General

SPACE DEBRIS MITIGATION STANDARD

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Japan Aerospace Exploration Agency

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1. GENERAL

1.1 PURPOSE

The Space Debris Mitigation Standard specifies the mitigation measures which should be taken during the planning, design and operational phases of launch vehicles and spacecraft (hereafter called space systems) in order to minimize the generation of space debris during launch, orbital injection, on-orbit operation, and after the end of mission.

The following seven measures are specified essentially in this standard:

(1) Preventing the on-orbit break-up of a space system after the end of its mission which could generate a large amount of debris.
(2) Re-orbiting a spacecraft operated in geostationary earth orbit (GEO) upon completion of its mission in order to preserve the GEO environment.
(3) Reducing interference of the orbital stage left in geostationary transfer orbit (GTO) with GEO protected region in order to preserve GEO environment.
(4) Minimizing the number of objects released in orbit during operation of a space systems.
(5) Reducing interference of a disposed space systems with LEO protected region and orbit for global navigation systems with an orbital period of 12 hours.
(6) Avoiding human casualties made by reentered space systems and collision of a launching space systems with a manned spacecraft.
(7) Minimizing damage induced by on-orbit collision.

1.2 SCOPE

1.2.1 Applicability

This standard is applied to all space systems and their components developed by JAXA. However, it could be exempted when an alternative requirement is specified in the program, such as the ISS. This standard shall also be applied to JAXA's contractors undertaking space system development.

In case JAXA will launch a space system which is developed by third party, application of this standard is to be coordinated.

This standard intends to specify additional requirements and recommendations from the perspective of space debris mitigation in addition to sufficient measures for mission assurance of an applied space systems.

1.2.2 Tailoring

The requirements in this standard may be tailored before being applied. The results of tailoring, however, shall be coordinated with Safety and Mission Assurance (S&MA) Department and be reviewed by JAXA Safety Review Board, if required.

The results of tailoring shall be described in the Space Debris Mitigation Plan (SDMP).

The typical rationales of tailoring are as follows:

(1) For space systems being in development, only feasible requirements would be applied.
(2) Only feasible requirements are applied based on comprehensive examination such as economical and technical feasibility, effect on reliability, benchmarking with world trend,

and other conditions related to space debris mitigation measures.

1.3 RELATION WITH OTHER CONTRACTUAL REQUIREMENTS

Any conflicts between the requirements herein and those in contractual documents will be coordinated.

The requirements in this standard may be exempted when identical requirements in other standards are already in place. The contractor shall clarify relationships and applicability of multiple requirements in case of duplication, and document it in the Space Debris Mitigation Plan (SDMP) described in 4.2.3.

2. RELATED DOCUMENTS

(1) Applicable Documents

a. JERG-1-007: Safety Regulation for Launch Site Operation
b. JERG-0-047: Safety standard for controlled reentry

(2) Reference Documents

a. JERG-2-144: Micro-debris Impact Survivability Assessment Procedure
b. JERG-0-002: Interpretations for the Space Debris Mitigation Standard

3. DEFINITION

3.1 DEFINITION OF TERMS

The definitions of terms used in this standard are given below.

(1) Spacecraft

Space systems that are so called “Satellite” which is operated in Earth orbit and systems operated through Earth orbit for planetary exploration.

(2) Space system

A generic term for systems performing a mission in orbit, such as a spacecraft or a launch vehicle.

(3) End of mission

When the designated spacecraft operation ends, or when a spacecraft or a launch vehicle upper stage goes into disposal operation.

(4) Retrieval

Recovering a space system in orbit using the returning vehicle or by other means that can transfer it to the Earth. Or recovering a system on the ground using a return capsule.

(5) Preservation of the orbital environment

Preservation of the orbital environment as much as possible while actively using it.

(6) On-orbit Break-ups

Phenomenon that generates space debris from a space system in orbit due to explosion, rupture with stored energy, or a collision with other object.

Break-ups do not include separation of a part of a space system due to degradation by aging.

(7) Probability of accidental break-up

Probability of all known failure modes capable of causing an accidental break-up, excluding those from external sources such as impacts with space debris and meteoroids.

(8) Conditional probability of successful disposal

Probability that disposal operation is successfully achieved with the system condition at the end of mission. Mission is basically assumed a planned normal operation and may or may not involve extended mission phases.

