# THE MASTER 2005 MODEL

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## ABSTRACT

The Meteoroid and Space Debris Terrestrial Environment Reference Model of the European Space Agency, ESA-MASTER, is currently being developed to its next release, MASTER$^{2005}$. The contract for the upgrade was awarded to the Institute of Aerospace Systems at the Technische Universitaet Braunschweig together with QinetiQ. This paper will focus on the changes to the flux browser, and it will explain the validation process for the new MASTER population. MASTER$^{2005}$ will be delivered with a single flux browser, the MASTER application. This new software will cover all the functionalities that had previously been covered by the two flux browsers delivered with previous versions of the software. By following a statistical approach for all populations, the storage volume for the databases could be kept at a reasonable size while increasing fidelity. Within seconds, the new MASTER application can deliver precise fluxes, making an engineering model undesirable and obsolete. The validation of the MASTER$^{2005}$ reference population will be based on both impact data and observations. For the validation of the small-sized debris population, impact data from the Eureca and LDEF satellites as well as from the Hubble Space Telescope solar panels retrieved during service missions 1 and 3B are used. Some of the results of the LDEF chemistry of micrometeoroids experiment had been the motivation for significant changes especially in small particle modelling within MASTER$^{2005}$. To validate the larger particles, radar and optical observations data are used. Here, data sources include the TIRA, Haystack, and Goldstone radars as well as the ESA Space Debris Telescope.

Key words: Modelling; MASTER.

## 1. MODEL UPGRADES

MASTER$^{2005}$ will feature major changes in the population generation mechanisms, the flux derivation mechanism, and the user interface. The majority of the underlying models for the space debris population generation tool POEM have been modified. The breakup model currently implemented in MASTER was extended to improve the properties of the fragments below 1 mm. This could be accomplished by re-defining the area-to-mass and velocity distributions for small particles. Another upgrade of POEM includes the introduction of a scientifically justified approach to model the size distribution of NaK droplets released during RORSAT reactor core ejections. The parameters of the size distribution function are derived from physical relations only and are confirmed by recent observations of NASA. Another major upgrade of POEM included the SRM slag size distribution. Here, a nozzle throat diameter dependency was introduced to accommodate a more precise modelling of SRM slag release events. Upgrades also included a major review the of models for paint flakes and ejecta.

### 1.1. NaK Droplets

NaK droplets consist of eutectic sodium-potassium alloy and have been released during RORSAT reactor core ejections mostly on orbits close to 950 km altitude. They contributed to the space debris environment in the centimeter and millimeter size regime. The new NaK model gives estimations of the parameters of the size distribution function, which are based on physical relations only. The core ejection causes an opening of the primary coolant circuit. The liquid coolant is released into space forming droplets up to a diameter of 5.67 cm. It is likely that the droplet generation process can be both capillary jet breakup and atomization.

A droplet size distribution is introduced, which is scientifically justified. The physical process of atomization resp. liquid jet breakup is considered, to derive the parameters of the size distribution function. The droplet size can be defined as function of the orifice diameter. The droplet sizes are related to the parameters of the size distribution function. The size distribution function shall contain only two parameters, which can be derived from the orifice diameter and the atomization conditions. In this

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way scientifically based estimations of the parameters are introduced. An estimation of the maximum droplet diameter assuming capillary jet breakup has been performed. The minimum droplet diameter is estimated to be one order of magnitude smaller than the orifice diameter, assuming effervescent atomization. A bimodal size distribution is derived, which is based on the Rosin-Rammler equation. The Rosin-Rammler equation is an empirical volume distribution function. The number of parameters is limited to two. It is likely that the coolant system contains two types of orifice diameters. This makes it necessary to apply the Rosin-Rammler distribution twice, resulting in a bimodal size distribution with altogether four parameters.

#### 1.1.1. Droplet Generation

Two different mechanisms of liquid jet breakup are considered here. One is the capillary jet breakup which is used to estimate the maximum droplet size. The other is the effervescent atomization which is used to estimate the smallest droplet size. It is likely that both processes occur together. Liquid jet disintegration can be divided into two categories:

- Capillary breakup: The Rayleigh mechanism forms droplets with a mean diameter in the order of the jet diameter. Maximum droplet diameter is twice the jet diameter.
- Formation of fibrous ligaments caused by gas bubble expansion: Fibrous round jets are formed at the orifice. They break into droplets via Rayleigh mechanism. Droplet diameters are considerably (one order of magnitude) smaller than the orifice diameter.

