraft carrying radioactive power supply units between 700 and 1300 km of altitude. To protect an object from a collision with a fragment of more than 1 cm is basically impossible, in practice.

So far, breakups of spacecraft and rocket bodies have been the most prolific source of these lethal-sized debris and are likely to play such a role for the immediate future. In fact, despite the active efforts of spacefaring nations to reduce the probability of such events (by expelling residual propellants and other forms of stored energy, in order to passivate their systems), the rate of breakup events has not subsided, varying from two to seven per year in the last decade.

Additionally, more than 90 percent of the debris population larger than 1 mm is believed to result from the past fragmentation events originated by in orbit explosions (Ref.11).

3. SATELLITE AND ROCKET BODIES FRAGMENTATIONS

Following the first on-orbit fragmentation, the explosion of the *Transit 4A* rocket body on June 29, 1961 (whose fragmentation debris are still tracked), a total of 143 breakups have been recorded by the U.S. orbital tracking facilities until August 31, 1997. A complete list of all the past fragmentation events recorded until January 1, 1997, is given in Tables 22 to 27 reported in annex A. The contents of each table are the following.

- Table 22:

⇒ Event Number
⇒ USSPACECOM Number
⇒ Breakup Object Nationality
⇒ Breakup Object Type
⇒ Breakup Classification
⇒ Epoch of the Event (in yyddd.dddd)
⇒ Breakup Object Mass
⇒ Pre-event Osculating Orbital Elements of the Parent Body (semimajor axis, eccentricity,
⇒ inclination, right ascension of the ascending node, perigee argument, mean anomaly)
⇒ Name of the Breakup Object

- Table 23:

⇒ Event Number
⇒ Name of the Breakup Object
⇒ COSPAR Identifier
⇒ USSPACECOM Number
⇒ Breakup Object Launch Date
⇒ Epoch of the Event
⇒ Number of the Catalogued Debris upon Breakup
⇒ Breakup Probable Cause
⇒ Breakup Classification

- Table 24:

⇒ Event Number
Epoch of the Fragmentation Event in:
⇒ yyddd.dddd (number of years after 1900.0, days and fraction of day)
⇒ yyyymmdd. (year, month, day)
⇒ hhmmss.sssss (hours, minutes, seconds and fractions)

- Table 25:

⇒ Event Number
⇒ USSPACECOM Number
⇒ Epoch of the Fragmentation Event (in yyyymmdd and hhmmss.sss)
⇒ Location of the Breakup Point (latitude, longitude, altitude on the terrestrial ellipsoid)

- Table 26:

⇒ Name of the Breakup Object
⇒ COSPAR Identifier
⇒ USSPACECOM Number
⇒ Explosion Intensity Parameter
⇒ Breakup Classification

- Table 27:

⇒ Name of the Breakup Object
⇒ COSPAR Identifier
⇒ Number of Fragments in the NORAD Catalog of January 1, 1997
⇒ Name of the Object in the Catalog

Table 28 (see annex A) includes the same information of Table 22 (as breakup characteristics are concerned), but additionally, lists the events in terms of:

⇒ Type of object (i.e., rocket body or satellite)
⇒ Groups of Breakups suffered by a same class of objects (e.g., *Delta* 2[nd] stages, *Proton* ullage motors, *Ariane* final stages, etc.)
⇒ Type of Breakup Orbit (i.e., LEO, GEO, Transfer, etc.)

recorded until August 31, 1997.

In order to better understand the meaning of some parameters listed in Tables 22 to 28, a description of the on-orbit fragmentation mechanisms will be given in the following.

3.1 EXPLOSION MECHANISMS

Generally, breakups may result from internal explosions or from an unplanned or deliberate collision with another orbiting object. Explosions have been the primary contributor to the orbital debris environment and they represent the dominant mechanism in the creation of larger size debris.

There is a wide variety of **on-orbit explosive mechanisms** including:

1. propulsion related explosions (e.g., due to a propulsion system malfunction)
2. deliberate breakups (e.g., caused by a destruction command done on purpose to dispose of spacecraft or as a result of the space weapons tests)
3. catastrophic failure of internal components such as batteries (e.g., resulting from an electrical system malfunction such as a battery overcharge)

Thus, **breakups may be accidental (1 and 3) or the result of intentional actions (2)**.

In cases 1 and 3 the cause of the explosion is the **stored energy** on-board of any object left in space, even after it has performed its desired functions. This kind of residual energy can be both chemical and mechanical in the form, for example, of:

⇒ Residual Propellants
⇒ Pressurized Containers (e.g., sealed batteries, thermal and attitude control systems, propulsion systems)
⇒ Momentum Devices

If the cause of breakup has yet to be determined (i.e., the event is one which cannot be categorically classified in one of the other groups), we say the object fragmented for unknown reasons (some would be undoubtedly propulsion related, some might have been intentional, while others might actually mask secret operational activities).

Table 1 lists the number of the past fragmentation events (until 31 August 1997) in terms of the most probable cause for breakup (see Ref. 6 and Table 23 for the breakup cause of each single object).

Table 1
Breakup Probable Cause

	NUMBER OF BREAKUPS
D deliberate	50
P propulsion related	41
U unknown	41
B battery	9
C accidental collision	2
TOTAL	143

3.1.1 DELIBERATE SATELLITE FRAGMENTATIONS

Tables 2 and 3 summarize the number of the on-orbit fragmentations in terms of the type of breakup assessed to have been the result of intentional actions.

Of the **50 deliberate breakups,** 46 were induced by a self-destruction mechanism on-board the satellite (see Table 3), of these:

⇒ 18% have been the result of Anti SATellite (ASAT) Tests
⇒ 32% have been attributed to a single class of Soviet Early Warning Satellites
⇒ 36% took place on-board Soviet Military Reconnaissance Satellites (when it became clear to their ground controllers that a successful recovery could not be guaranteed)
⇒ A command breakup only occurred once (the man-related spacecraft *Cosmos 57* fragmented because the operational ground instructions were misinterpreted by the on-board system, and the self-destruct device was activated)
⇒ Two satellites (*1966-088A* and *1966-101A*) of the Soviet Fractional Orbit Bombardment System (FOBS) Tests exploded soon after orbital injection

The other 4 intentional breakups (see Table 2) were those of:

⇒ the *Saturn S-IVB stage* (after orbital insertion, the vehicle was intentionally subjected to dynamic integrity tests)
⇒ the only confirmed American ASAT test (a solar observation satellite named *Solwind P78-1* was destroyed by an air-launched homing vehicle)
⇒ the military satellite *USA 19* that deliberately collided with its rocket body (*USA 19 r/b*). This was a complex space exercise (also known as *Delta 180* SDI orbital mission) to demonstrate that small kinetic energy weapons could destroy ballistic missiles during the launch phase. Probably one of the objects exploded before collision (Ref.12).

Table 2
Deliberate Breakups

BREAKUP TYPE	NUMBER OF BREAKUPS
Self-destruction	46
Saturn (AS-203 r/b)	1
Collision (Solwind)	1
USA 19 and USA 19 r/b	2
TOTAL	50

Table 3
Self-Destruction Breakups

COUNTRY	MISSION TYPE	NUMBER OF BREAKUPS
CIS	Anti-satellite tests (ASAT)	9
CIS	Early warning satellites	16
CIS	Photo reconnaissance satellites	18
CIS	FOBS	2
CIS	Man-related spacecraft	1
TOTAL		46

ASAT Tests (Weapons)

The testing of the Soviet ASAT began in 1968 and were characterized by the planned disintegration of the ASAT interceptor (the weapon loaded with explosive material) as it approached the previously-launched target. Most of these experiments were carried out in the early seventies and were stopped at the beginning of eighties.

Early Warning Satellites

The Soviet Early Warning Satellites are known to have been the first generation of the Oko missile Early Warning Satellites (Ref. 13). Launched into Molniya-class orbits between 1976 and 1983, they were normally observed to disintegrate in orbit. Probably the breakup was caused by an on-board explosive charge that would have destroyed the satellite in the case of a malfunction. After a change in the satellite design, to eliminate the explosive charge, none of the successive launched satellites suffered a breakup and *Cosmos 1481* was the last to disintegrate on 9 July 1983.

Photoreconnaissance Satellites

The Photographic Reconnaissance Satellites deliver high resolution photos for military purposes. Their nominal mission profile foresaw a re-entry of the film material within a capsule specifically designed to survive the rigors of reentry. If the retro-burn failed or there were other malfunctions preventing the landing within the Soviet/Russian territory, the satellite had to be fragmented through an on-board self-destructive system. The first satellite to explode was *Cosmos 50* on 5 November

1964. It disintegrated after eight days in orbit, when the recovery of the satellite was expected. There followed other 17 breakups. The latest in the series, the satellite *Cosmos 2262*, operated for 102 days before disintegrating in orbit on December 18, 1993. Since all these explosions (except the event of *Cosmos 2243*, that was probably accidental) took place close to the time when the satellite would be expected to be de-orbited for recovery, one might think this was the normal way of terminating this type of missions.

3.1.2 PROPULSION RELATED EXPLOSIONS

Accidental explosions of spent upper stages have been the primary source of long-lived debris in LEO. The principal sources of energy for these events have been the structural failure of pressurized vessels or a failure allowing residual propellants to ignite.

Table 4 lists (in order of time of the 1st recorded event) failures of upper stages believed to be caused by their propulsion systems.

Table 4
Propulsion Related Breakups

BREAKUP OBJECT	NUMBER OF BREAKUPS
Ablestar	1
Molniya (SL-6) final stage	3
Centaur stage	1
Titan Transtage	1
Saturn SIVB stage	1
TE 364-4 stage	1
Proton (SL-13) 3rd stage	1
Delta 2nd stage	8
PAM-D upper stage	2
Proton (SL-12) ullage rockets SOZ	16
Cosmos (SL-8) 2nd stage	1
Zenit (SL-16) 2nd stage	3
CZ-4A final stage	1
TOTAL	41

The first classified on-orbit fragmentation was that of the *Transit 4A* rocket stage (*Ablestar*) in 1961. In October 1965 a *Titan Transtage* broke up, producing almost 470 catalogued debris. There have been other random disintegrations of rocket stages. However, the most serious series of launch vehicle failures, registered by far, involved nine devastating fragmentations of the *Delta* 2nd stages (8 classified as propulsion related and 1 as due to unknown reasons) during the period 1973-1991 and, more recently, the ullage rockets of the fourth stages of the Russian *Proton (SL-12)* launch vehicle. The cause of both these event families is thought to be the same, namely hypergolic ignition of residual propellants due to bulkhead failure, probably caused by thermal (e.g. solar) stress.

Delta 2nd stages

The *Delta* 2nd stages did not fragment during operations, but only after they had successfully completed their delivery mission and had been abandoned. Apart the *Himawari 1* rocket stage, fragmenting the same day of the launch (on 14 July 1977), the other eight stages experienced breakups after:

- more than one month (*NOAA 3* r/b)
- almost one year (*NOAA 4* r/b, *Landsat 2* r/b and *NOAA 5* r/b)
- nearly three years (*Landsat 1* r/b, *Landsat 3* r/b and *Nimbus 7* r/b)
- almost 16 years (*Nimbus 6 r/b*)

since the launch date.
After a number of breakups, the *Delta* 2nd stage was redesigned (by disposing of the residual propellants after mission completion) in 1972. However, about 25 upper stages (launched before the redesign) are still in sun-synchronous orbits, posing a potential danger, as proven by the explosion of the *Nimbus 6* rocket stage. All the *Delta* explosions took place in LEO and produced a large number of long-lived debris, most of which are still in orbit.

Proton SL-12 Auxiliary Motor Units (SOZ)

The *Astron* mission led to the first detected *Proton SL-12* fourth stage debris breakup event on 3 September 1984. The *SL-12* launch vehicle is a four-stage booster and represents one of the working horses of the Soviet space program. The *Block-D* fourth stage was used until 1976 for deep space missions (moon, planets). Since 1974, a modified version, called *Block-DM*, was introduced for GEO launches. The mission profile in earth orbit foresees that the *SL-12* fourth stage (with its payload) will be released in a low parking orbit. From here, the fourth stage is used to transfer the payload in the final orbit by mean of two firings (at the perigee and apogee of the transfer orbit). Between the first and second firing, two objects (small auxiliary motor units or SOZ) are released and left in the transfer orbit. One of these objects (even indicated as ullage motors), that apparently have an internal engineering design reminiscent of the ill-fated *Delta* 2nd stage and are fueled by hypergolic propellants, is the source of this type of breakups (Ref. 14).

The majority of *SL-12* missions are GEO in nature, but three other mission profiles (*Astron*-type, *Cosmos 1656*-type and GLONASS) are also employed. Today, about 200 *Proton SL-12* have been launched and 16 explosions of these small engines have been registered:

- 3 in LEO
- 4 in GLONASS transfer orbit
- 9 in geosynchronous transfer orbit.

Even if remedies, like those taken for the *Delta* stage, will be adopted to prevent a recurrence of the *Proton Block-DM* problem on future missions, a large number of these engines that has yet to explode remains in orbit. The historical trend of this object type indicates a possibility that a given unit will fragment between 2-6 years after launch or even more (see the case of the *Cosmos 1883-85* mission, where the *SOZ* exploded after almost ten years since launch).

3.1.3 BREAKUPS DUE TO ELECTRICAL BATTERY FAILURES

Table 5 lists (in order of time of the 1st registered event) the on-orbit fragmentation events probably caused by a malfunction of the satellite electrical devices.

In 1978, the Soviet *Ekran 2* satellite experienced an explosion in GEO nine months after launch. The cause of the incident was attributed to an over-pressurized battery. The same kind of problem has also been blamed by the Russians for the fragmentation of *Cosmos 1691* and *Cosmos 1823* (Ref. 13).

Cosmos 1275 was a military navigation satellite carrying no propellant on-board. Therefore, there was nothing internal to the satellite which could have caused the destructive explosion on 24 July 1981. The *Cosmos 1275* event was reclassified from a collision back to unknown (Ref. 15). It is possible that this satellite had been lost due to electrical batteries exploding (Ref. 13).

ASAT Tests (Targets)

At least in four cases the ASAT targets (*Cosmos 248*, *Cosmos 839*, *Cosmos 880* and *Cosmos 1375*) disintegrated some time after the ASAT tests have been carried out. Since the ASAT targets did not carry the explosive charge of the weapons, it is possible that their breakup might has been caused by a failure of the on-board electrical batteries.

Table 5
Breakups due to Electrical Batteries Failures

COUNTRY	MISSION TYPE	NUMBER OF BREAKUPS
CIS	Anti-satellite tests (target satellites)	4
CIS	Communication satellites (Ekran 2, Cosmos 1691)	2
CIS	Navigation satellite (Cosmos 1275)	1
US	Weather satellite (NOAA 8)	1
CIS	Geodetic satellite (Cosmos 1823)	1
TOTAL		9

3.1.4 ACCIDENTAL COLLISIONS

Until July 1996, no satellite was definitely known to have experienced a breakup due to an accidental collision in space (the hypervelocity collisions of *Solwind P78-1* and *Delta 180* were intentional).

The first time that two objects previously catalogued have collided was on 24 July 1996. The French satellite *CERISE* was struck by a fragment left in space by the *Spot 1* upper stage fragmentation in November 1986. Despite this, the satellite is still functioning nominally, the debris fragment is still intact and only one new piece of debris was generated.

Another collision in space happened on 25 June 1997 between the *Mir* space station and the *Progress M-34* spacecraft (Ref. 16).

3.1.5 BREAKUPS FOR UNKNOWN REASONS

The cause of many fragmentations (about 28%) remains unknown, in part due to the limited data available for analysis.

Tables 6 and 7 list (in order of time of the breakup event), respectively, the fragmentation of the rocket stages and satellites for which the breakup cause is yet unknown.

Various rockets, including *Atlas, Agena, Ariane* and Soviet stages as *Cosmos, Vostok, Tsyklon, Briz* etc., and satellites, as the Soviet EORSATs, have fragmented for unknown reasons. Some might have been propulsion-related or intentional, while others might mask secret operational activities. In any case, the cause of breakup has yet to be determined.

Ariane

On 13 November 1986 the *Spot 1* third stage violently separated into some 489 detectable fragments. This breakup was probably caused by propulsion-related forces.

To date, six Ariane rocket bodies have been positively linked to on-orbit fragmentations:

- two *Ariane 1* (*CAT* and *Spot 1* upper stages)
- one *Ariane 3* (*Aussat K3/ECS 4* r/b)
- three *Ariane 4* (*Telecom 2B/Inmarsat* 2, *Astra 1B/MOP* 2 and *Eutelsat-II-F2* rocket stages)

The last event (*Eutelsat-II-F2* r/b) is characterized by the longest time (5 years) from launch to breakup. The energy for the breakup of the *Ariane* stages, like many similar rocket body explosions, suggest they are a result of residual propellants on-board the stages, but the actual causes are not known.

Pegasus Hydrazine Auxiliary Propulsion System (HAPS)

The most severe in orbit breakup yet recorded was represented by the explosion of the *STEP M2* rocket stage (a Pegasus Hydrazine Auxiliary Propulsion System, HAPS) on June 1996 at an altitude of 633 km (see Table 25). The HAPS was reported to have had 5-10 kg of residual propellants left on-board from its original primary mission due to the engine stopping prematurely (Ref.17). It represents the first known explosive breakup of a carbon-composite tank in earth orbit. By June 20, about 601 fragments had preliminary orbital characteristics determined by the U.S. Space Surveillance Network. It became clear in the first few weeks after the HAPS breakup that the number of pieces created was far in excess of the number that would normally be expected from such a small rocket body (dry mass: 97 kg).

Table 6

Fragmentations of Rocket Stages for Unknown Reasons

BREAKUPS OF ROCKET STAGES	NUMBER OF BREAKUPS
Cosmos (SL-2) 2nd stage	1
Atlas core stage	1
Vostok (SL-3) final stage	1
Agena D stage	2
Ariane	6
Delta 2nd stage	1
Tsyklon (SL-14) 3rd stage	1
Titan Transtage	2
Titan II G	1
Briz	1
H-II 2nd stage	1
Pegasus HAPS	1
TOTAL	19

The *OPS 3031* and *PAGEOS* were inflated sphere with masses, respectively, of 4 and 55 kg. The first disintegrated the same day of the launch (on February 1966) in a short-lived orbit. It decayed, with all debris generated, within one week of launch. The *PAGEOS* (*Passive Geodetic Earth-Orbiting Satellite*) was extensively observed and photographed around the world for almost ten years since launch, in June 1966. It experienced at least three fragmentations (on 12 July 1975, 20 January 1976 and June 1978). A variety of possible causes were investigated, including static electric discharge, but no definitive agent was identified.