(9) Space debris

A non-functional artificial object in the Earth orbit, including accessories separated from space systems, fragments generated by break-ups, and space systems that have completed their missions.

(10) Objects released during normal operation

Fasteners, protectors, lower fairings and other objects which are separated and released onto the orbit according to the design during normal operation of the space system. Combustion products from solid rocket motors, paint flakes and other materials released by aging and deterioration are not included.

(11) Disposal by the reduction of orbital lifetime

Removing a space system from orbit by descending its orbit.

(12) Disposal phase

The timeframe performing disposal operation (orbital change maneuvers, venting residual propellants, passivation of batteries, etc.) after the end of mission.

(13) Protected orbital region

A currently useful orbital region where is designated to be maintained. This includes the LEO protected region, 12-hour-period orbital region, and GEO protected region, defined respectively as follows.

a. LEO protected region: 2,000km in altitude and lower
b. 12-hour-period orbital region: Orbital region between 19,900km and 20,500km
c. GEO protected region: GEO +/- 200km within +/- 15 deg inclination

(14) Descent

Especially indicating the final phase of entry of orbital objects to the Earth atmosphere in the process of decay. It is also said “natural descent” which excludes intentional re-entry.

(15) Ground casualty risk

Scale indicating risk on the ground upon impact of surviving re-entered objects from space. There are evaluating indexes such as casualty area calculated from the projected area of impacting object with consideration of standing human envelope. And total number of persons to be injured by an event calculated with casualty area, hereafter called "expected number of casualties". The equations for casualty area and expected number of casualties are defined in the Attachment.

(16) Launch Vehicles

Launch Vehicles for launching a spacecraft. The upper stage left in Earth orbit after launch is called orbital stage. In case of the H-IIA, this would be the second stage.

3.2 DEFINITION OF ABBREVIATIONS

The definition of the abbreviations used in this standard is given below.

(1) GEO: Geostationary Earth Orbit

(2) GTO: Geostationary Transfer Orbit

(3) LEO: Low-Earth Orbit

4. GENERAL REQUIREMENTS

4.1 BASIC REQUIREMENTS

Project organization and contractors shall plan and conduct effective measures to minimize space debris generation in planning and executing the development and operation of space systems, as coordinated with JAXA.

The associated activities shall include the followings:

(1) Considerations for space debris mitigation measures in studying the development plans of comprehensive systems including space systems and related ground systems.

(2) Efforts to minimize the generation of debris in the design and manufacturing phases of space systems.

(3) Efforts to minimize the generation of debris during the launch and orbital injection of space systems.

(4) Efforts to minimize the generation of debris during the orbital operation phase and the disposal phase on mission completion.

(5) Efforts to minimize the generation of debris, even in the event of failures during the on-orbit operation phase.

(6) Establishment and improvement of the management system to reflect the efforts requested by the above paragraphs (1) through (5) to respective development and operation phases.

4.2 SPACE DEBRIS MITIGATION MANAGEMENT

4.2.1 Outline

Responsible organization for each step in development and operations by JAXA, hereafter called "Project organizations," and contractors shall properly plan and perform space debris mitigation measures effectively through design and operation phases, then manage these outcomes under predefined organizational control for review.

4.2.2 Organization

Project organizations and contractors shall establish a responsible organization in order to properly study, plan, and implement each space debris mitigation measure required in this standard.

Assigned organization or individuals shall be with authority and resources to accomplish their responsibilities and shall report the status of their progress to the project managers. This roll could be a part of the system safety management section in JAXA Project organizations and contractors unless otherwise specified.

4.2.3 Space Debris Mitigation Plan (SDMP)

The Project organization shall develop a feasible Space Debris Mitigation Plan (SDMP) as coordinated with S&MA Department and document it in such as a part of the System Safety Program Plan. The plan will be subjected to the review by JAXA Safety Review Board, if required.

Contractors shall draft their SDMP that include contents (1) through (4) based on SDMP presented by JAXA, then have approval from JAXA.

SDMP may be documented in the System Safety Program Plan.

(1) The responsibilities and functions of the organizations regarding planning, evaluation, review and implementation of space debris mitigation measures against every cause of space debris generation listed in this standard
(2) The description and rationale for tailoring, if any.
(3) Description of work and schedule of mitigation activity against each cause of space debris generation.
(4) List of documents which will be prepared to satisfy the requirements of this standard, and other related documents including applicable documents.