Further breakup mechanisms may occur which are not considered here, because they cannot be modelled sufficiently. There may be collisions of droplets with the casing of the reactor or with other droplets. This may cause a wider spreading of droplet sizes. These processes are neglected in detail. But the spreading is considered by estimating the smallest and largest droplet size and allowing the droplets in between these boundaries to follow the Rosin-Rammler size distribution. In this way it is hoped to cover neglected breakup mechanisms.

#### 1.1.2. Droplet Size Distribution

As a size distribution function, the Rosin-Rammler distribution will be implemented in the NaK source model of MASTER$^{2005}$. The Rosin-Rammler equation is often used in atomization studies to describe experimentally measured droplet size distributions. Today it is the most widely used expression for droplet distributions. There is no evidence for a physical meaning of the equation, except that it fits to measured data.

### 1.2. SRM Dust

The validation of the MASTER debris population confirmed that the raw generation model generally renders good results in terms of flux distribution quality. However, it could also be shown that there exists a clear under-prediction of the flux quantity for at least some of the modelled source terms. Measurements obtained from space returned hardware now allow for a more precise validation of the SRM particle generation mechanisms. This is going to be done in the course of the MASTER$^{2005}$ project.

#### 1.2.1. SRM Dust Size Distribution

Fundamental publications related to the modelling of SRM dust originate from the publications of Mueller and Kessler (Mueller and Kessler, 1985) as well as Akiba and Inatani (Akiba and Inatani, 1990). Mueller and Kessler's assumptions are based on investigations with the PAM-A (Payload Assist Module) motor originally performed by Burris (Burris, 1978), and are then applied to the IUS (Inertial Upper Stage) and SSUS (Spinning Solid Upper Stage) motors. The resulting distribution function is a fit to experimental data of Varsi (Varsi, 1977). Akiba and Inatani have performed many ground- and in-flight tests using ISAS motors (Institute of Space and Astronautical Science) and two-phase flow analysis to obtain sampling data. The distribution function postulated by Akiba and Inatani exists only in raw-data format.

A comparison of the distributions shows that both models expose fundamental differences in the share of large dust particles greater than about $0.5\,\mu$m. Akiba and Inatani find a certain dependency of the distribution of such particles on the nozzle throat diameter and thus on the size of the motor. The distribution postulated by Mueller and Kessler remains several orders of magnitude below the data of even the smallest engine investigated by Akiba and Inatani.

A viable solution for the diameter distribution is an approximation by two sections of an exponential law approach below and above a certain switch particle diameter $d^{\circ}$. The distribution function currently used by the SRM dust module in MASTER$^{2001}$ is written as the normalised object number and can be interpreted as the fraction of objects larger than a certain diameter:

$$\hat{N}_d(d) = \begin{cases} e^{-b_1 d} & \forall\, d \le d^\circ \\ e^{b_2(d^\circ - d) - b_1 d^\circ} & \forall\, d > d^\circ \end{cases} \qquad (1)$$

$$\begin{aligned} \hat{N}_d &= \text{Normalised object number} \\ d &= \text{Object diameter } [\mu\text{m}] \\ d^\circ &= \text{Switch diameter } [\mu\text{m}] \\ b_1, b_2 &= \text{Function parameters } [1/\mu\text{m}]\,. \end{aligned}$$

The database presented by Akiba and Inatani seems to be more reliable than the report to which Mueller and Kessler refer, because it is based on their own analysis. Therefore, it has been chosen to adopt the slope of the sampling motor distribution for very small dust particles below 1.5 $\mu$m. Since the model is intended as a generic approach to the historic SRM dust generation, the distribution also has to reflect larger particles as generated by huge orbital stages like the IUS. Therefore, the distribution is continued using the slope of the larger motors investigated by Akiba and Inatani. This is additionally supported by results of Hörz (Hörz et al.,2002), who found evidence for aluminium oxide dust particles clustering on the nozzle surface. This leads to larger aggregates being continuously shed throughout the burn. Therefore, the default dust size distribution model calls for the function parameters being set to:

$$b_1 = 2.0 \frac{1}{\mu\text{m}} \qquad b_2 = 0.5 \frac{1}{\mu\text{m}} \qquad d^\circ = 1.5\,\mu\text{m}\,. \quad (2)$$

More detailed information on the implementation of an SRM particle generation approach into the MASTER model can be found in Wegener (Wegener,1999).

