By Leonard David

Spacecraft Reentry: Safety by Design

While the sky is not falling… things do fall from the sky

Last year saw the uncontrolled reentry of NASA's Upper Atmosphere Research Satellite (UARS) on September 24, followed by the downfall of Germany's Röntgensatellit, or ROSAT, a month later.

In the case of UARS, some twenty-six satellite components, weighing a total of about 545 kilograms, were assessed to probably survive reentry and strike the surface of Earth. Similarly, an appraisal of ROSAT indicated that a significant amount of satellite remainders could live on after their fiery fall through Earth's atmosphere.

Then there was the blazing encore to these satellite reentries of the out-of-control Russian Phobos-Grunt spacecraft on January 15 of this year. Scraps of the errant interplanetary probe were deemed likely to endure reentry, particularly the spacecraft's nose-cone shaped descent vehicle. It was built to bring back to Earth bits and pieces of Phobos, a moon of Mars, and was designed to make a hard landing on terra firma, *sans* parachute.

Each spacecraft, according to orbital debris analysts, yielded leftover space junk that survived the plunge and reached the surface of our planet. Adding to public angst – driven in part by extensive media coverage of these reentries – is that orbital debris experts are unable to pinpoint in advance the time and location of when and where an uncontrolled spacecraft will auger in, coupled with no guarantee that residual rubbish would not lead to subsequent harm to person or property.

> "Responsibility for a project must encompass the entire lifespan"

Although the majority of the Earth's surface is covered by water, and much of the remainder is uninhabited, uncontrolled reentries can still pose a small but estimable risk to the human population.

In the case of Germany's ROSAT reentry, Johann-Dietrich Wörner, Chairman of the Executive Board of the German Aerospace Center (Deutsches Zentrum für Luft- und Raumfahrt; DLR), headquartered in Bonn, personally drew a number of lessons from his country's satellite fall:

Recovery of the Hayabusa sample return capsule. A similar capsule was part of the ill-fated Phobos-Grunt. - Credits: JAXA

Artist's impression of an ATV spacecraft upon reentry. Controlled reentry over the open ocean greatly reduces the risk connected with falling debris. - Credits: ESA

> "A risk greater than 1 in 10,000 is considered unacceptable by NASA"

- *Responsibility for a project must encompass the entire lifespan and take every eventuality into consideration.*
- *National and international collaboration, regardless of whether personal or institutional, has now achieved a level that is marked by a very engaging, positive attitude and mutual trust, which must be used accordingly.*
- *Communication concerning projects should be as transparent as possible, but always reliable and correct in every respect. In this regard, successes and potential risks must be communicated equally.*

Design for demise

New efforts are now underway to purposely build spacecraft hardware to generate the least number of fragments possible during reentry.

A risk greater than 1 part in 10,000 for any reentry is considered by NASA to be unacceptable, and measures are taken to reduce that risk. One approach is to design the spacecraft so that it can perform a controlled reentry into the open ocean at the end of mission life.

Yet another avenue is to redesign some of the surviving components so that they are likely to burn up during reentry heating. Indeed, one tactic is to redesign a component to a different shape, such that it will reenter faster, thus generating more heat during reentry.

This approach and other steps have been termed by orbital debris specialists as "Design for Demise", or D4D for short.

"D4D involves first identifying those components predicted to survive reentry which could most reduce the reentry risk by 'demising' instead," said Scott Hull an orbital debris engineer at NASA Goddard Space Flight Center in Greenbelt, Maryland. "This could be a result of either a very large component – like a propulsion tank – or a large quantity of a single surviving component type. Large quantities of surviving objects have a higher likelihood of causing an injury, somewhat analogous to a shotgun blast compared to a rifle bullet…so it is beneficial to address any objects which could survive in high quantity," he explained.