4.3 MANAGEMENT IN EACH PHASE OF LIFECYCLE

In the development of space systems, preservation of the orbital environment shall be considered in the system concept as important factor from the beginning of project lifecycle, then it should be realized in each development phase. And implementation of the concept shall be reviewed in each phase.

It is also required to define “disposal phase” at the last part of project lifecycle, and adopt measures to minimize negative effect on the orbital environment.

4.3.1 Management in Concept Study, Concept Design and Mission Definition Phases

In developing space systems, it is necessary to study the system concepts, system architecture, mission, launching methods, operation orbit, the way of operation, and the way of disposal so as to capture the purpose in the section 1.1 and space debris mitigation measures required in section 5 shall be taken into consideration.

The adequate safety, reliability and quality program shall be planned under the understanding that failure of the space system would cause not only the loss of mission of itself but also deteriorate the orbital environment.

4.3.2 Management in Design Phases

Space systems shall be designed to minimize space debris generation during normal operation, and to minimize possibility of themselves to become a space debris. It is required to confirm compliance to design requirements associated with space debris mitigation by the critical design review.

4.3.3 Management in Operation Phases

Checkout operation, normal operation and extended operation (refer to the next section for disposal phase) shall be conducted with consideration for space debris mitigation. The following practices shall be taken.

(1) The spacecraft developer shall inform operator organizations with the relevant criteria and design parameters on the spacecraft such as propellant-measurement-accuracy,

propellant-loading-capacity, re-orbiting procedures as a part of data in the operation documents upon spacecraft handover.

(2) The appropriate flight path and relevant events shall be taken into account for the launch vehicle flight trajectory so as to accomplish the disposal of orbital stage (including venting of the residual propellants, orbital change maneuvers, etc.).

(3) Residual propellants shall be confirmed during operation and the decision for mission termination shall be made while necessary amount of the propellants to achieve the re-orbit operation can be guaranteed.

The amount of residual propellants shall be evaluated using the estimation procedure transferred as part of design information with careful observation of the spacecraft conditions.

4.3.4 Management in Disposal Phases

Upon disposal it is required to perform space debris mitigation measures such as removal of spacecraft from the protected regions, removal of residual energy and so on.

5. PLANNING AND IMPLEMENTATION OF THE SPACE DEBRIS MITIGATION MEASURES

5.1 MINIMIZING THE OBJECTS RELEASED DURING NORMAL OPERATIONS

5.1.1 Limitation of Released Components, Parts and Its Fragments

(1) Space systems shall be designed not to release parts such as fasteners that could possibly stay in Earth orbit, unless either serious technical or economical problem would result.
(2) In the mission which intentionally releases objects, the effect on the orbital environment shall be evaluated based on characteristics of the released objects such as mass-area-ratio, orbital lifetime, and so on.
(3) Tethers shall be properly used with tradeoff of its benefits vs. negative effects to the other space systems.

5.1.2 Consideration of Combustion Products

(1) Pyrotechnic devices, except for solid rocket motors and igniter devices, shall be designed and used so as not to release combustion products larger than 1 mm in their largest dimension into Earth orbit.
(2) Solid rocket motors shall be designed and operated so as not to release solid combustion products into GEO protected region. It is evaluated on a case by case basis when the effect on GEO protected region by released products is limited due to its trajectory such as moon, planetary and other missions with highly elliptical orbit.
(3) Solid rocket motors should be operated avoiding release of solid combustion products into LEO protected region.

5.2 PREVENTION OF ON-ORBIT BREAK-UPS

The following on-orbit break-ups shall be prevented.

(1) Break-ups after mission completion
(2) Break-ups during operation
(3) Intentional destruction

5.2.1 Prevention of break-ups after the end of mission

In order to prevent break-ups of retired space systems and subsequent generation of space debris, space systems shall be designed toward eliminating accidental break-ups to the reasonable extent, and the causes of accidental break-ups shall be removed as much as possible, immediately after the final disposal maneuver or before the retrieval.

The following measures shall be followed.

(1) Measures for residual liquid propellants and high pressure fluids

Liquid propellants and high pressure fluids left in the retiring space systems shall be used or vent while re-orbiting operation so as not to be a potential cause of break-ups. Otherwise the analysis shall verify that residual fluids will not cause break-ups.