The satellite *Cosmos 1484* (the last of the Soviet experimental Meteor-Priroda remote sensing satellites) was launched on 24 July 1983 and failed in February 1984, when it was abandoned. At just past noon of 18 October 1993, the satellite broke up at an altitude of about 552 km over the Java sea. Data indicated that the satellite was virtually intact with no apparent rupture of the main body or solar panels (Ref. 18). Even if one of the suggested hypotheses for breakup was a battery failure (as for *Cosmos 1275*), further investigations will be needed to identify the area from which the debris were ejected, together with the breakup cause.

What we named the "*Mystery Family*" is a debris cloud observed by the Haystack radar, with inclinations near 90 degrees and altitudes between 600 and 1000 km (Ref. 8). The size distribution of this family resembles that of the *Cosmos 1484* (similar type of production mechanism) but, so far, no clear source for these debris has been identified. We considered this family by introducing a generic explosion event, the results of which may reproduce the debris distribution observed by Haystack.

Table 7
Fragmentations of Satellites for Unknown Reasons

SATELLITES BREAKUPS	NUMBER OF BREAKUPS
Cosmos 95	1
OPS 3031	1
EORSAT (Cosmos 699 class)	17
PAGEOS	1
Cosmos 1484	1
Mystery Family	1
TOTAL	22

ELINT Ocean Reconnaissance Satellites (EORSAT)

Almost one-half of the breakups for unknown reasons involved the Soviet ELINT Ocean Reconnaissance Satellites (EORSAT). These satellites began flying in 1974 and just the first of the series (*Cosmos 699*) broke up about four months after launch. The EORSAT program foresaw an increase of the orbital period of these satellites at the end-of-operations and in the majority of cases the satellite was observed to fragment during the successive period of orbital decay. There are no apparent reasons for the fragmentation of the EORSAT, although the events are generally judged as intentional.

Certain satellites have experienced multiple breakups events (see Table 8). The last EORSAT to breakup (on June 1997) was *Cosmos 2313*, about ten years after the *Cosmos 1646* disintegration (see also Table 28).

Table 8
Multiple Fragmentation Events of the EORSAT

SATELLITE	Breakup Events Number	Date of the breakup events
Cosmos 699	2	17 April 1975, 2 August 1975
Cosmos 1220	2	20 June 1982, 25 August 1982
Cosmos 1260	2	8 May 1982, 10 August 1982
Cosmos 1306	2	12 July 1982, 18 September 1982
Cosmos 1355	3	8 August 1983, 1 February 1984, 21 February 1984
Cosmos 1461	2	11 March 1985, 13 May 1985

3.2 NUMBER OF FRAGMENTATIONS BY YEAR

Figure 1 (see annex B) illustrates the number of fragmentations by year from 1961 to August 1997, while Table 9 lists the same events by adding, for each, the most probable cause for breakup (i.e., P: propulsion-related, D: deliberate, B: battery, U: unknown, C: collision).

Table 9
Number of Fragmentations by Year

	TOTAL BREAKUPS	SATELLITE BRE KUPS	ROCKET BODIES BREAKUPS	PROBABLE CAUSE
1961	1	0	1	P
1962	1	0	1	P
1963	1	0	1	P
1964	1	1	0	D
1965	3	1	2	DUP
1966	6	4	2	UUUDDD
1967	0	0	0	
1968	5	4	1	DPDDB
1969	3	0	3	UPU
1970	3	2	1	UDD
1971	2	2	0	DD
1972	0	0	0	
1973	3	1	2	PDP
1974	0	0	0	
1975	4	2	2	PUPD
1976	6	5	1	UUPDDD
1977	7	5	2	DUPBDDP
1978	4	4	0	DBDB
1979	3	3	0	DDU
1980	3	2	1	DUD
1981	9	6	3	PDDUBPDDU
1982	5	4	1	UUUUP
1983	5	5	0	DDUDU
1984	4	1	3	DPPP
1985	7	6	1	UDDBBPB
1986	6	4	2	UDDUDU
1987	6	5	1	DDUUUB
1988	4	2	2	PDDU
1989	2	2	0	DD
1990	3	1	2	PDP
1991	5	1	4	PPPDP
1992	5	0	5	UPPPP
1993	7	4	3	PDPUDUD
1994	7	1 (*)	6	UUUUPPU
1995	4	0	4	UPPP
1996	5	1	4	PUUCP
1997	3	2	1	UCP
TOTAL	143	81	62	

(*) Mystery Family

It is evident that the number of fragmentations is not abating, even if the causes of these events are better understood. Although the Americans, the Russians and the French have made efforts to prevent their rocket stages from fragmenting in orbit and deliberate tests have been suspended, there remains a large deposit of objects in space which have the potential to breakup. Moreover, as new satellite launching organizations develop their launch capability, one can expect continued accidental explosions in space. The rate of breakup events increased noticeably during the 1970's and continued through the 1990's with an average of about 4 to 5 breakups per year. A number of fragmentation classes (as the ASAT tests, the Soviet Early Warning Satellites, the *Delta* 2nd stages) may be considered as inactive, while others, as the Soviet Photoreconnaissance Satellites or the *Proton* auxiliary motor units fragmentations, still occur.

3.3 BREAKUP OBJECT NATIONALITY

Table 10 lists the number of the registered breakups for spacefaring nation. For the period 1961 to August 1997, 143 on-orbit explosions were recorded (for the one named *Mistery Family,* the source is not known and has been indicated with N/A). Of these:

- 71% are attributed to the ex-USSR and the CIS
- 22% to the U.S.
- 7% to the other launching nations together

Tables 22 to 28 (in annex A) give a detailed characterization of each breakup event.

Table 10
Breakup Object Nationality

COUNTRY	NUMBER OF BREAKUPS	OBJECT TYPE R/B	SAT
CIS	102	28	74
USA	31	26	5
ESA	6	6	0
CHINA	1	1	0
JAPAN	1	1	0
FRANCE	1	0	1
N/A	1		1 (*)
TOTAL	143	62	81

(*) Mystery Family

Tables 11 and 12 show, respectively, the ex-USSR/CIS satellites and rocket stages that have suffered breakups (ordered in terms of increasing number of fragmentations).

Tables 13 and 14 show, respectively, the U.S. satellites and rocket stages that have suffered breakups (ordered in terms of increasing number of fragmentations).

Finally, the remaining rocket bodies breakups are listed in Table 15.

Table 11
Breakups of CIS Satellites

TYPE OF MISSION	NUMBER OF BREAKUPS	SATELLITE
Space Station	1	Mir
Milsat	1	Cosmos 95
Remote Sensing	1	Cosmos 1484
Geodetic	1	Cosmos 1823
Navigation	1	Cosmos 1275
Man-related	1	Cosmos 57
Communication	2	Cosmos 1691, Ekran 2
FOBS series	2	1966-088A, 1966-101A
Anti-Satellite (ASAT) Tests	13	9 **weapons**: Cosmos 249, 252, 374, 375, 397, 462, 886, 970, 1174. 4 **targets** : Cosmos 248, 839, 880, 1375.
Early Warning	16	Cosmos 862, 903, 917, 931, 1030, 1109, 1124, 1191, 1217, 1247, 1261, 1278, 1285, 1317, 1456, 1481.
EORSAT	17	Cosmos 699, 777, 838, 1094, 1167, 1220, 1260, 1286, 1306, 1355, 1405, 1461, 1588, 1646, 1682, 1769, 2313.
Photoreconnaissance	18	Cosmos 50, 199, 554, 758, 844, 884, 1654, 1813, 1866, 1906, 1916, 2030, 2031, 2101, 2163, 2225, 2243, 2262.

Table 12
Breakups of CIS Rocket Bodies

ROCKET BODY	NUMBER OF BREAKUPS
Proton (SL-12) SOZ	16
Zenit (SL-16) 2nd stage	3
Molniya (SL-6) final stage	3
Cosmos (SL-8) 2nd stage	2
Proton (SL-13) 3rd stage	1
Briz	1
Tsyklon (SL-14) 3rd stage	1
Vostok (SL-3) final stege	1
TOTAL	28

Table 13
Breakups of US satellites

SATELLITE	NUMBER OF BREAKUPS
OPS 3031	1
PAGEOS	1
Solwind P78-1	1
NOAA 8	1
USA 19	1
TOTAL	5

Table 14
Breakups of US Rocket Bodies

ROCKET BODY	NUMBER OF BREAKUPS
Delta 2nd stage	9
Titan Transtage	3
Agena D stage	2
PAM-D upper stage	2
Saturn SIVB stage	2
Ablestar stage	1
Atlas core stage	1
Centaur AC-2 stage	1
Pegasus HAPS	1
TE 364-4 stage	1
TE-M-364-15 upper stage	1
Titan II G	1
USA 19 r/b	1
TOTAL	26

Table 15
Other Rocket Bodies Breakups

COUNTRY	ROCKET BODY	NUMBER OF BREAKUPS
Japan	H-II 2nd stage	1
China	CZ-4A final stage	1
European Space Agency	Ariane 1 final stage	2
	Ariane 3 final stage	1
	Ariane 4 final stage	3

3.4 BREAKUP CLASSIFICATION

Many efforts have been made to predict the outcomes of the spacecraft breakup events in a quantitative way, using a variety of models with different degrees of complexity. Fragmentation events have multiple possible causes and may vary widely in intensity. For this reason, the breakup models adopted the following three generic types of fragmentation:

⇒ low intensity explosions
⇒ high intensity explosions
⇒ hypervelocity collisions

A low intensity explosion was defined by Bess as an event caused by a "charge not being in direct contact with the spacecraft structure", such as a pressure vessel explosion. On the other hand, a high intensity explosion was assumed to occur when the charge is in direct contact with the spacecraft structure, e.g. due to the ignition of excess fuel (Ref. 19).

A number of collision experiments have been carried out and a variety of breakup events have been studied in order to derive empirical analytical expressions for the mass and velocity distributions of fragments. The results have shown that the number of fragments vs. size (or mass) distribution has a functional form that depends on the cause of the fragmentation: explosions give rise to mass distributions which approximately fit an exponential curve, whereas collisions more closely match power-law distributions. Additionally, for very energetic explosions, some fragments are distributed according to a power law relation, others, according to an exponential law. For a low intensity explosion, almost the whole fragment mass lie in the size range exceeding about 10 cm, and the most probable ejection velocity would be approximately 50 m/sec (Ref. 20). On the contrary, the fragments generated by a high intensity explosion or by a hypervelocity collision, would include a substantial number of particles smaller than 10 cm. Moreover, the smaller fragments have larger ejection velocity values.

Based on the explosion intensity parameter B (Ref. 5), reported in Table 26 for each fragmentation event, the following classification criteria were adopted:

⇒ $B < 1.3$	Low Intensity Explosion (Ref. 21)	(LI)
⇒ $1.3 < B < 2.3$	High Intensity Explosion, Jehn-Parrinello model (Ref. 22)	(HI-JP)
⇒ $B > 2.3$	High Intensity Explosion, EVOLVE model (Ref. 23)	(HI-E)

with some exceptions based on additional investigations like:

- *Cosmos 1275* exploded following the HI-E model;
- *Ekran 2* was a LI in GEO;
- the *SL-12 SOZs* fragmented according to HI-E;
- the *Solwind P78-1* breakup was produced by a collision, simulated using the EVOLVE model for collisions (CO);
- the collision between *CERISE* and a debris of the *Spot 1* r/b was not simulated, having produced only one detectable new fragment;
- the explosion of *Cosmos 1484* was simulated using the HI-JP model only for the exploded pressurized tank of about 30 kg;

- the *"Mystery Family"* was simulated as a generic explosion that, according to the HI-JP model, reproduced the size distribution observed by Haystack (Ref. 8);
- and so on ... (see Table 26).

The new classification of the past breakup events, introduced for modeling purposes, is that illustrated in Table 16 (here the events cover the period from 1961 to 1 January 1997).

Table 16
Breakups Classification based on the Event Energy

CLASSIFICATION	NUMBER OF BREAKUPS
Low intensity explosion (LI)	60
High intensity explosion (HI-JP)	63
High intensity explosion (HI-E)	15
Collisions (CO)	2
TOTAL	140

Table 17 lists our classification of the fragmentation events (until 1 January 1997) based either on the breakup probable cause or the explosion intensity.

Table 17
Breakups Classification based on the Event Energy and Breakup Cause

CLASSIFICATION	LI	HI - JP	HI - E	CO
Propulsion related	15	18	7	0
Deliberate	28	21	0	1
Battery	3	5	1	0
Unknown	14	19	7	0
Collision	0	0	0	0
TOTAL	60	63	15	1

3.5 CONTRIBUTION OF THE PAST FRAGMENTATION EVENTS TO THE CATALOGUED POPULATION

Table 18 shows the contribution (in number of debris and percentage) of the past 140 (events number up to January 1997) on-orbit breakups to the catalogued population of the 1st January 1997 (column 3). Even the number (and percentage) of fragments catalogued upon breakup is given (column 2). The NORAD catalog of the 1st January 1997 accounts for almost 8478 space objects in earth orbit. As we can see from Table 18, the catalogued debris represent the forty percent of the whole population. Moreover, propulsion related events have left in orbit the greatest number of large fragments (almost 47%), while, in spite of the great number of deliberate explosions, the number of catalogued debris released in orbit by intentional events is lower.

Table 18

Contribution of the Past Fragmentation Events to the Catalogued Population

BREAKUP PROBABLE CAUSE	CATALOGED DEBRIS (upon break-up) number	%	CATALOGED DEBRIS (Jan. 1, 1997) number	%
Propulsion related (P)	2931	35	1599	47
Deliberate (D)	2458	30	399	12
Unknown (U)	2285	27	961	28
Battery (B)	620	8	452	13
Collision (C)	1	0	1	0
TOTAL	8295	100	3412	100

Additionally, Table 27 (see annex A) lists the number of debris in the NORAD catalog of 1st January 1997 relative to each of the 140 documented breakup events.

3.6 REVIEW OF THE WORST BREAKUPS

In Table 19 , a review of the worst breakups (as of January 1997) is given.

Table 19

Review of the Worst Breakups

EVENT DATE	SATELLITE	BREAKUP ALTITUDE (km)	CATALOGUED DEBRIS UPON BREAKUP	CATALOGUED DEBRIS IN ORBIT THE 1st JAN 97
3 June 1996	Pegasus HAPS	633	N/A	515
27 April 1993	Cosmos 2243	210	172	0
26 December 1992	SL-16 2nd stage	855	209	217
1 May 1991	Delta 2nd stage	1104	236	190
29 January 1987	Cosmos 1813	398	194	0
13 November 1986	Ariane 1 final stage	800	489	56
13 September 1985	P-78/Solwind	524	285	8
13 May 1985	Cosmos 1461	842	158	2
24 July 1981	Cosmos 1275	986	306	274
27 January 1981	Delta 2nd stage	931	209	141
24 December 1977	Delta 2nd stage	1522	159	153
14 July 1977	Delta 2nd stage	1318	169	75
25 July 1976	Cosmos 844	214	207	0
20 August 1975	Delta 2nd stage	1478	148	128
22 May 1975	Delta 2nd stage	735	226	50
28 December 1973	Delta 2nd stage	1521	197	178
6 May 1973	Cosmos 554	325	195	0
17 October 1970	Agena D stage	1091	372	274
4 October 1969	Agena D stage	925	260	0
1 November 1968	Cosmos 252	549	140	52
15 October 1965	Titan Transtage	739	470	0
22 February 1965	Cosmos 57	384	167	0
29 June 1961	Ablestar stage	990	298	199

3.7 ANOMALOUS EVENTS

In addition to destructive fragmentations of satellites and rocket bodies, there have been a series of debris producing events which have been classified as "anomalous events" by the space debris community. An anomalous event is one which does not appear to be destructive since it usually involves only a few pieces of debris being tracked.

In Table 20 a list of the known anomalous event is presented (Ref. 24).

Table 21 lists other objects causing more than six catalogued debris in orbit as of 1st January 1997.

Table 20
Known Anomalous Events

SPATIAL OBJECT	COSPAR IDENTIFIER	CATALOG NUMBER	CATALOGUED OBJECTS ON 1st Jan 97
Koreasat 1 r/b	1995-041B	23640	1
Cobe	1989-089A	20322	68
Noaa 7	1981-059A	12553	2
Noaa 6	1979-057A	11416	2
Tiros N	1978-096A	11060	4
Cosmos 1043	1978-094A	11055	0
Seasat	1978-064A	10967	2
Kyokko 1	1978-014A	10664	4
Geos 3 r/b	1975-027B	7735	2
Meteor 1-12 r/b	1972-049B	6080	1
Meteor 1-7 r/b	1971-003B	4850	0
Cosmos 206 r/b	1968-019B	3151	0
Ops 4947	1967-092A	2965	0
Ops 7218	1967-048A	2807	1
Ops 0100	1967-034A	2754	2
Ops 0856	1966-077A	2403	10
Ops 1117	1966-024A	2119	0
Ops 1593	1966-005A	1952	1
Oscar 30	1965-066A	15935	0
Ops 8480	1965-048A	1420	1
Ops 4682	1965-027A	1314	48
Ops 4988	1965-016A	1271	1
Cosmos 44 r/b	1964-053B	877	1
Ops 4412	1964-026A	801	1

Table 21

Objects causing more than 6 Catalogued Debris (Jan. 1997)

SATELLITE	COSPAR IDENTIFIER	CATALOGUED DEBRIS
Cosmos 2297	1994-077	8
USA 101	1994-017	12
CRRES	1990-065	16
USA 40 r/b	1989-061	62
Cosmos 1741	1986-030	6
Mir	1986-017	39
Tansei 3	1977-012	8
OPS 6431	1976-038	6
Intelsat 2-F2	1967-001	20
OV2-1/LCS	1965-082	53
Elektron 1	1964-006	15

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ACKNOWLEDGMENT

The work described in this paper was supported by the Italian Space Agency (ASI) on the behalf of the Space Object Monitoring Service, activated at the CNUCE Institute of the National Research Council of Italy (CNR). Luciano Anselmo, of CNUCE/CNR, provided invaluable comments and suggestions.

