Adventures in Parallel Processing: Entry, Descent and Landing Simulation for the Genesis and Stardust Missions

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Introduction:

Both Genesis and Stardust are sample return missions. Genesis has already returned to Earth and Stardust is scheduled to return on January 15, 2006. Both spacecraft use a heatshield and a backshell to protect the sample during reentry. Both entry capsules use a drogue chute to maintain attitude stability at supersonic speeds and a main chute to control the final descent speed. This paper will describe the Entry, Descent and Landing simulation tradeoffs and techniques that were used to provide the data required for an approval to proceed with entry.   This approval had to be made during the critical time following the last maneuver that targeted entry and the next maneuver that prevented the main spacecraft from reentering. Minimizing the dispersion at entry requires performing the last targeting maneuver as close to entry as practical, while allowing time to track the spacecraft after the maneuver, estimate the entry state and uncertainty, authorize the release of the entry capsule, and upload the commands to enable release and the subsequent deflection maneuver. The desire to minimize the entry dispersions meant that only one hour was available for doing the required Monte Carlo simulation which propagated 2000 dispersed entry states to the ground. Creative simulation tradeoffs combined with parallel processing were needed to provide the landing footprint statistics that were an essential part of the Go/NoGo decision that had to be made in the exciting final hours before entry.

Mission Descriptions:

The 494 kg Genesis mission was launched on August 8, 2001 on a mission to collect samples of the solar wind in high purity wafers of several different types. After orbiting L1 for several years, Genesis returned to Earth on September 8, 2004. The 206 kg Sample Return Capsule (SRC) landed in the Utah Test and Training Range (UTTR), while the main spacecraft was diverted by a propulsive maneuver to miss the Earth. Although the parachutes failed to deploy, the SRC landed very close to the targeted location. The initial despair of seeing the entry capsule embed itself in the dirt has gradually receded as good news or successful recovery of the samples from the collection wafers has been released.

The 385 kg Stardust mission was launched on Feb 7, 1999 on a mission to collect dust samples from the tail of comet and from interplanetary space. Stardust flew within 236 km of comet Wild-2 on January 2, 2004 and collected dust samples in high purity aerogel collectors. It also took pictures as it flew by the asteroid Anne Frank on November 2, 2002. Stardust is scheduled to return to Earth on January 15, 2006. The 46 kg sample return capsule will also land in the Utah Test and Training Range Southwest of

Salt Lake City. Both Genesis and Stardust were designed and built by Lockheed Martin Astronautics in Denver, Colorado.

One interesting difference between the two missions that is important for Entry, Descent and Landing (EDL) is the entry speed. Genesis never achieved escape velocity, and thus returned to Earth with a relatively low entry speed that was slightly less than escape velocity (11 km/sec). On the other hand, Stardust will reenter with a speed of 12.8 km/sec and become the fastest man-made object to enter the Earth's atmosphere. The difference in entry speed required a different material for the heat shield for Stardust in order to survive the higher heating rate at entry.
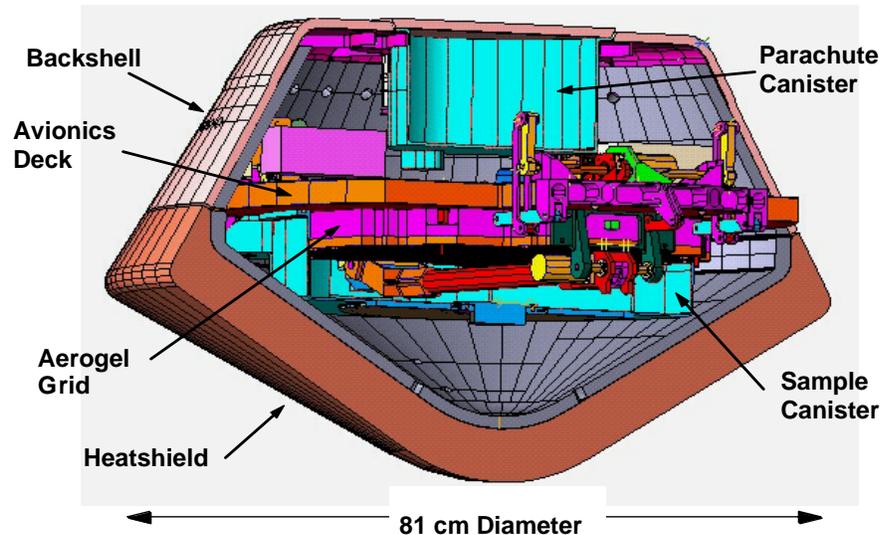

