D4D – MiCRA CDF
Final Session Presentations

This is a compilation of the presentations given during the final session of the MiCRA CDF study on D4D.

Please note that this material was not originally intended to be released and has not been checked for possible errors or typos.
D4D – Design for Demise

Systems

Session 4
ESTEC, 2nd October 2013

Prepared by the D4D / CDF* Team

(*) ESTEC Concurrent Design Facility
Session 4 Objectives

Session 1: Introduction
Factors that influence casualty risk and potential techniques to reduce it

Session 2: Components & subsystems
Techniques to build spacecraft components and subsystems leading to reduced casualty risk

Session 3: S/C architecture
Design options at system level for reduced casualty risk

Session 4: Wrap-up
Preliminary ranking of techniques and roadmaps for future work
Session 4 Agenda

09:40  Understanding demisability design space (follow-up)
   - Aerothermodynamics (Neil)
   - Space debris office (Holger)
   - Systems (Sven, Friederike)

10:30 Promoting earlier structure break-up (follow-up)
   - Mechanisms (Adam)
   - Structure & configuration (Tiziana & Sandra)

11:30 Coffee break

11:40  Design for demise within the project life cycle

12:10 Study wrap-up
   - Domain specialists
   - Systems (Friederike, Sven, Carlos)

13:15 Conclusion
Design for demise within the project life cycle

1. Decision uncontrolled vs. controlled re-entry should be taken ideally **early during phase A**
   a. Keeping the two design options in parallel is only possible for a limited period of time
      – Significant impact at system level of controlled re-entry: mainly propulsion S/S (tank, thrusters), but also configuration and mass (launcher compatibility)

2. First survivability analysis and re-entry casualty risk calculations may be based on expected S/C and payload mass, presence of critical components, orbit
   a. Estimations may be based on comparison to similar missions or low-fidelity calculations
DfD - Micro Study: Aerothermodynamics

Neil Murray

02/10/2013
Reentry of random shape

a. More heat is applied to a surface that has an attached oblique shock wave as opposed to a surface that has a bow shock in front (all other aspects being equal).

b. The same body can have an attached or bow shock depending on its orientation relative to the wind.
Temperature – sphere from 85km

\[ \dot{q} = 1,103 \times 10^8 \left( \frac{\rho_{\infty}}{\rho_{SL}} \right)^{0.5} \left( \frac{u_{\infty}}{u_{GO}} \right)^{3.15} \sqrt{\frac{1}{R_N}} \]
Temperature – inside ATV

- ATV-1 Docking System Forward Cone Structure
- ATV-1 ICC Forward Cone Structure
- ATV-1 RDS Hatch
Increased Demise?

1. A stable attitude can occur if the CoP is aft of the CoM and if a change in attitude causes further changes that tend to restore the vehicle to its original orientation.
   
   a. Torque = 0  
   b) Torque = ACW  
   c) Torque = CW  

2. Demise of the leading edge will move the CoP and CoM and likely to a neutrally stable position. Therefore tumbling seems the most likely outcome after the initial demise of sharp edges.

3. Loading the high density components to the fore of the reentry craft can therefore stabilise the reentry initially and provide a localised point where demise will be known to occur.

4. Knock on effect is that the BC stays high for longer and therefore demise in the lower atmosphere could be increased.
Space Debris

Session 2
ESTEC, 18th September 2013

Prepared by the D4D / CDF* Team

(*) ESTEC Concurrent Design Facility
From your analysis with SCARAB, can you see a difference of demise properties between NiCD battery (Metop) and LiIon battery (S2)

- It has not been studied systematically (existing results are not comparable: batteries have different sizes, masses, positions in the spacecraft)
- Thermal properties can differ in the approach taken (average density and thermal properties over all involved materials)
Could you state if SCARAB is able to simulate battery explosion? If not, any idea on the degradation of the results?

Scarab can compute the point of time when the bursting pressure of a container is reached (requires knowledge on support pressure levels, and thermal properties of the liquid/gas)

Scarab cannot compute the consequences of such a computation

A several explosive break-up can be modelled using a standard statistical explosion model
Questions & Answers (3/15)

- Is there evidence of large compound components (as predicted by SCARAB) discovered on the ground?
  - Most recovered fragments are tanks
  - There is no systematic survey (and possibly large compounds are not always recognised as space objects)

Source: Paul Maley
In the example shown on slide 1855 is there a graph showing front panel temperature versus altitude for a unit that is not tumbling?

This is theoretically possible with Scarab (DRAMA makes a standard assumption of randomly tumbling components). However, this requires modification to the code in order to trigger constant stable attitude.
- Has an assessment been done in DRAMA to understand if there is an optimal release altitude for fragments to demise based on the material and ballistic coefficient of the fragment?
  - Excellent idea
  - Independently, we started such an analysis (should be ready by session #3)
Are the shapes shown (Krag presentation) for relative demise solid, or finite thickness shells? Hollow objects are more realistic for spacecraft components. A more appropriate similarity condition would be to match the ballistic coefficient (not mass or area) as this would provide the same trajectory for each shape. Has a constant ballistic coefficient test been performed using the simple correlations for the different shapes to provide an indication of demisability?

- This must refer to the analysis performed on the various shapes with DRAMA
- The idea to study this along with a constant ballistic coefficient is excellent and can be done
could it be possible to get the model definition of wheels and MTQ and the parts which have survived

- Wheels and MTQs are modelled as monolithic objects without going into subcomponent level
- Mass and dimension are properly reflected
- The model for the wheels is typically a circular disk made of A316, A304
- The model for MTQ is typically a cylindrical rod made of AA7075, A286, Invar, Copper
How is the initial temperature of the structure calculated in SCARAB? Is it a radiative equilibrium with solar flux? I would think that in the early stages of entry (for melting of module joints) it would

- The initial temperature is a simulation result after one or two simulated revolutions (i.e., close to an equilibrium).
- The temperature is a result of solar radiation, orientation of the S/C to sun, shadow passes and thermal conduction inside the spacecraft.
Heard 600K @ 100km altitude? Can it be confirmed? Can this aspects be further developed in final Webcast? It's an Important design driver for those mechanism (impact strongly the TRL of those solutions) From COTS to full new redevelopment, with new SMA

- Exposed components can reach maximum (!) temperatures of 600K at 100km altitude under re-entry angles that correspond to uncontrolled re-entries
- It depends on size and material
- Indeed, this is an interesting option for so-called triggered material failures. We will elaborate on this
could you provide details on the measurements planned for the GOCE re-entry, which would support validation of re-entry simulation softwares?