### 1.3. Fragmentations

Until the end of 2003, a total of 179 fragmentation events (Johnson, 1985) in Earth orbit have been recorded (Johnson et al., 2004), making this one of the most important debris sources to be considered. Simulations show that about 100 tons of debris generated during these events are still in orbit. As far as space debris objects above 1 mm diameter are concerned, fragments are the most important debris source in most of the LEO region and the GEO region.

Until the '99 version of MASTER the Battelle breakup model was used. It was succeeded by the NASA breakup model (Johnson et al., 2000; Bade et al., 2000) that was first implemented in the 2001 version (Krag et al., 2002) of MASTER (Wegener et al., 2001). While the new fragmentation model showed a good alignment with measurement results gained by radars and optical devices for diameters above 5 mm, the application of that breakup model for the small-sized population in MASTER showed some problems to be mentioned below in more detail.

#### 1.3.1. Review of the A/m Distribution

The most critical shortcoming of the current implementation of the MASTER breakup model is its postulation of ultra-dense particles in the sub-millimetre regime. The shortcoming can be overcome by a re-definiton of the area-to-mass distribution for small particles. Currently, the breakup model assumes a constant mean value. A formulation increasing to lower diameters has to be defined instead.

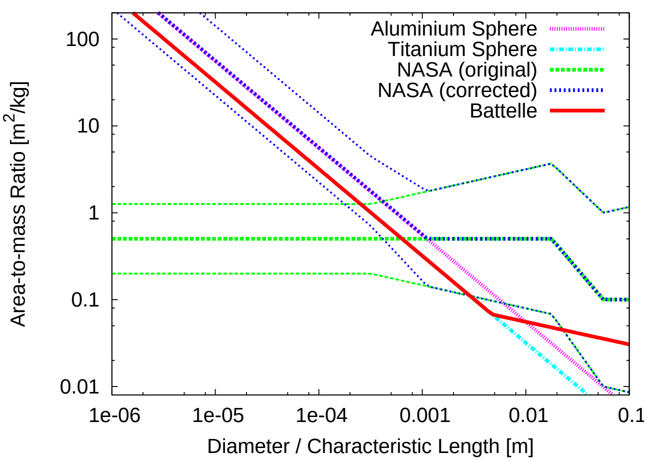


*Figure 1. Comparison of original and corrected NASA area-to-mass ratio with the Battelle breakup model and a pure aluminium or titanium sphere*

As it can be seen in Fig. 1, the correction encloses the Battelle model's assumption of a titanium sphere as a near-borderline special case.

## 2. THE MASTER FLUX BROWSER

The new MASTER flux browser will combine the benefits of a precision analysis tool with that of an engineering application. In previous versions of MASTER, two flux browsers delivering differing results were delivered. This was confusing to the user. But at that time an additional engineering application had been the only way to deliver flux data for all epochs from 1957 to 2050 with reasonable storage volume. With the introduction of the new MASTER flux browser this is no longer the case. The high speed and reasonable storage volume required make a seperate engineering application obsolete.

## 2.1. Statistical Approach

The statistical approach for the new MASTER flux browser is based on the stochastical reproduction of objects following a multi-dimensional probability table, thus also considering cross-couplings betweeen the coded quantities. The probability table contains information on perigee radius, eccentricity, inclination, argument of perigee, and object diameter, hence being five-dimensional.

The database files containing that probability table are generated by the developer branch software tool PROBDENS, which analyses the multi-dimensional distribution of the coded quantities when processing MASTER population files. The resulting 5D probability table is then folded into a one-dimensional vector and stored in compressed form within the database file. This database can then be used by the MASTER application to reproduce the quality of the original population with high fidelity.