ANNEX A

TABLE 22

BREAKUP CHARACTERICTICS IN TERMS OF BREAKUP ORBITS

Event Number
USSPACECOM Number
Breakup Object Nationality
Breakup Object Type
Breakup Classification
Epoch of the Event in yyddd.dddd
Breakup Object Mass in kg
Pre-event Osculating Orbital Elements of the Parent Body (semimajor axis, eccentricity, inclination, right ascension of the ascending node, perigee argument, mean anomaly)
Name of the Breakup Object

HISTORY OF ON-ORBIT FRAGMENTATIONS (1961- January 1997)

BREAKUP CHARACTERISTICS

DEFINITION OF PARAMETERS

NE	Event Number	
SATNO	USSPACECOM Number	
NA	Nationality:	
	1	US
	2	CIS
	3	ESA
	4	Other
TY	Object type:	
	1	satellite
	2	rocket body
	0	N/A
CL	Breakup classification:	
	0	Low-intensity explosion
	2	Collision
	3	High-intensity explosion using the Evolve model
	4	High-intensity explosion using the Jehn-Parinello model
E_D	Epoch of the event in yydd.dddd	
MASS	Objects mass in kg	

PRE-EVENT OSCULATING ORBITAL ELEMENTS OF THE PARENT BODY

SMA	Semimajor axis in km
ECC	Eccentricity
INC	Inclination in deg
RAN	Right ascension of the ascending node in deg
AP	Perigee argument in deg
MA	Mean anomaly in deg
OBJECT	Breakup Object Name

NE	SATNO	NA	TY	CL	E_D	MASS (kg)	SMA (km)	ECC	INC (deg)	RAN (deg)	AP (deg)	MA (deg)	OBJECT
1	118	1	2	3	61180.2555	625.	7316.1	0.0070	66.88	96.15	296.38	206.16	Transit 4A r/b (Ablestar stage)
2	443	2	2	0	62302.0000	1976.	6608.1	0.0055	65.09	320.83	89.97	157.59	Sputnik 29 (SL-6 final stage)
3	694	1	2	0	63331.0000	4600.	7512.3	0.0873	30.40	163.86	106.25	150.12	Centaur AC-2 r/b (Centaur stage)

4	919	2	1	4	64310.0000	4730.	6589.2	0.0033	51.21	163.40	354.64	318.55	Cosmos 50
5	1093	2	1	4	65053.4146	5682.	6672.1	0.0192	64.66	299.73	70.91	132.05	Cosmos 57
6	1270	2	2	4	65074.7181	1443.	7420.6	0.1065	56.05	357.78	105.60	136.53	Cosmos 61-63 r/b (SL-8 2nd stage)
7	1640	1	2	4	65288.7639	3130.	7091.3	0.0071	32.20	84.67	194.12	115.81	OV2-1-LCS 2 r/b (Titan 3C-4 Transtage)
8	1706	2	1	4	66015.0000	325.	6743.2	0.0230	48.40	359.87	265.27	172.94	Cosmos 95
9	2015	1	1	3	66046.0000	4.	6594.4	0.0117	96.59	147.42	127.02	68.79	OPS 3031
10	2188	1	2	4	66166.0000	3400.	6641.6	0.0028	28.74	215.72	138.79	74.64	Gemini 9 ATDA r/b (Atlas core stage)
11	2289	1	2	0	66186.8827	26600.	6581.6	0.0024	31.99	4.40	22.27	125.47	AS-203 r/b (Saturn S-IVB stage)
12	2437	2	1	4	66260.0000	3000.	6983.4	0.0638	49.59	342.60	78.99	326.43	Cosmos U-1
13	2536	2	1	4	66306.0000	3000.	6893.8	0.0542	49.61	54.91	83.61	68.46	Cosmos U-2
14	3099	2	1	4	68024.0000	4730.	6658.0	0.0120	65.60	18.28	31.07	17.16	Cosmos 199
15	3171	1	2	0	68104.4542	30000.	6663.8	0.0115	32.59	290.63	284.30	307.18	Apollo 6 r/b (Saturn S-IVB stage)
16	3504	2	1	4	68294.6021	1400.	7703.4	0.1098	62.42	118.76	76.78	220.40	Cosmos 249
17	3530	2	1	4	68306.1681	1400.	7715.1	0.1051	62.44	77.62	73.67	358.27	Cosmos 252
18	3503	2	1	0	68306.1750	3500.	6884.8	0.0042	62.35	77.29	305.17	165.99	Cosmos 248
19	3836	2	2	4	69087.7812	1100.	7031.9	0.0277	81.23	32.55	180.68	306.80	Meteor 1-1 r/b (SL-3 final stage)
20	4052	1	2	4	69207.1028	1100.	9231.8	0.2794	30.45	132.62	183.37	359.50	Intelsat 3 F-5 r/b (TE 364-4 stage)
21	4159	1	2	3	69277.6618	600.	7380.6	0.0127	69.86	279.98	107.91	11.45	OPS 7613 r/b (Agena D stage)
22	4367	1	2	3	70290.1368	600.	7450.4	0.0013	99.83	204.07	180.33	127.93	Nimbus 4 r/b (Agena D stage)
23	4594	2	1	4	70296.6340	1400.	7701.8	0.1040	62.94	129.10	60.50	285.58	Cosmos 374
24	4598	2	1	4	70303.2500	1400.	7689.9	0.1031	62.92	104.70	56.03	8.06	Cosmos 375
25	4964	2	1	4	71056.6049	1400.	7765.3	0.1055	65.75	355.11	50.94	9.70	Cosmos 397
26	5646	2	1	4	71337.7021	1400.	7392.7	0.1072	65.64	297.12	54.13	4.84	Cosmos 462
27	6399	2	2	0	73093.9417	4185.	6597.9	0.0039	51.42	332.55	16.50	95.91	Salyut 2 r/b (SL-13 3rd stage)
28	6432	2	1	4	73126.3084	6000.	6634.6	0.0142	72.74	303.56	25.41	239.51	Cosmos 554
29	6921	1	2	3	73362.3778	924.	7881.9	0.0013	102.14	44.20	112.95	207.95	NOAA 3 r/b (Delta 2nd stage)
30	6127	1	2	4	75142.7688	924.	7146.2	0.0200	98.30	196.22	40.09	287.14	Landsat 1 r/b (Delta 2nd stage)
31	7587	2	1	4	75214.6826	3000.	6804.5	0.0012	64.90	273.26	308.47	232.89	Cosmos 699
32	7532	1	2	4	75232.5465	924.	7828.3	0.0018	101.55	277.87	69.15	165.80	NOAA 4 r/b (Delta 2nd stage)
33	8191	2	1	4	75249.7959	6000.	6624.8	0.0124	67.12	188.66	69.01	326.55	Cosmos 758
34	2253	1	1	3	[illegible].0000	55.	10555.6	0.1187	85.00	209.49	66.58	334.73	Pageos
35	8416	2	1	4	76025.5834	3000.	6812.6	0.0001	64.90	302.64	80.64	342.90	Cosmos 777
36	7616	1	2	4	76170.2909	924.	7202.1	0.0121	97.76	95.58	142.68	353.54	Landsat 2 r/b (Delta 2nd stage)
37	9046	2	1	4	76207.7209	6000.	6638.6	0.0146	67.21	151.39	71.68	52.34	Cosmos 844
38	9634	2	1	4	76362.7778	1400.	7823.0	0.1084	65.72	336.91	198.79	113.30	Cosmos 886
39	9614	2	1	4	76364.0000	6300.	6608.0	0.0106	65.00	228.85	117.59	11.87	Cosmos 884
40	9495	2	1	0	77074.5389	1250.	26586.8	0.7305	63.28	97.29	318.67	13.00	Cosmos 862
41	8932	2	1	4	77137.4292	3000.	6805.6	0.0012	65.17	129.36	299.44	250.85	Cosmos 838
42	10144	1	2	4	77195.6749	924.	7663.3	0.0977	28.90	270.58	52.56	86.84	Himawari 1 r/b (Delta 2nd stage)
43	9011	2	1	4	77272.3035	650.	7917.0	0.0705	66.01	82.06	351.04	231.73	Cosmos 839
44	10150	2	1	0	77297.0000	1250.	26537.4	0.7330	62.74	304.27	318.79	7.34	Cosmos 931
45	10531	2	1	4	77355.7153	1400.	7419.3	0.0138	65.69	281.68	114.60	203.92	Cosmos 970
46	9063	1	2	4	77358.4812	924.	7889.1	0.0016	102.12	42.09	54.32	263.71	NOAA 5 r/b (Delta 2nd stage)
47	9911	2	1	0	78159.0000	1250.	26556.8	0.7103	63.32	114.88	319.86	107.57	Cosmos 903
48	10365	2	1	0	78174.0000	1750.	42183.7	0.0001	8.93	315.03	34.69	211.58	Ekran 2
49	11015	2	1	0	78283.0000	2030.	26590.9	0.7338	62.78	335.62	318.39	226.22	Cosmos 1030
50	9601	2	1	4	78331.7104	650.	6962.6	0.0042	65.88	10.38	311.18	314.26	Cosmos 880
51	10059	2	1	0	79089.6563	1250.	26596.0	0.6973	63.04	155.63	322.53	352.18	Cosmos 917
52	11509	2	1	0	79252.1042	2030.	26565.5	0.7375	62.78	287.48	318.37	16.50	Cosmos 1124
53	11333	2	1	0	79260.4437	3000.	6769.8	0.0009	64.88	271.12	327.85	275.28	Cosmos 1094
54	11417	2	1	0	80046.0000	2030.	26569.5	0.7230	63.51	104.38	318.53	172.91	Cosmos 1109
55	11659	3	2	0	80106.0000	1400.	22990.5	0.7151	18.07	93.17	279.47	155.02	CAT r/b (Ariane 1 final stage)
56	11765	2	1	4	80109.3097	1400.	7395.7	0.0858	65.96	251.07	248.42	160.94	Cosmos 1174
57	10704	1	2	4	81027.1889	924.	7282.6	0.0009	99.01	68.58	127.76	145.76	Landsat 3 r/b (Delta 2nd stage)
58	12376	2	1	0	81121.0000	1250.	26571.3	0.7360	62.87	278.51	316.59	117.43	Cosmos 1261
59	11871	2	1	0	81134.0000	1800.	26562.9	0.7170	62.63	197.92	319.70	314.13	Cosmos 1191

60	11729	2	1	0	81196.3896	3000.	6779.8	0.0059	65.02	173.78	245.21	126.18	Cosmos 1167
61	12504	2	1	3	81205.9938	800.	7362.5	0.0044	83.11	118.98	127.62	302.30	Cosmos 1275
62	12827	2	2	0	81254.0000	1976.	13577.7	0.4852	62.97	70.77	286.57	286.53	Cosmos 1305 r/b (SL-6 final stage)
63	12303	2	1	0	81293.0000	1250.	26559.1	0.7230	62.95	213.69	318.47	241.71	Cosmos 1247
64	12627	2	1	0	81325.0000	1250.	26787.2	0.7350	63.03	248.93	317.15	238.55	Cosmos 1285
65	11081	1	2	0	81360.0000	924.	7320.3	0.0020	99.13	277.15	68.70	16.04	Nimbus 7 r/b (Delta 2nd stage)
66	12054	2	1	4	82171.7625	3000.	7103.7	0.0219	64.92	329.94	0.18	190.31	Cosmos 1220
67	12828	2	1	0	82193.9757	3000.	6769.4	0.0011	65.06	40.96	302.47	333.35	Cosmos 1306
68	12364	2	1	4	82222.9826	3000.	6976.4	0.0211	65.15	45.11	296.08	184.34	Cosmos 1260
69	12631	2	1	0	82272.2223	3000.	6689.7	0.0007	65.14	132.47	263.77	155.20	Cosmos 1286
70	13696	2	2	4	82342.6167	1976.	6707.6	0.0152	62.82	315.84	58.28	220.38	Cosmos 1423 r/b (SL-6 final stage)
71	12032	2	1	0	83043.0000	1800.	26558.1	0.7022	65.20	257.98	274.70	165.47	Cosmos 1217
72	14182	2	1	0	83190.0000	1250.	26301.5	0.7340	62.93	165.82	318.12	109.51	Cosmos 1481
73	13150	2	1	4	83220.9799	3000.	6754.8	0.0015	64.87	276.37	307.11	17.07	Cosmos 1355
74	14034	2	1	0	83225.0000	1250.	26518.7	0.7315	63.44	79.51	319.95	3.75	Cosmos 1456
75	13508	2	1	4	83354.5104	3000.	6701.4	0.0016	65.16	124.63	346.08	223.42	Cosmos 1405
76	12933	2	1	0	84028.0000	1250.	26563.3	0.7099	62.61	218.66	324.38	37.79	Cosmos 1317
77	14694	1	2	0	84034.9063	30.	6689.5	0.0004	28.54	156.37	5.23	354.11	Westar 6 r/b (PAM-D upper stage)
78	14693	1	2	0	84037.6666	30.	6663.6	0.0002	28.59	135.79	323.34	39.95	Palapa B2 r/b (PAM-D upper stage)
79	13902	2	2	0	84247.8493	56.	7102.6	0.0702	51.72	90.54	248.48	312.01	Astron ullage motor (SL-12 SOZ)
80	14064	2	1	4	85133.0646	3000.	7104.9	0.0215	65.00	331.39	232.32	137.76	Cosmos 1461
81	15734	2	1	0	85172.4493	6000.	6617.5	0.0094	64.86	359.26	51.70	317.38	Cosmos 1654
82	11278	1	1	2	85256.8632	850.	6906.0	0.0033	97.63	182.21	96.14	300.96	P-78/Solwind
83	13259	2	1	4	85294.1618	650.	7372.4	0.0013	65.80	349.15	67.51	21.41	Cosmos 1375
84	16139	2	1	4	85326.3611	220.	7790.0	0.0007	82.56	341.08	95.56	52.42	Cosmos 1691
85	16435	2	2	0	85362.0000	8300.	6877.1	0.0484	71.00	282.00	0.00	178.00	Cosmos 1714 r/b (SL-16 2nd stage)
86	13923	1	1	0	85364.4201	1000.	7192.3	0.0010	98.70	32.30	190.24	57.79	NOAA 8
87	15167	2	1	4	86054.7847	3000.	6799.6	0.0013	64.83	246.84	296.20	95.89	Cosmos 1588
88	16937	1	1	0	86248.7445	930.	6872.3	0.0407	39.16	39.27	12.59	8.39	USA 19
89	16938	1	2	0	86248.7445	1455.	6798.6	0.0291	22.82	19.47	39.05	359.77	USA 19 r/b
90	16615	3	2	4	86317.8194	1400.	7193.3	0.0027	98.76	30.15	43.64	325.69	Spot 1 r/b (Ariane 1 final stage)
91	12547	2	1	0	86335.0000	1250.	26553.7	0.6599	66.94	287.49	291.95	214.72	Cosmos 1278
92	16054	2	1	0	86352.8451	3000.	6807.2	0.0075	64.93	333.86	49.98	285.79	Cosmos 1682
93	17297	2	1	4	87029.2465	6000.	6762.2	0.0044	72.62	255.47	167.44	281.38	Cosmos 1813
94	18184	2	1	0	87207.6521	6000.	6580.8	0.0083	67.36	98.11	65.26	230.50	Cosmos 1866
95	18352	3	2	0	87262.0000	1200.	24767.9	0.7333	6.95	175.44	181.96	222.02	Aussat K3/ECS 4 r/b (Ariane 3 final stage)
96	16895	2	1	0	87264.5035	3000.	6755.0	0.0090	65.19	119.66	290.19	325.56	Cosmos 1769
97	15653	2	1	0	87324.0632	3000.	6775.7	0.0009	64.83	285.30	237.68	215.82	Cosmos 1646
98	17535	2	1	4	87351.7354	1500.	7878.6	0.0025	73.59	183.86	194.54	2.19	Cosmos 1823
99	15773	2	2	4	88005.0743	56.	7211.5	0.0025	66.50	198.74	264.79	183.53	Cosmos 1656 ullage motor (SL-12 SOZ)
100	18713	2	1	4	88031.4646	6000.	6629.3	0.0023	82.38	253.48	125.54	63.89	Cosmos 1906
101	18823	2	1	0	88058.1972	6000.	6565.3	0.0067	64.62	263.87	57.14	18.24	Cosmos 1916
102	11087	2	2	4	88130.5125	1407.	8069.5	0.0020	82.55	353.47	74.28	134.16	Cosmos 1045 r/b (SL-14 3rd stage)
103	20124	2	1	0	89209.1771	6000.	6556.3	0.0055	67.37	88.57	63.45	354.07	Cosmos 2030
104	20136	2	1	0	89243.7854	6000.	6683.2	0.0101	50.35	242.21	58.58	61.14	Cosmos 2031
105	20791	4	2	4	90277.8430	1000.	7265.0	0.0013	98.76	288.90	131.78	137.17	Fengyun 1-2 r/b (CZ-4A final stage)
106	20828	2	1	0	90334.7222	6000.	6614.9	0.0070	64.70	346.52	147.19	331.10	Cosmos 2101
107	20978	1	2	4	90335.6736	855.	7167.4	0.0081	98.87	3.43	6.38	165.74	USA 68 r/b (TE-M-364-15 upper stage)
108	14608	2	2	4	91035.1333	56.	15952.4	0.5781	52.14	131.15	316.97	201.01	Cosmos 1519-21 ullage motor (SL-12 SOZ)
109	21108	2	2	4	91064.5729	1443.	7970.6	0.0159	74.10	163.40	241.50	72.96	Cosmos 2125-32 r/b (SL-8 2nd stage)
110	7946	1	2	4	91121.3722	924.	7473.4	0.0015	99.46	336.90	103.67	326.65	Nimbus 6 r/b (Delta 2nd stage)
111	21741	2	1	0	91340.8480	6000.	6597.9	0.0060	64.91	36.10	138.81	337.06	Cosmos 2163
112	16446	2	2	0	91363.3771	56.	16143.4	0.5650	65.43	37.16	243.88	337.53	Cosmos 1710-12 ullage motor (SL-12 SOZ)
113	3432	2	2	3	92052.0000	3130.	41835.7	0.0085	11.99	22.27	75.71	246.64	OV2-5 r/b (Titan Transtage)
114	20399	2	2	0	92183.0000	56.	20353.4	0.6704	46.95	305.19	319.33	9.57	Cosmos 2054 ullage motor (SL-12 SOZ)
115	15338	2	2	4	92249.6188	56.	7217.3	0.0011	66.54	352.31	50.64	181.42	Cosmos 1603 ullage motor (SL-12 SOZ)