- The measurements to be performed on GOCE are strictly limited to orbit measurements (from where we can derive mean ballistic coefficients)
- Exceptionally, it will be possible to determine the attitude
- The spacecraft sensors will not be operational anymore at the “interesting” altitudes
what's about the possibility to separate the platform and the payload at mission end: can we assume each element has to comply 10E-4? For given mission, multiple small S/C each one complying with 10E-4, instead of big S/C?

- The requirements read:
  - “For space systems that are disposed of by re-entry, the prime contractor shall perform an analysis to determine the characteristics of fragments surviving to ground impact, and assess the total casualty risk to the population on ground assuming an uncontrolled re-entry.”
  - “In case the total casualty risk is larger than 10-4, uncontrolled re-entry is not allowed.”

- Having re-entering parts of one spacecraft counted separately is definitely not the intention. Still lawyers may find the formulation weak.
Questions & Answers (12/15)

For the comparison of GOCE, METOP and S2, the SCARAB results for harness ad electronic are rather different. Are the SCARAB versions identical?

- Scarab 3.1L was used for METOP and S2
- Scarab 1.5 was used for GOCE
- However, the S/W version can only explain a minor portion of the differences. The bulk will come from the fidelity of the user-generated model and of the actual specific design of the harness
Questions & Answers (13/15)

All along the D4D CDF study the 15J Kinetic Energy has clearly been identified as threshold for maximum acceptable energy to avoid death or severe injury of a single man. On the other hand, in order to limit casualty risk containment technics are considered as possible valuable solutions to limit excessive not-demisable S/C components dispersion and consequent casualty area. This means that quite large and heavy reentering objects can be tolerated. Did you assess the related kinetic energy and the possible effects on large population concentration areas (bomb effects on building, aircraft, etc...)? Could this point introduce a new maximum acceptable energetic threshold associated to building/aircraft, etc. distribution?

• Both the energetic threshold of 15J and the (admittedly simple but logical) way of computing the casualty cross-section (under the assumption of the whole population being unsheltered and standing upright with a standard cross-section) goes back to a NASA safety standard that has become the de-facto standard across all major space farers. Eventhough the assumptions are coarse and will not reflect the real risk, they are the assumptions to be used in association with the risk level of 1:10000 which originates from the same standard. I have seen many attempts to use more accurate modelling, e.g. using database for country specific housing/sheltering, body sizes and secondary effects (fall of roofs, ejected material,...). You can show very quickly that you can "fake" all kinds of risks with your modelling assumptions. In order for risk levels to be comparable (that what standards are for) it is important to work with the assumptions that fit with the logic under which the threshold of 1:10000 was once defined. Otherwise, also the figure of 1:10000 needs to be put in question.
Questions & Answers (14/15)

A very important resource to assess Design for Demise technics and their efficiency are, of course, the modeling and simulation tools as those you used during this study (DRAMA and SCARAB). Does ESA foresee to make these SWs available for industry?

- Yes, DRAMA is a tool that is developed exactly for this purpose. It comes as a fully licensed self-installable product with a graphical interface and full user support.
- The new DRAMA v2.0 will be available in early 2014.
- Scarab is not licensable and it is meant to be an expert tool as it requires several days of training for its use.
Could you provide me information about the possibility to attend the DRAMA Workshop expected the 22 October?

- People interested in participating to the final presentation of the DRAMA upgrade activity should drop an Email to holger.krag@esa.int
CDF Micra D4D
Design for Demise

Space Debris

Session 4
ESTEC, 2\textsuperscript{nd} October 2013

Prepared by the D4D / CDF* Team

(*) ESTEC Concurrent Design Facility
Effect of break-up altitude on demise
Effect of break-up altitude on demise

- 4 DRAMA models with parametric release altitude
- Above 1 ton Earth observation satellites
- Mixture of materials (Aluminium, Steel, Electronics, SiC, CFRP, ...)
- Two different CFRP models
- Optimal release altitude in terms of fragments surviving to ground?
Effect of break-up altitude on demise

- Minimum altitude for blow-up: 83km
- Maximum reasonable altitude for blow-up: 95km
Temperature history

- Massive objects
- Same mass (100kg)
- Initial temperature 300K
- Non-melting aluminium
- Significant increase in temperature driven by heat flux at around 90km
- Maximum increase in temperature driven by heat flux from around 70-40km
Effect of break-up altitude on materials

- Hollow spheres
- Same diameter
- Same mass/area
- Melting temperature and heat of melting important
- Very little impact on strong materials (Tungsten, TiAl6V4, A316, SiC)
- Dependent on geometry and mass as well
Eccentricity at re-entry

- Re-entry always from circular orbit
- Not dependent on disposal orbit

\[ H_{pe} = 200\text{km}, \ m/A = 100\text{kg/m}^2 \]
Temperature profile on release mechanisms

- Analyse the heat ranges encountered by passive release mechanism.

- Modular spacecraft of un-demisable material connected by cylindrical ring Al.
  
  1. Aluminium ring (0.5, 0.3, 0.01).
  2. Modules (1, 1, 1).

- Eight Aluminium boxes (0.1, 0.1, 0.05).

