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TECHNICAL NOTE

GUIDE TO USING THE DEBRISK TOOL FOR SATELLITE APPLICATIONS

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AUTHOR(S):

ANNALORO Julien	DTN/TVO/PR
GALERA Stephane	DTN/TVO/PR
BELLUCCI Aurélie	DTN/DV/IFL

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List of TBC parameters:

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1. GENERAL

1.1. REFERENCE DOCUMENTS

REFERENCE DOCUMENT	DOCUMENT TITLE
[DR1]	*REGLEMENTATION - GUIDE DES BONNES PRATIQUES MAITRISE D'UN OBJET SPATIAL [REGULATIONS - GOOD PRACTICE GUIDEBOOK FOR CONTROLLING A SPACE OBJECT]* ***RNC-LOS-GR-CNF-8-CNES***
[DR2]	*DEBRISK SOFTWARE USER'S MANUAL - LOS MODE* ***DBK-MU-LOG-0268-GMV_02_18***
[DR3]	*PROJECTED AREA AND DRAG COEFFICIENT OF HIGH VELOCITY IRREGULAR FRAGMENTS THAT ROTATE OR TUMBLE* ***John F. Moxnes et al*.** ***Defence Technology, 13(4), 269-280. Doi:10.1016/j.dt.2017.03.008***
[DR4]	*ESA SPACE DEBRIS MITIGATION COMPLIANCE VERIFICATION GUIDELINES* ***ESSB-HB-U-002 DATE 19 FEBRUARY 2015 ISSUE 1 REV 0***
[DR5]	*On the ConnectByCnes site, on which the CNES Patrius library is described, you can consult the Release Note and download the library free of charge:* https://www.connectbycnes.fr/en/patrius http://patrius.cnes.fr/index.php/Accueil
[DR6]	*DOSSIER DE SYNTHESE DE LA METHODE ELECTRA POUR LE CALCUL DES RISQUES LIES A LA RETOMBEE DE VEHICULES SPATIAUX* [SUMMARY OF THE ELECTRA METHOD FOR CALCULATING THE RISKS ASSOCIATED WITH SPACECRAFT FALLBACK] **ELECT–DS–2200–89–CNES, V3.0**

1.2. APPLICABLE DOCUMENTS

2. INTRODUCTION

2.1. OBJECTIVE

The aim of this document is to provide a set of recommendations for those wishing to use the DEBRISK tool to analyse a complete atmospheric re-entry of a spacecraft and its fragments.

When setting up simulations with DEBRISK, these recommendations cover the choice of:

- the methodology for selecting initial re-entry conditions,
- the appropriate atmosphere model,
- and of the geometric shapes for modelling the spacecraft and its fragments.

This user guide is a technical aid provided to accompany the ***GUIDE DES BONNES PRATIQUES POUR L'APPLICATION DE LA RÉGLEMENTATION TECHNIQUE ASSOCIÉE À LA LOI SPATIALE***, hereinafter referred to as "GBP" [DR1].

Each of the sections devoted to recommendations/requirements can be read in the following way:

1. Context
2. Recommendation or Requirement
3. Implementation
4. Examples

The Recommendations/Requirements sections are broken down into a recommendation or requirement number, a title and the statement framed in red, as detailed below, indicated respectively by "REC" and "EX":

DBSK_REC_XXX_YYY or DBSK_EX_XXX_YYYY

Title of recommendation

Recommendation or Requirement

2.2. OVERVIEW OF CHAPTERS

This document is structured as follows:

- **§3 - Presentation of the DEBRISK software**

  This chapter introduces release V3 of the DEBRISK software, as well as the main physical models involved in an ablation calculation and the determination of debris likely to cause a casualty.

- **§4 - Calculation of the casualty area**

  This chapter provides the main formulas proposed by DEBRISK V3 for calculating the casualty area. This area is recommended for calculating the risk of a person being hit by an object reaching the ground.

- **§5 - Recommendations on initial conditions and choosing the atmosphere model prior to using DEBRISK**

  This chapter deals with recommendations concerning both the initial orbit to be considered according to the type of re-entry envisaged, and also the atmosphere model to be selected.

- **§6 - Recommendations for fragmentation analysis prior to using DEBRISK**

This chapter deals with the "Fragmentation analysis" procedure to be carried out before using the DEBRISK V3 software. This section covers both the modelling of the main parent (spacecraft) and its fragments (children and/or components).

- **§7 - Recommendations for phase 0 analysis with DEBRISK V3**

  This chapter deals with the approach to be adopted when preparing a phase 0.

3. PRESENTATION OF THE DEBRISK SOFTWARE

3.1. ALGORITHM

DEBRISK is a tool for assessing the survivability of fragments from a spacecraft re-entering the Earth's atmosphere, using an object-oriented approach. This assumes that the incoming spacecraft (referred to hereafter as the parent spacecraft) can be modelled as a set of several objects, based on a library of elementary geometric shapes. This tool therefore needs as input, the initial kinematic conditions of the parent spacecraft, its physical characteristics, and a list of objects. This list represents the fragments of the spacecraft under study, which may or may not be linked to each other by various types of relationship, and which will emerge from the main fragmentation altitude of the said spacecraft, or when the parent object containing them disintegrates. The operator who draws up the list shall be responsible for it. The geometry of all the fragments is identified using the shapes already available in the software.

Based on all this information, DEBRISK can calculate the trajectory and thermal characteristics of the spacecraft re-entering the Earth's atmosphere and take into account its fragmentation at the assumed altitude of the event. From this event, each object representing a fragment is simulated step by step, via its trajectory, its temperature and its possible ablation as a function of the incoming and outgoing flows.

More precisely, DEBRISK models at each time step and for each object:

- the Earth's atmosphere, so as to define local flow conditions,
- the equations of motion in an inertial reference frame – **trajectory modelling**,
- the drag coefficient as a function of local flow – **aerodynamic modelling**,
- the thermal heat flux depending on the upstream flow – **aerothermodynamic modelling**,
- the evolving temperature of the object – **thermal modelling**,
- the ablation of the material and calculation of the new dimensions – **ablation modelling**.

The main physical models used in DEBRISK are described below.

- **Trajectory modelling** and numerical propagation use the CNES Patrius library, see [DR5].

- **The calculation of aerodynamic forces** considers only drag forces. Aerodynamic reference coefficients and surface areas are defined for each shape and for each flow regime. The flow regime is based on the Knudsen number, itself calculated using a reference length that depends on the geometric characteristics of each object.

- **The thermal heat flux** on each object includes the contribution of the following different heating modes:
  - Convective transfer, which applies to the thermal reference surface,
  - Oxidation transfer, which applies to the thermal reference surface,
  - Radiation: losses due to radiation from the wall; applied to the total surface area of the object exposed to the outside,
  - Transfer by contact: transfer of energy between two objects by means of a contact coefficient applied to the interaction surface between these objects.

- **The drag coefficient of** the object and the **heat absorbed** depend on its shape, dimensions, flow conditions and attitude. The wall temperature is calculated as a function of the thermal heat flux and the object's specific heat and mass. The amount of ablated mass is determined by integrating the fluxes once the melting point has been reached. Finally, the integration of equations of motion depends on the ballistic coefficient and local flow conditions. These conditions dependent on the object's displacement and the Earth's atmosphere.

- **The aerodynamic and thermal reference surface areas and the total surface area** of the object exposed to the outside depend directly on the shape being considered: sphere, cylinder, box, plate, complex shapes, etc.
- **The temperature** of each object is considered to be uniform in the material, on the assumption that conduction in the material is infinite. When the melting point of an object is reached, the energy transferred

to the object no longer causes the temperature to rise, but the material melts, reducing its mass and external dimensions.

- **The mass of material ablated** at each time step is calculated as the ratio of the total heat absorbed by the object to the enthalpy of fusion of the material. The specific way in which an object is ablated depends on its geometric characteristics.

- **The object is considered to have been destroyed** if it triggers one of the following criteria:
  - The remaining mass reaches a minimum limit value defined and set in the software (0%).
  - One dimension of the object reaches a minimum limit value defined and set in the software (10^{-5} m).
  - The deceleration reaches a maximum value defined and set in the software (100 G).
  - The kinetic energy reaches a minimum limit value defined and set in the software (14 J).

Here are some important definitions:

Fragmentation

There are four types of fragmentation:

- The main break-up is the moment when the satellite components, connected directly by glue or inserts, separate and give rise to all the elements pre-listed by the user (i.e. children).
- The fragmentation of the solar panels is the "automatic" process of separating the solar panels from the spacecraft, which takes place either at an altitude of 95 km or at the main fragmentation altitude if the latter is greater than 95 km.
- The fragmentation (without specifying "main" or "solar panels") is the classic process giving 'birth' to:
  - a child which was part of a parent, and which takes place automatically when the parent has disappeared in the sense of DEBRISK (on triggering of a disappearance criterion, as seen above)
  - a component, which takes place automatically when the separation temperature set by the user has been reached.

Ablation

This is the process by which an object loses mass as it re-enters the Earth's atmosphere.

3.2. NEW MODELS IN DEBRISK V3

Table 1 shows all the new physical models (in violet) that have been integrated into DEBRISK V3 and a comparison with the previous release, DEBRISK V2.