The following measures shall be incorporated in design.

(a) For the bi-propellant propulsion system, especially with the hypergolic propellants, tanks and lines should be designed to prevent unintentional mixing propellants and combustion even after a failure on a piece of parts.

(b) Residual propellants in the tanks and lines should be vent after the end of re-orbiting operation. If simultaneous venting for bi-propellant propulsion system is not feasible, the propellant with higher self-reactivity should be preferentially vented.

(c) If the venting is not feasible, there should be enough safety margins for break-ups even with possible heating, otherwise pressure limiting functions should be incorporated in design.

(d) Vent lines should be designed so that freezing does not prevent venting.

(2) Measures to prevent break-up of batteries

Batteries shall be adequately designed and manufactured, both electrically and mechanically not to cause neither excessive pressure increasing nor structural fracture.

At the end of operations battery charging lines shall be de-activated.

If feasible, a battery should have pressure limiting functions to prevent rupture and subsequent damage on a space system.

(3) Flight termination system

Pyrotechnic devices shall have enough margins for spontaneous ignition temperature which considers temperature increasing by solar heating and so on. The command receivers shall be deactivated to eliminate accidental fire, immediately after the flight termination function completed its duty.

(4) Heat pipes, etc.

Sealed pressure systems shall be designed with a sufficient safety margin against rupture with possible heating condition during orbital lifetime.

(5) Rotating equipment

Rotating equipment such as wheels shall be stopped after the end of operations.

5.2.2 Prevention of break-ups during operation of space systems

5.2.2.1 Certainty of design

It should be confirmed in the space system design review that adequate reliability and quality control have been conducted to prevent failures that may lead to break-up events during operation.

In general, the probability of accidental break-up of a space system shall be 0.001 or less.

5.2.2.2 Monitoring of a spacecraft during operation

For the operation control of spacecraft, the procedures shall document monitoring of malfunctions on propulsion system, batteries, attitude control system, and other function which could lead to the massive generation of space debris when it failed, and proper organizations shall be maintained during operation so that immediate reaction can be taken upon malfunctions. At least the following status shall be monitored from the ground.

(1) Tank pressure and associated temperature to evaluate remaining propellants.

(2) Parameters (temperature and voltage and so on) to detect battery failures.
(3) Parameters to detect attitude control system failure.

5.2.2.3 Space Debris Mitigation Measures in Case of Malfunction

When the malfunctions on the operating spacecraft could lead to a break-up, or a loss of mission essential function, feasible space debris mitigation measures such as removal of residual energy sources, reduction of orbital lifetime, or re-orbiting from protected orbital regions) shall be assessed and executed unless a spacecraft may recover.
However re-orbiting operation shall not be conducted if it should create a subsequent break-up.

5.2.3 Prohibition of Intentional Destruction

Intentional destruction of a space system in orbit shall not be conducted. However, the intentional destruction at a lower altitude, intended to reduce the ground risk caused by reentering space systems is exempted.

5.3 REMOVAL OF SPACE SYSTEMS FROM PROTECTED ORBITAL REGIONS AFTER THE END OF MISSION

5.3.1 Basic Requirements

Space systems shall be disposed to minimize the interference with protected orbital regions by the most effective means such as orbital lifetime reduction, natural decay, re-orbiting, re-entry, or retrieval and so on, according to their orbital characteristics and other factors.
In order to make space systems capable to perform re-orbiting operation after the end of mission, they shall be designed with the following considerations.

(1) Conditional probability of successful disposal in case a re-orbiting operation is required
Conditional probability of successful disposal shall be 0.9 or higher. For spacecrafts whose specification does not require reliability calculation, the design target life shall be set including disposal operation.

(2) Securing the amount of propellants necessary for re-orbit
The sufficient amount of propellants shall be taken into account for design of the spacecraft so as to perform planned re-orbit. Propellant mass margin shall take into account performance error of the propulsion system and propellant amount measurement errors.

(3) Design of the measurement and monitoring systems for on-board propellant
A spacecraft shall equip with propellant measurement and monitoring systems which allow to measure the amount of on-board propellants in real-time to support prompt determination for timeline toward the end of the mission. Especially for GEO spacecraft, this measurement and monitoring systems shall support high precision analysis to ensure the re-orbiting delta-V.