116	19771	2	2	0	92353.0000	56.	15253.0	0.5693	46.48	264.90	354.82	10.57	Gorizont 17 ullage motor (SL-12 SOZ)
117	22285	2	2	4	92361.3181	8300.	7226.7	0.0015	70.85	226.79	83.72	347.99	Cosmos 2227 r/b (SL-16 2nd stage)
118	20116	2	2	0	93012.0000	56.	21874.5	0.6976	46.56	212.03	47.85	309.00	Gorizont 18 ullage motor (SL-12 SOZ)
119	22280	2	1	0	93049.7889	6000.	6610.9	0.0043	65.09	91.81	107.46	7.08	Cosmos 2225
120	22566	2	2	0	93087.3028	8300.	7223.1	0.0003	70.76	260.31	75.22	8.15	Cosmos 2237 r/b (SL-16 2nd stage)
121	21941	3	2	0	93111.0000	1240.	24318.4	0.7245	3.44	223.61	111.79	169.56	Telecom 2B/Inmarsat 2 r/b (Ariane 4 H10)
122	22641	2	1	4	93117.4473	6000.	6606.9	0.0055	70.55	56.77	82.07	349.81	Cosmos 2243
123	14207	2	1	4	93291.5027	30.	6947.4	0.0027	97.35	317.36	328.95	22.85	Cosmos 1484
124	22789	2	1	0	93352.2993	6000.	6602.2	0.0075	64.75	208.49	69.53	21.43	Cosmos 2262
125	00000	0	0	4	94001.0000	100.	7178.0	0.0010	90.00	42.70	200.39	163.38	90 deg Mystery Family
126	22974	1	2	4	94038.7215	2860.	6610.4	0.0033	67.18	45.80	135.08	113.33	Clementine r/b (Titan II G)
127	2868	1	2	3	94039.0000	3130.	39840.6	0.0053	11.7	307.63	129.58	109.93	OPS 9331-34 r/b (Titan Transtage)
128	21141	3	2	0	94117.6377	1240.	20927.7	0.6824	6.74	139.15	177.67	0.50	Astra 1B/MOP 2 r/b (Ariane 4 H10)
129	21114	2	2	0	94127.3958	56.	17394.5	0.6204	46.83	109.38	161.43	211.96	Cosmos 2133 ullage motor (SL-12 SOZ)
130	22067	2	2	4	94312.3000	56.	16135.6	0.5749	64.85	65.20	316.80	217.05	Cosmos 2204-06 ullage motor (SL-12 SOZ)
131	23440	2	2	4	94360.3000	1120.	8418.2	0.0190	64.80	83.74	283.80	273.88	RS-15 r/b (Briz)
132	23231	4	2	0	95090.9300	3000.	18543.1	0.6490	28.50	7.08	16.22	0.00	ETS-VI r/b (H-II 2nd stage)
133	23338	2	2	3	95131.6000	56.	24188.1	0.7299	46.71	200.00	300.00	200.00	Elektro ullage motor (SL-12 SOZ)
134	23174	2	2	3	95294.0000	56.	23990.2	0.7222	46.97	157.14	127.94	322.60	Cosmos 2282 ullage motor (SL-12 SOZ)
135	20957	2	2	3	95348.0000	56.	12911.7	0.4944	46.50	140.58	117.08	93.62	Gorizont 22 ullage motor (SL-12 SOZ)
136	23797	2	2	3	96050.0000	56.	24798.6	0.7321	48.58	282.00	0.00	178.00	Raduga 33 ullage motor (SL-12 SOZ)
137	21057	3	2	0	96122.0000	1240.	21974.2	0.6990	6.64	96.14	149.23	37.77	Eutelsat-II-F2 r/b (Ariane 4 H10)
138	23106	1	2	3	96155.6375	97.	7081.8	0.0153	81.97	342.00	210.00	35.00	STEP M2 r/b (Pegasus HAPS)
139	23606	4	1	2	96206.0000	50.	7049.1	0.0017	98.01	141.79	48.51	271.19	Cerise
140	18374	2	2	3	96335.0000	56.	16121.4	0.5839	64.90	299.57	180.62	312.06	Cosmos 1883-85 ullage motor (SL-12 SOZ)

History of on-orbit fragmentations (1961 - January 1, 1997)

TABLE 23

BREAKUP CHARACTERISTICS IN TERMS OF LAUNCH/EVENT DATE AND BREAKUP CAUSE AND CLASSIFICATION

Event Number
Name of the Breakup Object
COSPAR Identifier
USSPACECOM Number
Breakup Object Launch Date
Epoch of the Event
Number of the Catalogued Debris upon Breakup
Breakup Probable Cause
Breakup Classification

HISTORY OF ON-ORBIT FRAGMENTATIONS (1961- January 1997)

BREAKUP CHARACTERISTICS

DEFINITION OF PARAMETERS

NE	Event Number
OBJECT	Breakup Object Name
I_DES	COSPAR Identifier
SATNO	USSPACECOM Number
L_D	Breakup object launch date
E_D	Epoch of the event
CAT_DEB	Number of catalogued debris upon breakup
BR_CAUSE	Probable cause for breakup: P Propulasion related D Deliberate U Unknown Battery Collision
EV_CL_SIM	Classification of the fragmentation event: HI-E High-intensity explosion simulated with the Evolve model HI-JP High-intensity explosion simulated with the Jehn-Parinello model LI Low-intensity explosion CO Collision

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NE	OBJECT	I_DES	SATNO	L_D	E_D	CAT_DEB	BR_CAUSE	EV_CL_SIM
1	Transit 4A r/b (Ablestar stage)	1961-015C	118	29 jun 61	29 jun 61	298	P (Ablestar S)	HI - E
2	Sputnik 29 (SL-6 final stage)	1962-057A	443	24 oct 62	29 oct 62	24	P (Molniya FS)	LI
3	Centaur AC-2 r/b (Centaur stage)	1963-047A	694	27 nov 63	27 nov 63	19	P (Centaur S)	LI
4	Cosmos 50	1964-070A	919	28 oct 64	5 nov 64	96	D (self-des.)	HI - JP
5	Cosmos 57	1965-012A	1093	22 feb 65	22 feb 65	167	D (self-des.)	HI - JP
6	Cosmos 61-63 r/b (SL-8 2nd stage)	1965-020D	1270	15 mar 65	15 mar 65	147	U (Cosmos 2nd S)	HI - JP
7	OV2-1-LCS 2 r/b (Titan Transtage)	1965-062B	1640	15 oct 65	15 oct 65	470	P (Titan Trans.)	HI - JP
8	Cosmos 95	1965-088A	1706	4 nov 65	15 jan 66	NA	U	HI - JP
9	OPS 3031	1966-012C	2015	15 feb 66	15 feb 66	38	U (infl. sphere)	HI - E
10	Gemini 9 ATDA r/b (Atlas core stage)	1966-048B	2188	1 jun 66	15 jun 66	51	U (Atlas core S)	HI - JP
11	AS-203 r/b (Saturn S-IVB stage)	1966-059A	2289	5 jul 66	5 jul 66	34	D (Saturn S)	LI
12	Cosmos U-1	1966-088A	2437	17 sep 66	17 sep 66	53	D (self-des.)	HI - JP
13	Cosmos U-2	1966-101A	2536	2 nov 66	2 nov 66	41	D (self-des.)	HI - JP
14	Cosmos 199	1968-003A	3099	16 jan 68	24 jan 68	NA	D (self-des.)	HI - JP
15	Apollo 6 r/b (Saturn S-IVB stage)	1968-025B	3171	4 apr 68	13 apr 68	16	P (Saturn S)	LI

16	Cosmos 249	1968-091A	3504	20 oct 68	20 oct 68	109	D (self-des.)	HI - JP
17	Cosmos 252	1968-097A	3530	1 nov 68	1 nov 68	140	D (self-des.)	HI - JP
18	Cosmos 248	1968-090A	3503	19 oct 68	1 nov 68	5	Battery (?)	LI
19	Meteor 1-1 r/b (SL-3 final stage)	1969-029B	3836	26 mar 69	28 mar 69	37	U (Vostok FS)	HI - JP
20	Intelsat 3 F-5 r/b (TE 364-4 stage)	1969-064B	4052	26 jul 69	26 jul 69	26	P (TE 374-4 S)	HI - JP
21	OPS 7613 r/b (Agena D stage)	1969-062AB	4159	30 sep 69	4 oct 69	260	U (Agena D S)	HI - E
22	Nimbus 4 r/b (Agena D stage)	1970-025C	4367	8 apr 70	17 oct 70	372	U (Agena D S)	HI - E
23	Cosmos 374	1970-089A	4594	23 oct 70	23 oct 70	103	D (self-des.)	HI - JP
24	Cosmos 375	1970-091A	4598	30 oct 70	30 oct 70	47	D (self-des.)	HI - JP
25	Cosmos 397	1971-015A	4964	25 feb 71	25 feb 71	116	D (self-des.)	HI - JP
26	Cosmos 462	1971-106A	5646	3 dec 71	3 dec 71	25	D (self-des.)	HI - JP
27	Salyut 2 r/b (SL-13 3rd stage)	1973-017B	6399	3 apr 73	3 apr 73	25	P (Proton 3rd S)	LI
28	Cosmos 554	1973-021A	6432	19 apr 73	6 may 73	195	D (self-des.)	HI - JP
29	NOAA 3 r/b (Delta 2nd stage)	1973-086B	6921	6 nov 73	28 dec 73	197	P (Delta 2nd S)	HI - E
30	Landsat 1 r/b (Delta 2nd stage)	1972-058B	6127	23 jul 72	22 may 75	226	P (Delta 2nd S)	HI - JP
31	Cosmos 699	1974-103A	7587	24 dec 74	2 aug 75	50	U (Cosmos 699 C)	HI - JP
32	NOAA 4 r/b (Delta 2nd stage)	1974-089D	7532	15 nov 74	20 aug 75	148	P (Delta 2nd S)	HI - JP
33	Cosmos 758	1975-080A	8191	5 sep 75	6 sep 75	76	D (self-des.)	HI - JP
34	Pageos	1966-056A	2253	24 jun 66	20 jan 76	62	U (Infl.sphere)	HI - E
35	Cosmos 777	1975-102A	8416	29 oct 75	25 jan 76	79	U (Cosmos 699 C)	HI - JP
36	Landsat 2 r/b (Delta 2nd stage)	1975-004B	7616	22 jan 75	9 feb 76	207	P (Delta 2nd S)	HI - JP
37	Cosmos 844	1976-072A	9046	22 jul 76	25 jul 76	248	D (self-des.)	HI - JP
38	Cosmos 886	1976-126A	9634	27 dec 76	27 dec 76	76	D (self-des.)	HI - JP
39	Cosmos 884	1976-123A	9614	17 dec 76	29 dec 76	NA	D (self-des.)	HI - JP
40	Cosmos 862	1976-105A	9495	22 oct 76	15 mar 77	11	D (self-des.)	LI
41	Cosmos 838	1976-063A	8932	2 jul 76	17 may 77	40	U (Cosmos 699 C)	HI - JP
42	Himawari 1 r/b (Delta 2nd stage)	1977-065B	10144	14 jul 77	14 jul 77	169	P (Delta 2nd S)	HI - JP
43	Cosmos 839	1976-067A	9011	8 jul 76	29 sep 77	70	Battery	HI - JP
44	Cosmos 931	1976-068A	10150	20 jul 77	24 oct 77	6	D (self-des.)	LI
45	Cosmos 970	1977-121A	10531	21 dec 77	21 dec 77	70	D (self-des.)	HI - JP
46	NOAA 5 r/b (Delta 2nd stage)	1976-077B	9063	29 jul 76	24 dec 77	159	P (Delta 2nd S)	HI - JP
47	Cosmos 903	1977-027A	9911	11 apr 77	8 jun 78	2	D (self-des.)	LI
48	Ekran 2	1977-092A	10365	20 sep 77	23 jun 78	1	Battery	LI
49	Cosmos 1030	1978-063A	11015	6 sep 78	10 oct 78	4	D (self-des.)	LI
50	Cosmos 880	1976-120A	9601	9 dec 76	27 nov 78	49	Battery	HI - JP
51	Cosmos 917	1977-047A	10059	16 jan 77	30 mar 79	1	D (self-des.)	LI
52	Cosmos 1124	1979-077A	11509	28 aug 79	9 sep 79	5	D (self-des.)	LI
53	Cosmos 1094	1979-033A	11333	18 apr 79	17 sep 79	1	U (Cosmos 699 C)	LI
54	Cosmos 1109	1979-058A	11417	27 jun 79	15 feb 80	6	D (self-des.)	LI
55	CAT r/b (Ariane 1 final stage)	1979-104B	11659	24 dec 79	15 apr 80	1	U (Ariane FS)	LI
56	Cosmos 1174	1980-030A	11765	18 apr 80	18 apr 80	46	D (self-des.)	HI - JP
57	Landsat 3 r/b (Delta 2nd stage)	1978-026C	10704	5 mar 78	27 jan 81	209	P (Delta 2nd S)	HI - JP
58	Cosmos 1261	1981-031A	12376	31 mar 81	1 may 81	4	D (self-des.)	LI
59	Cosmos 1191	1980-057A	11871	2 jul 80	14 may 81	2	D (self-des.)	LI
60	Cosmos 1167	1980-021A	11729	14 mar 80	15 jul 81	12	U (Cosmos 699 C)	LI
61	Cosmos 1275	1981-053A	12504	4 jun 81	24 jul 81	306	Battery	HI - E
62	Cosmos 1305 r/b (SL-6 final stage)	1981-088F	12827	11 sep 81	11 sep 81	3	P (Molniya FS)	LI
63	Cosmos 1247	1981-016A	12303	19 feb 81	20 oct 81	4	D (self-des.)	LI
64	Cosmos 1285	1981-071A	12627	4 aug 81	21 nov 81	3	D (self-des.)	LI
65	Nimbus 7 r/b (Delta 2nd stage)	1978-096B	11081	24 oct 78	26 dec 81	1	U (Delta 2nd S)	LI
66	Cosmos 1220	1980-089A	12054	4 nov 80	20 jun 82	78	U (Cosmos 699 C)	HI - JP
67	Cosmos 1306	1981-089A	12828	14 sep 81	12 jul 82	8	U (Cosmos 699 C)	LI
68	Cosmos 1260	1981-028A	12364	20 mar 81	10 aug 82	68	U (Cosmos 699 C)	HI - JP
69	Cosmos 1286	1981-072A	12631	4 aug 81	29 sep 82	2	U (Cosmos 699 C)	LI
70	Cosmos 1423 r/b (SL-6 final stage)	1982-115E	13696	8 dec 82	8 dec 82	29	P (Molniya FS)	HI - JP
71	Cosmos 1217	1980-085A	12032	24 oct 80	12 feb 83	NA	D (self-des.)	LI

72	Cosmos 1481	1983-070A	14182	8 jul 83	9 jul 83	3	D (self-des.)	LI
73	Cosmos 1355	1982-038A	13150	29 apr 82	8 aug 83	29	U (Cosmos 699 C)	HI - JP
74	Cosmos 1456	1983-088A	14034	25 apr 83	13 aug 83	4	D (self-des.)	LI
75	Cosmos 1405	1982-088A	13508	4 sep 82	20 dec 83	32	U (Cosmos 699 C)	HI - JP
76	Cosmos 1317	1981-108A	12933	31 oct 81	28 jan 84	4	D (self-des.)	LI
77	Westar 6 r/b (PAM-D upper stage)	1984-011F	14694	3 feb 84	3 feb 84	14	P (PAM-D US)	LI
78	Palapa B2 r/b (PAM-D upper stage)	1984-011E	14693	3 feb 84	6 feb 84	3	P (PAM-D US)	LI
79	Astron ullage motor (SL-12 SOZ)	1983-020B	13902	23 mar 83	3 sep 84	1	P (Proton bl DM)	LI
80	Cosmos 1461	1983-044A	14064	7 may 83	13 may 85	158	U (Cosmos 699 C)	HI - JP
81	Cosmos 1654	1985-039A	15734	23 may 85	21 jun 85	18	D (self-des.)	LI
82	P-78/Solwind	1979-017A	11278	24 feb 79	13 sep 85	285	D (Hyperv. impact)	CO
83	Cosmos 1375	1982-055A	13259	6 jun 82	21 oct 85	58	Battery	HI - JP
84	Cosmos 1691	1985-094B	16139	9 oct 85	22 nov 85	14	Battery	HI - JP
85	Cosmos 1714 r/b (SL-16 2nd stage)	1985-121B	16435	28 dec 85	28 dec 85	0	P (Zenit 2nd stage)	LI
86	NOAA 8	1983-022A	13923	28 mar 83	30 dec 85	7	Battery	LI
87	Cosmos 1588	1984-083A	15167	7 aug 84	23 feb 86	45	U (Cosmos 699 C)	HI - JP
88	USA 19	1986-069A	16937	5 sep 86	5 sep 86	13	D	LI
89	USA 19 r/b	1986-069B	16938	5 sep 86	5 sep 86	5	D	LI
90	Spot 1 r/b (Ariane 1 final stage)	1986-019C	16615	22 feb 86	13 nov 86	489	U (Ariane 1 FS)	HI - JP
91	Cosmos 1278	1981-058A	12547	19 jun 81	1 dec 86	2	D (self-des.)	LI
92	Cosmos 1682	1985-082A	16054	19 sep 85	18 dec 86	23	U (Cosmos 699 C)	LI
93	Cosmos 1813	1987-004A	17297	15 jan 87	29 jan 87	194	D (self-des.)	HI - JP
94	Cosmos 1866	1987-059A	18184	9 jul 87	26 jul 87	9	D (self-des.)	LI
95	Aussat K3/ECS 4 r/b (Ariane 3 FS)	1987-078C	18352	16 sep 87	19 sep 87	2	U (Ariane 3 FS)	LI
96	Cosmos 1769	1986-059A	16895	4 aug 86	21 sep 87	4	U (Cosmos 699 C)	LI
97	Cosmos 1646	1985-030A	15653	18 apr 85	20 nov 87	24	U (Cosmos 699 C)	LI
98	Cosmos 1823	1987-020A	17535	20 feb 87	17 dec 87	110	Battery	HI - JP
99	Cosmos 1656 u.m. (SL-12 SOZ)	1985-042E	15773	30 may 85	5 jan 88	6	P (Proton bl DM)	HI - JP
100	Cosmos 1906	1987-108A	18713	26 dec 87	31 jan 88	37	D (self-des.)	HI - JP
101	Cosmos 1916	1988-007A	18823	3 feb 88	27 feb 88	1	D (self-des.)	LI
102	Cosmos 1045 r/b (SL-14 3rd stage)	1978-100D	11087	26 oct 78	9 may 88	45	U (Tsyklon 3rd S)	HI - JP
103	Cosmos 2030	1989-054A	20124	12 jul 89	28 jul 89	1	D (self-des.)	LI
104	Cosmos 2031	1989-056A	20136	18 jul 89	31 aug 89	9	D (self-des.)	LI
105	Fengyun 1-2 r/b (CZ-4A final stage)	1990-081D	20791	3 sep 90	4 oct 90	73	P (CZ-4A FS)	HI - JP
106	Cosmos 2101	1990-087A	20828	1 oct 90	30 nov 90	4	D (self-des.)	LI
107	USA 68 r/b (TE-M-364-15 US)	1990-105A	20978	1 dec 90	1 dec 90	29	P (TE-M-364-15 US)	HI - JP
108	Cosmos 1519-21 u.m. (SL-12 SOZ)	1983-127H	14608	29 dec 83	4 feb 91	5	P (Proton bl DM)	HI - JP
109	Cosmos 2125-32 r/b (SL-8 2nd stage)	1991-009J	21108	12 feb 91	5 mar 91	73	P (Cosmos 2nd S)	HI - JP
110	Nimbus 6 r/b (Delta 2nd stage)	1975-052B	7946	12 jun 75	1 may 91	236	P (Delta 2nd S)	HI - JP
111	Cosmos 2163	1991-071A	21741	9 oct 91	6 dec 91	1	D (self-des.)	LI
112	Cosmos 1710-12 u.m. (SL-12 SOZ)	1985-118L	16446	24 dec 85	29 dec 91	2	P (Proton bl DM)	LI
113	OV2-5 r/b (Titan Transtage)	1968-081E	3432	26 sep 68	21 feb 92	20	U (Titan Trans.)	HI - E
114	Cosmos 2054 u.m. (SL-12 SOZ)	1989-101E	20399	27 dec 89	1 jul 92	2	P (Proton bl DM)	LI
115	Cosmos 1603 u.m. (SL-12 SOZ)	1984-106F	15338	28 sep 84	5 sep 92	22	P (Proton bl DM)	HI - JP
116	Gorizont 17 u.m. (SL-12 SOZ)	1989-004E	19771	26 jan 89	18 dec 92	1	P (Proton bl DM)	LI
117	Cosmos 2227 r/b (SL-16 2nd stage)	1992-093B	22285	25 dec 92	26 dec 92	209	P (Zenit 2 2nd S)	HI - JP
118	Gorizont 18 u.m. (SL-12 SOZ)	1989-052F	20116	5 jul 89	12 jan 93	1	P (Proton bl DM)	LI
119	Cosmos 2225	1992-091A	22280	22 dec 92	18 feb 93	6	D (self-des.)	LI
120	Cosmos 2237 r/b (SL-16 2nd stage)	1993-016B	22566	26 mar 93	28 mar 93	27	P (Zenit 2 2nd S)	LI
121	Telecom 2B/Inmarsat 2 r/b (Ariane 4)	1992-021C	21941	15 apr 92	21 apr 93	NA	U (Ariane 4 FS)	LI
122	Cosmos 2243	1993-028A	22641	27 apr 93	27 apr 93	172	D (self-des.)	HI - JP
123	Cosmos 1484	1983-075A	14207	24 jul 83	18 oct 93	39	U	HI - JP
124	Cosmos 2262	1993-057A	22789	7 sep 93	18 dec 93	0	D (self-des.)	LI
125	Mystery Family				1 jan 94 (?)		U	HI - JP
126	Clementine r/b (Titan II G)	1994-004B	22974	25 jan 94	7 feb 94	40	U	HI - JP
127	OPS 9331-34 r/b (Titan Transtage)	1967-066G	2868	1 jul 67	8 feb 94	NA	U (Titan Trans.)	HI - E