	V2	V3
Type of relationship	• "Child" means a parent/child relationship	• "Child" means a parent/child relationship, with conductive transfer. • "Component" means a relationship in which an object is made up of primitives. The components will inherit the temperature of the parent at the time of fragmentation.
S/C	The primitives available are box/cylinder.	The primitives available are sphere/box/cylinder.
Fragmentation	"Child" relationships are broken according to the criteria activated. When several criteria are defined, fragmentation takes place as soon as the first criterion has been activated. When a relationship is broken, a list of fragments is generated	"Child" or "component" relationships are broken according to the criteria activated. When several criteria are defined, fragmentation takes place as soon as the first criterion has been activated. When a relationship is broken, a list of fragments is generated
Fragmentation criteria	DEBRISK distinguishes between the parent spacecraft and one of its elements. The fragmentation criteria are therefore different. **For the parent spacecraft**: • The fragmentation altitude can be set by the user. **For fragments**: • For "child" relationships, fragmentation occurs when there is total ablation.	DEBRISK distinguishes between the parent spacecraft and one of its elements. The fragmentation criteria are therefore different. **For the parent spacecraft**: • The fragmentation altitude can be set by the user or based on thermal criteria. **For fragments**: • For "child" relationships, fragmentation occurs when there is total ablation. • For "component" relationships, fragmentation occurs when the separation temperature is reached.
Composition of the list of fragments	Predefined list of primitives: • Sphere • Cylinder • Box • Plate	Predefined list of primitives: • Sphere • Flat-edged cylinder • Box • Plate • Hemispherical-edged cylinder • Tube/Ring • Open and closed cone • Spherical cap • Tube/ring sector • Spherical cap sector
Equation of motion	3ddl modelling • Dormand-Prince of order 5/3 with different relative and absolute tolerances depending on the variable. The min and max time steps are 10^{-15} and 5s.	3ddl modelling • Dormand-Prince of order 5/3 with different relative and absolute tolerances depending on the variable. The min and max time steps are 10^{-15} and 5s.
Coupling	The thermal and dynamic aspects are coupled, ensuring that the mass is kept up to date throughout the re-entry phase.	The thermal and dynamic aspects are coupled, ensuring that the mass is kept up to date throughout the re-entry phase.
Earth environment model	Earth model • WGS84 model, for which the Earth is modelled by a sphere slightly flattened at the poles. Atmospheric model: • The default is a static US76 model. Gravity model: • J0	Earth model • WGS84 model, for which the Earth is modelled by a sphere slightly flattened at the poles. Atmospheric model: • The default is a static US76 model. • A dynamic model is also available as an option, based on the NRLMSISE-00 model. Gravity model: • J0 or J2
Materials database	A database is provided by default.	A database is provided by default (different from that of

	The user can enter materials. The characteristics can be entered as a function of temperature.	V2). The user can enter materials. The characteristics can be entered as a function of temperature.
Thermal modelling	Thermal is type 0D. A thermal network is constructed in which each primitive is represented by a thermal node. The thermal evolution is the result of incoming and outgoing thermal heat fluxes.	Thermal is type 0D. A thermal network is constructed in which each primitive is represented by a thermal node. The thermal evolution is the result of incoming and outgoing thermal heat fluxes. Conduction is only considered in a "child" relationship.
Attitude modelling	Only one attitude mode is possible: random motion.	Only one attitude mode is possible: random motion.
Aerothermodynamic modelling	Whatever the attitude, the modelling of the drag and convective flows of each primitive is based on methods derived from Klett.	The methods are based on the use of a database created from 3D CFD/DSMC calculations.
Aerodynamic modelling in the "low speed" regime	Modelling taken from ORSAT, and partly from HOERNER's formulations.	Modelling below Mach 5 specific to each primitive, based on experimental data.
Ablation model	Ablation modelling is based on metals.	Ablation modelling is based on metals.
Oxidation model	Cropp's model	• The influence of oxidation on emissivity is considered • New oxidation flow model • Mass loss model for titanium
Calculation-stop criteria	• **Fragmentation**: the primitives related to the fragment are released into the flow. • **Disappearance**: The fragment is fully ablated if: ○ Mass equal to zero, ○ Minimum dimension of 10µm • **Ground impact**: The fragment drops below 100m in altitude. • **Kinetic energy**: The fragment's kinetic energy falls below 14J. • **Acceleration**: the fragment exceeds 100G of acceleration.	• **Fragmentation**: the primitives related to the fragment are released into the flow. • **Disappearance**: The fragment is fully ablated if: ○ Mass equal to zero, ○ Minimum dimension of 10µm • **Ground impact**: The fragment drops below 100m in altitude. • **Kinetic energy**: The fragment's kinetic energy falls below 14J. • **Acceleration**: the fragment exceeds 100G of acceleration.

Table 1 - Comparison of modelling using DEBRISK V3 as compared to DEBRISK V2

4. METHOD FOR CALCULATING THE CASUALTY AREA FOR DEBRISK AND ELECTRA

The aim of this chapter is to explain to the reader the method used to calculate the casualty area of a piece of debris. For the sake of consistency, it applies to both DEBRISK and ELECTRA.

Once the DEBRISK simulation has been completed and the list of surviving fragments has been obtained, the reference calculation used to estimate the risk of a person being hit by an object reaching the ground is the casualty area (A_C). This surface area describes the potential danger of an object reaching the ground in relation to the possible presence of a human being nearby. It is therefore specific to each form of object. This method is defined in Figure 1 such that:

$$A_C = \left(\sqrt{A_h} + \sqrt{A_d}\right)^2$$

Equation 1

where A_h represents the surface area of a disc of diameter $D_h = 0.677m$ (representative of a human being [DR6]), and A_d represents the projected surface area of the debris on the ground.

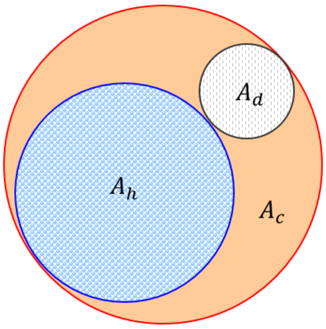

Figure 1 – Casualty area

The projected surface area of the debris on the ground A_d is calculated in DEBRISK V3 as an average projected surface area that is statistically representative of the position of the object during its fall, also recommended by ESA in its "ESA Space Debris Mitigation Compliance Verification Guidelines" [DR4].

The motion of objects is not random for all shapes. As a result, the projected surface area must be consistent with the motion assumptions adopted:

1. For spheres, cylinders and "complex" shapes: it is the weighted average in random rotation of the surface area projected onto a plane perpendicular to the direction of flow.
2. For boxes and plates: it is the weighted average pitch motion of the surface area projected onto a plane perpendicular to the direction of flow.

The formulas are distinguished as follows:

- For convex forms, these formulations are analytical and are taken from [DR3]:
    - For spheres and cylinders:

$$A_d = \frac{S_{ext}}{4}$$

Equation 2

where S_{ext} represents the outer surface area of the object.

- For boxes:

$$A_d = \frac{2}{\pi} L(W + H)$$

Equation 3

where L, W, H represent the length, width and height of the box, respectively.

- For plates:

$$A_d = \frac{2}{\pi} L(W + \tau)$$

Equation 4

where L, W, τ represent the length, width and height of the plate, respectively.

- For frame and tube shapes, A_d is calculated and inserted as follows:

$$A_d = \frac{(S_{out} + S_{top} + S_{bot} + S_{in})}{4}$$

Equation 5

with:

$$S_{top} = S_{bot} = \pi(R^2 - (R - e)^2)$$

Equation 6

$$S_{out} = 2\pi RL$$

Equation 7

$$S_{in} = \pi\,(R - e)L(\sqrt{N^2 + 4} - N)$$

Equation 8

$$N = \frac{L}{R - e}$$

Equation 9

where R and e represent the radius and thickness respectively. Equation 5 is derived from that used for convex shapes such as spheres and cylinders, and is taken from [DR3], applied to each side. The inner side takes into account the view factor of the inner cylinder, the expression for which is taken from [DR1].

- For other types of shapes, as there are no existing analytical formulations, an interpolation method has been used, see [DR3]. This methodology is associated with a dedicated database. The database is produced using a validated numerical tool for calculating projected shadows on a number of shapes and dimensions.

The lethality of a piece of debris depends not only on its casualty area but also on its kinetic energy when it hits the ground. For a given casualty area, the most energetic debris is the most dangerous. DEBRISK defines for each piece of debris a weighting coefficient for the casualty area $\alpha_{CA}(E_{c_{imp}})$ depending on the impact energy E_{c_imp}. The weighted casualty area is thus defined by:

$$A_{c\_pond} = \alpha_{CA}\left(E_{c_{imp}}\right) A_c$$

Equation 10

Where:

$$\alpha_{CA} = \begin{cases} 0 & if\ E_{c\_imp} < E_{c\_min} \\ \dfrac{1}{2} - \dfrac{1}{2}\cos\left(\pi \dfrac{\ln\left(E_{c_{imp}}\right) - c_0}{c_1 - c_0}\right) & if\ E_{c\_min} \leq E_{c_{imp}} \leq E_{c\_max} \\ 1 & if\ E_{c\_max} < E_{c\_imp} \end{cases}$$

Equation 11

With $c_0 = \ln\left(E_{c\_min}\right)$ and $c_1 = \ln\left(E_{c\_mac}\right)$, and such that $E_{c\_min} = 14J$ and $E_{c\_mac} = 296J$

5. RECOMMENDATIONS PRIOR TO USING DEBRISK FOR SELECTING INITIAL CONDITIONS AND ATMOSPHERE MODELS

5.1. INTRODUCTION

To calculate the list of surviving fragments during atmospheric re-entry, the DEBRISK software calculates the trajectory of an integrated spacecraft and its fragments. The trajectory of an object depends both on its characteristics (size, materials, shape, etc.) and its interaction with its environment (atmospheric drag, force of gravity, heat, etc.). As this environment is not necessarily uniform around the Earth, depending on the models chosen, the initial orbit bulletin also influences the trajectory, particularly if it is short (less than one orbital period, for example).

The purpose of this chapter is to give recommendations on:
- the atmosphere model to be selected,
- the initial orbit to be considered.

These recommendations are based on two complementary studies concerning the influence of initial conditions on spacecraft velocities at the standard fragmentation altitude (78 km) and the influence of the atmosphere model.

The recommendations depend on the type of re-entry being considered: natural re-entry, also known as random re-entry, or controlled re-entry.

However, this is still a case of preparing a compliance dossier, and thus well in advance of the atmospheric re-entry, which will take place on a date that is unknown when the dossier is submitted.

5.2. CHOICE OF ATMOSPHERE MODEL

Context

Since release 3.2 of DEBRISK, users can choose from two atmosphere models: US76 and MSIS00. The US76 model is a simple model in which density and temperature vary only as a function of geodetic altitude. It does not take into account any seasonal or geographical effects. This model is well suited to design studies. In contrast, the MSIS00 model is empirical and depends on the date, time, solar activity and position (geodetic altitude, latitude and longitude) of the object in question throughout its re-entry trajectory. Any variation in these data leads to a variation in the atmospheric characteristics used in a DEBRISK simulation and therefore a potential variation in the result.

5.2.1. Determining the type of re-entry

DBSK_REC_ATM_010

Choice of atmosphere model, first calculation

As the re-entry date is unknown, we recommend using the US76 model to determine the type of re-entry that can be envisaged. Be sure to use an inclination that corresponds to the mission.

DBSK_REC_ATM_020

Choice of atmosphere model, second calculation

To avoid an atypical and unrepresentative case, it is recommended that the US76 calculation be repeated, while modifying the initial conditions (see 5.3) to ensure that the result varies little and remains within the same range of values.

Implementation

The atmosphere model is selected in the "Simulation Parameters" tab, as described in detail in the User's Manual, see [DR2].

5.2.2. Case of controlled re-entry

Context

If the calculation recommended by DBSK_REC_ATM_010, carried out using a US76 atmosphere, gives a casualty area value well above the threshold required to comply with the Technical Regulations [DR1] for the year in question, controlled re-entry should be considered. The notion of "well above the threshold" is not quantified because it depends on the development phase of the project in question.

