

Human Safety Analysis for the Genesis Sample Return Mission

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Extended Abstract

The Genesis sample return capsule (SRC) was NASA's first high-profile ballistic re-entry over the United States. Because of the ΔV -imparting nature of the SRC release sequence, the SRC was targeted to various points in Northeast Nevada and Northwest Utah. Its final target was the Utah Test and Training Range, which is operated by the US Air Force.

Both the USAF and NASA have different levels of acceptable risk for individuals or collective populations combined with the populations respective mission essential or mission non-essential (or general public) status. The Genesis project had the obligation to comply with the more stringent requirements wherever both requirements apply. To certify the re-entry of the SRC, JPL performed analyses of human casualty probability for Northeast Nevada and Northwest Utah. This paper discusses the methods and results from this risk analysis.

JPL was provided with two sets of population data in the UTTR region. The first data set was provided by UTTR in the summer of 2004. In all, there were over 100 locations labeled Mission Non-Essential. There were two locations (Wig Fallback Complex and TPQ-39) labeled Mission Essential. For each site, the central geodetic latitude and longitude, geometric area, and population data were given. This information was converted to geocentric latitude for use in EarthLS and an EarthLS-area file was created. This area file assumed triangular shapes for the locations that did not give any other geometric shape (usually less than 10,000 sq-ft in geometric area) and set vertices as such. For areas where a shape was given (circle or rectangle), that shape was used for the vertices at that site. The EarthLS-area file also contains geometric area and population data for each site.

JPL received another set of population data for Northeast Nevada and Northwest Utah from the Oak Ridge Laboratory, by way of the Johnson Space Center. These data are from a database of global population information (LandScan), which was last updated in 2002. The data are a Matlab array, where each cell corresponds to a geodetic latitude and longitude value and the value of the cell is the population of that cell. The cells are $1/120^\circ$ geodetic latitude by $1/120^\circ$ longitude, about 0.64 km^2 at this latitude. JPL converted these cells into geocentric latitude and created an EarthLS-area file from the four corners of each cell. Figure 2 is a contour of the original data set, with contours at each level of person per cell (0–2674) for maximum resolution.

Using entry and descent simulation software, such as JPL's AEPL or LARC's POST, the landing point of a trajectory started at atmospheric entry can be found. By sampling the orbit-determination covariance before atmospheric entry and varying the atmospheric and drag parameters of the entry body in a Monte Carlo analysis, these simulation programs can generate a dispersion of landing points. Because of the Gaussian methods of the orbit-determination and Monte Carlo analysis, the resulting dispersion of points is best characterized as a two-dimensional Gaussian distribution and can be represented by an ellipse (landing ellipse).

To determine the probability of landing in a region, or site, EarthLS can integrate the (Gaussian) bivariate probability distribution (BVPDF) function over that site. The integral of the BVPDF for each site, $P_S(i)$, is stored in memory to be combined with the probability of casualty in that area later in the process. The probability of landing in a site

can also be summed to find the overall probability of landing in any populated region. This can be a conservative approximation of the probability of impacting property. The probability of casualty in a specific site is a function of the following parameters:

- A_H = Area of one human (varies by interested party)
- $A_S(i)$ = Area of manned location/site "i"
- $C(i)$ = Population of site "i"
- $P_S(i)$ = Probability of landing in site "i" based on integration of the BVPDF

The risk to humans in these sites is separated into two categories: collective and individual. Collective risk can be described as the probability of *anyone* suffering from a casualty resulting from flight-project activities. Collective risk for a site can be mathematically described as:

- $D(i)$ = $C(i) / A_S(i)$, Population density of site "i"
- $P_C(i)$ = $C(i) * (A_H / A_S(i))$, Collective probability of adverse contact with any human being in site "i" based on a uniform distribution of humans
- P_{DC} = $\Sigma [P_C(i) * P_S(i)]$, Overall collective risk

A uniform distribution of humans is used because there is no simple way to approximate for the random motion of humans within a site. If the area of the site is small enough or if the population density is small enough, a uniform distribution is an appropriate approximation (a graphical example of a uniform distribution appears in the Appendix). Data in this analysis are used at their highest fidelity to support this assumption.

