**NASA CARA Size-Mass Tables**

Fact Sheet

Introduction

A number of foundational calculations in orbital safety require as inputs estimates of the sizes and masses of space objects. In assessing collision likelihood, size estimates of the two spacecraft in conjunction with each other are required for any of the mainstream calculation approaches: the most basic approach of using relative miss distance compares this calculated distance to the combined sizes of the two objects, and more sophisticated techniques that assess collision probability or confidence intervals on the miss vector/distance must compute these in reference to an estimated joint spacecraft size and/or volume. Similarly, in assessing collision consequence, here understood as an estimate of the number of debris fragments expected to be produced were a particular conjunction to result in a collision, estimates of the mass of both objects are necessary for standard breakup models, such as the NASA 4.0 EVOLVE model. For both components of spacecraft collision risk assessment, likelihood and consequence, estimates of spacecraft size and mass are both required.

To this point, it has not always been straightforward to obtain these data for CA calculations. Owners/operators often define a nominal spacecraft size to use as the calculation input for the primary object; but information on the secondary object, especially when this object is space debris, has remained elusive. As a practical alternative, many O/Os have elected to proceed by designating as the objects’ joint size a very large sphere that would in principle circumscribe the two objects’ sizes were they to be placed next to each other; while this method does allow calculations of parameters such as the probability of collision (Pc) to be calculated expeditiously, the substantial overestimation of the objects’ combined sizes common with this approach produces an excessive number of false alarms. In an attempt to add size sophistication, in some cases secondary object debris estimates have been generated by presuming the radar cross-section (RCS) value for the secondary object represents a projected area in the conjunction plane; this area is then combined with a similar nominal projected area for the primary to form a region over which an area integral in the conjunction plane can be calculated. Such an approach, however, is not consistent with the nature of RCS measurements, for RCS values asymptotically approach the value of a projected area only as the radar wavelength becomes extremely small with respect to the object size, which is rare in current space surveillance; and in any case substantial RCS value vetting and error control are necessary in order even to have a durable RCS dataset for a given object from which to work.

The present size/mass tables produced by NASA CARA are an attempt to make durable spacecraft size and mass estimate values more broadly available to the CA community. The accompanying journal article (Hall and Baars 2023 in the References folder) explains in some detail the particular data sources, process control, calculation methods employed in producing these estimates, as well as estimation uncertainties; but for convenience an abbreviated statement of the approaches used is given here in this overview. Users must be mindful of the inherent uncertainties in these estimated data when applying them for any specific applications.

Spacecraft Size Estimation

For intact spacecraft, such as active payloads, dead payloads, and rocket bodies, the best approach to size estimation is to obtain, when possible, actual measurements of such objects and use these to generate a three-dimensional sized rendering and from that an appropriate projected area. The European Space Agency’s DISCOS (Database and Information System Characterising Objects in Space) database is an excellent repository of such dimension data (and spacecraft mass values as well, when these are known), and the present size/mass tables make use of these data when they are available. Because of ESA licensing restrictions, however, a somewhat roundabout method must be used to obtain these data and place them in the tables. The recommended procedure is given below:

1. Establish an account with ESA for access to DISCOSweb (discosweb.esoc.esa.int)
2. Deploy the software accompanying the size-mass tables for DISCOS update
3. Run the software with your login credentials. This software will automatically download the size (and mass) information for the intact catalogued objects for which DISCOS has size/mass information available and place these data in the appropriate places in the NASA CARA size/mass tables

For debris objects, there is of course no *a priori* size information; sizes must therefore be estimated from sensor signature data, either through dedicated signature passes or as additional data collected as part of metric tracking. In LEO, the signature data used for this procedure is RCS data obtained by the USSF Space Fence, operating at S-band. For each object, a number of quality checks are first applied to determine the precise RCS dataset to use for the size estimation. Surviving data are then sent as a group through the NASA Size Estimation Model (SEM; Stokely *et al.,* 2006), which is the intended method of using the model: it is not accurate for point-estimates but can reasonably transform entire distributions of RCS into distributions of object characteristic dimensions. The results from the NASA SEM are then summarized statistically in order to produce an expected value for the object size, along with an estimation uncertainty. This process is described in much greater detail in the Hall and Baars journal article, previously cited. In most cases, the size estimate is within a factor of three of the actual object size; one can either accept that level of fidelity or inflate the size estimate by this factor, to be conservative. CARA’s general recommendation is to save the incorporation of conservatism as an omnibus correction applied at the end of the collision likelihood calculation through the judicious setting of the CA mitigation threshold associated the particular likelihood calculation chosen.