128	Astra 1B/MOP 2 r/b (Ariane 4 FS)	1991-015C	21141	2 mar 91	17 apr 94	7	U (Ariane 4 FS)	LI
129	Cosmos 2133 u.m. (SL-12 SOZ)	1991-010D	21114	12 feb 91	7 may 94	1	P (Proton bl DM)	LI
130	Cosmos 2204-06 u.m. (SL-12 SOZ)	1992-047A	22067	30 jul 92	8 nov 94	0	P (Proton bl DM)	HI - JP
131	RS-15 r/b (Briz)	1994-085B	23440	26 dec 94	26 dec 94	21	U	HI - JP
132	ETS-VI r/b (H-II 2nd stage)	1994-056B	23231	28 aug 94	31 mar 95	0	U (H-II 2nd S)	LI
133	Elektro u.m. (SL-12 SOZ)	1994-069E	23338	31 oct 94	11 may 95	0	P (Proton bl DM)	HI - E
134	Cosmos 2282 u.m. (SL-12 SOZ)	1994-038F	23174	7 jul 94	21 oct 95	NA	P (Proton bl DM)	HI - E
135	Gorizont 22 u.m. (SL-12 SOZ)	1990-102E	20957	23 nov 90	14 dec 95	NA	P (Proton bl DM)	HI - E
136	Raduga 33 u.m. (SL-12 SOZ)	1996-010D	23797	19 feb 96	19 feb 96	0	P (Proton bl DM)	HI - E
137	Eutelsat-II-F2 r/b (Ariane 4 H10)	1991-003C	21057	15 jan 91	1 may 96	NA	U (Ariane 4 FS)	LI
137	STEP M2 r/b (Pegasus HAPS)	1994-029B	23106	19 may 94	3 jun 96	0	U (Pegasus HAPS)	HI - E
139	Cerise	1995-033B	23606	7 jul 95	24 jul 96	1	Collision	CO*
140	Cosmos 1883-85 u.m. (SL-12 SOZ)	1987-079G	18374	16 sep 87	30 nov 96	1	P (Proton bl DM)	HI - E

History of on-orbit fragmentations (1961 - January 1, 1997)

TABLE 24

EPOCH OF THE FRAGMENTATION EVENTS

Event Number

Epoch of the Fragmentation Event in:

yyddd.dddd (number of years after 1900.0, days and fraction of day)

yyyymmdd. (year, month, day)

hhmmss.sssss (hours, minutes, seconds and fractions)

HISTORY OF ON-ORBIT FRAGMENTATIONS (1961- January 1997)

EPOCH OF THE FRAGMENTATION EVENT

DEFINITION OF PARAMETERS

NE	Event Number
SATNO	USSPACECOM Number
E_D	Event Epoch in YYDDD.DDDD and YYYYMMDD HHMMSS.

NE	SATNO	E_D YYDDD.DDDD	YYYYMMDD.	HHMMSS.SSSSS
1	118	61180.2555	19610629.	60755.20000
2	443	62302.0000	19621029.	0.00000
3	694	63331.0000	19631127.	0.00000
4	919	64310.0000	19641105.	0.00000
5	1093	65053.4146	19650222.	95701.44000
6	1270	65074.7181	19650315.	171403.84000
7	1640	65288.7639	19651015.	182000.96000
8	1706	66015.0000	19660115.	0.00000
9	2015	66046.0000	19660215.	0.00000
10	2188	66166.0000	19660615.	0.00000
11	2289	66186.8827	19660705.	211105.28000
12	2437	66260.0000	19660917.	0.00000
13	2536	66306.0000	19661102.	0.00000
14	3099	68024.0000	19680124.	0.00000
15	3171	68104.4542	19680413.	105402.88000
16	3504	68294.6021	19681020.	142701.44000
17	3530	68306.1681	19681101.	40203.84000
18	3503	68306.1750	19681101.	41200.00000
19	3836	69087.7812	19690328.	184455.68000
20	4052	69207.1028	19690726.	22801.92000
21	4159	69277.6618	19691004.	155259.52000
22	4367	70290.1368	19701017.	31659.52000
23	4594	70296.6340	19701023.	151257.60000
24	4598	70303.2500	19701030.	60000.00000
25	4964	71056.6049	19710225.	143103.36000
26	5646	71337.7021	19711203.	165101.44000
27	6399	73093.9417	19730403.	223602.88000
28	6432	73126.3084	19730506.	72405.76000
29	6921	73362.3778	19731228.	90401.92000
30	6127	75142.7688	19750522.	182704.32000
31	7587	75214.6826	19750802.	162256.64000
32	7532	75232.5465	19750820.	130657.60000
33	8191	75249.7959	19750906.	190605.76000
35	2253	76020.0000	19760120.	0.00000
34	8416	76025.5834	19760125.	140005.76000
36	7616	76170.2909	19760618.	65853.76000
37	9046	76207.7209	19760725.	171805.76000
38	9634	76362.7778	19761227.	184001.92000
39	9614	76364.0000	19761229.	0.00000
40	9495	77074.5389	19770315.	125600.96000
41	8932	77137.4292	19770517.	101802.88000
42	10144	77195.6749	19770714.	161151.36000
43	9011	77272.3035	19770929.	71702.40000
44	10150	77297.0000	19771024.	0.00000
45	10531	77355.7153	19771221.	171001.92000
46	9063	77358.4812	19771224.	113255.68000
47	9911	78159.0000	19780608.	0.00000
48	10365	78174.0000	19780623.	0.00000

49	11015	78283.0000	19781010.	0.00000
50	9601	78331.7104	19781127.	170258.56000
51	10059	79089.6563	19790330.	154504.32000
52	11509	79252.1042	19790909.	23002.88000
53	11333	79260.4437	19790917.	103855.68000
54	11417	80046.0000	19800215.	0.00000
55	11659	80106.0000	19800415.	0.00000
56	11765	80109.3097	19800418.	72558.08000
57	10704	81027.1889	19810127.	43200.96000
58	12376	81121.0000	19810501.	0.00000
59	11871	81134.0000	19810514.	0.00000
60	11729	81196.3896	19810715.	92101.44000
61	12504	81205.9938	19810724.	235104.32000
62	12827	81254.0000	19810911.	0.00000
63	12303	81293.0000	19811020.	0.00000
64	12627	81325.0000	19811121.	0.00000
65	11081	81360.0000	19811226.	0.00000
66	12054	82171.7625	19820620.	181800.00000
67	12828	82193.9757	19820712.	232500.48000
68	12364	82222.9826	19820[illegible]10.	233456.64000
69	12631	82272.2223	19820929.	52006.72000
70	13696	82342.6167	19821208.	144802.88000
71	12032	83043.0000	19830212.	0.00000
72	14182	83190.0000	19830709.	0.00000
73	13150	83220.9799	19830808.	233103.36000
74	14034	83225.0000	19830813.	0.00000
75	13508	83354.5104	19831220.	121458.56000
76	12933	84028.0000	19840128.	0.00000
77	14694	84034.9063	19840203.	214504.32000
78	14693	84037.6666	19840206.	155954.24000
79	13902	84247.8493	19840903.	202259.52000
80	14064	85133.0646	19850513.	13301.44000
81	15734	85172.4493	19850621.	104659.52000
82	11278	85256.8632	19850913.	204300.48000
83	13259	85294.1618	19851021.	35259.52000
84	16139	85326.3611	19851122.	83959.04000
85	16435	85362.0000	19851228.	0.00000
86	13923	85364.4201	19851230.	100456.64000
87	15167	86054.7847	19860223.	184958.08000
88	16937	86248.7445	19860905.	175204.80000
89	16938	86248.7445	19860905.	175204.80000
90	16615	86317.8194	19861113.	193956.16000
91	12547	86335.0000	19861201.	0.00000
92	16054	86352.8451	19861218.	201656.64000
93	17297	87029.2465	19870129.	55457.60000
94	18184	87207.6521	19870726.	153901.44000
95	18352	87262.0000	19870919.	0.00000
96	16895	87264.5035	19870921.	120502.40000
97	15653	87324.0632	19871120.	13100.48000
98	17535	87351.7354	19871217.	173858.56000
99	15773	88005.0743	19880105.	14659.52000
100	18713	88031.4646	19880131.	110901.44000
101	18823	88058.1972	19880227.	44358.08000
102	11087	88130.5125	19880509.	121800.00000
103	20124	89209.1771	19890728.	41501.44000
104	20136	89243.7854	19890831.	185058.56000
105	20791	90277.8430	19901004.	201355.20000
106	20828	90334.7222	19901130.	171958.08000
107	20978	90335.6736	19901201.	160959.04000
108	14608	91035.1333	19910204.	31157.12000
109	21108	91064.5729	19910305.	134458.56000
110	7946	91121.3722	19910501.	85558.08000
111	21741	91340.8480	19911206.	202107.20000
112	16446	91363.3771	19911229.	90301.44000
113	3432	92052.0000	19920221.	0.00000
114	20399	92183.0000	19920701.	0.00000
115	15338	92249.6188	19920905.	145104.32000

116	19771	92353.0000	19921218.	0.00000
117	22285	92361.3181	19921226.	73803.84000
118	20116	93012.0000	19930112.	0.00000
119	22280	93049.7889	19930218.	185600.96000
120	22566	93087.3028	19930328.	71601.92000
121	21941	93111.0000	19930421.	0.00000
122	22641	93117.4473	19930427.	104406.72000
123	14207	93291.5027	19931018.	120353.28000
124	22789	93352.2993	19931218.	71059.52000
125	0	94001.0000	19940101.	0.00000
126	22974	94038.7215	19940207.	171857.60000
127	2868	94039.0000	19940208.	0.00000
128	21141	94117.6377	19940427.	151820.00000
129	21114	94127.3958	19940507.	92957.12000
130	22067	94312.3000	19941108.	71200.00000
131	23440	94360.3000	19941226.	71200.00000
132	23231	95090.9000	19950331.	213600.00000
133	23338	95131.6000	19950511.	142400.00000
134	23174	95294.0000	19951021.	0.00000
135	20957	95348.0000	19951214.	0.00000
136	23797	96050.0000	19960219.	0.00000
137	21057	96122.0000	19960501.	0.00000
138	23106	96155.6375	19960603.	151800.00000
139	23606	96206.0000	19960724.	0.00000
140	18374	96335.0000	19961130.	0.00000

TABLE 25

LOCATION OF THE BREAKUP POINT

Event Number

USSPACECOM Number

Epoch of the Fragmentation Event in yyyymmdd and hhmmss.sss

Location of the Breakup Point (latitude, longitude, altitude on the terrestrial ellipsoid)

HISTORY OF ON-ORBIT FRAGMENTATIONS (1961- January 1997)

LOCATION OF THE BREAKUP POINT

DEFINITION OF PARAMETERS

NE	Event Number
SATNO	USSPACECOM Number
E_D	Epoch of the Event in yyyymmdd and hhmmss.sss
LAT	Latitude (deg) of the breakup point
LON	Longitude (deg) of the breakup point
ALTITUDE	Altitude (km) of the breakup point on the earth ellipsoid

NE	SATNO	E_D yyyymmdd	hhmmss.sss	LAT (deg)	LON (deg)	ALTITUDE (km)
1	118	19610629	60755.200	34.4998	250.1347	990.817
2	443	19621029	0.000	-57.2868	149.8854	278.691
3	694	19631127	0.000	-30.1462	358.1662	1720.897
4	919	19641105	0.000	-34.9739	85.1942	201.780
5	1093	19650222	95701.440	-22.2059	189.4446	384.125
6	1270	19650315	171403.840	-51.2943	162.7347	1664.531
7	1640	19651015	182000.960	-23.9859	101.0220	738.879
8	1706	19660115	0.000	47.3178	318.8708	530.542
9	2015	19660215	0.000	-17.0579	180.8492	190.962
10	2188	19660615	0.000	-15.5891	163.2442	260.115
11	2289	19660705	211105.280	16.4253	275.2583	214.348
12	2437	19660917	0.000	30.1994	16.6023	248.835
13	2536	19661102	0.000	16.6955	179.4063	398.255
14	3099	19680124	0.000	43.3138	281.0275	213.624
15	3171	19680413	105402.880	-24.6739	150.9726	243.615
16	3504	19681020	142701.440	-56.6745	180.7929	2018.805
17	3530	19681101	40203.840	57.4019	30.7555	541.706
18	3503	19681101	41200.000	55.8108	103.7736	549.317
19	3836	19690328	184455.680	54.3475	92.9789	554.706
20	4052	19690726	22801.920	-1.2474	334.1075	274.494
21	4159	19691004	155259.520	54.8574	177.4076	924.899
22	4367	19701017	31659.520	-50.7612	141.7709	1091.007
23	4594	19701023	151257.600	-22.8809	216.8741	1191.822
24	4598	19701030	60000.000	54.6027	22.1773	542.824
25	4964	19710225	143103.360	54.4966	21.3939	596.662
26	5646	19711203	165101.440	52.3935	8.2268	238.986
27	6399	19730403	223602.880	46.2772	285.4847	233.633
28	6432	19730506	72405.760	-71.7169	217.6109	324.509
29	6921	19731228	90401.920	-38.3205	181.2240	1520.994
30	6127	19750522	182704.320	-34.7370	45.4629	735.476
31	7587	19750802	162256.640	-1.1400	257.4171	431.301
32	7532	19750820	130657.600	-53.5602	276.9270	1477.621
33	8191	19750906	190605.760	31.8654	291.9929	184.357
34	2253	19760120	0.000	34.6551	94.4237	3083.399
35	8416	19760125	140005.760	54.3452	9.0393	447.888
36	7616	19760618	65853.760	43.6271	271.6250	747.517
37	9046	19760725	171805.760	48.9434	99.6997	214.257
38	9634	19761227	184001.920	-33.5740	303.2316	1859.188
39	9614	19761229	0.000	44.3936	284.3096	171.766
40	9495	19770315	125600.960	38.2921	113.5246	5291.294
41	8932	19770517	101802.880	-9.2733	284.1507	430.699
42	10144	19770714	161151.360	13.8204	248.9323	1318.151