- 9 runs varying inclination (90 vs 30 deg), eccentricity and attitude.
Temperature profile on release mechanisms

- Strong shielding effects on the cylinder for given attitude behaviour.
- Break-up can be reached without fragmenting in more favourable attitude paths.
- It is hard to deterministically influence the attitude at low altitudes.
Temperature profile on release mechanisms

- On the outside, the effect of the attitude/shielding is less pronounced.
- The blue curve corresponds to a ballistic re-entry.
- A Monte-Carlo set-up can be applied to determine the temperature uncertainties at given altitude.
Effect of high altitude panel release

- Top level D4D.
- Full S/C estimated casualty cross-section \( \sim 17 \text{ m}^2 \).
- Release 4 minor panels.
- 120 km release altitude, inclination 98.
- 3 runs with stripped S/C.
- Separate runs with panels.
- Varying attitude and eccentricity conditions.
Effect of high altitude panel release

- Preliminary results.
- Detached panels demise.
- ECDF expected value 8.760 m²
- 48% risk reduction.
- Main contributor: tanks
- Effect of EB and OI minimised.
- Effect of RW significantly reduced.
D4D – Design for Demise

Systems

Session 4
ESTEC, 2\textsuperscript{nd} October 2013

Prepared by the D4D / CDF* Team

(*) ESTEC Concurrent Design Facility
Kinetic Impact Energy (1/4)
Kinetic Impact Energy (2/4)

![Kinetic Impact Energy for Hollow Spheres](image)

- **Diameter [m]**
- **Kinetic Impact Energy [J]**

- KE_AI 1mm
- KE_AI 2mm
- KE_AI 3mm
- KE_AI 4mm
- KE_AI 5mm
- 15 J Limit
Kinetic Impact Energy (3/4)

Kinetic Impact Energy for Hollow Spheres
Titanium

Mass for Hollow Spheres
Titanium

D4D – Session 4 | Slide 4
ESA UNCLASSIFIED – Releasable to Public Systems
Kinetic Impact Energy (4/4)

Kinetic Impact Energy for Hollow Spheres
Stainless Steel 316

![Graph of Kinetic Impact Energy for Hollow Spheres](image)
D4D – Design for Demise

<Mechanisms>
Adam Tvaruzka (TEC-MSM)

Session 4
ESTEC, 2nd OCTOBER 2013

(*) ESTEC Concurrent Design Facility
Break up of S/C scenarios

1. It was confirmed on system level that break up of satellite reduces shading and improves exposure of surfaces to aero-thermal loads.
   a. Spacecraft can break up **actively via a mechanism**
   b. Spacecraft can break up **passively via an demisable joint**

2. Break up mechanisms can be:
   a. **Electrically actuated** – standard mechanisms based on pyros, shape memory alloys, paraffin actuators, etc. , there is large variety of hold down and release mechanisms including heritage but they require source of energy – not guaranteed after 25 years in orbit, SC can be passivated already (they will not be discussed further)
   b. **Heat actuated** – mechanisms activated by environment during re-entry
      • physical principles of actuation can be the same as for the case of heritage mechanisms
      • energy source is external – heat during re-entry
Demisable joints

- Large parts could be composed of stacked layers connected with joints.
  - Joints could be made of easy demisable materials – once joint has melted the stack would break apart to pieces.
  - Joint would be initially protected by thermal shield (MLI) - which would ablate quickly and expose the joint
Active break up mechanisms

Some of heritage mechanisms which can be used for break up of spacecraft are

1. Shape memory alloys based
2. Paraffin actuators
3. Burn wire/split spool mechanisms
4. Pyrotechnics based mechanisms

- The S/C would have to be specifically designed for use of break up mechanisms usage – splitting the S/C body into more parts.
- The mechanisms which are heat actuated require heat conductive path which would bring the external heat to the mechanisms (thermal straps).
- This conductive path can be initially covered with MLI to reduce radiated heat exchange. The MLI would burn quickly during re-entry and expose the path to convective->conductive heat transfer.
Shape memory alloy - SMA

**Principle** – release of strain energy during thermally induced change of phase from superplastic Martensite to elastic Austenite

**Actuation principle** – SMA washer is heated up and expands. This overloads bolt which breaks at notched point.

Transition temperature can be tuned between — 270degC to +250degC

**Advantages**
- simple principle
- fast actuation (miliseconds +)

**Constraints**
- high temperatures (~500degC during few minutes) can print-in the new shape and effectively disable the actuator

Paraffin actuators

**Principle** is based on wax volume expansion during phase change. Expanding wax acts on piston which pushes in/out a pin. Phase transition temperature can be tuned around +100deg C.

**Advantage**
- simple principle

**Disadvantage**
- larger size compared to SMA actuation
- longer actuation times (~20 seconds +)
- Actuation principle goes towards pin-pull or pin-push principle – leading to more complicated mechanism compared to SMA frangibolt

Burn wire - split spool principle

**Split spool principle:**

- The principle is based on a spool which holds a bolt in place. The spool is split into two or more parts which are wrapped around with a cable/spring/wire.
- This cable produces enough friction to keep the spool parts together. At the end of the cable, a thin wire is used to hold it down. The wire can be burned electrically as a fuse and release the cable and consequently the whole joint.
- **Electrical burning of the fuse-wire can be done with the help of re-entry heat**
Burn wire - split spool principle - continued

**Advantage**
- big heritage
- simple principle
- fast operation
- possible low cost compared to paraffin, SMA?

**Idea** – use polymer cable which would degrade during satellite life and would be weakened at time of re-entry (UV degradation, creep). The cable is used in Dutch space thermal knife HDRM.
Pyrotechnics based mechanisms

Explosive separation mechanisms have large heritage and exist in different versions with various functional principles:

1. Explosive/Fragmenting bolts, nuts
2. Gas operated pistons – pin pushers, pin pullers
3. Shaped charge – cuts through structure
4. Detonating fuse – detonating cord breaks structure at notched point

... 

The use of pyrotechnics can be foreseen if the initiation of charges can be done via heat or different principle based on re-entry environment.
Common constraints

**Non-operational**

1. Need for high number of mechanisms – necessary to develop principle of grouping multiple connection with single actuation – **Hold down and release edge mechanism**
2. Risk of unwanted actuation
3. Long term thermal stability – sudden release of strain energy during satellite life can affect precision of instruments (shocks, microvibrations)
4. Can we really design effective bolted connection – mass vs. strength vs. cost?