DBSK_REC_ATM_030

Choice of atmosphere model for controlled re-entry

If a controlled re-entry is envisaged, it is recommended that a calculation be carried out using the US76 atmosphere model with an atmospheric density both reduced and increased by 50% in order to assess how the number of surviving fragments and the total casualty area evolve. If the new surviving fragments thus revealed have lower or higher ballistic coefficients than those already identified, this will affect the size of the projected impact area (shortest fragments or longest fragment).

DBSK_REC_ATM_040

Choice of atmosphere model, end of mission

At the end of the mission, it is advisable to perform a DEBRISK calculation using the MSIS00 model, as the re-entry date and solar activity are known, or if a parametric study is required.

Implementation

In the "Simulation Parameters" tab, you can apply a multiplication coefficient to the atmospheric density to increase or decrease it (see User's Manual [DR2]).

5.2.3. Case of natural re-entry

Context

If the calculation recommended by DBSK_REC_ATM_010, carried out using a US76 atmosphere, gives a casualty area value well below the threshold required to comply with the Technical Regulations [DR1] for the year in question, a natural re-entry may be considered. The notion of "well below the threshold" is not quantified because it depends on the development phase of the project in question.

DBSK_REC_ATM_050

Choice of atmosphere model for natural re-entry

If a natural re-entry is envisaged, it is recommended that a calculation be carried out using the US76 atmosphere model with an atmospheric density both reduced and increased by 50% in order to check that the result remains sufficiently below the threshold specified in the Technical Regulations.
If not, a parametric study (variation of initial conditions + MSIS00) is recommended.

Implementation

In the "Simulation Parameters" tab, you can apply a multiplication coefficient to the atmospheric density to increase or decrease it (see User's Manual [DR2]).

5.3. DEFINITION OF INITIAL CONDITIONS

Context

This involves defining the initial conditions for the DEBRISK calculation, which are defined by a date and six osculating orbital parameters. Of the parameters required, inclination is the best known. This is the inclination of the mission orbit. It changes very little over time, at most +/- 1° over 25 years.

5.3.1. Natural re-entry

Context

For a natural re-entry, the initial conditions are completely unknown, apart from the mission inclination. The influence of the various parameters was studied in order to arrive at the recommendations below. The choices were made in order to guarantee a reasonable computation time, to avoid differences between geocentric and geodetic altitudes and the effect of the Earth's flattening, while bearing in mind that the influence of each parameter remains small in the case of a calculation using the US76 atmosphere model recommended above. The studies have nevertheless revealed some results that are sensitive to threshold effects, so several initial AOL (Argument of Latitude) values need to be tested.

DBSK_REC_CI_010

Initial conditions for natural re-entry

The following initial conditions are recommended for natural re-entry:

- Date: 01-01-2020 0h00
- Perigee altitude: 140 km
- Apogee altitude: 140 km
- Inclination: mission value
- Right ascension of the ascending node Ω: 0°
- Argument of perigee ω: 0°
- True anomaly ν: 180° as a first approximation, then 0°, 90° and 270° to check the variability of the result. If necessary, the possible values are scanned every 30°.
- Atmosphere model: US76

Implementation

The 1st tab of DEBRISK is used to enter the initial orbit bulletin for calculating the trajectory of the integrated spacecraft. This bulletin (date + 6 osculating orbital parameters) is given in the J2000 reference frame.

5.3.2.Controlled re-entry

Context

By definition, the human risk for a controlled re-entry is zero. The aim of the risk study is to estimate the probability of casualties in the event of a contingency arising before or during controlled re-entry. The calculation of the overall risk of a controlled re-entry combines the risk in the event of a random re-entry (contingency before the last manoeuvre) and the risk in the event of a contingency arising during the last manoeuvre which directs the spacecraft towards the target fallback zone (see [DR1]).

DBSK_REC_CI_020

Initial conditions for controlled re-entry

In the case of a controlled re-entry, it is thus recommended to perform two calculations with DEBRISK:
- one with the initial conditions of a natural re-entry (see §5.3.1),
- the other with the bulletin following the last manoeuvre provided by the mission analysis.

Implementation

Each DEBRISK calculation will produce a list of surviving fragments. When calculating the overall risk, the appropriate list should be used for each stage of the calculation. When using ELECTRA, the appropriate list must be used for each mode.

5.4. SUMMARY DIAGRAM

All these recommendations are set out in the diagram in Figure 2:

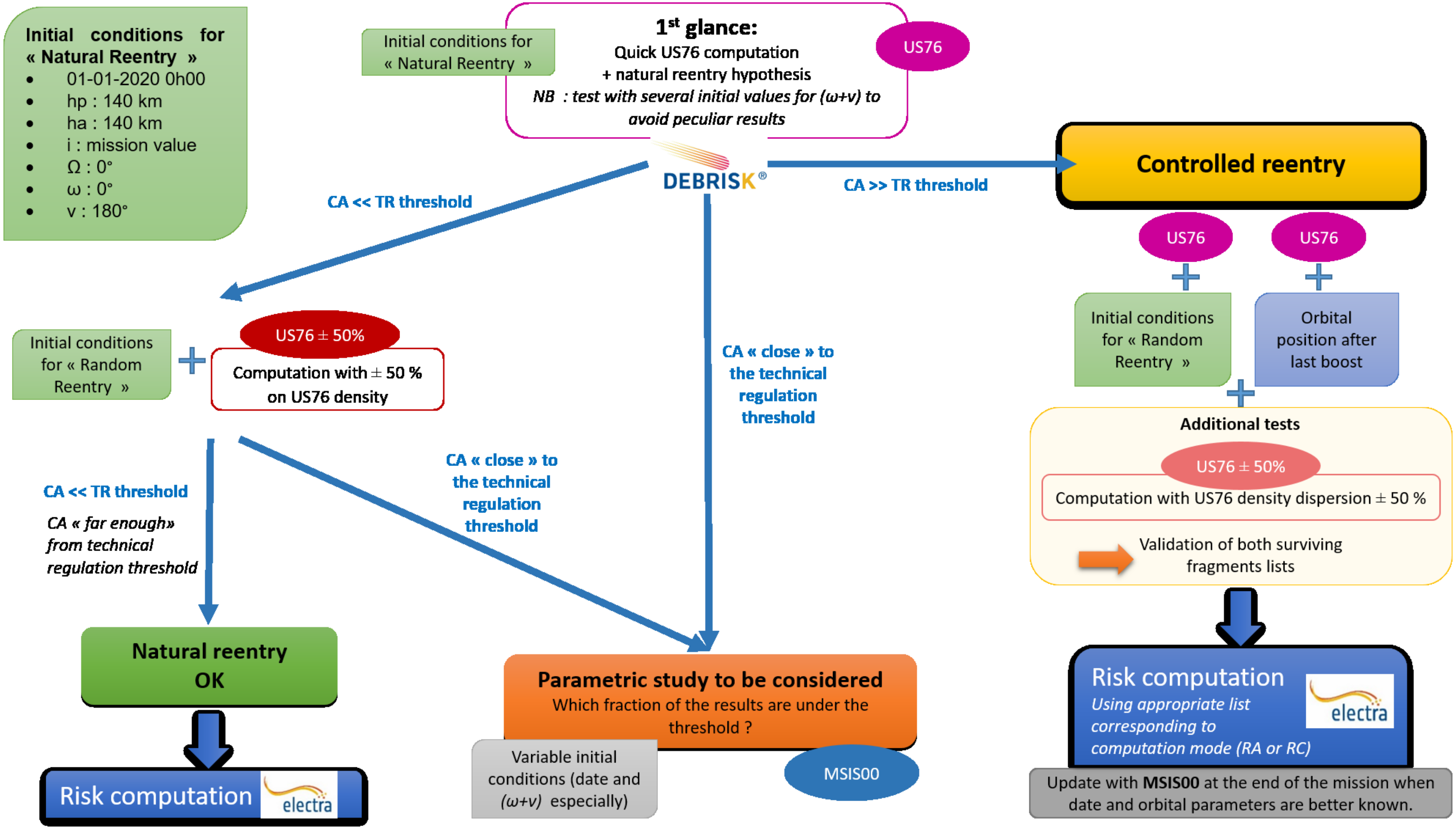

Figure 2 – Diagram of recommendations on the choice of atmosphere model and orbital conditions

6. RECOMMENDATIONS PRIOR TO USING DEBRISK FOR FRAGMENTATION ANALYSIS

6.1. INTRODUCTION

In the following sections, we detail the various recommendations for fragmenting a spacecraft as correctly as possible as part of a compliance study using DEBRISK.

This stage therefore consists in establishing and justifying how fragmentation takes place, as the DEBRISK software does not define it: it is a process that requires the skills of engineers specialised in mechanics, structures and materials.

When assessing fragmentation, the following minimum steps should be taken:

- ***Representation of the integrated spacecraft before fragmentation.***
- ***Breakdown into primary and secondary fragment objects, etc.***
- ***Determination of the materials that make up each element of the satellite.***

To do this, the operator must rely on documents such as

- ***DJD: Dossiers de Justification et de Définition [Design Justification File]***
- ***CIDL (Configuration Item Data List): Equipment configuration (parts list, S/S assemblies)***
- ***DML (Declared Material List): The materials used and their characteristics***
- ***DPL (Declared Process List): The processes used to assemble the elements (bonding, soldering, etc.) and their characteristics (conduction, fusion, etc.)***
- ***MICD: Parts drawings, geometries***
- ***MCI assessment: Element masses***
- ***CAD: Computer Aided Design***

DEBRISK requires precise knowledge of the volume of all the fragments in order to simulate a realistic fragmentation. For example, the operator needs to know the elements that make up the inside of a reaction wheel, the dimensions/masses (or thickness) of the shell of the electronics unit and its boards, the thickness of the skins and the NIDA of a sandwich panel, etc.

The main fragmentation altitude of the parent spacecraft should be estimated using the methodology recommended in § 6.4.

DBSK_EX_MOD_010

Generic modelling

For each fragment to be described correctly, whether it is derived from the disintegration of the parent spacecraft, or concerns the parent spacecraft itself, the following information must be provided:

- Explicit name (with definition of acronyms),
- Quantity (this only concerns fragments resulting from the disintegration of the parent spacecraft)
- The type of relationship with other fragments, following the methodology recommended in § 6.2,
- The shape chosen for its modelling, following the recommended methodologies in § 6.4 and § 6.5. In particular, it should specify:
  - The geometric characteristics: external and internal dimensions, thermal mass, etc. 6.5.1
  - The physical characteristics:
    - Conductivity coefficients, see § 6.3,
    - Materials see § 6.6.

To assist the operator in this process, we recommend that you follow the rules set out below, in order to benefit from all the features offered by DEBRISK. To use this tool, the operator should refer to the DEBRISK User's Manual [DR2].