Figure 1 Stardust Sample Return Capsule (SRC)

After passing through the maximum deceleration and heating phases, both entry capsules were designed to use a deceleration sensor to trigger deployment of a drogue chute to maintain attitude stability until the main chute could be deployed. Genesis planned a mid-air capture during the day using a helicopter to snatch the parafoil chute. Stardust will descend all the way to the ground on a circular, disk band gap chute during a night entry.

Further information about these and other exciting NASA missions can be found at   http://www.jpl.nasa.gov/

Entry, Descent and Landing Simulation:

Both missions were designed such that the Navigation team would provide a nominal and a set of dispersed entry states at the 125 km entry interface. Two independent Entry, Descent and Landing (EDL) software programs propagated these states from entry to the surface in order to provide the 99% landing footprint on the surface. The primary EDL tool was POST, a high heritage program that was developed and used by engineers at the NASA Langley Research Center in Virginia. The backup

EDL tool was AEPL, a high heritage program that was developed and used by engineers at the Jet Propulsion Laboratory in Pasadena California.

The entire landing footprint was intensely scrutinized both during the early planning and the final execution stages. One of the key products of the EDL team was to provide not only landing footprints for the entry capsule, but also probabilistic assessments of the possibility of landing on a person or on property outside the footprint. To minimize the chance of landing in an unwanted location, the spacecraft are targeted to miss the Earth until just before arrival. Once the final targeting maneuver has been executed, the spacecraft must be tracked for a reasonable amount of time to provide enough data to accurately predict the actual entry state, as well as the uncertainty in the entry state. Performing the final targeting maneuver as close to arrival as possible minimizes the effect of the maneuver execution uncertainties. Although the delta-V required to deflect the primary spacecraft so that it will miss the Earth after the entry capsule is released increases as the final targeting maneuver is moved closer to arrival, delta-V was not a consideration in this case because the spacecraft had a very large margin. The limiting factor was the operations timeline required to perform the necessary functions including: collecting tracking data, estimating the entry state and dispersions from the tracking data, propagating the entry state and dispersed states to the ground, generating landing footprints and hazard probabilities, holding a Go/NoGo conference to authorize release of the entry capsule, and uploading the commands required to make it so. If the landing footprint predicted a dangerous overlap with a proscribed area, then release of the entry capsule would not have been authorized, and the entry capsule would have remained attached to the primary spacecraft during the divert maneuver. The footprint for Genesis allowed release of the entry capsule to be authorized. The objective is the same for the return of Stardust in January.

The Genesis timeline was such that there was approximately 1 hour available from the time that the Navigation entry state predicts were scheduled to be available until the Landing Footprints were due for incorporation into the Go/NoGo review package. During preliminary testing of AEPL for the Genesis application, each trajectory simulation took several minutes to propagate from entry to the surface. Since 2000 such propagations were required in less than an hour wall clock time to provide the desired statistics, something had to be done to speed up the simulation throughput! Although tuning the integration tolerances and the atmospheric data table information density provided some improvement, developing an automated process to distribute the cases among a collection of computer nodes so that cases could run in parallel proved to be the most effective way to achieve the required throughput.

Results:

Both POST and AEPL used a different approach for parallelizing the EDL simulation computations. These computational approaches will be described in the paper, and results from operations will be shown. Lessons that may be useful to future sample return projects will be summarized.

Conclusions:

Parallel processing proved to be a very effective way to achieve the simulation throughput required to support operations for Genesis. These same techniques will be used to support operations for Stardust in January of 2006.

100 Word Abstract:

Both Genesis and Stardust are sample return missions. Genesis has already returned to Earth and Stardust is scheduled to return on January 15, 2006. This paper will describe the Entry, Descent and Landing simulation tradeoffs and techniques that were used to provide the Monte Carlo data required to approve entry during a critical period just before entry. Only one hour was available for the simulation which propagated 2000 dispersed entry states to the ground. Creative simulation tradeoffs combined with parallel processing were needed to provide the landing footprint statistics that were an essential part of the Go/NoGo decision.