**Operational**

1. The mechanisms shall be able to operate at wide range of elevated temperatures before they actually start “melting”
2. Need for effective conductive path which is able to bring thermal energy to the actuation part of the mechanism (thermal straps).
Research needed

1. Number of active mechanisms needed shall be derived by common system-structural-mechanisms-AIT design approach

2. Heritage mechanisms – large extension of life, actuation under extreme conditions

3. Development of mechanisms towards actuation and breaking up long edges – clamp band mechanism type

4. Idea - some mechanisms could be actively actuated early – no need to keep high strength and stiffness of the spacecraft after launch. The break up would rely on reduced number of passive mechanisms

Clamp-band type connection
D4D – Design for Demise

Structures

Session 4
ESTEC, 2\textsuperscript{nd} October 2013

Prepared by:
Tiziana Cardone (TEC-MSS)
The vulnerability of internal (and external) components depends on various factors:

1. the position of the component with respect to the predominant micrometeoroids and debris flux (for example, a component placed internally behind the HC panel in the direction of the velocity may be more vulnerable than the same component placed outside and attached to the anti-velocity panel.)

2. the standoff distance from the HC external panel

3. shadowing effects provided by other components and external appendages, thickness of the component case.

4. Radiation environment (to be taken into account especially for S/C where ionizing radiations are an issue)

Therefore, in principle, (if the effect of the MMOD environment is properly taken into account in the analysis) it is possible to adopt design choices that improve demise without affecting the vulnerability from debris, or maybe even reducing it.
Joints

Normal joints

Integrated joints

Limitation: load path, assembly
## Titanium and Al-Li

### Titanium

<table>
<thead>
<tr>
<th>Thermal Properties</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>CTE, linear 20°C</td>
<td>8.6 µm/m°C</td>
</tr>
<tr>
<td>CTE, linear 250°C</td>
<td>9.2 µm/m°C</td>
</tr>
<tr>
<td>CTE, linear 500°C</td>
<td>9.7 µm/m°C</td>
</tr>
<tr>
<td>Specific Heat Capacity</td>
<td>0.5263 J/g°C</td>
</tr>
<tr>
<td>Thermal Conductivity</td>
<td>6.7 W/m·K</td>
</tr>
<tr>
<td>Melting Point</td>
<td>1604 - 1660 °C</td>
</tr>
</tbody>
</table>

### Table 11. Coefficient of Thermal Expansion vs. Temperature for X2096 Al Li alloy

| Temperature | AVG 9L-1 | STD DEV | AVG 9L-2 | STD DEV | AVG 9L-3 | STD DEV | AVG 10L-1 | STD DEV | AVG 10L-2 | STD DEV | AVG 10L-3 | STD DEV | AVG 10L-4 | STD DEV |
|-------------|----------|---------|----------|---------|----------|---------|----------|---------|----------|---------|----------|---------|----------|---------|---------|
| 148°C       | 18.5     | 0.2     | 18.2     | 0.2     | 18.0     | 0.2     | 18.0     | 0.2     | 18.0     | 0.2     | 18.0     | 0.2     | 18.0     | 0.2     |
| 173°C       | 19.0     | 0.2     | 18.7     | 0.2     | 18.4     | 0.2     | 18.4     | 0.2     | 18.4     | 0.2     | 18.4     | 0.2     | 18.4     | 0.2     |
| 248°C       | 22.2     | 0.2     | 21.9     | 0.2     | 21.6     | 0.2     | 21.6     | 0.2     | 21.6     | 0.2     | 21.6     | 0.2     | 21.6     | 0.2     |
| 273°C       | 22.2     | 0.2     | 22.0     | 0.2     | 21.8     | 0.2     | 21.8     | 0.2     | 21.8     | 0.2     | 21.8     | 0.2     | 21.8     | 0.2     |
| 298°C       | 22.2     | 0.2     | 21.9     | 0.2     | 21.7     | 0.2     | 21.7     | 0.2     | 21.7     | 0.2     | 21.7     | 0.2     | 21.7     | 0.2     |
| 323°C       | 22.2     | 0.2     | 21.9     | 0.2     | 21.7     | 0.2     | 21.7     | 0.2     | 21.7     | 0.2     | 21.7     | 0.2     | 21.7     | 0.2     |
| 348°C       | 22.2     | 0.2     | 21.9     | 0.2     | 21.7     | 0.2     | 21.7     | 0.2     | 21.7     | 0.2     | 21.7     | 0.2     | 21.7     | 0.2     |

1 µm/m | 1 part per million | 1 ppm | 1 x 10⁻⁶
The idea is to let the flux go inside the S/C -> the panel (or more panels) will have to host one or more venting disk
Conclusions

• Before considering to move internal component outside the S/C main structure, several issues has to be taken into account. Design improvements are possible but are S/C and equipment dependent.

• Where possible, using Al-Li joints outside the panel (one side or more) can be adopted as solution to open the satellite and allow the atmosphere flux to enter inside and demise the demisable components quicker.

• Burst disk can be an easy solution that do not require many design changes and can be better accommodated within the design of satellites that have to be launched in the next years.
D4D – Design for Demise

Configuration

Session 4
ESTEC, 2\textsuperscript{nd} October 2013

the D4D / CDF* Team

(*) ESTEC Concurrent Design Facility
Spacecraft configuration – Modular assembly

Modular assembly:
- Propulsion Module
- Service module
- Payload Module

Modules allow separate organizations, procurements, building and testing schedules. It all comes together at observatory integration and test.

Interface control between modules is very important: structural, electrical, thermal

→ Weak point

Interface can also be designed to have 2 interface design at the same connection point such as: GAIA SVM/PLM interface
The interface of the optical bench with the service module (SVM) top floor is ensured by 3 identical assemblies:

- specific in-orbit Glass Fibre Reinforced Plastic (GFRP) bipods provide the required mechanical and thermal decoupling from the service module,
- leaving the stiff support function to releasable Carbon Fibre Reinforced Plastic (CFRP) launch bipods.
Integrated assembly

• Find a weak structural area to break i.e. panel joints.
• Introduce mechanisms to open the structure.
D4D – Design for Demise

(Materials and Processes)

Session 4: ESTEC, 2nd October 2013

Prepared by Benoit Bonvoisin TEC-QTM

(*) ESTEC Concurrent Design Facility
Satellites outer panel composition

Context:

- LEO Satellites outer structure can be made of aluminum sandwich panel, which are attached to an aluminium frame.

- LEO Satellites outer structure can be made of CFRP sandwich panel (higher ratio stiffness/density) which are attached together with Titanium brackets. The choice of titanium is partially justify by the CTE match with CFRP.

The first option with Al sandwich might be easier to be demised.