6.2. DISMANTLING AND RELATIONSHIP BETWEEN OBJECTS

Context

The list of fragments resulting from the disintegration of the parent spacecraft is a succession of elements. During the main fragmentation of the satellite, the very first level elements are released: these represent the fragments that are attached directly to the structural panels, whether they are interacting with the flow (i.e. outside the structure) or inside the satellite. The elements are independent of each other.

Otherwise, certain elements may have specific relationships with each other. DEBRISK thus offers two types of relationship:

- A "Parent/Child" relationship (already present in DEBRISK V2): this is a relationship between two elements where one is contained within the other. In this case, the parent fragment contains children. These children are then released back into the flow once the parent fragment has disappeared. The child object appears under the same flow conditions as the disappeared parent object. The child's birth temperature is either 300 K (if the child has no heat exchange with the parent), or greater than 300 K if a contact conductance has been defined between the parent and the child, see § 6.3.
- A "Parent/Components" relationship (new relationship available in DEBRISK V3): this is a relationship between an element and the sub-elements that make it up. A component is released into the flow only when a separation temperature criterion on the parent object has been satisfied (defined by the term "Separation Temperature" in DEBRISK). For this relationship, the component object appears under the same flow conditions as the parent object that has disappeared and also inherits its temperature, since the component elements have interacted with the flow (unlike the parent/child relationship). This model is particularly interesting and applicable to NIDA sandwich panels. It makes it possible to simulate the separation of the skins with the NIDA at the pyrolysis temperature of the adhesives, thus establishing the link between these two sub-elements (see § 6.4.2). In this case, the parent object would be the integrated sandwich panel with the two skins and the NIDA as in the three components.

DBSK_REC_MOD_010

Choice of relationship

The use of the "Parent/Child" relationship is recommended for two situations:

1- When creating first-level elements, because they represent children whose parent is the satellite. Even if the elements outside the structure are not encapsulated by the satellite in the same way as the elements inside, they are considered to be at the same level.
2- When other secondary elements are encapsulated, such as electronic boards in a PCDU unit.

The use of the "Parent/Components" relationship is recommended when an elementary fragment can break up into sub-elements (referred to hereafter as components), such as a sandwich panel whose skin would separate from the NIDA.

Implementation

The relationship is selected when the shape is created, via the "Relationship" tab, as detailed in the User's Manual, see [DR2].

6.3. ENERGY TRANSFER

Context

In the case of a "Parent/Child" relationship, DEBRISK V3 now allows energy to be transferred between the parent and its children, enabling the children to be pre-heated even if they are protected from the outside environment. To do this, enter the contact conductance C_c (Conduction Coefficient) as $C_c = h\, S_{contact}$ (W/K) where h represents the contact coefficient (W/K/m²) between the parent and child and $S_{contact}$ represents the contact surface between the two.

DBSK_REC_MOD_020

Heat transfer

It is recommended to leave this option at 0 when the nature of the contact is unknown.

If the operator wishes to account for a transfer of energy for a contact between two objects, they will have to justify the approach, as well as the conductance coefficients it uses.

Implementation

This option is used by entering the contact conductance value C_c ("Conduction Coefficient") when creating the shape, as detailed in the User's Manual, see [DR2].

6.4. PARENT SPACECRAFT MODELLING RULES

This section deals with the modelling of the parent spacecraft and the recommended methodology for defining its main fragmentation altitude and that of the loss of solar panels (systematically referred to hereafter as GS (*Générateur Solaire*). Two types of parent spacecraft are considered here: those with a NIDA/Aluminium sandwich structure and others.

The methodology applied to DEBRISK V3, and detailed in the following sections, follows the logical sequence below:

- Definition of parent spacecraft
- Determination of the fragmentation altitude
- Modelling of structural panels
- Modelling of solar panels

6.4.1. Definition of parent spacecraft

DBSK_EX_MOD_020

Definition of parent spacecraft

The characteristics of the parent spacecraft should be defined as follows:

- **Main body shape**: The shape must be chosen from among the shapes proposed by DEBRISK that most closely resemble it.
- **Main body dimensions**: The dimensions must include the maximum external dimensions of the spacecraft, excluding the extended elements.
- **Total mass of the main body**: this is the total dry mass of the satellite, including the solar panels.
- **Main body thermal mass**: this corresponds to the mass of the parent spacecraft structure that is heated during atmospheric re-entry, i.e. the structural panels.
- **Solar panels**: solar panels are represented by "plate" shapes in DEBRISK. If the panels are deployed, you must enter:
  - The number of solar panels.
  - The total mass of each panel.
  - The surface area S_{panel} of each panel, according to the following formula:

$$S_{panel} = LW$$

Equation 12

where L and W represent the length and width respectively of the "plate" shape associated with the panel.

Implementation

The values for the characteristics of the parent spacecraft must be entered when creating the initial shape, which is referred to, by default, in DEBRISK as "Spacecraft", see the User's Manual [DR2].

For example:

Figure 3 below shows the external structure of the MICROSCOPE satellite. In terms of the parent spacecraft figure, it is defined as follows:

- The body of the parent spacecraft must be modelled by a box that encompasses its maximum dimensions.
- The total mass of the spacecraft must represent the total mass of MICROSCOPE.
- The thermal mass of the spacecraft is the sum of the masses of the six structural panels.
- You also need to consider the two solar panels as plates.

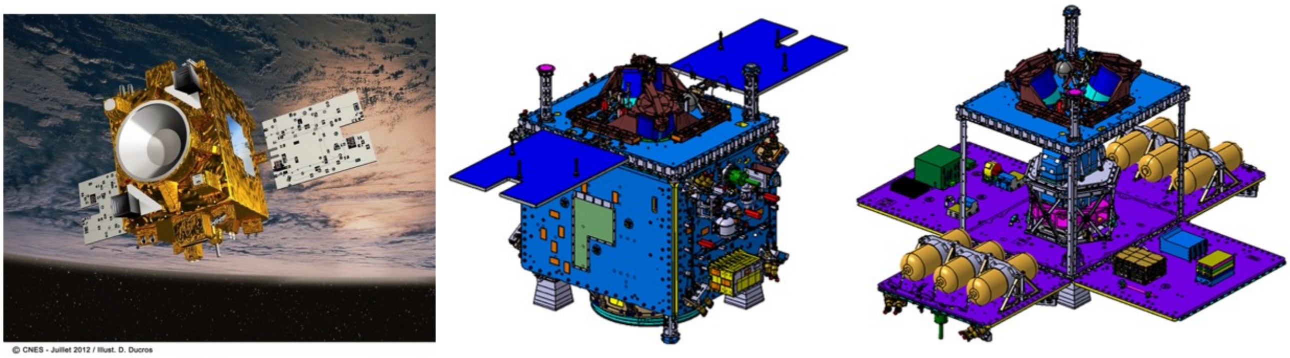

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Figure 3** – **External structure of MICROSCOPE

6.4.2. Determination of the main fragmentation altitude

Context

DEBRISK V3 offers a choice of two methods, allowing this altitude to be determined automatically or imposed as in DEBRISK V2.

DBSK_REC_MOD_030

Main fragmentation

For a spacecraft consisting mainly of a NIDA/Aluminium sandwich structure assembled with an epoxy resin adhesive, the recommended methodology is to choose as the main spacecraft fragmentation criterion the altitude at which the temperature of the object representing the parent spacecraft reaches the degradation temperature of the adhesives that fix the laminates to the NIDA.
When the parent spacecraft is not configured in such a way that the above recommendation can be applied, it is recommended that 78 km be chosen as the main fragmentation altitude.

Implementation

To automatically determine the main fragmentation of a spacecraft consisting mainly of a NIDA/Aluminium sandwich structure assembled with an epoxy resin adhesive, the recommendation applies as follows:

- Use the "Separation temperature" fragmentation option to calculate changes in the temperature of the parent spacecraft during its re-entry phase.
- Define the separation temperature, duly justified, or choose the recommended default value of 573K.

When the parent spacecraft is not configured in such a way that the above recommendation can be applied, 78 km should be entered as the "Fragmentation altitude" option.

6.4.3. Modelling the survival of structural panels

DBSK_REC_MOD_040

Structural panels

It is recommended that structural panels be taken into account in the list of fragments released at the time of the main fragmentation, defined in § 6.4.2, and that they be modelled according to the type of material:

- If the structural panels are of the NIDA/Aluminium sandwich type, only the two Aluminium skins need to be modelled.
- If the structural panels are made of solid aluminium (a propulsion panel, for example), they should normally be modelled as "solid plates".

Implementation

If the structural panels are of the NIDA/Aluminium sandwich type, only the two Aluminium skins need to be modelled, as described in Table 2 below.

Shape	Plate
Length and width	Actual skin dimensions
Mass/Thickness	Actual mass or thickness of skins
Material	Skin material
Type of relationship with parent	Parent/Component

Table 2 – Characteristics of the two plates modelling a NIDA/Aluminium sandwich panel

If the structural panels are solid aluminium, they should be modelled as described in Table 3 below.

Shape	Plate
Length and width	Actual panel dimensions
Mass	Actual panel mass
Material	Panel material
Type of relationship with parent	Parent/Component

Table 3 – Characteristics of the plates modelling a solid aluminium panel

6.4.4. Modelling the survival of solar panels

DBSK_REC_MOD_050

Deployed solar panels

If solar panels are deployed, it is not recommended that they be included in the initial list of fragments.

Implementation

If the solar panels are deployed, the user has no action to take.

DBSK_EX_MOD_030

Stowed solar panels

If solar panels are still stowed, they are to be included in the initial list of fragments.

Implementation

If the solar panels are stowed, they should be modelled as described in §6.5.4.2 - NIDA/CFRP sandwich panels.

6.5. MODELLING RULE FOR FRAGMENTS

This section deals with the modelling of the fragments resulting from the disintegration of the parent spacecraft.

6.5.1. Definition of shapes

DBSK_EX_MOD_040

Definition of shapes

The characteristics of each shape are defined as follows:

- **Shape**:
  - The shape that most closely resembles it must be chosen from among the shapes proposed by DEBRISK.
  - For certain actual shapes that are not available, an equivalence is recommended.
- **Dimensions**: The external dimensions (radius, length, width, height, thickness, angles of revolution, curvature, etc.) must be respected as far as possible. Once the external dimensions have been entered, the user can either enter the thermal mass of the object or the thickness. It is advisable to give priority to mass when this is known.
- **Thermal mass**: This mass corresponds to the mass of the fragment structure, i.e. the mass that heats up during atmospheric re-entry. It should not be confused with aerodynamic mass, which corresponds to the total mass of a fragment and is used to calculate the ballistic coefficient.
- **Heat conduction**: The phenomenon of energy transfer between a parent and a child can only be taken into account if a non-zero conductance coefficient is provided.
- **Separation temperature**: This is the temperature at which a shape breaks down into its component parts. This temperature must be below the melting point of the associated material.
- **Material**: The material can be chosen from the materials proposed by DEBRISK or proposed by the user if they can justify their sources (publications, experiments, internal data, etc.).