## 2.2. Fidelity and Performance

Since it is generally impracticable to process each object of a debris sub-population individually, at least smaller particles have to be factorised with a sampling factor, thus allowing for the handling of only one object, which then represents a certain number of other particles with the same characteristics and orbit parameters. On one hand, the data compression technique internally used by the CPE approach restricts the object populations pre-processed with this algorithm to a maximum of 249,999 representative objects. On the other hand, CPU and storage limitations do not allow for a higher number of such 'representative' objects. Taking into account the resulting limited number of representative objects, the sampling factor gets very large if the number of objects per diameter class increases. Especially for areas where a low particle density contrasts with a high bin resolution, the target object often collects only a single representative object while crossing the volume discretisation bins defined around the Earth. Large sampling factors then result in a significant noise level for certain critical spatial areas.

With the introduction of new sources in MASTER$^{99}$, which were mainly contributing to the diameter range below the $100\,\mu$m model threshold of MASTER$^{96}$, representative objects with very high sampling factors could be expected. In order to avoid an even worse situation for these new sources due to the above mentioned stochastic problems of the CPE method, a new flux determination scheme on the basis of statistical object reproduction from a generic population description has been developed and implemented into the ANALYST flux browser tool. In MASTER$^{99}$ and MASTER$^{2001}$, it was applied for the 'small' sources only, i.e. paint flakes, ejecta, and solid rocket motor (SRM) dust.

In the upcoming release of MASTER$^{2005}$ this statistical scheme will be used for the 'large' sub-populations as well, hence for SRM slag, fragments, NaK droplets, and launch/ mission related objects (LMRO). To this end, the approach has undergone a series of modifications and extensions.

## 2.3. Damage Laws

The validation process for the MASTER$^{2001}$ release showed that it is desirable to provide the ANALYST application with a feature to generate flux distributions not only versus diameter, but also whith respect to some damage characteristics. The reason for this requirement is that all data currently available for the small particle validation originates from damage features observed on returned surfaces. Thus, the flux for a certain feature size is known, which can not unequivocally be transformed into a flux versus diameter.

On the other hand, ground experiments led to the formulation of several damage laws describing the feature size for a certain combination of particle material, target material, impactor size, velocity and direction. All these parameters, whith the exception of target characteristics, are known to the model. Thus, the implementation of one or more of these damage laws into the model allows for the derivation of flux distributions vs. feature size, which in turn are required for the comparison with data material in the frame of the validation process.

When the new MASTER$^{2005}$ is released, even more damage laws will be implemented, enhancing the capabilities of MASTER from being a pure flux and spatial density analysis tool towards an end-to-end tool for satellite risk assessment.

# 3. MODEL VALIDATION

The strategy for the validation process depends on the type of available measurement data, which in turn is clearly related to the size and altitude regime in question.

The TLE catalogue provides data for objects larger than about 10 cm in LEO and 1 m in GEO on a regular base and with a satisfactory level of completeness. For the LEO range, the catalogue is mainly based on tracking data from a net of ground based radars. For higher altitude regimes like GEO, optical observations using large telescopes have to be used, since the performance of radar facilities fades out at some thousand kilometres altitude due to the $1/r^4$ correlation implied by the two-way signal path. Sporadic observation campaigns using dedicated very large radar and optical devices deliver at least statistical measurement data down to a limiting size of about 5 mm in LEO and 10 cm in GEO.

For particles smaller than the limiting threshold of 5 mm, detection by ground based sensors is no viable option any more. Since the rare data available from in-situ detectors turned out to be quite inconclusive, the only remaining clue to the orbital particle environment are surfaces returned from space, which experienced micro-object impacts over a comparatively long period of time. Unfortunately, only few parts fulfilling this latter condition have been recovered, the most prominent ones being the LDEF experiment carrier and the solar arrays from the Hubble Space Telescope (HST). They all have in common that they were orbiting in an altitude which allows for human maintenance and retrieval, hence below the maximum altitude achievable by the US Space Shuttle. Also the declination band covered is for most cases restricted to the Space Shuttles' standard inclination of 28.5 °.