5.3.2 Disposal related to GEO region

(1) Space systems that terminate their missions near GEO shall be re-orbited to the orbit where fulfill at least one of the following conditions in order to avoid collision with other spacecrafts in GEO

a) The initial eccentricity after re-orbit is less than 0.003. the minimum perigee altitude delta-H (km) above GEO is calculated by the following equation.

delta-H = 235 + 1000 × C_R × A / m [km]

Where:
C_R: Solar radiation coefficient
A: Effective sectional area of the spacecraft (m^2)
m: Mass of the spacecraft (kg)

b) The perigee altitude after disposal is sufficiently higher than GEO, and no interference with GEO protected region within 100 years, even accounting long-term perturbation.

(2) Space systems passing through near-GEO, such as GTO missions, shall be planned its apogee altitude to be away from 200km lower than GEO.

(3) The apogee propulsion system for GEO spacecraft shall be basically designed not to separate from the spacecraft. If it have to be separated, the system shall be left on the orbit satisfying requirement in (2) or lower. Regardless of separation, liquid apogee propulsion system shall be vent to eliminate the risk of accidental break-ups immediately after the end of mission.

5.3.3 Disposal related to LEO region

For the space systems passing through LEO, orbital lifetime after the end of mission shall be minimized as far as possible. Therefore one of the following measures shall be applied.

(1) Reduction of orbital lifetime

In case the orbital lifetime of the retired spacecraft could be more than 25 years, it is required to adopt a method to accelerate decay to be within 25 years, or re-orbit to the altitude where the spacecraft naturally decays within 25 years.

The same requirement is applied to a launch vehicle orbital stage.

Note that the risk upon ground impact shall be mitigated in accordance with requirements in 5.4.

(2) Natural decay

In case the orbital lifetime could naturally be within 25 years by atmospheric drag, the space systems may be left in their operational orbit. Note that the risk upon ground impact shall be mitigated in accordance with requirements in 5.4.

(3) Re-orbit higher than LEO protected region

If neither (1) nor (2) can be chosen because of unacceptable ground risk or infeasibility due to operating orbit, the space systems shall be disposed sufficiently higher orbit than LEO protected region to avoid collision with operational space systems and other objects.

(4) On-orbital retrieval

Retrieve space systems on orbit to remove them out of LEO protected region. No object shall be released during retrieval operation.

(5) On-ground retrieval

Retrieve space systems on the ground after their planned reentry. Left objects on orbit which are separated and released before re-entry shall be minimized. Note that the risk upon ground impact shall be mitigated in accordance with requirements in 5.4.

5.3.4 Disposal in mid-higher orbital regions

Space systems operated in orbit with 12 hour period cycle shall be disposed out of the operating region.

5.4 REQUIREMENTS FOR DISPOSAL WITH RE-ENTRY / NATURAL DESCENT

5.4.1 Safety of the ground

If space systems are disposed per (1) or (2) in 5.3.3, the following requirements shall be applied.

(1) Risk, i.e. Expected number of casualties (Ec), induced by the ground impact with surviving objects shall be estimated prior to the launch of the spacecraft. In case Ec would be 1×10^{-4} person or higher per event, the maximum effort, such as a controlled reentry toward designated safe impact area, should be made to the extent technically practicable paying attention to the regular implementation in the world.

(2) For both natural decay and a controlled re-entry, the maximum effort should be made to realize space systems with higher melting rate for minimizing ground risk, to the extent technically practicable paying attention to the regular implementation in the world.

(3) Controlled reentry of a space system shall be conducted per "Safety Standard for Controlled Reentry (JERG-0-047)."

5.4.2 Prediction of re-entry and disclosure of related information

JAXA assesses available trajectory information of own space systems using available analysis technique, then predicts re-entry trajectory, day and time. These information are disclosed in appropriate ways.

5.4.3 Destruction before re-entry

When intentional destruction prior to re-entry is planned in order to minimize the ground risk, the destruction shall be happened at sufficiently low altitude so as not to make fragments back to orbit, besides this altitude shall not induce undesirable effects on the ground.

5.4.4 Prevention of contamination on the ground environmental by on-board materials

If a space system will be reentered to the earth upon disposal, radioactive substances, toxic substances or any other environmental pollutants shall not be left in surviving fragments, or those effects shall be permissible.