There are two estimation notes that deserve mention here. First, characteristic sizes are given as hard-body radii, which simply means they are half the size of the actual estimated characteristic dimension. The values can therefore be used directly as HBR values (for that object) or doubled if an estimate of the full characteristic dimension is desired. Second, the publicly-releasable version of these tables has a “floor” set at the 5cm HBR level (10cm full characteristic dimension level). Objects smaller than this size are simply indicated as smaller than the 5cm HBR level. For nearly all CA applications, using a 5cm HBR (10cm object size) as a limiting object size does not affect the utility of the result.

Spacecraft Mass Estimation

The estimation of spacecraft mass is more difficult and less reliable, both because the overall technique is less well suited to this particular application and because it has a dependency on the size estimation described in the previous section and therefore inherits its particular estimation errors. The basic procedure begins with the recognition that in the object’s orbit determination solution, the spacecraft mass is a component in the ballistic coefficient solved for as part of the drag acceleration solution and is also a component of the solar radiation pressure coefficient solved for as part of the solar radiation pressure acceleration solution. With histories of these coefficients available as part of a history of orbit determination solutions, if one can determine all of the other input components with the exception of the mass, it is possible to solve for the mass as the one remaining component; and with a history of such solutions, then a history of solved-for mass values is available, which can then be statistically summarized. The ballistic coefficient, for example, is a combination of the object’s mass, frontal area (which can be estimated using the satellite size estimate from the previous section), and drag coefficient (which has a bounded set of expected values depending on the object type). One can proceed similarly with the solar radiation pressure coefficient, although the acceptable ranges of values of the “reflectivity” coefficient have been less well studied. As with the size estimation, the particular estimation procedures employed and statistical controls applied are detailed in the Hall and Baars journal article, previously referenced.

The mass estimates that emerge from this process are believed to be better than an order of magnitude in accuracy. Such a level of uncertainty for an estimated parameter would be unacceptable in many applications; but in this particular case, for which the expected use is to determine whether a very large or relatively small amount of debris would be produced by a conjunction were it to result in a collision, it is adequate: it should be able to determine reliably whether the amount of produced debris is on the order of 10 pieces, or 100, or 1000, or 10,000. This level of fidelity is sufficient to assign an appropriate level of collision consequence and thus enable the risk assessment process.

Default HBR and Mass Values

For non-DISCOS objects that do not receive appreciable (or perhaps any) S-band tracking, default HBR and mass values are assigned based on object category designations. Previously, defaults were set to 1.5 m for HBR and 10 kg for mass, regardless of object type. Although these values were derived from debris data, they were applied to diverse object categories where they were not reflective of typical HBRs and masses. The new defaults are set to the 99th percentile HBRs and masses of each object type to capture the upper spectrum of typical values while minimizing the influence of extreme outliers, which tend to fall within the top 1%. Unrepresentative data were excluded when possible.

For rocket bodies and payloads, data was limited to recently tracked objects to ensure that the defaults reflect the current operational environment and objects launched within the last 10 years to prevent the defaults from being skewed by outdated technology. Additionally, the payloads category was split into GEO and non-GEO since there is a clear difference in HBR and mass. For unknown objects, data was limited to recently tracked objects, but older launches could not be filtered out since launch dates were generally unavailable. Rocket and payload mission-related object datasets did not have a sufficient sample size to apply the recent tracking and launch date filters.

The default values are shown in the table below:

|  |  |  |
| --- | --- | --- |
| **Object Type** | **Default HBR (m)** | **Default Mass (kg)** |
| Debris | 1.5 | 10.0 |
| Rocket Bodies | 8.0 | 5000.0 |
| Rocket Mission-Related | 3.7 | 1000.0 |
| Non-GEO Payloads | 14.5 | 2550.0 |
| GEO Payloads | 22.5 | 7712.0 |
| Payload Mission-Related | 4.1 | 2449.3 |
| Unknown | 1.1 | 448.3 |

Errata/Corrigenda

The process of estimating spacecraft size and mass using the procedures outlined here, while well founded and vetted with statistical process control and outlier identification, are nonetheless capable of miscarriage that can result in wildly large (or small) values. Object RCS histories presume proper object tagging of these data, and RCS returns can manifest specular response that can push the values orders of magnitude higher than regularly-observed values. Poor updates of ballistic and solar radiation pressure coefficients can affect the mass estimation substantially, and objects can have varying frontal-area exposures to the particular perturbing non-conservative force (Earth’s atmosphere or solar radiation) that introduce additional uncertainty. At times, all of these possibilities can align to produce results that must be viewed as aberrant.

If users encounter estimated size and mass values that simply do not align with reasonable expectations for the particular object, they are kindly asked to notify NASA CARA of this condition using the CARA github maintenance e-mail. This will allow CARA to examine the situation and, if appropriate, issue corrections. There are a large number of objects represented in this database; and while reasonable profiling and examination of the tables have been performed, it is simply not possible to conduct a manual inspection of each solution. As such, the community is asked to inform CARA of any encountered regularities so that a better product may be offered to all.