Implementation

The recommended shapes and choices are detailed in § 6.5.3 to 6.5.7. The above characteristics must be entered when creating the shape, as detailed in the User's Manual [DR2].

6.5.2. Recommendation on minimum masses to be modelled

Context

During the atmospheric re-entry of a spacecraft, there are fragments for which it is not necessary to carry out simulations, as they do not represent any risk on the ground within the meaning of the French Space Operations Act (LOS). This is the case for fragments that are fully ablated, or for which the kinetic energy falls below 14J. For an "uncontrolled" re-entry, a study has been carried out to establish Table 4, which provides, for each family of object, the extreme values of fragment masses that represent no risk within the meaning of the LOS, for a given topology, ballistic coefficient and material.

DBSK_REC_MOD_060

Minimum masses

It is recommended not to model, in the first-level fragmentation list, a fragment whose (initial) mass is strictly less than that given in Table 4.

Implementation

You can choose whether or not to include an element in the fragmentation list by using Table 4.

This table is worth using for natural or controlled re-entry, and for the shapes/materials and ballistic coefficients shown in it.

To determine the ballistic coefficient of the parent spacecraft, the user can run an initial simulation with DEBRISK, modelling only the parent spacecraft, and then consult the results files (output file in .csv format).

			Masses to be taken into account for a ballistic coefficient:		
	Number of calculations	Ballistic coefficient of parent spacecraft $[kg/m^2]$ / Materials	≥ 10	≥ 100	≥ 1000
Sphere	~ 4000	Aluminium	0.501	1.585	1.995
		Steel	0.025	0.04	0.04
		Titanium	0.02	0.025	0.02
Box	~ 10^6	Aluminium	0.251	1.259	1.585
		Steel	0.01	0.016	0.016
		Titanium	0.01	0.01	0.01
Plate	~ 50,000	Aluminium	0.158	0.794	1.259
		Steel	0.04	0.063	0.063
		Titanium	0.063	0.05	0.05
Cylinder	~ 200,000	Aluminium	0.398	2.512	3.162
		Steel	0.02	0.032	0.032
		Titanium	0.02	0.02	0.02
Tube	~40,000	Aluminium	0.631	3.981	7.943
		Steel	0.025	0.063	0.063
		Titanium	0.02	0.025	0.025

Table 4 – Minimum critical mass [kg] to be taken into account during simulations

6.5.3. DEBRISK shapes

This chapter deals with fragments that can be directly represented by the shapes proposed by DEBRISK.

DBSK_EX_FRAG_010

Solid shapes

For all the shapes below, if the object to be modelled is solid, do not use the hollow shape to fill it, but use the solid shape provided.

6.5.3.1. Sphere shape

Context

DEBRISK offers two types of spheres: hollow and solid. The primitive variables presented below are only valid for the hollow shape. In the case of the solid sphere, the notion of thickness does not exist, and neither does that of internal dimension.

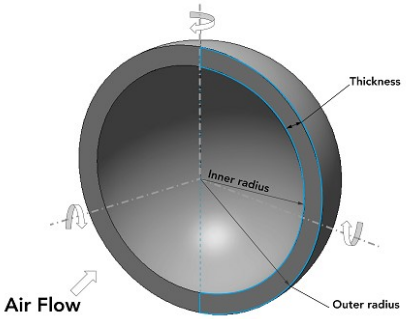


Figure 4: Definition of the dimensions of a sphere

The variables to be entered to describe the sphere in Figure 4 are:

- Dimension 1: the external radius R_{outer}, known as the "outer radius" in $[m]$.
- Dimension 2: the inner radius R_{inner}, known as the "inner radius" in $[m]$.
- The mass in [kg].
- The thickness in [mm].

Examples include propellant tanks (empty) and pressurisation spheres.

6.5.3.2. Flat-edged cylinder shape

Context

DEBRISK offers two types of cylinders: hollow and solid. The primitive variables presented below are only valid for the hollow shape. In the case of the solid cylinder, the notion of thickness does not come into play, and neither does that of internal dimension.

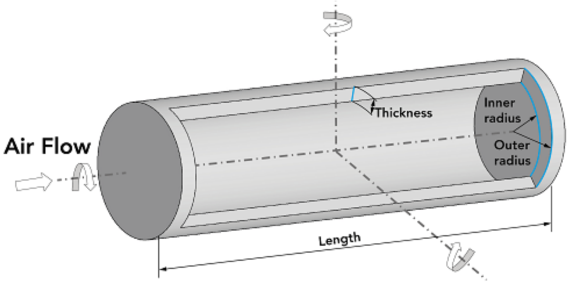


Figure 5: Defining the dimensions of a flat-edged cylinder

The variables to be entered to describe the cylinder in Figure 5 are:

- Dimension 1: the external radiusR_{outer}, known as the "outer radius" in $[m]$.
- Dimension 2: the inner radius R_{inner}, known as the "inner radius" in $[m]$.
- Dimension 3: the external lengthL_{outer}, known as the "outer length" in $[m]$.
- The mass in [kg].
- The thickness in [mm].

By way of example, this category includes:

- Long cylinders: Magneto couplers, connecting rods, masts, piping, etc.
- Flat cylinders: Reaction wheels, mirrors, etc.

6.5.3.3. Hemispherical-edged cylinder shape

Context

In DEBRISK, this shape is hollow.

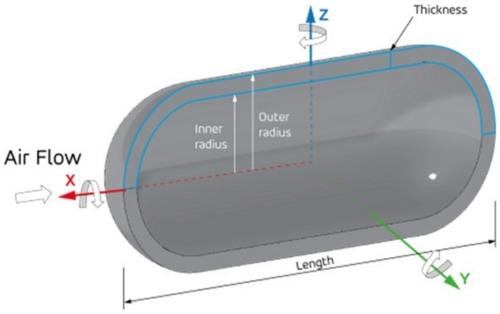


Figure 6: Defining the dimensions of a hemispherical-edged cylinder

The variables to be entered to describe the cylinder Figure 6 are:

- Dimension 1: the external radiusR_{outer}, known as the "outer radius" in $[m]$.
- Dimension 2: the inner radius R_{inner}, known as the "inner radius" in $[m]$.
- Dimension 3: the external lengthL_{outer}, known as the "outer length" in $[m]$.
- The mass in [kg].
- The thickness in [mm].

Examples include propellant tanks (empty).

6.5.3.4. Box shape

Context

In DEBRISK, this shape is hollow.

Note: the length must always be the largest dimension, followed by the width and the height, which is the smallest.

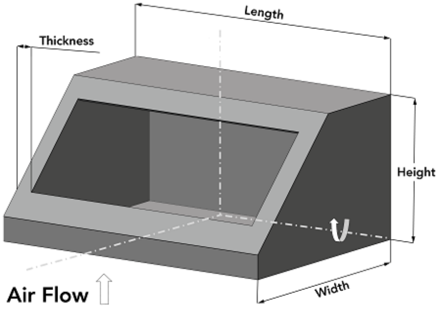


Figure 7: Definition of the dimensions of a hollow box

The variables to be entered to describe a hollow box (see Figure 7) are:

- Dimension 1: external length L_{outer}, "length" $[m]$.
- Dimension 2: external width W_{outer}, "width" $[m]$.
- Dimension 3: external height H_{outer}, "height" $[m]$.
- Dimension 4: thickness τ_s, "thickness" in $[mm]$.
- The mass in [kg].

- The thickness in [mm].

Examples of objects that fit into this category include electronics units and batteries.

6.5.3.5. Flat plate shape

Context

In DEBRISK, this shape is solid.

Remarks:

1. The length must always be greater than the width.
2. This shape is only valid when the thickness (height) is less than 10% of the width. In other cases, DEBRISK requires the use of the box form, see § 6.5.3.4.

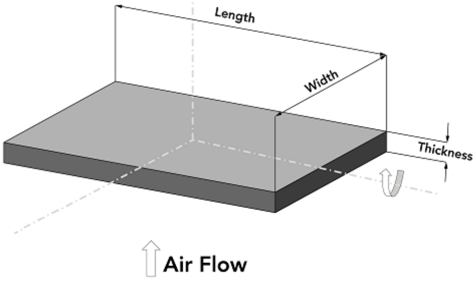


Figure 8: Defining the dimensions of a flat plate

The variables to be entered to describe the flat plate in Figure 8 are:

- Dimension 1: external length L_{outer}, "length" $[m]$.
- Dimension 2: external width W_{outer}, "width" $[m]$.
- Dimension 3: thickness τ_s, "thickness" in $[mm]$.
- The mass in [kg].

Examples include equipment trays, structural panels, sandwich panel laminates and covers.

6.5.3.6. Complex form

In DEBRISK, this form is solid, as shown in Figure 9 and Figure 10. Depending on the geometric characteristics entered by the operator, it can be broken down into:

- Ring, tube
- Open cone
- Open spherical cap
- Closed spherical cap
- Ring/tube sector
- Cone sector
- Open spherical cap sector
- Closed spherical cap sector

Examples include ferrules, parabolic antennas, satellite/launcher interface adapters and parts of launcher stages.

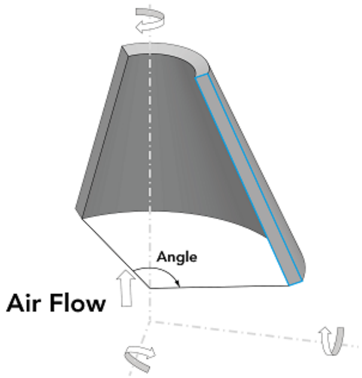


Figure 9: Conical profile of a complex shape

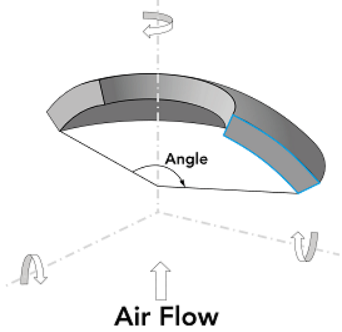


Figure 10: Spherical profile of a complex shape

The so-called "complex" shape can be defined exactly from the following six primitive variables:

- R_G, the large external radius, known as the "Large Radius" in $[m]$. This gives the diameter D_G.
- R_P, the small external radius, known as the "Small Radius" in $[m]$. This gives the diameter D_P.
- h, the height, in $[m]$.
- e, the thickness of the material making up the fragment, in $[mm]$.
- θ, the angle of revolution of the shape profile, in [°].
- $flatness$, the curvature of the profile, which can take on the value of "conical" for a linear profile (open cylinder, open truncated cone and associated sectors) and "spherical" for a profile with a spherical curvature (spherical cap and associated sectors).