Individual risk is from the point of view of the individual, where the individual is selfishly concerned with only his or her own safety. In a civil society, we would hope that all humans are altruistic and are concerned primarily with the collective risk. However, in order to put a bound on what is acceptable to humankind, the individual risk is also calculated:

- $P_H(i)$ = $1 * (A_H / A_S(i))$, Probability of adverse contact with a specific individual human being in site "i"
- P_{DH} = $\max[P_H(i) * P_S(i)]$, overall individual risk

The maximum is used in calculating the overall individual risk because no individual can be in more than one site at a time.

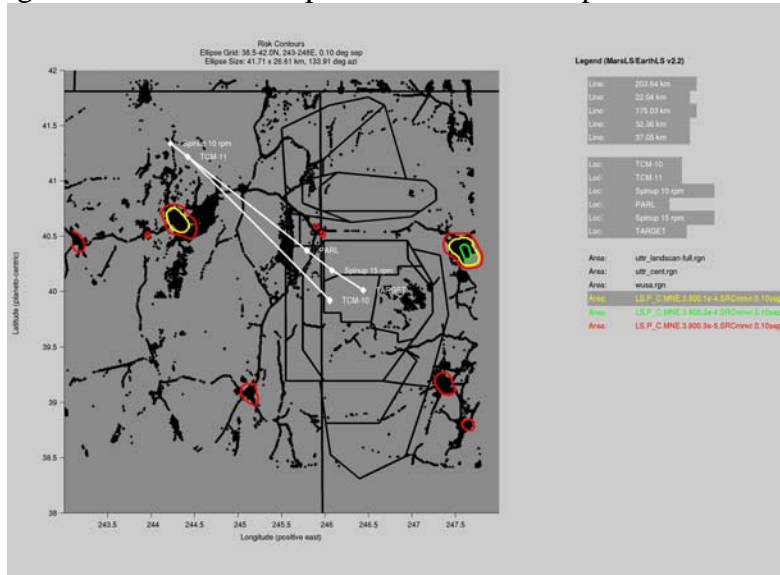
While the above formulations are appropriate for specific landing ellipses, the Project would like to characterize the risk based on the nominal landing point over the entire region. Since the two data sets—LandScan and UTTR-provided—were different enough, two analyses were performed. The process of performing each analysis is identical and has heritage from the MER mission.

A grid of nominal landing ellipses is spread over the region in which population data exist (NE Nevada and NW Utah for the LandScan data, UTTR for the UTTR-provided data). The ellipses are spaced at 0.05 degrees and are 41.71 by 26.61 km, with an azimuth of 133.91 degrees clockwise from north. This is the ellipse that results from

predicting the SRC release sequence, based on a tracking-data cutoff before the SRC release.

The probability of landing in each area for each ellipse is then calculated, $P_S(i)$, for each ellipse. The probability of collective and individual casualty for each area is also calculated and combined with $P_S(i)$ to get the overall probability of collective (total) and individual (maximum) casualty for each ellipse.

At this point, contours could be made for the risk levels, showing where risk levels are exceeded. However, these points could be interpolated to better approximate the contours at a finer resolution. Either way, contours based on the risk thresholds are created. The figure below is an example of such a contour plot.



In this plot, red contours indicate areas that exceed a $3e-5$ probability of collective risk, yellow exceeds $1e-4$, and green exceeds $3e-4$. The small, black areas are LandScan cells. The large, black areas are either state boundaries or the UTTR. The white lines are the instantaneous impact point paths for a nominal set of SRC release events.

Condensed Abstract

In order to certify that the risks of the Genesis Sample Return were acceptable to NASA and the Utah Test and Training Range (the target site), a thorough analysis of collective and individual risk for the public and mission personnel was performed. This analysis was performed by finding the probability of landing in an inhabited area based on a Gaussian distribution multiplied by the uniform probability of casualty in that area. This process was repeated for all areas in two different data sets. Both nominal and off-nominal scenarios had to be considered, so contour analyses based on a grid of representative ellipses were performed to satisfy the entire Northwest Utah and Northeast Nevada region. The results showed that there are few contours that exceed the maximum risk requirements in this region and that the Genesis Sample Return Capsule was safe to return. Subsequent analyses based on designed maneuvers and updated trajectories were performed to ensure that the safety criteria continued to be met.