- Screws integrated on satellite for structural links are mainly made off Ti alloys or Stainless steel.
Conclusion D4D micra study
(materials point of view)

Needs for material perspective:

- Test House facility
- Standardization of testing
- Understanding the demisability mechanisms
- Better understanding the impact of CFRP laying up on demisability properties
- Testing coatings
- Joining technologies (fasteners vs welding)
- Testing material combinations

Materials that may be promising for demisability:
Aluminium Lithium alloys, GLARE, Technical Polymers, Magnesium alloys

Manufacturing processes that may be promising for demisability:
ALM (Topological optimization)
The demisability of a spacecraft is a complex mechanism impacted by a broad variety of parameters.

We understood that materials can play a major role in D4D, but we also understood that changing the material of one specific part is not the most appropriate approach.

Design for demise is highly interesting and exciting from the material point of view.

Demisability is a new requirement for the material selection and will imply the possible development of new materials for space applications.
Thank you for your attention
D4D – Design for Demise

<Propulsion>

Session 2: ESTEC, 18 September 2013

Prepared by the D4D / CDF* Team

(*) ESTEC Concurrent Design Facility
Applicability

1. This presentation concentrates on LEO satellites which, if equipped with a propulsion system, are typically equipped with hydrazine propulsion systems, or cold gas propulsion systems.

2. LEO satellites equipped with MON-MMH systems are less common

3. Perhaps GEO (GTO) satellites shall be considered as well when re-entering in an uncontrolled way, due to e.g. an Apogee boost failure or launcher failure. These systems typically operate on MON-MMH. MON-MMH systems have a secondary priority, but perhaps common conclusions can be drawn.
Example of a typical LEO satellite with hydrazine propulsion system
(usually only 1 tank is used)
**Typical LEO propulsion system architecture example**

<table>
<thead>
<tr>
<th>PROPULSION SYSTEM COMPONENTS</th>
<th>Typical order of mass [kg] (ROM)</th>
<th>Comment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Thrusters</td>
<td>0.2 – 0.5 kg</td>
<td>Heat resistant metal alloy (especially combustion chamber, throat, nozzle)</td>
</tr>
<tr>
<td>High thrust engine (not common)</td>
<td>2.5 kg</td>
<td>Heat resistant metal alloy (especially combustion chamber, throat, nozzle)</td>
</tr>
<tr>
<td>Propellant tank</td>
<td>1-25 kg</td>
<td>Light weight high strength Ti6Al4V alloy</td>
</tr>
<tr>
<td>Pressurant tank</td>
<td>10 kg</td>
<td>Liner: Ti6Al4V, Steel, Overwrap: Fiber (Kevlar, Glass, Carbon), Epoxy</td>
</tr>
<tr>
<td>Latch valves</td>
<td>0.2 – 1 kg</td>
<td>Metal</td>
</tr>
<tr>
<td>Pyro valves</td>
<td>0.1 – 0.4 kg</td>
<td>Metal</td>
</tr>
<tr>
<td>Pressure transducers</td>
<td>0.1-0.5 kg</td>
<td>Metal</td>
</tr>
<tr>
<td>Filters</td>
<td>0.1 kg range</td>
<td>Metal</td>
</tr>
<tr>
<td>Fill and Drain / Vent Valves</td>
<td>0.1 kg range</td>
<td>Metal</td>
</tr>
<tr>
<td>Piping</td>
<td>Xxx kg/m</td>
<td>Metal (Usually Ti3Al2.5V)</td>
</tr>
<tr>
<td>Thruster brackets</td>
<td>0.5 kg range</td>
<td>Metal (Usually Aluminium alloy)</td>
</tr>
<tr>
<td>Standoffs</td>
<td>Nihil</td>
<td>Metals / Plastics</td>
</tr>
<tr>
<td>Mounting screws</td>
<td>Nihil</td>
<td>Metal</td>
</tr>
<tr>
<td>Propellant</td>
<td>0-500 kg</td>
<td></td>
</tr>
<tr>
<td>Pressurant</td>
<td>0-5 kg</td>
<td></td>
</tr>
</tbody>
</table>
Example of a bi-propellant propulsion system, not typically found in LEO but more often in GTO/GEO and interplanetary high performance missions.

Needs to demise in case of GTO-GEO transfer failure?

(Note: this is not a focal point of this presentation, but perhaps some common conclusions can be drawn)
## Typical GTO-like high performance propulsion system architecture example