The most fundamental problem in validating a space debris model against reality – even if measurement data is available – is to transform the model output to a physical quantity which is suitable for comparison. Although measurement results are often presented also in form of an object flux vs. diameter, which at the first glance would be compatible with the results of the MASTER flux calculation tool, the transformation used to derive these 'secondary' data is always based on simplifying assumptions (e.g. circular orbit, average impact velocity, aluminium projectile, etc.). The reason is that detailed object and orbit characteristics, although naturally contained in a model, are not known to the measurement side. These simplifications therefore often represent the only way to derive rough estimates of certain object characteristics from the measurement data alone. This is the case e.g. for the diameter assessment (primary data is radar cross section or crater diameter) or estimation of the orbit inclination (primary data derived by radar is the Doppler inclination). However, although these assessments may be valuable for other purposes, it is not proved to use this secondary data for the validation of a model, which is able to render the data that is missing in pure measurement.

### 3.1. PROOF

In the case of radar and telescope observations, the results are usually given as detection rates, while the output of the basic model is a reference population at certain snapshot epochs. In order to allow for a direct comparison with the observation data, the Program for Radar and Optical Observation Forecasting (ESA-PROOF) is used. It is a sophisticated tool offering the possibility to simulate detections of orbital debris by ground- and space-based sensors, including radars and telescopes. Its primary purpose is the validation of debris environment models against observation data, taking into account both geometrical parameters of the observations and the physical parameters of the instruments used. PROOF thus offers a highly reliable prediction of debris detections based on any kind of assumed debris population. In the course of the current project, PROOF has been further developed to support the simulation of bistatic radars and phased array radars. More details on the new PROOF can be found in future papers of this author.

### 3.2. Small object validation

Although results from the evaluation of returned orbital surfaces are already given as flux, they are usually related to the characteristics of the impact features, i.e. crater diameter $d_c$ or conchoidal diameter $d_{co}$. At least for aluminium targets, a transformation law allows for a conversion of crater size to the ballistic limit $f_{\max}$, which is a theoretical quantity representing the minimum equivalent foil thickness perforated by the projectile. However, any damage law deriving the projectile diameter $d_p$ requires detailed knowledge of several parameters like impact velocity, impact angle as well as projectile material, which can only partly or very roughly be determined from the crater. Hence, the only way to arrive at a common base for a comparison is the implementation of those damage laws into the flux calculation tool of the model, which has access to the impact and projectile characteristics. This procedure is completely analogous to that applied to the radar and telescope detections, with the only difference that the new MASTER flux browser does not work on the reference population itself, but on the probability tables and CPE databases derived from that population. The flux prediction obtained by MASTER can be compared directly to the primary flux data derived from the surface evaluations. In the course of this work, two damage laws for the LDEF aluminium surfaces as well as HST/EuReCa cover glass material have been implemented to the MASTER flux browser to allow for a correct comparison with measurement data.

An additional problem for the model validation arises from the fact that each measurement reflects the state of the orbital environment at a certain epoch and for a limited period of time only. Hence, any validation efforts have to use a population snapshot as close as possible to the measurement epoch. While this is no problem for typical 24 h radar observation campaigns, satellite surfaces of limited area have to

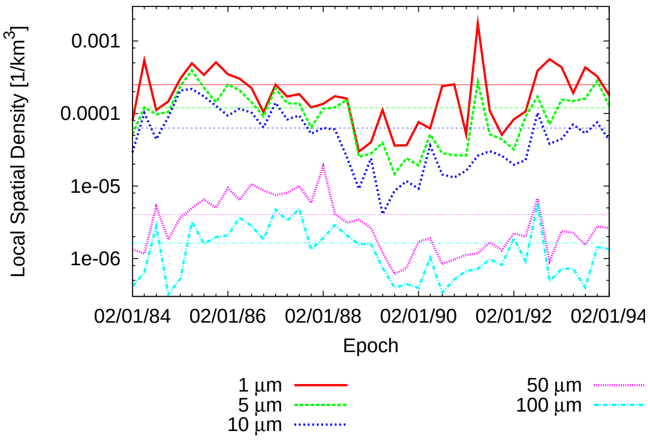


*Figure 2. Temporal variation of the local ejecta spatial density at 400 km altitude for different limiting diameters (20 km altitude class width)*

be exposed to the environment for a comparatively long time in order to collect a statistically significant amount of impact data. However, any change in the orbital environment during the mission time will not be reflected by a post-mission impact count, which will always represent the average flux level.