43	9011	19770929	71702.400	-33.3282	161.7591	1913.689
44	10150	19771024	0.000	16.2592	280.5729	2569.667
45	10531	19771221	171001.920	-37.8564	273.6065	1142.992
46	9063	19771224	113255.680	-41.1971	146.7390	1521.596
47	9911	19780608	0.000	50.2276	2.0095	33736.218
48	10365	19780623	0.000	-8.2235	290.2273	35809.588
49	11015	19781010	0.000	27.2679	122.1075	37590.483
50	9601	19781127	170258.560	-65.5607	306.5187	581.813
51	10059	19790330	154504.320	-63.1670	359.0938	3318.282
52	11509	19790909	23002.880	47.5907	296.4266	7040.178
53	11333	19790917	103855.680	-53.9804	335.4483	405.054
54	11417	19800215	0.000	37.9046	117.5415	39359.582
55	11659	19800415	0.000	18.1491	343.5231	32521.816
56	11765	19800418	72558.080	46.4395	320.7789	1633.675
57	10704	19810127	43200.960	-80.3747	302.4368	930.663
58	12376	19810501	0.000	49.4293	203.1999	35799.117
59	11871	19810514	0.000	-5.4543	149.0825	19151.866
60	11729	19810715	92101.440	10.8740	105.4781	426.181
61	12504	19810724	235104.320	68.5448	196.3823	985.655
62	12827	19810911	0.000	19.1529	250.7031	8433.964
63	12303	19811020	0.000	23.3889	352.6481	35547.976
64	12627	19811121	0.000	25.7153	354.9306	36614.987
65	11081	19811226	0.000	79.5743	122.5614	948.771
66	12054	19820620	181800.000	-9.1566	331.1037	879.262
67	12828	19820712	232500.480	-64.5938	42.6411	402.028
68	12364	19820810	233456.640	51.8081	236.4697	758.225
69	12631	19820929	52006.720	51.2448	79.7735	328.774
70	13696	19821208	144802.880	-62.0283	302.9683	424.415
71	12032	19830212	0.000	65.3227	209.1649	38639.477
72	14182	19830709	0.000	49.9993	22.2226	34231.349
73	13150	19830808	233103.360	-32.1243	309.6891	372.986
74	14034	19830813	0.000	-5.6827	115.8095	1287.697
75	13508	19831220	121458.560	-26.5854	45.6697	335.310
76	12933	19840128	0.000	62.7669	182.3011	16120.623
77	14694	19840203	214504.320	-0.3197	56.2538	308.699
78	14693	19840206	155954.240	1.5914	122.7316	284.455
79	13902	19840903	202259.520	-11.1395	350.5205	412.291
80	14064	19850513	13301.440	10.6635	82.3767	842.026
81	15734	19850621	104659.520	7.5993	291.4975	194.228
82	11278	19850913	204300.480	36.5808	233.0082	523.746
83	13259	19851021	35259.520	65.9233	348.8559	1003.140
84	16139	19851122	83959.040	31.8282	325.1831	1414.449
85	16435	19851228	0.000	1.7300	4.9979	831.646
86	13923	19851230	100456.640	-66.6797	301.6227	828.342
87	15167	19860223	184958.080	29.0308	185.9972	427.382
88	16937	19860905	175204.800	13.5882	163.8539	218.880
89	16938	19860905	175204.800	14.1578	163.4562	223.892
90	16615	19861113	193956.160	9.1074	41.1350	799.666
91	12547	19861201	0.000	51.7927	5.4363	36536.074
92	16054	19861218	201656.640	-22.6966	291.2697	418.684
93	17297	19870129	55457.600	72.6518	123.1841	397.784
94	18184	19870726	153901.440	-56.9234	240.0535	252.649
95	18352	19870919	0.000	1.4179	189.7079	34909.133
96	16895	19870921	120502.400	-61.4959	176.2968	343.381
97	15653	19871120	13100.480	64.7600	302.0516	419.977
98	17535	19871217	173858.560	-16.1427	18.1576	1482.418
99	15773	19880105	14659.520	66.5829	153.8501	869.338
100	18713	19880131	110901.440	-9.6442	137.6152	245.073
101	18823	19880227	44358.080	61.2298	95.7441	161.811
102	11087	19880509	121800.000	-28.5018	125.4854	1707.458
103	20124	19890728	41501.440	51.2716	110.0892	155.267
104	20136	19890831	185058.560	41.6265	112.5266	282.398
105	20791	19901004	201355.200	-81.2472	68.3733	914.678
106	20828	19901130	171958.080	53.2196	158.3029	209.976
107	20978	19901201	160959.040	7.6119	231.8673	845.927
108	14608	19910204	31157.120	27.8808	105.2629	18551.501
109	21108	19910305	134458.560	-41.9133	139.6366	1566.675

110	7946	19910501	85558.080	68.2936	319.5506	1104.340
111	21741	19911206	202107.200	54.9407	154.1948	197.629
112	16446	19911229	90301.440	12.1102	338.4910	3384.360
113	3432	19920221	0.000	-7.4866	194.1697	35601.454
114	20399	19920701	0.000	11.8028	37.0762	1820.656
115	15338	19920905	145104.320	-46.5308	351.6342	858.316
116	19771	19921218	0.000	26.9286	206.6753	925.605
117	22285	19921226	73803.840	63.8869	61.9452	855.172
118	20116	19930112	0.000	-46.6732	14.7899	15764.331
119	22280	19930218	185600.960	55.7317	156.4526	219.118
120	22566	19930328	71601.920	69.8172	36.1687	861.636
121	21941	19930421	0.000	-3.2670	303.9345	35460.598
122	22641	19930427	104406.720	63.7378	85.6223	210.171
123	14207	19931018	120353.280	-8.0659	110.4421	552.399
124	22789	19931218	71059.520	64.8681	106.8225	195.518
125	0	19940101	0.000	3.8283	302.2856	806.833
126	22974	19940207	171857.600	-59.3842	233.3985	256.764
127	2868	19940208	0.000	-10.1897	49.3179	33536.087
128	21141	19940427	151817.280	-0.1526	235.4824	273.885
129	21114	19940507	92957.120	-6.5044	95.7975	21165.384
130	22067	19941108	71200.000	27.7000	75.7811	18251.362
131	23440	19941226	71200.000	-14.0880	67.9189	2033.524
132	23231	19950331	221912.000	7.7103	217.8057	130.870
133	23338	19950511	142400.000	36.9969	250.2665	35112.289
134	23174	19951021	0.000	0.6036	128.7293	13966.226
135	20957	19951214	0.000	-45.5766	312.4924	9591.518
136	23797	19960219	0.000	0.3428	313.4658	36571.829
137	21057	19960501	0.000	-6.6736	150.2113	12076.953
138	23106	19960603	151800.000	-64.9363	57.5809	632.980
139	23606	19960724	0.000	-40.2088	206.5811	679.601
140	18374	19961130	0.000	53.6773	269.6912	8281.524

TABLE 26

EVENT CLASSIFICATION BASED ON THE VALUE OF THE EXPLOSION INTENSITY PARAMETER

Name of the Breakup Object
COSPAR Identifier
USSPACECOM Number
Explosion Intensity Parameter
Breakup Classification

HISTORY OF ON-ORBIT FRAGMENTATIONS (1961- January 1997)

Events classification based on the value of the explosion intensity parameter

OBJECT NAME	COSPAR IDENTIFIER	USSPACECOM NUMBER	EXPLOSION INTENSITY PARAMETER	EVENT CLASSIFICATION AND SIMULATION
Transit 4A r/b (Ablestar stage)	1961-015C	118	2.54	HI-E
Sputnik 29 (SL-6 final stage)	1962-057A	443	1.23	LI
Centaur AC-2 (Centaur stage)	1963-047A	694	1.16	LI
Cosmos 50	1964-070A	919	1.64	HI-JP
Cosmos 57	1965-012A	1093	1.80	HI-JP
Cosmos 61-63 r/b (SL-8 2nd stage)	1965-020D	1270	2.01	HI-JP
OV2-1-LCS 2 r/b (Titan Transtage)	1965-062B	1640	2.06	HI-JP
Cosmos 95	1965-088A	1706	NA	HI-JP
OPS 3031	1966-012C	2015	4.00	HI-E
Gemini 9 ATDA r/b (Atlas core stage)	1966-048B	2188	1.46	HI-JP
AS-203 r/b (Saturn S-IVB stage)	1966-059A	2289	1.29	LI
Cosmos U-1	1966-088A	2437	1.50	HI-JP
Cosmos U-2	1966-101A	2536	1.42	HI-JP
Cosmos 199	1968-003A	3099	NA	HI-JP
Apollo 6 r/b (Saturn S-IVB stage)	1968-025B	3171	1.08	LI
Cosmos 249	1968-091A	3504	1.93	HI-JP
Cosmos 252	1968-097A	3530	2.16	HI-JP
Cosmos 248	1968-090A	3503	0.82	LI
Meteor 1-1 r/b (SL-3 final stage)	1969-029B	3836	1.40	HI-JP
Intelsat 3 F-5 r/b (TE 364-4 stage)	1969-064B	4052	1.50	HI-JP
OPS 7613 r/b (Agena D stage)	1969-062AB	4159	2.45	HI-E
Nimbus 4 r/b (Agena D stage)	1970-025C	4367	4.30	HI-E
Cosmos 374	1970-089A	4594	1.97	HI-JP
Cosmos 375	1970-091A	4598	1.60	HI-JP
Cosmos 397	1971-015A	4964	1.98	HI-JP
Cosmos 462	1971-106A	5646	1.35	HI-JP
Salyut 2 r/b (SL-13 3rd stage)	1973-017B	6399	1.23	LI
Cosmos 554	1973-021A	6432	1.72	HI-JP
NOAA 3 r/b (Delta 2nd stage)	1973-086B	6921	3.00	HI-E
Landsat 1 r/b (Delta 2nd stage)	1972-058B	6127	1.93	HI-JP
Cosmos 699	1974-103A	7587	1.47	HI-JP
NOAA 4 r/b (Delta 2nd stage)	1974-089D	7532	2.03	HI-JP
Cosmos 758	1975-080A	8191	1.56	HI-JP
Pageos	1966-056A	2253	2.50	HI-E
Cosmos 777	1975-102A	8416	1.54	HI-JP
Landsat 2 r/b (Delta 2nd stage)	1975-004B	7616	1.84	HI-JP
Cosmos 844	1976-072A	9046	1.82	HI-JP
Cosmos 886	1976-126A	9634	1.39	HI-JP
Cosmos 884	1976-123A	9614	NA	HI-JP
Cosmos 862	1976-105A	9495	0.89	LI
Cosmos 838	1976-063A	8932	1.40	HI-JP
Himawari 1 r/b (Delta 2nd stage)	1977-065B	10144	1.69	HI-JP
Cosmos 839	1976-067A	9011	1.89	HI-JP
Cosmos 931	1976-068A	10150	0.85	LI
Cosmos 970	1977-121A	10531	1.72	HI-JP
NOAA 5 r/b (Delta 2nd stage)	1976-077B	9063	2.26	HI-JP
Cosmos 903	1977-027A	9911	0.48	LI
Ekran 2	1977-092A	10365	3.50	LI *
Cosmos 1030	1978-063A	11015	0.73	LI
Cosmos 880	1976-120A	9601	1.64	HI-JP
Cosmos 917	1977-047A	10059	0.72	LI
Cosmos 1124	1979-077A	11509	0.29	LI
Cosmos 1094	1979-033A	11333	0.51	LI
Cosmos 1109	1979-058A	11417	0.84	LI
CAT r/b (Ariane 1 final stage)	1979-104B	11659	0.71	LI
Cosmos 1174	1980-030A	11765	1.59	HI-JP
Landsat 3 r/b (Delta 2nd stage)	1978-026C	10704	1.90	HI-JP
Cosmos 1261	1981-031A	12376	0.70	LI

Cosmos 1191	1980-057A	11871	0.49	LI
Cosmos 1167	1980-021A	11729	1.04	LI
Cosmos 1275	1981-053A	12504	NA	HI-E **
Cosmos 1305 r/b (SL-6 final stage)	1981-088F	12827	0.66	LI
Cosmos 1247	1981-016A	12303	0.72	LI
Cosmos 1285	1981-071A	12627	0.64	LI
Nimbus 7 r/b (Delta 2nd stage)	1978-096B	11081	0.52	LI
Cosmos 1220	1980-089A	12054	1.61	HI-JP
Cosmos 1306	1981-089A	12828	0.92	LI
Cosmos 1260	1981-028A	12364	1.57	HI-JP
Cosmos 1286	1981-072A	12631	0.51	LI
Cosmos 1423 r/b (SL-6 final stage)	1982-115E	13696	1.39	HI-JP
Cosmos 1217	1980-085A	12032	NA	LI
Cosmos 1481	1983-070A	14182	0.59	LI
Cosmos 1355	1982-038A	13150	1.30	HI-JP
Cosmos 1456	1983-088A	14034	0.73	LI
Cosmos 1405	1982-088A	13508	1.33	HI-JP
Cosmos 1317	1981-108A	12933	0.74	LI
Westar 6 r/b (PAM-D upper stage)	1984-011F	14694	1.09	LI
Palapa B2 r/b (PAM-D upper stage)	1984-011E	14693	0.64	LI
Astron ullage motor (SL-12 SOZ)	1983-020B	13902	0.77	LI
Cosmos 1461	1983-044A	14064	1.77	HI-JP
Cosmos 1654	1985-039A	15734	1.14	LI
P-78/Solwind	1979-017A	11278	NA	CO
Cosmos 1375	1982-055A	13259	1.78	HI-JP
Cosmos 1691	1985-094B	16139	1.57	HI-JP
Cosmos 1714 r/b (SL-16 2nd stage)	1985-121B	16435	NA	LI
NOAA 8	1983-022A	13923	0.92	LI
Cosmos 1588	1984-083A	15167	1.44	HI-JP
USA 19	1986-069A	16937	1.14	LI
USA 19 r/b	1986-069B	16938	0.81	LI
Spot 1 r/b (Ariane 1 final stage)	1986-019C	16615	2.20	HI-JP
Cosmos 1278	1981-058A	12547	0.50	LI
Cosmos 1682	1985-082A	16054	1.23	LI
Cosmos 1813	1987-004A	17297	1.72	HI-JP
Cosmos 1866	1987-059A	18184	0.94	LI
Aussat K3/ECS 4 r/b (Ariane 3 FS)	1987-078C	18352	0.73	LI
Cosmos 1769	1986-059A	16895	0.72	LI
Cosmos 1646	1985-030A	15653	1.25	LI
Cosmos 1823	1987-020A	17535	1.67	HI-JP
Cosmos 1656 ullage motor (SL-12 SOZ)	1985-042E	15773	1.49	HI-JP
Cosmos 1906	1987-108A	18713	1.35	HI-JP
Cosmos 1916	1988-007A	18823	0.51	LI
Cosmos 1045 r/b (SL-14 3rd stage)	1978-100D	11087	1.67	HI-JP
Cosmos 2030	1989-054A	20124	0.51	LI
Cosmos 2031	1989-056A	20136	0.94	LI
Fengyun 1-2 r/b (CZ-4A final stage)	1990-081D	20791	1.80	HI-JP
Cosmos 2101	1990-087A	20828	0.70	LI
USA 68	1990-105A	20978	1.44	HI-JP
Cosmos 1519-21 u.m. (SL-12 SOZ)	1983-127H	14608	1.33	HI-JP
Cosmos 2125-32 r/b (SL-8 2nd stage)	1991-009J	21108	1.81	HI-JP
Nimbus 6 r/b (Delta 2nd stage)	1975-052B	7946	2.08	HI-JP
Cosmos 2163	1991-071A	21741	0.51	LI
Cosmos 1710-12 u.m. (SL-12 SOZ)	1985-118L	16446	0.80	LI
OV2-5 r/b (Titan Transtage)	1968-081E	3432	3.50	HI-E
Cosmos 2054 ullage motor (SL-12 SOZ)	1989-101E	20399	0.77	LI
Cosmos 1603 ullage motor (SL-12 SOZ)	1984-106F	15338	1.81	HI-JP
Gorizont 17 ullage motor (SL-12 SOZ)	1989-004E	19771	0.77	LI
Cosmos 2227 r/b (SL-16 2nd stage)	1992-093B	22285	1.86	HI-JP
Gorizont 18 ullage motor (SL-12 SOZ)	1989-052F	20116	0.77	LI
Cosmos 2225	1992-091A	22280	0.82	LI
Cosmos 2237 r/b (SL-16 2nd stage)	1993-016B	22566	1.25	LI
Telecom 2B/Inmarsat 2 r/b (Ariane 4)	1992-021C	21941	NA	LI
Cosmos 2243	1993-028A	22641	1.91	HI-JP
Cosmos 1484	1983-075A	14207	1.39	HI-JP
Cosmos 2262	1993-057A	22789	0.31	LI
Clementine r/b (Titan 23G)	1994-004B	22974	1.45	HI-JP
OPS 9331-34 r/b (Titan Transtage)	1967-066G	2868	NA	HI-E
Astra 1B/MOP 2 r/b (Ariane 4 H10)	1991-015C	21141	1.14	LI
Cosmos 2133 ullage motor (SL-12 SOZ)	1991-010D	21114	0.77	LI
Cosmos 2204-06 u.m. (SL-12 SOZ)	1992-047A	22067	2.25	HI-JP
RS-15 r/b (Briz)	1994-085B	23440	1.49	HI-JP
ETS-VI r/b (H-II 2nd stage)	1994-056B	23231	0.57	LI
Elektro ullage motor (SL-12 SOZ)	1994-069E	23338	2.34	HI-E

Cosmos 2282 ullage motor (SL-12 SOZ)	1994-038F	23174	5.68	HI-E
Gorizont 22 ullage motor (SL-12 SOZ)	1990-102E	20957	4.15	HI-E
Raduga 33 ullage motor (SL-12 SOZ)	1996-010D	23797	NA	HI-E
Eutelsat-II-F2 r/b (Ariane 4 H10)	1991-003C	21057	NA	LI
STEP M2 r/b (HAPS)	1994-029B	23106	NA	HI-E
Cerise	1995-033B	23606	NA	CO ***
Cosmos 1883-85 u.m. (SL-12 SOZ)	1987-079G	18374	NA	HI-E

* EKRAN 2 was a LI explosion in GEO
** This event was reclassified from a collision back to unknown (Orbital Debris Monitor, 1 July 1993)
*** This event produced only one catalogued fragment. It was not simulated.