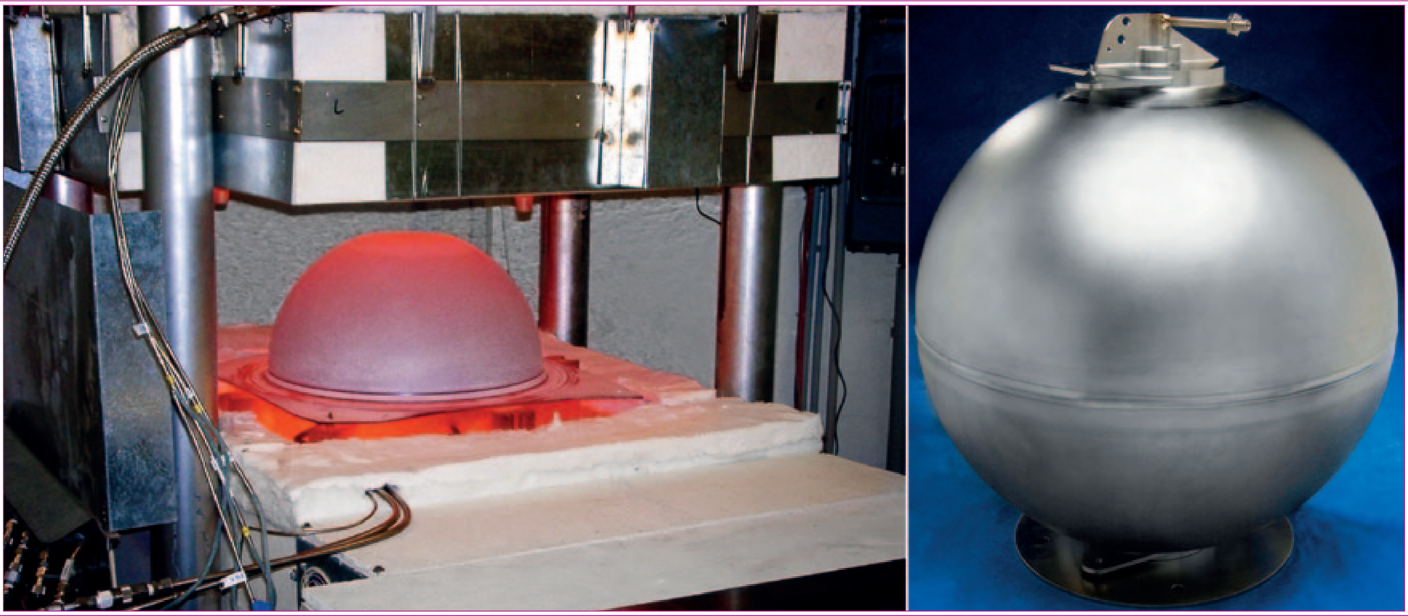
Pursuit of the D4D strategy, Hull told *Space Safety Magazine*, could mean switching to a different material, altering the shape of a component, using two smaller objects to perform the same job, or switching to a whole new technology.

Some common materials on spacecraft with high heats of ablation include titanium, stainless steel, glass, ceramics, and beryllium, Hull pointed out, whereas graphite-epoxy composites, aluminum, and polymers all generally have low heat of ablation.

"In consultation with the component designers, it is often possible to redesign a titanium component using graphite-epoxy, for example, to retain approximately the same thermal expansion coefficient, but with a component that will now burn up on reentry," Hull said.

Of course, all material properties must be taken into account, since titanium may have been selected initially for its chemical properties or strength, which the new material might not meet, Hull added. Aluminum can be a handy substitution material because it not only has a low heat of ablation, but also experiences generous oxidation heat-

The Global Precipitation Measurement (GPM) satellite, under construction, is fitted to the bed of the High Capacity Centrifuge for spin testing. This spacecraft has undergone a "Design for Demise" overhaul. - Credits: NASA/GSFC



Forming of an Ariane 5 titanium fuel tank, and the final result. Titanium tanks are among the components that are most likely to survive reentry. - Credits: ESA

ing and burning, generating even more heat during reentry, especially at lower altitude.

Chronic survivor

Also spotlighted by Hull are spacecraft flywheels, a chronic survivor of reentry, that don't necessarily have to be. Off-the-shelf reaction wheels sometimes use stainless steel or titanium flywheels which allow higher torque or faster wheel speeds in a small diameter.

"We've found that the same torque can often be created by using a larger diameter flywheel made from aluminum, which will demise readily," Hull continued. "There is a penalty to the project in that the wheel is larger, but this impact is often preferable to the additional hardware and other constraints imposed to perform a controlled reentry."

Metal Hydride battery cells have been a concern for a while, due to their large quantity. If they survive, then the battery alone typically exceeds the Debris Casualty Area (DCA) threshold for the entire spacecraft. One way to deal with that is to ensure that the cells remain together as a single object with lower overall DCA.

NASA's Nicholas Johnson, chief scientist for orbital debris at the Johnson Space Center in Houston, Texas, said that the future launch of the Global Precipitation Measurement (GPM) spacecraft is a mission that has undergone D4D scrutiny.

An analysis of GPM done years ago had flagged the spacecraft's titanium tank – to be loaded to the brim with more than 500 kilograms of hydrazine – as a significant reentry risk. A NASA-sponsored effort produced a flight-qualified, equal-capacity aluminum tank and an all-aluminum internal propellant management device. The result was that the re-entry risk for the tank was reduced to zero. At the same time, a weight savings in the tank was also achieved.

JAXA work underway

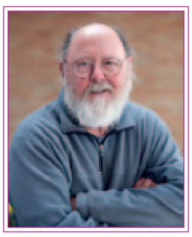
There is growing interest in D4D beyond NASA. This was in evidence at the just concluded forty-ninth session of the Scientific and Technical Subcommittee of the Committee on the Peaceful Uses of Outer Space in Vienna, Austria.

Officials from the Japan Aerospace Exploration Agency (JAXA) announced that work is underway on a demisable propellant tank.

"A propellant tank is usually made of titanium alloy, which is superior because of its light weight and good chemical compatibility with propellant. But its melting point is so high that a propellant tank would not demise during reentry, and that presents one of the major risks of ground casualty," a JAXA document observed. Research is in progress in Japan to replace the titanium tank design for hazard prevention.

> "Large quantities of surviving objects have a higher likelihood of causing injury"

NASA's Nicholas Johnson said, within the United States, spacecraft component vendors need to do a better job defining what is acceptable or not acceptable. Doing so takes time and will not happen quickly. There's an educational aspect to D4D, he concluded.



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