It is therefore important to either use a snapshot population which is representative for the complete mission (if such a 'typical' snapshot exists for all sources and diameter regimes, compare Fig. 2), or to generate multiple population snapshots and apply each one to the related interval of the mission only. In the frame of this work, the MASTER flux browser therefore has been extended to loop over multiple epochs and to draw for each part of the mission from the closest available population snapshot. The databases required for the validation have been generated for all sources in a 3-month interval (February, May, August and November of each year).

The accurate flux predictions generated this way can then be used for a calibration of the underlying debris generation models against flux data derived from returned surfaces. However, due to the decreasing object number toward larger diameters, also the object flux level collected by such surfaces drops, thus reducing statistical significance of the impact counts at and above about 100 $\mu$m. In addition, the impact rates above about 20 $\mu$m impactor diameter are dominated by the natural meteoroid flux. In consequence, there exists a region between the upper diameter range covered by impact analysis and the lower diameter threshold of observation facilities, where the validation options for micro space debris remain very poor.

It can be concluded that validation is generally restricted to certain size and altitude bands as well as to distinct epochs. Comparatively good validation is possible above 5 mm in LEO using radars, above about 10 cm in GEO using ground based telescopes and below 20 $\mu$m and 650 km altitude using returned space hardware. For all other areas of this multi-dimensional parameter space, some of the validation results can only be extrapolated. This is especially the case for the 20 $\mu$m – 5 mm size regime, where only rough estimates can be derived from the integral flux level and the only valuable data source are the LDEF-CME experiments, and for the overall small particles population beyond 650 km altitude and outside the 28.5° declination window. (Wegener, 2004)

### 3.3. Validation Procedure

The upgraded POEM software will be used to generate the next MASTER reference population. However, since the population as modelled has to be validated against measurement data, considerations from the validation process have to be looped back into the underlying generation models, thus giving this procedure an iterative character.

The first step in this iterative procedure is to generate an initial population version using revised MASTER$^{2001}$ parameter settings. The resulting initial population has then to be validated against available measurement data. For the large object fraction, this data is observation data from radars and telesocpes, for small particles it mostly results from impact counts on returned surfaces.

However, as pointed out in the previous section, the primary measurement data – detections or craters – cannot be directly compared to the MASTER reference population. Instead, the population has to be processed by validation tools, which are able to duplicate the process leading from a given object population to the observed measurement quantity.

For the large population fraction, the PROOF tool qualifies as an excellent validation tool, simulating in detail the detection process for given observation campaigns. The spectra and scatter plots resulting from the application of the tool to these observation campaings can then be compared to the original measurement data. In the course of this process, the necessity to enhance or mitigate single events or to scale complete parts of the modelled population will arise. However, the new internal scaling algorithm, introduced in the frame of the project, will help to keep the number of required iterations as low as possible.

For the small population fraction, the upgraded MASTER application, which has been extended by fundamental damage laws in the frame of this study, can be used as a validation tool. In analogy to the PROOF tool, it simulates the impact of objects from the modelled population onto orbiting oriented surfaces or detectors. Again, conclusions drawn from the comparison of the resulting flux spectra against the measured object flux can be expected to lead to model adaptations, thus triggering a further iteration loop.

In general, the validation process has to comprise

1. Correlation of fragments with the TLE object catalogue
2. Iterative adaptation of single fragmentation events using the new internal scaling feature of PROOF
3. Iterative re-generation of the fragment population with the modified event scaling, and re-evaluation of the single fragmentation event scaling factors
4. Corrective scaling of the upper diameter range for remaining inconsistencies
5. Iterative adaptation of model parameters affecting the low diameter range using the MASTER flux browser, and re-generation of the affected populations
6. Corrective scaling of the lower diameter range for remaining inconsistencies

In case of contradictory results for different measurements, a reasonable compromise has to be found.

A cyclic re-iteration of the complete validation process with critical reviews of the results and adaptions of model parameters will then converge to a final reference population. Following verification, production runs will be initiated to generate the final MASTER$^{2005}$ reference population and the related database files for historic snapshots and for the reference epoch.