A few clarifications on terminology:

Ring: Complex form for which $R_G = R_P$
Tube: A ring whose thickness is greater than its height, which translates into $e/h \geq 0.1$.

The definition of these parameters is explained by Figure 11 and Figure 12 referring respectively to a linear profile ($flatness = \text{conical}$) and a spherical profile ($flatness = \text{spherical}$), the complete geometry of the resulting fragment being generated by rotating these profiles by an angle θ.

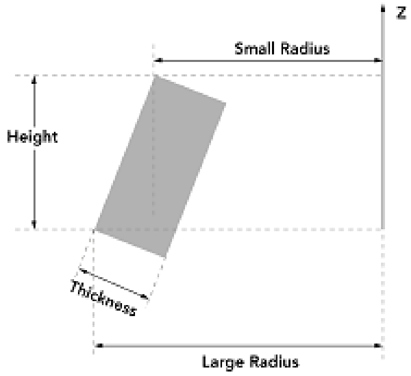


Figure 11: Definition of the geometric parameters for the profile of a launcher shape such as an open cylinder, an open truncated cone or a sector of these

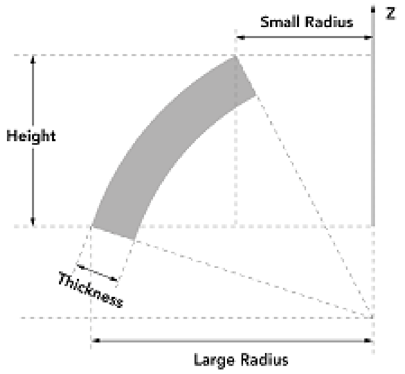


Figure 12: Definition of the geometric parameters for the profile of a spherical cap-type launcher shape (unperforated or perforated) or sector of the latter

6.5.4. Sandwich panels

Most structural panels and solar panels are sandwich structures, as are certain panels inside the satellite, such as shear panels. They are mainly made up of a NIDA aluminium core and laminates made of aluminium or epoxy matrix carbon fibre fabric (CFRP, Carbon Fibre Reinforced Polymer) laminates, as shown in Figure 13 below.

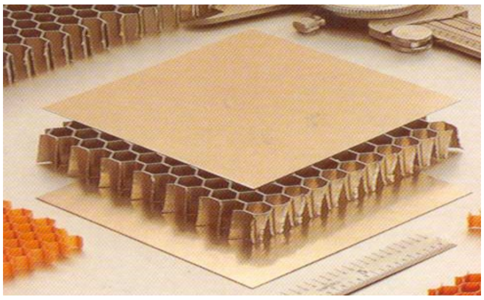


Figure 13 – NIDA/Aluminium sandwich panel

As in the example above, some fragments can be roughly considered as a stack of several layers of different materials. For some of them, the following models are recommended.

6.5.4.1. NIDA/Aluminium sandwich panels (excluding structural panels)

Context

This part only concerns the panels that are inside the central body and which are therefore thermally protected from the external flow.

DBSK_REC_FRAG_010

NIDA/Aluminium sandwich panels

We recommend modelling each panel as a "child" of its "parent" element.

Implementation

The method to be applied is as follows:

1. Enter the sandwich panel in question with the characteristics of the Aluminium, the actual mass and the actual dimensions (except the thickness, which will be adapted automatically by DEBRISK),
2. Enter a separation temperature of 573 K (temperature at which the adhesive between the skin and the NIDA breaks down),
3. As components of this panel, just enter the skins with the characteristics of Aluminium, and the actual dimensions. As a priority, we recommend that you indicate the mass, so that support assembly, inserts and other hooked elements can be taken into account, or by indicating the thickness of the skin.

In the case of a sandwich panel, it is easy to determine its mass if you know the mass of the NIDA part. Simply apply the following formula:

$$m_{skin} = \frac{(m_{tot} - m_{NIDA})}{2}$$

Equation 13

The integrated panel is characterised by the following Table 5:

Length and width	Actual panel dimensions
Mass	Actual panel mass
Material	Skin material
Separation temperature	Recommended value of 573 K
Type of relationship with parent	Parent/Child

Table 5 – Characteristics of the object modelling a complete NIDA/Aluminium sandwich panel

The newly separated Aluminium skins will be components of the parent object, characterised by Table 6 below:

Length and width	Actual skin dimensions
Mass	Actual skin masses
Material	Skin material
Type of relationship with parent	Parent/Component

Table 6 – Characteristics of the object modelling the skins of the NIDA/Aluminium sandwich panel

6.5.4.2. NIDA/CFRP sandwich panels (excluding deployed solar panels)

DBSK_REC_FRAG_020

NIDA/CFRP sandwich panels

We recommend modelling the sandwich panel as a "child" of its "parent" element.

Implementation

The method to be applied is as follows:

1. Enter the sandwich panel in question with the characteristics of the DEBRISK CFRP, the actual mass and the actual dimensions (except the thickness, which will be adapted automatically by DEBRISK),
2. Set a separation temperature of 773 K (the temperature at which the matrix disintegrates, leaving the CFRP to fray),
3. Unlike NIDA/Alu panels, it is not necessary to include CFRP fibres as a component.

The integrated panel is thus characterised by the following Table 7:

Length and width	Actual panel dimensions
Mass	Actual mass of solar panel
Material	DEBRISK CFRP
Separation temperature	Recommended value of 773 K
Type of relationship with parent	Parent/Child

Table 7 – Characteristics of the object modelling a complete NIDA/CFRP sandwich panel

6.5.5. Other CFRP elements

Context

Feedback now shows that some fragments can fall back to the ground without being damaged, mainly because of their structural composition.

Examples

Examples in this category include tanks with carbon-fibre-wound metal liners, optical supports or bipods.

DBSK_REC_FRAG_030

CFRP elements

In the following cases:

- tanks with metal liner and carbon fibre reinforcing,
- support sleeves.

It is recommended to model the element by imposing the external dimensions, the actual mass and by taking as the only material, the CFRP to be created by the user, for which the melting point is such that the element re-enters without ablating.

Implementation

The [DR2] User's Manual can be used to create this model, following the instructions in Table 8.

Dimensions	External dimensions
Mass	Actual mass
Material	CFRP to be created by the user
melting point of CFRP	Recommended value of 3000 K

Table 8 - Characteristics of the CFRP element.

To create the recommended CFRP, simply duplicate the DEBRISK CFRP and change the melting point. The name to be given to this new material must not contain the word "DEBRISK".

6.5.6. Electronics units equipment

Context

Some fragments cannot be modelled independently of their content. This is the case, for example, with electronics units, see Figure 14, where the metal structure of the enclosure must be taken into account, as well as the various elements (electronic boards, electronic components, wiring, connection elements, etc.) that it contains.

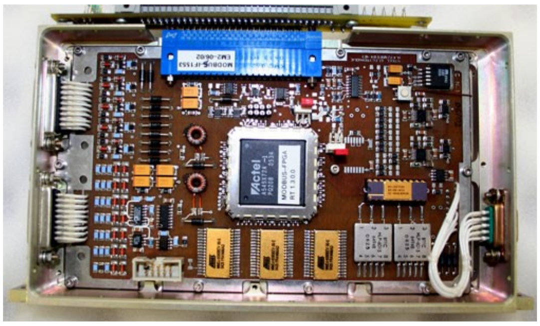


Figure 14 - Electronics unit – inside view.

DBSK_REC_FRAG_040

Cabinets

It is recommended that Electronics units equipment be modelled as a hollow box filled with ballast in a "parent/child" type relationship.

Implementation

The [DR2] User's Manual shows you how to apply the following method:

- For a parent, you need to enter a hollow box with the actual dimensions of the cabinet in question, as well as the associated material. The outer box is characterised by Table 9.

Shape	Hollow box
Dimensions	External dimensions
Mass	Actual mass of the external structure
Material	Actual material

Table 9 - External box characteristics

- For a child, you need to enter all the contents, boards and so on, in the form of a solid sphere. The total actual mass of the sphere is imposed, and you need to choose a material that allows it to disappear as soon as it is created (to be created by the user). Electronic boards are characterised by Table 10.

Shape	Solid sphere
Mass	Total actual mass of contents
Material	Material to be created by the user
melting point of Material	Recommended value of 301 K

Table 10 - Characteristics of the box contents

To create the recommended material, simply duplicate the DEBRISK Aluminium and change the melting temperature. The name to be given to this new material must not contain the word "DEBRISK".

6.5.7. Shapes not directly comparable to a DEBRISK shape

Context

Some shapes cannot be directly represented by the shapes proposed by DEBRISK. The default proposal is to use the shape that is closest to the object's envelope shape, while retaining the mass, external surface areas or external dimensions, depending on the shape to be processed. Below are recommendations for some of the most representative fragments.

6.5.7.1. Propulsion type panel (solid perforated plate)

Context/Example

The case of the solid perforated plate is typically that of the propulsion panel of a satellite, as illustrated by Figure 15 below.

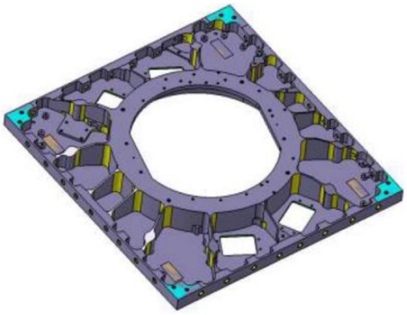


Figure 15 – Perforated panel

DBSK_REC_FRAG_050

Perforated plate

It is recommended that this plate be modelled by a tube (in the sense of DEBRISK shapes) for which, and using the normal name, see §6.5.3.6:

- The mass of the tube must be equal to the mass of the perforated plate
- R_G and R_P, respectively the large and small outer radii of the tube, are defined such that the blue areas of the Figure 16 below are equal.

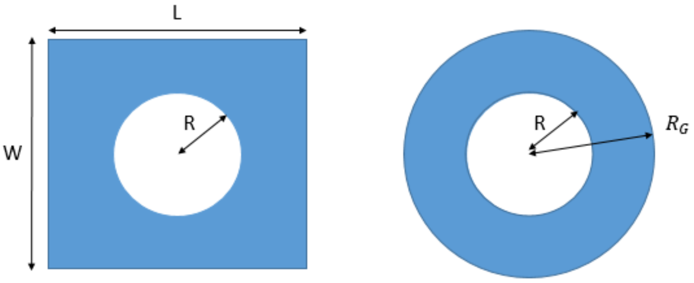


Figure 16 – Modelling the perforated plate

Implementation

- The radii R_G and R_P are calculated as follows:

$$R_G = R_P = \left(\frac{S_{struct_{externe}}}{\pi}\right)^{\frac{1}{2}}$$

Equation 14

where $S_{struct_{externe}}$ represents the surface area of the side, taking into account the external dimensions, as if there were no holes. For example, for a perforated plate, this surface area would be equal to $S_{struct_{externe}} = LW$, regardless of the hole.