Fragmentations classification criteria

Based on the value of the explosion intensity parameter (B):

B < 1.3	Low Intensity Explosion (LI)
1.3 =< B < 2.3	High Intensity Explosion simulated with the Jehn-Parrinello model (HI-JP)
B >= 2.3	High Intensity Explosion simulated with the Evolve model (HI-E)

TABLE 27

CONTRIBUTION OF THE ON-ORBIT FRAGMENTATIONS TO THE CATALOGUED POPULATION ON 1st JANUARY 1997

Name of the Breakup Object
COSPAR Identifier
Number of Fragments in the NORAD Catalog on 1st January 1997
Name of the Catalogued Objects

HISTORY OF ON-ORBIT FRAGMENTATIONS (1961- January 1997)

Contribution of the on-orbit fragmentations to the catalogued population of January 1, 1997

OBJECT NAME	COSPAR IDENTIFIER	NUMBER OF CATALOGUED DEBRIS (Jan 1, 1997)	NAME IN THE CATALOG
Transit 4A r/b (Ablestar stage)	1961-015C	199	THOR ABLESTAR DEB
Sputnik 29 r/b (SL-6 final stage)	1962-057A	0	
Centaur AC-2 (Centaur stage)	1963-047A	8	ATLAS CENTAUR 2 DEB
Cosmos 50	1964-070A	0	
Cosmos 57	1965-012A	0	
Cosmos 61-63 r/b (SL-8 2nd stage)	1965-020D	22	SL-8 DEB
OV2-1-LCS 2 r/b (Titan Transtage)	1965-062B	0	
Cosmos 95	1965-088A	0	
OPS 3031	1966-012C	0	
Gemini 9 ATDA r/b (Atlas core stage)	1966-048B	0	
AS-203 r/b (Saturn S-IVB stage)	1966-059A	0	
Cosmos U-1	1966-088A	0	
Cosmos U-2	1966-101A	0	
Cosmos 199	1968-003A	0	
Apollo 6 r/b (Saturn S-IVB stage)	1968-025B	0	
Cosmos 249	1968-091A	53	COSMOS 249 DEB
Cosmos 252	1968-097A	52	COSMOS 252 DEB
Cosmos 248	1968-090A	0	
Meteor 1-1 r/b (SL-3 final stage)	1969-029B	0	
Intelsat 3 F-5 r/b (TE 364-4 stage)	1969-064B	1	DELTA 1 DEB
OPS 7613 r/b (Agena D stage)	1969-062AB	0	
Nimbus 4 r/b (Agena D stage)	1970-025C	274	THORAD AGENA D DEB
Cosmos 374	1970-089A	34	COSMOS 374 DEB
Cosmos 375	1970-091A	25	COSMOS 375 DEB
Cosmos 397	1971-015A	57	COSMOS 397 DEB
Cosmos 462	1971-106A	0	
Salyut 2 r/b (SL-13 3rd stage)	1973-017B	0	
Cosmos 554	1973-021A	0	
NOAA 3 r/b (Delta 2nd stage)	1973-086B	178	DELTA 1 DEB
Landsat 1 r/b (Delta 2nd stage)	1972-058B	50	DELTA 1 DEB
Cosmos 699	1974-103A	0	
NOAA 4 r/b (Delta 2nd stage)	1974-089D	128	THORAD DELTA 1 DEB
Cosmos 758	1975-080A	0	
Pageos	1966-056A	3	PAGEOS 1 DEB
Cosmos 777	1975-102A	0	
Landsat 2 r/b (Delta 2nd stage)	1975-004B	37	DELTA 1 DEB
Cosmos 844	1976-072A	0	
Cosmos 886	1976-126A	63	COSMOS 886 DEB
Cosmos 884	1976-123A	0	
Cosmos 862	1976-105A	10	COSMOS 862 DEB
Cosmos 838	1976-063A	0	
Himawari 1 r/b (Delta 2nd stage)	1977-065B	75	DELTA 1 DEB
Cosmos 839	1976-067A	67	COSMOS 839 DEB
Cosmos 931	1976-068A	0	
Cosmos 970	1977-121A	65	COSMOS 970 DEB
NOAA 5 r/b (Delta 2nd stage)	1976-077B	153	DELTA 1 DEB
Cosmos 903	1977-027A	1	COSMOS 903 DEB
Ekran 2	1977-092A	0	
Cosmos 1030	1978-063A	0	
Cosmos 880	1976-120A	2	COSMOS 880 DEB
Cosmos 917	1977-047A	0	
Cosmos 1124	1979-077A	4	COSMOS 1124 DEB *
Cosmos 1094	1979-033A	0	
Cosmos 1109	1979-058A	5	COSMOS 1109 DEB
CAT r/b (Ariane 1 final stage)	1979-104B	0	
Cosmos 1174	1980-030A	7	COSMOS 1174 DEB
Landsat 3 r/b (Delta 2nd stage)	1978-026C	141	DELTA 1 DEB
Cosmos 1261	1981-031A	3	COSMOS 1261 DEB
Cosmos 1191	1980-057A	1	COSMOS 1191 DEB
Cosmos 1167	1980-021A	0	

Cosmos 1275	1981-053A	274	COSMOS 1275 DEB
Cosmos 1305 r/b (SL-6 final stage)	1981-088F	2	SL-6 DEB
Cosmos 1247	1981-016A	3	COSMOS 1247 DEB
Cosmos 1285	1981-071A	2	COSMOS 1285 DEB
Nimbus 7 r/b (Delta 2nd stage)	1978-098B	0	
Cosmos 1220	1980-089A	0	
Cosmos 1306	1981-089A	0	
Cosmos 1260	1981-028A	0	
Cosmos 1286	1981-072A	0	
Cosmos 1423 r/b (SL-6 final stage)	1982-115E	0	
Cosmos 1217	1980-085A	0	
Cosmos 1481	1983-070A	2	COSMOS 1481 DEB
Cosmos 1355	1982-038A	0	
Cosmos 1456	1983-088A	0	
Cosmos 1405	1982-088A	0	
Cosmos 1317	1981-108A	3	COSMOS 1317 DEB
Westar 6 r/b (PAM-D upper stage)	1984-011F	0	
Palapa B2 r/b (PAM-D upper stage)	1984-011E	0	
Astron Ullage motor (SL-12 SOZ)	1983-020B	0	
Cosmos 1461	1983-044A	2	COSMOS 1461 DEB
Cosmos 1654	1985-039A	0	
P-78/Solwind	1979-017A	8	SOLWIND DEB
Cosmos 1375	1982-055A	57	COSMOS 1375 DEB
Cosmos 1691	1985-094B	10	COSMOS 1691 DEB
Cosmos 1714 r/b (SL-16 2nd stage)	1985-121B	0	
NOAA 8	1983-022A	0	
Cosmos 1588	1984-083A	0	
USA 19	1986-069A	0	
USA 19 r/b	1986-069B	0	
Spot 1 r/b (Ariane 1 final stage)	1986-019C	56	ARIANE 1 DEB
Cosmos 1278	1981-058A	1	COSMOS 1278 DEB
Cosmos 1662	1985-082A	0	
Cosmos 1813	1987-004A	0	
Cosmos 1866	1987-059A	0	
Aussat K3/ECS 4 r/b (Ariane 3 FS)	1987-078C	1	ARIANE 3 DEB
Cosmos 1769	1986-059A	0	
Cosmos 1646	1985-030A	0	
Cosmos 1823	1987-020A	42	COSMOS 1823 DEB
Cosmos 1656 ullage motor (SL-12 SOZ)	1985-042E	5	SL-12 DEB
Cosmos 1906	1987-108A	0	
Cosmos 1916	1988-007A	0	
Cosmos 1045 r/b (SL-14 3rd stage)	1978-100D	40	SL-14 DEB
Cosmos 2030	1989-054A	0	
Cosmos 2031	1989-056A	0	
Fengyun 1-2 r/b (CZ-4A final stage)	1990-081D	82	CZ-4 DEB
Cosmos 2101	1990-087A	0	
USA 68	1990-105A	4	USA 68 DEB
Cosmos 1519-21 u.m. (SL-12 SOZ)	1983-127H	3	SL-12 DEB
Cosmos 2125-32 r/b (SL-8 FS)	1991-009J	84	SL-8 DEB
Nimbus 6 r/b (Delta 2nd stage)	1975-052B	190	DELTA 1 DEB
Cosmos 2163	1991-071A	0	
Cosmos 1710-12 u.m. (SL-12 SOZ)	1985-118L	10	SL-12 DEB
OV2-5 r/b (Titan Transtage)	1968-081E	0	
Cosmos 2054 ullage motor (SL-12 SOZ)	1989-101E	1	COSMOS 2054 DEB
Cosmos 1603 ullage motor (SL-12 SOZ)	1984-106F	0	
Gorizont 17 ullage motor (SL-12 SOZ)	1989-004E	0	
Cosmos 2227 r/b (SL-16 2nd stage)	1992-093B	217	SL-16 DEB
Gorizont 18 ullage motor (SL-12 SOZ)	1989-052F	0	
Cosmos 2225	1992-091A	0	
Cosmos 2237 r/b (SL-16 2nd stage)	1993-016B	30	SL-16 DEB
Telecom 2B/Inmarsat 2 r/b (Ariane 4)	1992-021C	12	ARIANE 44L DEB
Cosmos 2243	1993-028A	0	
Cosmos 1484	1983-075A	9	COSMOS 1484 DEB
Cosmos 2262	1993-057A	0	
Clementine r/b (Titan 23G)	1994-004B	0	
OPS 9331-34 r/b (Titan Transtage)	1967-066G	0	
Astra 1B/MOP 2 r/b (Ariane 4 H10)	1991-015C	3	ARIANE 44LP DEB
Cosmos 2133 ullage motor (SL-12 SOZ)	1991-010D	0	
Cosmos 2204-06 u.m. (SL-12 SOZ)	1992-047A	1	SL-12 DEB
RS-15 r/b (Briz)	1994-085B	20	SL-19 DEB
ETS-VI r/b (H-II 2nd stage)	1994-056B	0	ETS 6 DEB
Elektro ullage motor (SL-12 SOZ)	1994-069E	0	
Cosmos 2282 ullage motor (SL-12 SOZ)	1994-038F	0	
Gorizont 22 ullage motor (SL-12 SOZ)	1990-102E	0	

HISTORY OF ON-ORBIT FRAGMENTATIONS (1961-August 1997)

DEFINITION OF PARAMETERS

NE	Fragmentation event in order of time
SATNO	USSPACECOM Number
E_D	Epoch of the event
MASS	Breakup object mass in kg
PRE-EVENT OSCULATING ORBITAL ELEMENTS OF THE PARENT BODY	
SMA	Semimajor axis in km
ECC	Eccentricity
INC	Inclination in deg
RAN	Right ascension of the ascending node
AP	Perigee argument in deg
MA	Mean anomaly in deg
OBJECT	Name of the breakup object

BREAKUPS OF ROCKET BODIES

16 BREAKUPS OF SL-12 SOZ

NE	SATNO	E_D	MASS (kg)	SMA (km)	ECC	INC (deg)	RAN (deg)	AP (deg)	MA (deg)	OBJECT
3 BREAKUPS IN LEO ORBIT										
1	13902	3 sep 84	56.	7102.6	0.0702	51.72	90.54	248.48	312.01	Astron ullage motor (SL-12 SOZ)
2	15773	5 jan 88	56.	7211.5	0.0025	66.50	198.74	264.79	183.53	Cosmos 1656 ullage motor (SL-12 SOZ)
6	15338	5 sep 92	56.	7217.3	0.0011	66.54	352.31	50.64	181.42	Cosmos 1603 ullage motor (SL-12 SOZ)
4 BREAKUPS IN GLONASS TRANSFER ORBIT										
3	14608	4 feb 91	56.	15952.4	0.5781	52.14	131.15	316.97	201.01	Cosmos 1519-21 ullage motor (SL-12 SOZ)
4	16446	29 dec 91	56.	16143.4	0.5650	65.43	37.16	243.88	337.53	Cosmos 1710-12 ullage motor (SL-12 SOZ)
10	22067	8 nov 94	56.	16135.6	0.5749	64.85	65.20	316.80	217.05	Cosmos 2204-06 ullage motor (SL-12 SOZ)
15	18374	30 nov 96	56.	16121.4	0.5839	64.90	299.57	180.62	312.06	Cosmos 1883-85 ullage motor (SL-12 SOZ)

9 BREAKUPS IN GEOSYNCHRONOUS TRANSFER ORBIT

5	20399	1 jul 92	56.	20353.4	0.6704	46.95	305.19	319.33	9.57	Cosmos 2054 ullage motor (SL-12 SOZ)
7	19771	18 dec 92	56.	15253.0	0.5693	46.48	264.90	354.82	10.57	Gorizont 17 ullage motor (SL-12 SOZ)
8	20116	12 jan 93	56.	21874.5	0.6976	46.56	212.03	47.85	309.00	Gorizont 18 ullage motor (SL-12 SOZ)
9	21114	7 may 94	56.	17394.5	0.6204	46.83	109.38	161.43	211.96	Cosmos 2133 ullage motor (SL-12 SOZ)
11	23338	11 may 95	56.	24188.1	0.7299	46.71	200.00	300.00	200.00	Elektro ullage motor (SL-12 SOZ)
12	23174	21 oct 95	56.	23990.2	0.7222	46.97	157.14	127.94	322.60	Cosmos 2282 ullage motor (SL-12 SOZ)
13	20957	14 dec 95	56.	12911.7	0.4944	46.50	140.58	117.08	93.62	Gorizont 22 ullage motor (SL-12 SOZ)
14	23797	19 feb 96	56.	24798.6	0.7321	48.58	282.00	0.00	178.00	Raduga 33 ullage motor (SL-12 SOZ)
16	18719	22 may 97	56.	18020.6	0.6289	46.60	-	-	-	Ekran 17 ullage motor (SL-12 SOZ)

9 BREAKUPS OF DELTA 2ND STAGE IN LEO

NE	SATNO	E_D	MASS (kg)	SMA (km)	ECC	INC (deg)	RAN (deg)	AP (deg)	MA (deg)	OBJECT
1	6921	28 dec 73	924.	7881.9	0.0013	102.14	44.20	112.95	207.95	NOAA 3 r/b (Delta 2nd stage)
2	6127	22 may 75	924.	7146.2	0.0200	98.30	196.22	40.09	287.14	Landsat 1 r/b (Delta 2nd stage)
3	7532	20 aug 75	924.	7828.3	0.0018	101.55	277.87	69.15	165.80	NOAA 4 r/b (Delta 2nd stage)
4	7616	9 feb 76	924.	7202.1	0.0121	97.76	95.58	142.68	353.54	Landsat 2 r/b (Delta 2nd stage)
5	10144	14 jul 77	924.	7663.3	0.0977	28.90	270.58	52.56	86.84	Himawari 1 r/b (Delta 2nd stage)
6	9063	24 dec 77	924.	7889.1	0.0016	102.12	42.09	54.32	263.71	NOAA 5 r/b (Delta 2nd stage)
7	10704	27 jan 81	924.	7282.6	0.0009	99.01	68.58	127.76	145.76	Landsat 3 r/b (Delta 2nd stage)
8	11081	26 dec 81	924.	7320.3	0.0020	99.13	277.15	68.70	16.04	Nimbus 7 r/b (Delta 2nd stage)
9	7946	1 may 91	924.	7473.4	0.0015	99.46	336.90	103.67	326.65	Nimbus 6 r/b (Delta 2nd stage)

6 BREAKUPS OF ARIANE FS

NE	SATNO	E_D	MASS (kg)	SMA (km)	ECC	INC (deg)	RAN (deg)	AP (deg)	MA (deg)	OBJECT
1 BREAKUP IN LEO										
2	16615	13 nov 86	1400.	7193.3	0.0027	98.76	30.15	43.64	325.69	Spot 1 r/b (Ariane 1 final stage)
5 BREAKUPS IN GEOSYNCHRONOUS TRANSFER ORBIT										
1	11659	15 apr 80	1400.	22990.5	0.7151	18.07	93.17	279.47	155.02	CAT r/b (Ariane 1 FS)
3	18352	19 sep 87	1200.	24767.9	0.7333	6.95	175.44	181.96	222.02	Aussat K3/ECS 4 r/b (Ariane 3 FS)
4	21941	21 apr 93	1240.	24318.4	0.7245	3.44	223.61	111.79	169.56	Telecom 2B/Inmarsat 2 r/b (Ariane 4 H10)
5	21141	17 apr 94	1240.	20927.7	0.6824	6.74	139.15	177.67	0.50	Astra 1B/MOP 2 r/b (Ariane 4 H10)
6	21057	1 may 96	1240.	21974.2	0.6990	6.64	96.14	149.23	37.77	Eutelsat-II-F2 r/b (Ariane 4 H10)

Raduga 33 ullage motor (SL-12 SOZ)	1996-010D	0	
Eutelsat-II-F2 r/b (Ariane 4 H10)	1991-003C	0	
STEP M2 r/b (HAPS)	1994-029B	515	PEGASUS DEB
Cerise	1995-033B	1	CERISE DEB
Cosmos 1883-85 u.m. (SL-12 SOZ)	1987-079G	0	

History of on-orbit fragmentations (1961 - August 31, 1997)

TABLE 28

BREAKUP CHARACTERISTICS

BREAKUPS OF ROCKET BODIES

- 16 BREAKUPS OF SL-12 SOZ

⇒ 3 IN LEO
⇒ 4 IN GLONASS TRANSFER ORBIT
⇒ 9 IN GEOSYNCHRONOUS TRANSFER ORBIT

- 9 BREAKUPS OF DELTA 2nd STAGE IN LEO

- 6 BREAKUPS OF THE ARIANE FINAL STAGE

⇒ 1 IN LEO
⇒ 5 IN GEOSYNCHRONOUS TRANSFER ORBIT

- 31 BREAKUPS OF VARIOUS ROCKET BODIES

⇒ 2 IN GEOSTATIONARY ORBIT
⇒ 2 IN ELLIPTICAL ORBIT
⇒ 27 IN LEO ORBIT

BREAKUPS OF SATELLITES

- 1 IN GEOSTATIONARY ORBIT

- 16 EARLY WARNING SATELLITES IN ELLIPTICAL ORBIT

- 18 PHOTORECONNAISSANCE SATELLITES IN LEO

- 13 ASAT TESTS IN LEO

- 17 EORSAT IN LEO

- 9 OTHER RUSSIAN SATELLITES IN LEO

- 6 OTHER SATELLITES (5 IN LEO, 1 IN ELLIPTICAL ORBIT)