<table>
<thead>
<tr>
<th>PROPULSION SYSTEM COMPONENTS</th>
<th>Typical mass [kg]</th>
<th>Comment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Thrusters</td>
<td>0.2 – 0.5 kg</td>
<td>Heat resistant metal alloy (especially combustion chamber, throat, nozzle)</td>
</tr>
<tr>
<td>Main engine</td>
<td>5 kg</td>
<td>Heat resistant metal alloy (especially combustion chamber, throat, nozzle)</td>
</tr>
<tr>
<td>Propellant tank</td>
<td>x – 85 kg</td>
<td>Ti6Al4V</td>
</tr>
<tr>
<td>Pressurant tank</td>
<td>10 kg</td>
<td>Liner: Ti6Al4V, Steel, Overwrap: Fiber (Kevlar, Glass, Carbon), Epoxy</td>
</tr>
<tr>
<td>Latch valves</td>
<td>0.2 – 1 kg</td>
<td>Metal</td>
</tr>
<tr>
<td>Pyro valves</td>
<td>0.1-0.4 kg</td>
<td>Metal</td>
</tr>
<tr>
<td>Pressure transducers</td>
<td>0.1 - 0.5 kg</td>
<td>Metal</td>
</tr>
<tr>
<td>Filters</td>
<td>0.1 kg range</td>
<td>Metal</td>
</tr>
<tr>
<td>Fill and Drain / Vent Valves</td>
<td>0.1 kg range</td>
<td>Metal</td>
</tr>
<tr>
<td>Piping</td>
<td>X0.1 kg/m</td>
<td>Metal (Usually Ti3Al2.5V)</td>
</tr>
<tr>
<td>Thruster brackets</td>
<td>0.5 kg range</td>
<td>Metal (Aluminium alloy)</td>
</tr>
<tr>
<td>Standoffs</td>
<td>Nihil</td>
<td>Metals / Plastic</td>
</tr>
<tr>
<td>Mounting screws</td>
<td>Nihil</td>
<td>Metal</td>
</tr>
<tr>
<td>Propellant</td>
<td>0-3000 kg</td>
<td></td>
</tr>
<tr>
<td>Pressurant</td>
<td>0-5 kg</td>
<td></td>
</tr>
<tr>
<td>PROPELLANTS</td>
<td>Usually stored in tanks of:</td>
<td>Comment</td>
</tr>
<tr>
<td>-------------</td>
<td>----------------------------</td>
<td>---------</td>
</tr>
<tr>
<td>Cold gas</td>
<td>COPV Liner: Ti6Al4V, Steel, Overwrap: Fiber (Kevlar, Glass, Carbon), Epoxy</td>
<td>The combination of an Aluminium liner with overwrapping, is favourable from the perspective of demise (reference)</td>
</tr>
<tr>
<td>Hydrazine</td>
<td>TI6AL4V tank alloy</td>
<td>Titanium is bad from a perspective of demise</td>
</tr>
<tr>
<td>MON</td>
<td>TI6AL4V tank alloy</td>
<td>Titanium is bad from a perspective of demise</td>
</tr>
<tr>
<td>MMH</td>
<td>TI6AL4V tank alloy</td>
<td>Titanium is bad from a perspective of demise</td>
</tr>
<tr>
<td>HPGP</td>
<td>TI6AL4V tank alloy (TBC)</td>
<td>Titanium is bad from a perspective of demise</td>
</tr>
<tr>
<td>H₂O₂</td>
<td>Aluminium (TBC)</td>
<td>Aluminium is better for demise (wall thickness dependent (not too thick and not too thin!))</td>
</tr>
<tr>
<td>He, N₂</td>
<td>COPV Liner: Ti6Al4V, Steel, Overwrap: Fiber (Kevlar, Glass, Carbon)</td>
<td>The combination of an Aluminium liner with overwrapping, is favourable from the perspective of demise (reference)</td>
</tr>
</tbody>
</table>
# Thrusters

<table>
<thead>
<tr>
<th>THRUSTERS</th>
<th>Propellant</th>
<th>Comment</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 N thrusters</td>
<td>Hydrazine</td>
<td>Heat resistant materials. See dedicated sheets</td>
</tr>
<tr>
<td>5 N thrusters</td>
<td>Hydrazine</td>
<td>Idem</td>
</tr>
<tr>
<td>20 N thrusters</td>
<td>Hydrazine</td>
<td>Idem</td>
</tr>
<tr>
<td>400 N thrusters</td>
<td>Hydrazine</td>
<td>Idem</td>
</tr>
<tr>
<td>μN</td>
<td>Cold gas</td>
<td>Machined out of the same piece of material as the thruster-valve (cold gas thruster is basically just a valve with a nozzle on top). Material e.g. stainless steel</td>
</tr>
<tr>
<td>1 N</td>
<td>Cold gas</td>
<td>Idem</td>
</tr>
<tr>
<td>4 N</td>
<td>MON-MMH</td>
<td>Heat resistant materials. See dedicated sheets</td>
</tr>
<tr>
<td>10 N</td>
<td>MON-MMH</td>
<td>Idem</td>
</tr>
<tr>
<td>22 N</td>
<td>MON-MMH</td>
<td>Idem</td>
</tr>
<tr>
<td>200 N</td>
<td></td>
<td>Idem</td>
</tr>
<tr>
<td>425 N</td>
<td>MON-MMH</td>
<td>Idem</td>
</tr>
</tbody>
</table>
Tank related findings and conclusions

From research (reference mentioned below):
Analysis showed:

• 8 tanks of 0.55 m³ and different materials were analyzed.
  • None of the Ti or Stainless steel (CRES) tanks (monolithic or CORP overwrapped) demised (not even with most favorable conditions).
  • Instead an equivalent sized Al2219 tank demised (with wall thickness could be up to up to 15.5 mm)
• Seems that for demise, Aluminium has preference over Ti or CRES
• The aforementioned wall thickness is well beyond the normal liner thickness of CFRP tanks (or tank thickness in general)
Tank related findings and conclusions

From research (reference mentioned below):
Analysis showed:
• 56 tanks of 0.922 m³ and different materials and shapes (cylindrical and spherical) were analyzed.
  • None of the monolythic Titanium alloy tanks demised (t=1.5 mm).
  • CRES 316 Graphite Epoxy did not demise either.
• Thin walled Aluminium turned out to demise slowly (surprising?!)
Cylindrical shapes demise better than circular shapes
Aluminium lined composite tanks demised under all assessed conditions (liner 0.75-2.5 mm) Composite layer 0.6-2.5 mm)

From the above, one may conclude that composite tanks with a thin Aluminium liner meet the needs for propellant storage AND demise.

Reference: An overview of demise calculations, conceptual design studies and hydrazine compatibility testing for the GPM core spacecraft propellant tank, R. Estes et al, Goddard Spaceflight Center, NASA, Greenbelt, MD, USA
Tanks: However

- A large tank-line exists in Europe (and elsewhere). These concern qualified tanks of various sizes.
- These tanks are nearly always manufactured of Titanium alloy.
- Tanks are always designed very close to the margin of the materials to minimize mass.
- Weakening a tank at a specific part (for the purpose of breaking it up intentionally, hence demise more easily), therefore immediately results in additional material / additional mass.
Tanks: However

- All existing tanks would become obsolete
- A whole new tank line would have to be developed (variety of sizes and shapes)
- Compatibility issues between propellant and Aluminium (although initials tests seemed to be favorable)
Tanks: However

- Manufacturing issues;
  - Difficult to produce (weld) a thin Aluminium liner
  - Difficult to apply compressive stress with fibers on a thin walled liner without buckling of this liner.
  - Difficult to get the surface tension device in place if “autofrettage” (over-pressurize beyond elastic material characteristics) is applied in order to settle the liner in the overwrapping, this is even impossible with membrane tanks which are typical for LEO.
  - Safety analysis becomes more complex.
  - Fracture mechanism analysis becomes more complex
  - Different and more complex Non Destructive Investigation methods need to be applied
Tanks: However

- When the tank material is changed also the surface tension device shall change (propellant management device).
- Surface tension device, as the name indicates functions in the principle of surface tension and on the capillary strength between the propellant and the tank material. In order to get the PMD right, precise hole size and angles between components shall be respected. This means that when the tank material / PMD material changes, hole size and angles of parts (e.g. vanes) w.r.t. the tank wall itself shall change as well. Therefore changing the tank material not only has an impact on the pressure vessel itself, but also the PMD needs to be completely redesigned.