- The height of the tube is calculated by:

$$h = \frac{m}{\rho_{mat}\ \pi\ (R_G^2 - R^2)}$$

Equation 15

where ρ_{mat} represents the density of the material used, and R the radius of the hole.

Comment

This methodology applies regardless of the initial shape, whether square, hexagonal plate or other, as the previous formulations can be easily adapted. In all cases, the shape must be modelled by imposing the mass and not the thickness.

6.5.7.2. Assemblies

Context

An assembly is a set of elements whose connections have been designed in such a way that it can be assumed (and justified by the operator) that they will remain joined together during re-entry to form a single fragment, resulting in a non-dispersed casualty area. Direct titanium bonds are considered to be strong, unlike resin/adhesive or bonded inserts, which are not covered in this section.

DBSK_REC_FRAG_060

Assemblies

It is recommended to model the assembly elements by a box such that:

- the mass corresponds to the actual mass of the assembly to be modelled.
- the dimensions chosen correspond to the maximum dimensions of the box inside which it is possible to enclose the element.

Implementation/Example

By way of example, the support assembly shown in Figure 17 fall into this category. The passage between the base and the sleeves is via a small cylindrical piece of solid titanium that must measure approximately 1 cm in diameter, so it' is hard to imagine that it will break.

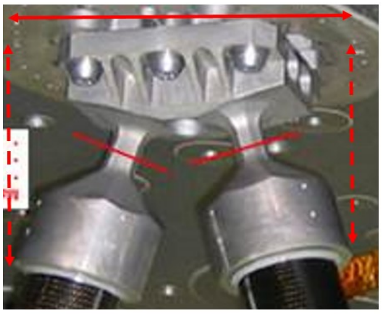


Figure 17 – Support assembly

The box modelled in this way is shown in Figure 18.

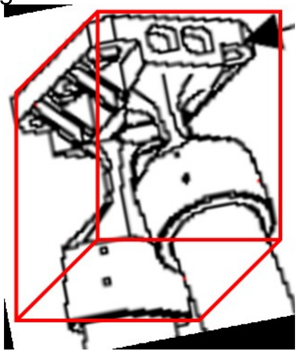


Figure 18 – Support assembly - box model

6.5.7.3. Harnesses

DBSK_REC_FRAG_070

Harnesses

We recommend that you not consider modelling the harnesses, as the assumption is that all the wiring will be destroyed on re-entry.

6.6. PROPERTIES OF MATERIALS

Context

A DEBRISK calculation requires that each fragment be assigned a homogeneous material.

DBSK_REC_MAT_010

Thermo-optical materials

With regard to the choice of parameters for thermo-optical materials, it is recommended, in the case of a preliminary calculation where the type of alloy is not fully known, to use one of the metallic, composite or ceramic materials in the list of basic materials proposed in DEBRISK.

DBSK_REC_MAT_020

Known materials

In the case of an advanced calculation where the type of alloy is known, it is recommended to use the materials available in the ESTIMATE database. An .xml DEBRISK file is available.

DBSK_REC_MAT_030

Unknown materials

It is recommended that you create your own reference if the material is not available, or modify a characteristic on the basis of documentary or experimental proof and provide the characteristics used. When the emissivity of a material is completely unknown at high temperatures, a value of 0.9 should be used.

DBSK_REC_MAT_040

Characteristics to be used

For materials such as Aluminium, Steel, Titanium, Inconel and Invar, it is recommended to use:

- the emissivity values proposed for DEBRISK materials, whatever the alloy of the material.
- the oxidation values proposed for DEBRISK materials, whatever the alloy (see DEBRISK .xml file for the parameters oxideHeatOfFormation, kOx, oxideConstantFlowRate, Aw and Ea_kB).

DBSK_REC_MAT_050

Zerodur

The default emissivity value for Zerodur is 0.8. It corresponds to a 10 cm thick object that has reached its melting point. Depending on the thickness of the fragment, we recommend reading the emissivity value in Figure 19 at the magenta curve at 1482 K. The value read will be entered into DEBRISK regardless of the temperature.

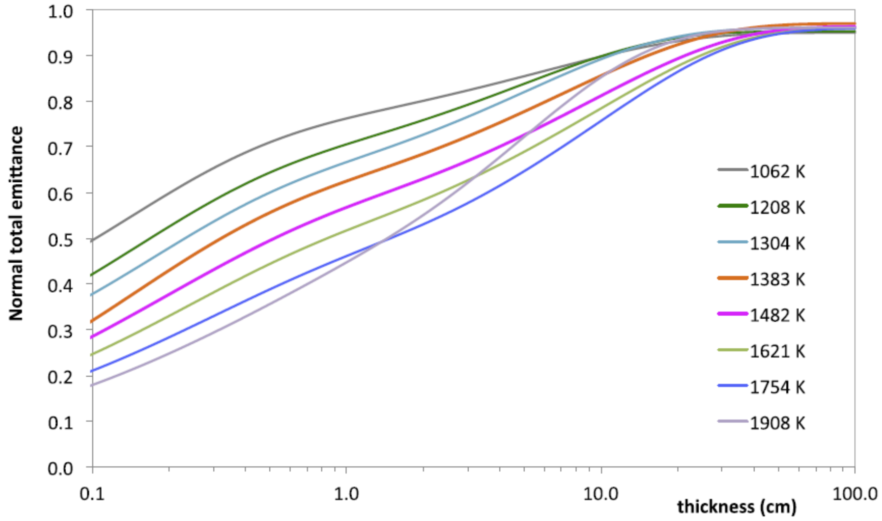


Figure 19 – Emissivity of Zerodur as a function of thickness and temperature

Implementation

The creation, editing and modifying of a material in DEBRISK are explained in the User's Manual [DR2].

The link to the ESTIMATE database is currently: https://estimate.sdo.esoc.esa.int/
The DEBRISK extended material file in .xml format can be downloaded from the "Database" tab.

6.7. SUMMARY OF THE V3 METHODOLOGY

A summary of all the methodologies proposed for DEBRISK V3 (in violet) and a comparison with those for DEBRISK V2 can be found in Table 11 below.

	V2	V3
Main fragmentation altitude	Recommended at an altitude of 78 km	For NIDA/Aluminium structures: calculated as a function of temperature change, and triggered when the temperature reaches 573 K. For other structures, recommended at an altitude of 78 km
Modelling of parent spacecraft	Thermal mass taken as equal to aerodynamic mass.	Thermal mass and aerodynamic mass are considered and are different.
Modelling of sandwich panels	Modelling of the plate as a solid object, without children, in Aluminium or CFRP.	Methodology from §6.5.4: • For the NIDA/Alu panel: component-type modelling. The parent is the solid plate, and the components are the aluminium laminates. Once separated at 573 K, the re-entry of the components is simulated. • For the NIDA/CFRP panel: component-type modelling. The parent is the solid plate, and the components are the CFRP laminates. Once separated at 773 K, the re-entry of the components is not simulated.
Modelling electronics units	Modelling is done using a box following two approaches: • An initial simplifying and conservative approach can be adopted by considering a single fragment of homogeneous material corresponding to that of the envelope structure and with a mass equal to the total mass of the equipment (the thermal mass and the aerodynamic mass are combined). • A second, more realistic approach is to use the notion of Parent/Child. The 'parent' corresponds to the structural envelope and the 'children' to the internal elements. (The thermal mass of the parent is reduced to the mass of the external structural envelope).	The modelling adopted for DEBRISK V3 corresponds to the second approach proposed on the left for DEBRISK V2, and detailed in §6.5.6.
Modelling solid flat perforated structures	Solid plate modelling with equivalence in mass and external surface area.	Modelling in the form of a tube with equivalence in mass and external surface area. This methodology is detailed in §6.5.3.2.
Modelling hemispherical tanks	Spherical or cylindrical shape with a flat edge, with equivalent mass, external surface area or identical external dimensions.	Shape modelled directly by DEBRISK V3, see §6.5.3.3
Modelling flattened cylinders	Below a certain L/D aspect ratio, modelling by a box or plate, with equivalence in mass, external surface area, and or identical external dimensions.	Shape modelled directly by DEBRISK V3, see §6.5.3.2
Modelling rings	Cylinder with equivalent mass, external surface area and or identical external dimensions.	Shape modelled directly by DEBRISK V3, see §6.5.3.6
Modelling assembly-type shapes	Modelling of the assembly using a box whose dimensions correspond to the maximum dimensions of the assembly.	The modelling used for DEBRISK V3 is the same as for DEBRISK V2.
Calculation of the casualty area	Surface area calculated using the value projected onto a plane perpendicular to the direction of flow, of the largest side of the object.	Surface area calculated using the weighted average value in motion of the surface area projected onto a plane perpendicular to the direction of flow.

Table 11 – Comparison of methodologies and recommendations associated with DEBRISK V3 versus DEBRISK V2

7. RECOMMENDATIONS FOR PHASE 0 STUDIES

Context

In phase 0, initial risk studies should be carried out as soon as possible. The aim is to ensure that the re-entry of the spacecraft analysed complies with the requirements of the LOS, to anticipate the type of atmospheric re-entry the operator will opt for and to rapidly consider developing technological solutions such as Design For Demise (D4D) or Design For Containment (D4C).

DBSK_REC_PHASE0_010

Preliminary phase

During the preliminary phases, the mass of each piece of equipment is not fully known. This is why we recommend running two types of simulations with DEBRISK:

- A simulation in which each fragment is modelled with its nominal mass
- A simulation in which each fragment is modelled with its maximum mass

The casualty area to be retained for the rest of the analysis must be the biggest of the two simulations.

Implementation

A DEBRISK .xml file must be created identical to the one used for the nominal mass. To simulate the case of maximum mass, the mass of each fragment can be increased by 20%.

DBSK_REC_PHASE0_020

Natural re-entry envisaged

In order to consider a natural re-entry (also known as an "uncontrolled" re-entry), the casualty area calculated by DEBRISK must be below a threshold that depends on the inclination of the mission orbit and the re-entry year considered. The threshold values are indicated in the good practice guide [DR1] and can be found in Figure 20. Compliance with the risk thresholds defined in the Technical Regulations must be calculated using a risk calculation tool such as ELECTRA. In phase 0 studies, we recommend using the table below to quickly define the type of re-entry that can be envisaged for the mission.