31 BREAKUPS OF VARIOUS ROCKET BODIES

NE	SATNO	E_D	MASS (kg)	SMA (km)	ECC	INC (deg)	RAN (deg)	AP (deg)	MA (deg)	OBJECT
2 BREAKUPS IN GEOSTATIONARY ORBIT										
24	3432	21 feb 92	3130.	41835.7	0.0085	11.99	22.27	75.71	246.64	OV2-5 r/b (Titan Transtage)
28	2868	8 feb 94	3130.	39840.6	0.0053	11.70	307.63	129.58	109.93	OPS 9331-34 r/b (Titan Transtage)
2 BREAKUPS IN ELLIPTICAL ORBIT										
14	12827	11 sep 81	1976.	13577.7	0.4852	62.97	70.77	286.57	286.53	Cosmos 1305 r/b (SL-6 final stage)
30	23231	31 mar 95	3000.	18543.1	0.6490	28.50	7.08	16.22	0.00	ETS-VI r/b (H-II 2nd stage)
27 BREAKUPS IN LEO ORBIT										
1	118	29 jun 61	625.	7316.1	0.0070	66.88	96.15	296.38	206.16	Transit 4A r/b (Ablestar stage)
2	443	29 oct 62	1976.	6608.1	0.0055	65.09	320.83	89.97	157.59	Sputnik 29 r/b (SL-6 final stage)
3	694	27 nov 63	4600.	7512.3	0.0873	30.40	163.86	106.25	150.12	Centaur AC-2 r/b (Centaur stage)
4	1270	15 mar 65	1443.	7420.6	0.1065	56.05	357.78	105.60	136.53	Cosmos 61-63 r/b (SL-8 2nd stage)
5	1640	15 oct 65	3130.	7091.3	0.0071	32.20	84.67	194.12	115.81	OV2-1-LCS 2 r/b (Titan 3C-4 Transtage)
6	2188	15 jun 66	3400.	6641.6	0.0028	28.74	215.72	138.79	74.64	Gemini 9 ATDA r/b (Atlas core stage)
7	2289	5 jul 66	6600.	6581.6	0.0024	31.99	4.40	22.27	125.47	AS-203 r/b (Saturn S-IVB stage)
8	3171	13 apr 68	0.	6663.8	0.0115	32.59	290.63	284.30	307.18	Apollo 6 r/b (Saturn S-IVB stage)
9	3836	28 mar 69	1100.	7031.9	0.0277	81.23	32.55	180.68	306.80	Meteor 1-1 r/b (SL-3 final stage)
10	4052	26 jul 69	1100.	9231.8	0.2794	30.45	132.62	183.37	359.50	Intelsat 3 F-5 r/b (TE 364-4 stage)
11	4159	4 oct 69	600.	7380.6	0.0127	69.86	279.98	107.91	11.45	OPS 7613 r/b (Agena D stage)
12	4367	17 oct 70	600.	7450.4	0.0013	99.83	204.07	180.33	127.93	Nimbus 4 r/b (Agena D stage)
13	6399	3 apr 73	4185.	6597.9	0.0039	51.42	332.55	16.50	95.91	Salyut 2 r/b (SL-13 3rd stage)
15	13696	8 dec 82	1976.	6707.6	0.0152	62.82	315.84	58.28	220.38	Cosmos 1423 r/b (SL-6 final stage)
16	14694	3 feb 84	30.	6689.5	0.0004	28.54	156.37	5.23	354.11	Westar 6 r/b (PAM-D upper stage)
17	14693	6 feb 84	30.	6663.6	0.0002	28.59	135.79	323.34	39.95	Palapa B2 r/b (PAM-D upper stage)
18	16435	28 dec 85	8300.	6877.1	0.0484	71.00	282.00	0.00	178.00	Cosmos 1714 r/b (SL-16 2nd stage)
19	16938	5 sep 86	1455.	6798.6	0.0291	22.82	19.47	39.05	359.77	USA 19 r/b
20	11087	9 may 88	1407.	8069.5	0.0020	82.55	353.47	74.28	134.16	Cosmos 1045 r/b (SL-14 3rd stage)
21	20791	4 oct 90	1000.	7265.0	0.0013	98.76	288.90	131.78	137.17	Fengyun 1-2 r/b (CZ-4A final stage)
22	20978	1 dec 90	855.	7167.4	0.0081	98.87	3.43	6.38	165.74	USA 68 r/b (TE-M-364-15 upper stage)
23	21108	5 mar 91	1443.	7970.6	0.0159	74.10	163.40	241.50	72.96	Cosmos 2125-32 r/b (SL-8 final stage)
25	22285	26 dec 92	8300.	7226.7	0.0015	70.85	226.79	83.72	347.99	Cosmos 2227 r/b (SL-16 2nd stage)
26	22566	28 mar 93	8300.	7223.1	0.0003	70.76	260.31	75.22	8.15	Cosmos 2237 r/b (SL-16 2nd stage)
27	22974	7 feb 94	2860.	6610.4	0.0033	67.18	45.80	135.08	113.33	Clementine r/b (Titan II G)
29	23440	26 dec 94	1120.	8418.2	0.0190	64.80	83.74	283.80	273.88	RS-15 r/b (Briz)
31	23106	3 jun 96	97.	7081.8	0.0153	81.97	342.00	210.00	35.00	STEP M2 r/b (Pegasus HAPS)

BREAKUPS OF SATELLITES

1 BREAKUP IN GEOSTATIONARY ORBIT

NE	SATNO	E_D	MASS (kg)	SMA (km)	ECC	INC (deg)	RAN (deg)	AP (deg)	MA (deg)	OBJECT
1	10365	23 jun 78	1750.	42183.7	0.0001	8.93	315.03	34.69	211.58	Ekran 2

16 BREAKUPS OF EARLY WARNING SATELLITES (CIS) IN ELLIPTICAL ORBIT

NE	SATNO	E_D	MASS (kg)	SMA (km)	ECC	INC (deg)	RAN (deg)	AP (deg)	MA (deg)	OBJECT
1	9495	15 mar 77	1250.	26586.8	0.7305	63.28	97.29	318.67	13.00	Cosmos 862
2	10150	24 oct 77	1250.	26537.4	0.7330	62.74	304.27	318.79	7.34	Cosmos 931
3	9911	8 jun 78	1250.	26556.8	0.7103	63.32	114.88	319.86	107.57	Cosmos 903
4	11015	10 oct 78	2030.	26590.9	0.7338	62.78	335.62	318.39	226.22	Cosmos 1030
5	10059	30 mar 79	1250.	26596.0	0.6973	63.04	155.63	322.53	352.18	Cosmos 917
6	11509	9 sep 79	2030.	26565.5	0.7375	62.78	287.48	318.37	16.50	Cosmos 1124
7	11417	15 feb 80	2030.	26569.5	0.7230	63.51	104.38	318.53	172.91	Cosmos 1109
8	12376	1 may 81	1250.	26571.3	0.7360	62.87	278.51	316.59	117.43	Cosmos 1261
9	11871	14 may 81	1800.	26562.9	0.7170	62.63	197.92	319.70	314.13	Cosmos 1191
10	12303	20 oct 81	1250.	26559.1	0.7230	62.95	213.69	318.47	241.71	Cosmos 1247
11	12627	21 nov 81	1250.	26787.2	0.7350	63.03	248.93	317.15	238.55	Cosmos 1285
12	12032	12 feb 83	1800.	26558.1	0.7022	65.20	257.98	274.70	165.47	Cosmos 1217
13	14182	9 jul 83	1250.	26301.5	0.7340	62.93	165.82	318.12	109.51	Cosmos 1481
14	14034	13 aug 83	1250.	26518.7	0.7315	63.44	79.51	319.95	3.75	Cosmos 1456
15	12933	28 jan 84	1250.	26563.3	0.7099	62.61	218.66	324.38	37.79	Cosmos 1317
16	12547	1 dec 86	1250.	26553.7	0.6599	66.94	287.49	291.95	214.72	Cosmos 1278

18 BREAKUPS OF PHOTORECONNAISSANCE SATELLITES (CIS) IN LEO

NE	SATNO	E_D	MASS (kg)	SMA (km)	ECC	INC (deg)	RAN (deg)	AP (deg)	MA (deg)	OBJECT
1	919	5 nov 64	4730.	6589.2	0.0033	51.21	163.40	354.64	318.55	Cosmos 50
2	3099	24 jan 68	4730.	6658.0	0.0120	65.60	18.28	31.07	17.16	Cosmos 199
3	6432	6 may 73	6000.	6634.6	0.0142	72.74	303.56	25.41	239.51	Cosmos 554
4	8191	6 sep 75	6000.	6624.8	0.0124	67.12	188.66	69.01	326.55	Cosmos 758
5	9046	25 jul 76	6000.	6638.6	0.0146	67.21	151.39	71.68	52.34	Cosmos 844
6	9614	29 dec 76	6300.	6608.0	0.0106	65.00	228.85	117.59	11.87	Cosmos 884
7	15734	21 jun 85	6000.	6617.5	0.0094	64.86	359.26	51.70	317.38	Cosmos 1654
8	17297	29 jan 87	6000.	6762.2	0.0044	72.62	255.47	167.44	281.38	Cosmos 1813
9	18184	26 jul 87	6000.	6580.8	0.0083	67.36	98.11	65.26	230.50	Cosmos 1866
10	18713	31 jan 88	6000.	6629.3	0.0023	82.38	253.48	125.54	63.89	Cosmos 1906
11	18823	27 feb 88	6000.	6565.3	0.0067	64.62	263.87	57.14	18.24	Cosmos 1916
12	20124	28 jul 89	6000.	6556.3	0.0055	67.37	88.57	63.45	354.07	Cosmos 2030
13	20136	31 aug 89	6000.	6683.2	0.0101	50.35	242.21	58.58	61.14	Cosmos 2031
14	20828	30 nov 90	6000.	6614.9	0.0070	64.70	346.52	147.19	331.10	Cosmos 2101
15	21741	6 dec 91	6000.	6597.9	0.0060	64.91	36.10	138.81	337.06	Cosmos 2163
16	22280	18 feb 93	6000.	6610.9	0.0043	65.09	91.81	107.46	7.08	Cosmos 2225
17	22641	27 apr 93	6000.	6606.9	0.0055	70.55	56.77	82.07	349.81	Cosmos 2243
18	22789	18 dec 93	6000.	6602.2	0.0075	64.75	208.49	69.53	21.43	Cosmos 2262

13 BREAKUPS OF ASAT (CIS) IN LEO

NE	SATNO	E_D	MASS (kg)	SMA (km)	ECC	INC (deg)	RAN (deg)	AP (deg)	MA (deg)	OBJECT
1	3504	20 oct 68	1400.	7703.4	0.1098	62.42	118.76	76.78	220.40	Cosmos 249
2	3530	1 nov 68	1400.	7715.1	0.1051	62.44	77.62	73.67	358.27	Cosmos 252
3	3503	1 nov 68	3500.	6884.8	0.0042	62.35	77.29	305.17	165.99	Cosmos 248
4	4594	23 oct 70	1400.	7701.8	0.1040	62.94	129.10	60.50	285.58	Cosmos 374
5	4598	30 oct 70	1400.	7689.9	0.1031	62.92	104.70	56.03	8.06	Cosmos 375
6	4964	25 feb 71	1400.	7765.3	0.1055	65.75	355.11	50.94	9.70	Cosmos 397
7	5646	3 dec 71	1400.	7392.7	0.1072	65.64	297.12	54.13	4.84	Cosmos 462
8	9634	27 dec 76	1400.	7823.0	0.1084	65.72	336.91	198.79	113.30	Cosmos 886
9	9011	29 sep 77	650.	7917.0	0.0705	66.01	82.06	351.04	231.73	Cosmos 839
10	10531	21 dec 77	1400.	7419.3	0.0138	65.69	281.68	114.60	203.92	Cosmos 970
11	9601	27 nov 78	650.	6962.6	0.0042	65.88	10.38	311.18	314.26	Cosmos 880
12	11765	18 apr 80	1400.	7395.7	0.0858	65.96	251.07	248.42	160.94	Cosmos 1174
13	13259	21 oct 85	650.	7372.4	0.0013	65.80	349.15	67.51	21.41	Cosmos 1375

17 BREAKUPS OF EORSAT (CIS) IN LEO

NE	SATNO	E_D	MASS (kg)	SMA (km)	ECC	INC (deg)	RAN (deg)	AP (deg)	MA (deg)	OBJECT
1	7587	2 aug 75	3000.	6804.5	0.0012	64.90	273.26	308.47	232.89	Cosmos 699
2	8416	25 jan 76	3000.	6812.6	0.0001	64.90	302.64	80.64	342.90	Cosmos 777
3	8932	17 may 77	3000.	6805.6	0.0012	65.17	129.36	299.44	250.85	Cosmos 838
4	11333	17 sep 79	3000.	6769.8	0.0009	64.88	271.12	327.85	275.28	Cosmos 1094
5	11729	15 jul 81	3000.	6779.8	0.0059	65.02	173.78	245.21	126.18	Cosmos 1167
6	12054	20 jun 82	3000.	7103.7	0.0219	64.92	329.94	0.18	190.31	Cosmos 1220
7	12828	12 jul 82	3000.	6769.4	0.0011	65.06	40.96	302.47	333.35	Cosmos 1306
8	12364	10 aug 82	3000.	6976.4	0.0211	65.15	45.11	296.08	184.34	Cosmos 1260
9	12631	29 sep 82	3000.	6689.7	0.0007	65.14	132.47	263.77	155.20	Cosmos 1286
10	13150	8 aug 83	3000.	6754.8	0.0015	64.87	276.37	307.11	17.07	Cosmos 1355
11	13508	20 dec 83	3000.	6701.4	0.0016	65.16	124.63	346.08	223.42	Cosmos 1405
12	14064	13 may 85	3000.	7104.9	0.0215	65.00	331.39	232.32	137.76	Cosmos 1461
13	15167	23 feb 86	3000.	6799.6	0.0013	64.83	246.84	296.20	95.89	Cosmos 1588
14	16054	18 dec 86	3000.	6807.2	0.0075	64.93	333.86	49.98	285.79	Cosmos 1682
15	16895	21 sep 87	3000.	6755.0	0.0090	65.19	119.66	290.19	325.56	Cosmos 1769
16	15653	20 nov 87	3000.	6775.7	0.0009	64.83	285.30	237.68	215.82	Cosmos 1646
17	23596	26 jun 97	3000.	6645.6	0.0087	65.00	-	-	-	Cosmos 2313

9 BREAKUPS OF OTHER RUSSIAN SATELLITES IN LEO

NE	SATNO	E_D	MASS (kg)	SMA (km)	ECC	INC (deg)	RAN (deg)	AP (deg)	MA (deg)	OBJECT
1	1093	22 feb 65	5682.	6672.1	0.0192	64.66	299.73	70.91	132.05	Cosmos 57
2	1706	15 jan 66	325.	6743.2	0.0230	48.40	359.87	265.27	172.94	Cosmos 95
3	2437	17 sep 66	3000.	6983.4	0.0638	49.59	342.60	78.99	326.43	Cosmos U-1
4	2536	2 nov 66	3000.	6893.8	0.0542	49.61	54.91	83.61	68.46	Cosmos U-2
5	12504	24 jul 81	800.	7362.5	0.0044	83.11	118.98	127.62	302.30	Cosmos 1275
6	16139	22 nov 85	220.	7790.0	0.0007	82.56	341.08	95.56	52.42	Cosmos 1691
7	17535	17 dec 87	1500.	7878.6	0.0025	73.59	183.86	194.54	2.19	Cosmos 1823
8	14207	18 oct 93	30.	6947.4	0.0027	97.35	317.36	328.95	22.85	Cosmos 1484
9	16609	25 jun 97	125000.	6760.1	0.0010	51.65	-	-	-	Space Station Mir

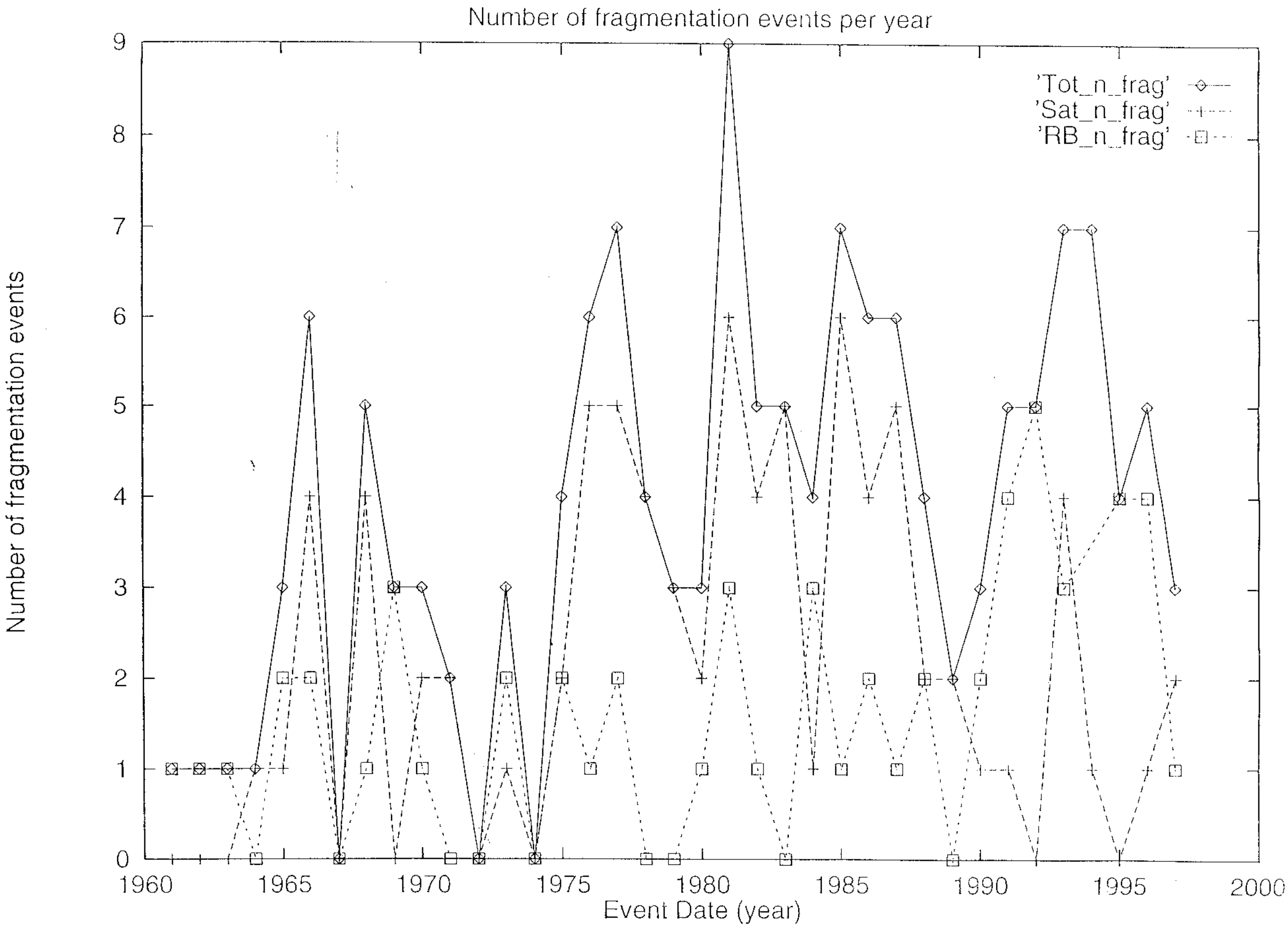
6 BREAKUPS OF OTHER SATELLITES (5 OF WHICH IN LEO)

NE	SATNO	E_D	MASS (kg)	SMA (km)	ECC	INC (deg)	RAN (deg)	AP (deg)	MA (deg)	OBJECT
1	2015	15 feb 66	4.	6594.4	0.0117	96.59	147.42	127.02	68.79	OPS 3031
2	2253	20 jan 76	55.	10555.6	0.1187	85.00	209.49	66.58	334.73	Pageos
3	11278	13 sep 85	850.	6906.0	0.0033	97.63	182.21	96.14	300.96	P-78/Solwind
4	13923	30 dec 85	1000.	7192.3	0.0010	98.70	32.30	190.24	57.79	NOAA 8
5	16937	5 sep 86	930.	6872.3	0.0407	39.16	39.27	12.59	8.39	USA 19
6	23606	24 jul 96	50.	7049.1	0.0017	98.01	141.79	48.51	271.19	Cerise

ANNEX B

History of on-orbit fragmentations (1961 - August 31, 1997)

FIGURE 1. Number of Fragmentation Events by Year



Number of fragmentation events per year
Number of fragmentation events
Event Date (year)
'Tot_n_frag'
'Sat_n_frag'
'RB_n_frag'
0
1
2
3
4
5
6
7
8
9
1960
1965
1970
1975
1980
1985
1990
1995
2000