Moving to tanks with a thin Aluminium liner has a huge impact (all existing tanks would become obsolete). An alternative solution might be preferred.
Destructive devices

- Destructive devices (e.g. shape charge or comparable, possibly activated by re-entry heat) seem to be the (only) way to break up (any) tank.
- Such a device can be generic and therefore applicable to virtually all existing tanks.

A generic device that could be implemented on every existing tank therefore has preference
Questions that came in during the first presentation

1. Hydrogen peroxide is normally stored in aluminium tanks (confirmed) (check safety datasheet of Hydrogen peroxide)

2. Questions via email:

3. A CNES patent is existing to destroy a tank. Difficulty is to be sure of activation after life+25 years.
   
   Correct: the activation after 25 years is probably where the development effort shall be.

4. Could you clarify if GREEN propellants (as HPGP) are not better in terms of material compatibility with Aluminium? (H2O2 is known Alu-compliant but 25% less efficient)

   The whole issue with HPGP was that in order for it to be successful, it shall be compatible with Ti6Al4V tanks, because otherwise HPGP would require new tank developments
Thrusters and engines

1. Thrusters and engines are manufactured of heat resistant materials. Thrusters to a certain extend also larger engines are located on the extreme points of spacecraft. Therefore these will see hot flow during re-entry from the moment this starts.

   Question remains: Will these heat resistant components demise?

Most thrusters are small. Some spacecraft also incorporate larger thrusters such as e.g. 400 N monoprop thruster or 425 N main engine (bipropellant).
## Thruster heat resistant parts

<table>
<thead>
<tr>
<th>Thruster / engine Propellant type</th>
<th>Chamber material</th>
<th>Melting temperature [°C]</th>
<th>Heat resistant parts equivalent to cylinder with: [D x l x t] all in mm</th>
</tr>
</thead>
</table>
| Monopropellant thrusters         | Inconel (Nickel-Chromium-based superalloy) | 1400 range               | 1N: 30 x 75 x 1.5  
20 N: 33 x 100 x 1.5  
400 N: 67 x 140 x 1.5 |
|                                 | High Tensile Steels                  | 1500 range               |                                                                                          |
| Bipropellant thrusters           | Pt20Rh 80% Platinum 20% Rhodium      | 1700 range               | 10 N: 35 x 80 x 1.5  
22 N: 55 x 110 x 1.5 |
|                                 | C103 (Niobium alloy) C103 (trade name), consists of 89% niobium, 10% Hafnium, 1% Titanium | 2000                     |                                                                                          |

Small mono propellant thrusters (example concerns a 1 N thruster): Valves: solid parts of approximately [Dxh] 2.5 mm x 2.5 mm which are included in the injector plate, valves and related parts: [Dxh] 80 mm x 20 mm (which typically is a long cylinder)

Bipropellant thruster (example concerns a 22 N thruster) Flanges and valves 90 x 90 x 40
## Engine heat resistant parts

<table>
<thead>
<tr>
<th>Thruster / engine type</th>
<th>Chamber material</th>
<th>Melting temperature [°C]</th>
<th>Bell shaped chamber, injector plate and valves with dimensions equivalent to a cone with: [D, h, t] in mm, and a top plate with: [D, h] in mm, and two valves with [D, h] in mm</th>
</tr>
</thead>
</table>
| Bipropellant liquid apogee engines | Pt20Rh 80% Platinum 20% Rhodium | 1700 | Approximately: 295 x 600 x 5 to 1  
Thickess is largest at combustion chamber area. Thickness could go up to the order of e.g. 5 mm. Thickness varies along the nozzle to about 1 at the exit. |
|                         | Pt10Ir 90% Platinum 10% Iridium | 1800 | 110 x 10  
Top plate is solid and about 10 mm thick and contains about 1 kg of valves and thick connecting parts |
|                         | C103 (Niobium alloy)  
C103 (trade name), consists of 89% niobium, 10% Hafnium, 1% Titanium | 2000 | 45 x 60 (2X)  
Two valves of above mentioned envelopes (Ti6Al4V and magnetic steel) |
|                         | Re/Ir  
(Rhenium Iridium) | 2500 | |
## Engine heat resistant parts

<table>
<thead>
<tr>
<th>Thruster / engine type</th>
<th>Chamber material</th>
<th>Melting temperature [°C]</th>
<th>Bell shaped chamber, injector plate and valves with dimensions equivalent to a cone with: [D, h, t] in mm And a top plate with: [D, h] in mm And two valves with [D, h] in mm</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bipropellant liquid apogee engines</td>
<td>C/SiC carbon silicon carbide (ceramic)</td>
<td>2700 (decomposes)</td>
<td>Approximately: 385 x 775 x 5 to 1 Similar assumptions as above 110 x 10 Similar assumptions as above 45 x 60 Similar assumptions as above</td>
</tr>
<tr>
<td>S.N. (ceramic)</td>
<td>1900 (decomposes)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*Carbon fibre-reinforced silicon carbide (C/SiC) is a development of pure carbon–carbon. C/SiC utilises silicon carbide with carbon fibre, and this compound is thought to be more durable than pure carbon–carbon.*
Small surviving parts of thrusters

Note on the impact of small surviving parts from thrusters, valves etc.