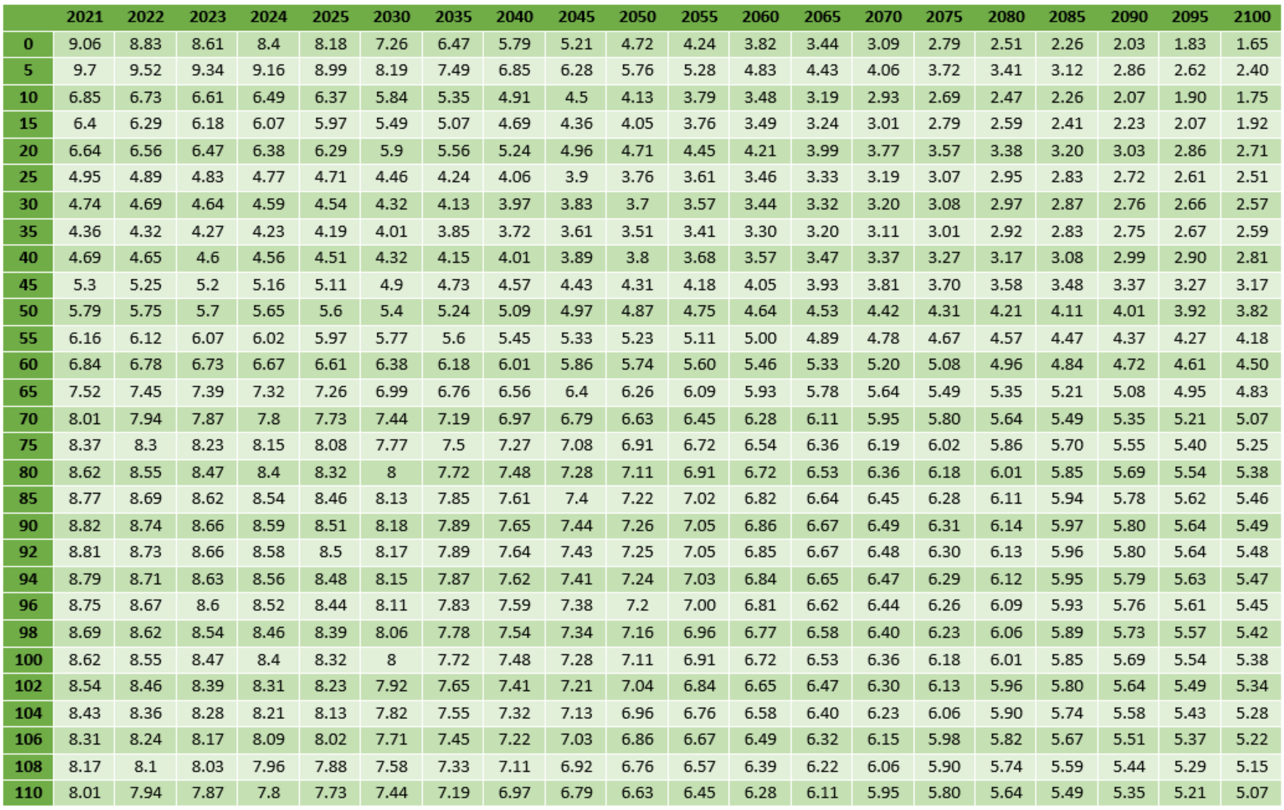
Implementation

Thus, as described in section 5.2, if the casualty area is well below the indicated threshold, this means that the spacecraft is on a very good path to achieving an uncontrolled re-entry. If, on the other hand, the value is well above the threshold, then a "controlled" re-entry should be seriously considered. For a value around the maximum authorised casualty area, there are certain recommendations for the spacecraft architecture, enabling the problem of minimising this casualty area to be addressed as effectively as possible. These can be broadly divided into two categories: Design For Demise (D4D) and Design For Containment (D4C).

The aim of the first category is to encourage the destruction of the fragment, while the second is to minimise dispersion on the ground. The most relevant are listed below:

- In the "D4D" category:
  - Minimise the mass of the elements.
  - Optimise the characteristics of the materials selected (mainly by choosing materials with a low melting point).

  - Increase thermal heat flux density locally, for example by favouring shapes with small radii of curvature.
  - Adding energy to the system by exothermic reactions (e.g. using thermites).
  - Fragmenting as early as possible, for example by using dedicated mechanisms or attachment points that encourage fragmentation.
- In the "D4C" category
  - Maintain highly resistant fragments and/or those with proven survivability and lethality.



	2021	2022	2023	2024	2025	2030	2035	2040	2045	2050	2055	2060	2065	2070	2075	2080	2085	2090	2095	2100
0	9.06	8.83	8.61	8.4	8.18	7.26	6.47	5.79	5.21	4.72	4.24	3.82	3.44	3.09	2.79	2.51	2.26	2.03	1.83	1.65
5	9.7	9.52	9.34	9.16	8.99	8.19	7.49	6.85	6.28	5.76	5.28	4.83	4.43	4.06	3.72	3.41	3.12	2.86	2.62	2.40
10	6.85	6.73	6.61	6.49	6.37	5.84	5.35	4.91	4.5	4.13	3.79	3.48	3.19	2.93	2.69	2.47	2.26	2.07	1.90	1.75
15	6.4	6.29	6.18	6.07	5.97	5.49	5.07	4.69	4.36	4.05	3.76	3.49	3.24	3.01	2.79	2.59	2.41	2.23	2.07	1.92
20	6.64	6.56	6.47	6.38	6.29	5.9	5.56	5.24	4.96	4.71	4.45	4.21	3.99	3.77	3.57	3.38	3.20	3.03	2.86	2.71
25	4.95	4.89	4.83	4.77	4.71	4.46	4.24	4.06	3.9	3.76	3.61	3.46	3.33	3.19	3.07	2.95	2.83	2.72	2.61	2.51
30	4.74	4.69	4.64	4.59	4.54	4.32	4.13	3.97	3.83	3.7	3.57	3.44	3.32	3.20	3.08	2.97	2.87	2.76	2.66	2.57
35	4.36	4.32	4.27	4.23	4.19	4.01	3.85	3.72	3.61	3.51	3.41	3.30	3.20	3.11	3.01	2.92	2.83	2.75	2.67	2.59
40	4.69	4.65	4.6	4.56	4.51	4.32	4.15	4.01	3.89	3.8	3.68	3.57	3.47	3.37	3.27	3.17	3.08	2.99	2.90	2.81
45	5.3	5.25	5.2	5.16	5.11	4.9	4.73	4.57	4.43	4.31	4.18	4.05	3.93	3.81	3.70	3.58	3.48	3.37	3.27	3.17
50	5.79	5.75	5.7	5.65	5.6	5.4	5.24	5.09	4.97	4.87	4.75	4.64	4.53	4.42	4.31	4.21	4.11	4.01	3.92	3.82
55	6.16	6.12	6.07	6.02	5.97	5.77	5.6	5.45	5.33	5.23	5.11	5.00	4.89	4.78	4.67	4.57	4.47	4.37	4.27	4.18
60	6.84	6.78	6.73	6.67	6.61	6.38	6.18	6.01	5.86	5.74	5.60	5.46	5.33	5.20	5.08	4.96	4.84	4.72	4.61	4.50
65	7.52	7.45	7.39	7.32	7.26	6.99	6.76	6.56	6.4	6.26	6.09	5.93	5.78	5.64	5.49	5.35	5.21	5.08	4.95	4.83
70	8.01	7.94	7.87	7.8	7.73	7.44	7.19	6.97	6.79	6.63	6.45	6.28	6.11	5.95	5.80	5.64	5.49	5.35	5.21	5.07
75	8.37	8.3	8.23	8.15	8.08	7.77	7.5	7.27	7.08	6.91	6.72	6.54	6.36	6.19	6.02	5.86	5.70	5.55	5.40	5.25
80	8.62	8.55	8.47	8.4	8.32	8	7.72	7.48	7.28	7.11	6.91	6.72	6.53	6.36	6.18	6.01	5.85	5.69	5.54	5.38
85	8.77	8.69	8.62	8.54	8.46	8.13	7.85	7.61	7.4	7.22	7.02	6.82	6.64	6.45	6.28	6.11	5.94	5.78	5.62	5.46
90	8.82	8.74	8.66	8.59	8.51	8.18	7.89	7.65	7.44	7.26	7.05	6.86	6.67	6.49	6.31	6.14	5.97	5.80	5.64	5.49
92	8.81	8.73	8.66	8.58	8.5	8.17	7.89	7.64	7.43	7.25	7.05	6.85	6.67	6.48	6.30	6.13	5.96	5.80	5.64	5.48
94	8.79	8.71	8.63	8.56	8.48	8.15	7.87	7.62	7.41	7.24	7.03	6.84	6.65	6.47	6.29	6.12	5.95	5.79	5.63	5.47
96	8.75	8.67	8.6	8.52	8.44	8.11	7.83	7.59	7.38	7.2	7.00	6.81	6.62	6.44	6.26	6.09	5.93	5.76	5.61	5.45
98	8.69	8.62	8.54	8.46	8.39	8.06	7.78	7.54	7.34	7.16	6.96	6.77	6.58	6.40	6.23	6.06	5.89	5.73	5.57	5.42
100	8.62	8.55	8.47	8.4	8.32	8	7.72	7.48	7.28	7.11	6.91	6.72	6.53	6.36	6.18	6.01	5.85	5.69	5.54	5.38
102	8.54	8.46	8.39	8.31	8.23	7.92	7.65	7.41	7.21	7.04	6.84	6.65	6.47	6.30	6.13	5.96	5.80	5.64	5.49	5.34
104	8.43	8.36	8.28	8.21	8.13	7.82	7.55	7.32	7.13	6.96	6.76	6.58	6.40	6.23	6.06	5.90	5.74	5.58	5.43	5.28
106	8.31	8.24	8.17	8.09	8.02	7.71	7.45	7.22	7.03	6.86	6.67	6.49	6.32	6.15	5.98	5.82	5.67	5.51	5.37	5.22
108	8.17	8.1	8.03	7.96	7.88	7.58	7.33	7.11	6.92	6.76	6.57	6.39	6.22	6.06	5.90	5.74	5.59	5.44	5.29	5.15
110	8.01	7.94	7.87	7.8	7.73	7.44	7.19	6.97	6.79	6.63	6.45	6.28	6.11	5.95	5.80	5.64	5.49	5.35	5.21	5.07

Figure 20 – Maximum acceptable casualty area [m²] leading to a 10^{-4} risk of casualty, as a function of the year of re-entry and the inclination of the orbit.

ANNEXE A : LIST OF RECOMMENDATIONS/REQUIREMENTS

Requirement	Title	Page
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DBSK_EX_MOD_030	• Solar panels stowed	P21
DBSK_EX_MOD_040	• Definition of shapes	P21
DBSK_REC_ATM_010	• Choice of atmosphere model, first calculation	P11
DBSK_REC_ATM_020	• Choice of atmosphere model, second calculation	P11
DBSK_REC_ATM_030	• Choice of atmosphere model for controlled re-entry	P12
DBSK_REC_ATM_040	• Choice of atmosphere model, end of mission	P12
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DBSK_REC_CI_010	• Initial conditions for natural re-entry	P13
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