## 4. DELTA

Within the MASTER model, the projections of the future debris environment are provided by the Debris Environment Long-Term Analysis (DELTA) model (Fig. 3). This high-resolution tool, which covers the near-Earth orbital region from LEO to GEO, uses the MASTER reference population as the basis for future projections. The future evolution of the debris environment is dependent upon many factors incorporating each of the sources and sinks of space debris. Such factors include the rate of future launches and on-orbit explosions, the prediction of collisions, the orbital evolution of objects and the measures adopted to contain the growth of the debris environment. The ESA DELTA model incorporates all of these factors.

During the development of MASTER$^{2005}$, DELTA will be upgraded to version 3.0, further enhancing the scientific and operational performance of the model. All upgrades to DELTA will ensure consistency with the debris generation models for the historical population for objects larger than one millimetre in size.

One aspect of the model that particular attention will be given to is the prediction of future launches, explosions and solid rocket motor firings. The difficulty in predicting future space activity with any accuracy has long been recognised. The approach adopted in DELTA is to use historic activity to develop a database of events, each with an associated probability of occurrence. Trends in launch, explosion and SRM firing activity must be taken into account within these databases, without biasing the results with temporary fluctuations.

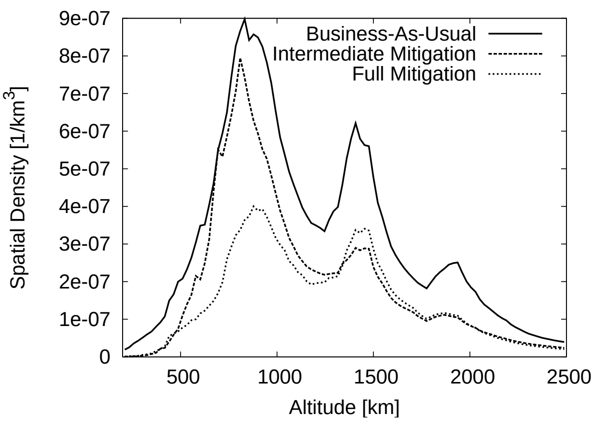


*Figure 3. Spatial density of objects in LEO larger than 1 cm in 2050 for different levels of debris mitigation, as predicted by DELTA 2.0 for MASTER$^{2001}$*

The number of launches shows significant variation over the last 15 years with a continuing trend towards fewer launches / payloads since the late 1980s (Tab. 1). It is noted that the year 2001 had the lowest number of launches since 1961. However, this reduction in launch rate is not due to a lack of capacity on launch vehicles and is not considered a permanent downturn - the number of launches is expected to be in the range 70 - 80 per year over the next 20 years. Similarly, the number of on-orbit explosions has reduced slightly in recent years, which is perhaps a positive indication of the implementation of passivation measures. This indication is further supported by the increasing age of the fragmenting objects. Indeed, all of the non-deliberate explosion events that occurred in the year 2003 were objects that have spent more than 12 years on-orbit.

| Year | No. Launches |
|---|---|
| 1989 | 101 |
| 1990 | 116 |
| 1991 | 88 |
| 1992 | 95 |
| 1993 | 79 |
| 1994 | 89 |
| 1995 | 75 |
| 1996 | 73 |
| 1997 | 86 |
| 1998 | 77 |
| 1999 | 73 |
| 2000 | 82 |
| 2001 | 58 |
| 2002 | 62 |
| 2003 | 61 |

*Table 1. Number of launches per year obtained from the ESA DISCOS database*

DELTA 3.0 will improve the fidelity of the analyses available within the model, in particular the spatial resolution of the semi-synchronous debris environment and the orbit propagation. It will provide the future projections for the MASTER$^{2005}$ model for the next 50 years considering a 'business-as-usual' scenario and two mitigation scenarios, one for a limited mitigation strategy and one incorporating a full set of mitigation measures, including post-mission disposal.

## 5. CONCLUSION

MASTER$^{2005}$ is a major step in the history of the MASTER software. It facilitates a large number of inprovements in all tools involved. The generation algorithms for the majority of debris sources will be refined with the focus on scientifically justified approaches based on recent but proven research. The modifications to the user-branch of MASTER will enable highly accurate flux predictions at high execution speed. The extension of the PROOF-Tool will enable the consideration of additional measurement data gained by beampark experiments or phased arrays. MASTER$^{2005}$ and PROOF$^{2005}$ will be available in 2006.

## ACKNOWLEDGMENTS

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