5.5 MINIMIZING ON-ORBIT COLLISIONS AND IMPACT DAMAGE

5.5.1 Launch collision avoidance with manned space systems

In the launching operation, the launching time shall be coordinated to avoid conjunction between a launch vehicle including satellites and other separated objects, and manned space systems, based on “Safety Regulation for Launch Site Operation (JERG-1-007).”

5.5.2 Collision avoidance of spacecrafts and mitigation of impact damage

(1) Selection of operation orbit

Geostationary spacecraft operations shall always be planned to maintain sufficient relative distance to avoid collisions and resultant break-ups.

Operations orbit of spacecrafts on other circular Earth orbit shall always be planned to mitigate the risk of conjunction and collision with other spacecraft operating at the same altitude, unless rendezvous and docking or other joint missions are planned.

(2) Collision with trackable large debris

For a spacecraft which is mandated collision avoidance because of importance of mission, orbital operation lifetime, distribution of space debris around the operating orbital region, and cross-sectional area toward the debris impact direction, it is required to detect possible conjunctions with other space objects and to perform a collision avoidance maneuvers if necessary.

(3) Collision with protectable small debris

It is required to calculate a probability of a loss of functions required for disposal operations including re-orbiting maneuver, venting of residual propellants, disabling batteries and so on, of a spacecraft by collisions with space debris.

Critical components and cablings shall be in the calculation then protection methods, redundancy and layout should be reconsidered when the result indicate risk to the certain extent. The acceptable criteria shall be defined for each mission taking into account for the technical maturity of collision risk calculation and protection methods.

Refer to "Micro-debris Impact Survivability Assessment Procedure (JERG-2-144)" about the collision risk calculation and protection design.

ATTACHMENT

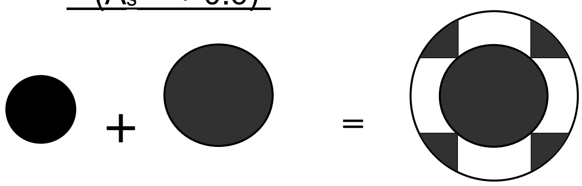
1. Casualty area

Casualty area (Ac) is defined based on the projected area of an impacting object and a human surface projection pseudo circle (0.36 m2). This is the area around the projected area of the impacting object plus the area of the radius (33.8 cm) of the human surface projection pseudo circle.
The formulas when the impacting object is a sphere and a polygon are shown below.

(1) In case of a sphere

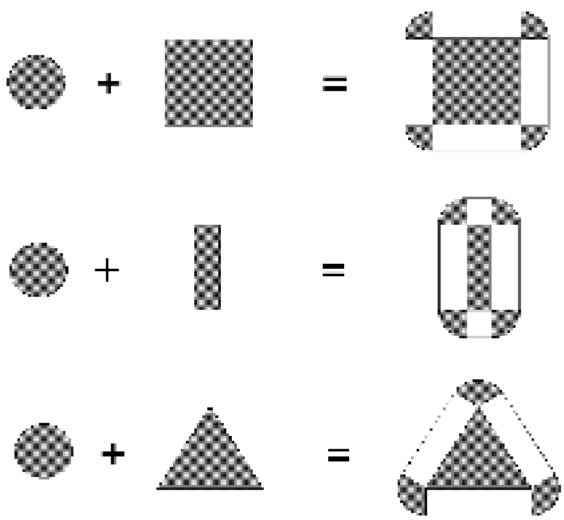
From the projected area (As) of Impacting object with radius r_h and the area of the human surface projection pseudo circle.

$$Ac = \pi(r + r_h)^2$$
$$= \pi\{(A_s/\pi)^{0.5} + (0.36/\pi)^{0.5}\}^2$$
$$= (A_s^{0.5} + 0.6)^2$$



(2) In case of a polygon

Ac = (projected area of Impacting object) + (perimeter of impacting object x r_h) + (the area of the human surface projection pseudo circle)



2. Expected Number of Casualties

Following is an equation for the expected number of casualties (Ec)
Summation should be done within the range of inclination.

$$Ec = Ac \sum_{i=inclination} (Pi\ Ni / Ai)$$

Where,

Ec = Expected number of casualties [number of people]
Ac = Casualty area [m^2]
Pi = probability of impact in the i-th latitude band [-]
Ni = Number of population in the i-th latitude band [number of people]
Ai = Area of the i-th latitude band [m^2]