Terminal velocity assumed (optimistic) 200 km/h; about 55 m/s
Part size assumed of 20 mm diameter and 20 mm height (e.g. thruster valve coil)
Densities assumed of:
Steel: 7800 kg/m³
Titanium 4500 kg/m³
Aluminium 2800 kg/m³
Kinetic Energy:
\[ E_{K_{\text{Steel}}} = 75 \text{ J} \]
\[ E_{K_{\text{Aluminium}}} = 30 \text{ J} \]
\[ E_{K_{\text{Titanium}}} = 45 \text{ J} \]
Nozzle diameter 33 mm
Nozzle diameter 67 mm
Pyrovalves

- 2 redundant Pyrotechnical Initiators (ARIANE 5 qualified)
- Interfaces: 1/4", 3/8" (modifications possible)
- Normally Open (NO) & Normally Closed (NC) Pyro Valves
- ~ 105 mm
- ~ 80 mm
10 N
Nozzle diameter 35 mm
22 N
Nozzle diameter 55 mm
Summary for 4th session:
- Major findings
- Promising solutions
For exact aerodynamic characteristics, please refer to other dedicated presentations

PROPELLANT TANKS

- Ti6Al4V propellant tanks demise less well than other tanks that are designed specifically for demise. Actually their performance w.r.t. demise is quite bad.
- Ti6Al4V tanks (any tank) are always designed very close to the margins of the material characteristics to minimize mass.
- Analysis showed that propellant tanks manufactured of an Aluminium liner with a thin Carbon fibre overwrap demise the best.
Major findings

For exact aerodynamic characteristics, please refer to other dedicated presentations

PROPELLANT TANKS (continued)

• When designing a spacecraft, it is desirable to use an existing off the shelf tank (saves development costs)
• Huge efforts and financial resources have been spent over the years, not only in Europe, but worldwide, on the development of an enormous variety of propellant tanks.
• Trying to find alternatives for Ti6Al4V tanks that demise better, is a welcome suggestion, but this shouldn’t automatically result in the conclusion that Ti6Al4V tanks are obsolete.
• A shaped charge, activated by re-entry heat, could potentially break-up the tanks at high altitude, which would increase the demisability of the Ti6Al4V tanks. (exposed thin walled tank edges demise quite well). It is suggested to put efforts in the development of such devices.
Major findings

PRESSURANT TANKS

• Pressurant tanks have thicker metallic liner, but especially thicker composite overwrapping. This means that they don’t demise.

• It is not clear at the moment if and how these pressurant tanks can be made more demisable. Perhaps the previously discussed shaped charge could provide an outcome as well. Fortunately pressurant tanks are less common on LEO spacecraft.

• This requires more in depth analysis
Major findings

THRUSTERS

- Thrusters are manufactured of a large variety of heat resistant materials. Melting temperatures are ranging from 1400 to 2500 degrees Celsius.
- Thrusters consist of rather massive parts, but also of thin walled parts (both quite heat resistant and these parts could be placed inside other parts; e.g. copper wire overwrapped magnetic steel cylinder enclosed in Ti6Al4V cylinder / block (valve)).
- Thrusters are located on the outside / corners of a spacecraft and therefore are exposed to the re-entry heat.
- When smaller parts survive because they are heat resistant or shielded from the re-entry heat by their enclosures, these smaller parts themselves already violate the rule of maximum kinetic energy (e.g. magnetic steel parts of thruster valves).
  - Assumed 55 m/s, 20 mm diameter, 20 mm height (e.g. thruster valve coil) then the kinetic energy becomes: $E_{K_{Steel \ part}} = 75 \text{ J}$, even if similar sized parts would be made of Aluminium or Titanium their kinetic energy would approximately be: $E_{K_{Aluminium}} = 30 \text{ J}$, $E_{K_{Titanium}} = 45 \text{ J}$. (Requirement: $E_K < 15 \text{ J}$) (More detailed analysis in dedicated Systems presentation)
THRUSTERS (continued)

- On the other hand, broken-off thruster nozzles might survive, but might not violate the $E_k < 15$ J requirement, due to their ballistic characteristics and resulting terminal velocity (again the Systems presentation of the 4th session provides indications in this direction)

- This topic requires more in depth analysis
Promising solutions

Shaped charge
- No detailed information available at this moment
- Any information, e.g. sent by email, is most welcome!
Question:
Is it possible to effect the attitude motion during reentry through AOCS activation at satellite EOL, which is about 25 years earlier?

Situation:
The LEO environment exerts very tangible disturbing torques on the S/C:
- Gravity gradient,
- Magnetic torque,
- Solar radiation pressure,
- Atmospheric differential pressure,
These torques typically lead to an eventual gravity-gradient stabilization of any S/C attitude.
Spinning Up the Satellite

Candidate solution:
- Create a bias by spinning up the satellite at EOL in order to achieve stable rotation axis,
- Rich experience with early telecoms, weather sats, rocket bodies,

Conditions:
- Satellite needs to be structurally designed to tolerate spin-up,
- Satellite AOCS needs to be designed to support spin-up,
Meteosat First Generation

- Meteosat First Generation satellite were spun-up to 100 rpm and operated in GEO,

- Assessment of free attitude motion between April 1991 and Feb 1997 showed a drift of about 0.2deg per year.
Scenario in LEO

- Perturbing torques in LEO are 2+ orders of magnitude larger than in GEO,
- LEO satellites do not and can not have rotational symmetry,
  - From initial assessment is appears unlikely that a spin-up of several rpm at EOL could ensure any residual rotational stabilization at beginning of reentry,
  - Slow tumbling motion or gravity-gradient stabilization appears far more likely (also see Envisat analysis),
  - Even if any residual rotational rate from spin-up remained, the axis of rotation will have drifted in an unpredictable way.

Conclusion:
Attitude motion during reentry is dominated by aerodynamic effects and for satellites can not be manipulated by EOL spin-up. This statement is not applicable in the same way to rocket bodies.
Conclusion – AOCS in D4D
Conclusions – AOCS in D4D (I/II)

• Space Debris experts have insufficient information available to generate representative models of AOCS equipment for spacecraft reentry safety analyses.

• System level shielding of AOCS components does prevent demise of components with problematic material properties from getting good exposure to the reentry heat flux.

• It is prudent to have a more detailed assessment of demisability of equipment bottom-up as well as on system level.
The following recommendations for actions and activities have been derived:

A. Collect, assess and compile information about demisability of AOCS equipment in order to ensure adequate modeling of this equipment by reentry risk analysis experts; this information needs to be distributed to industry (e.g. Astrium, HTG, Belstead, Astos Solutions) as well as institutional reentry safety risk experts (e.g. ESOC, Safety Office), who are in charge of carrying out detailed reentry risk analyses,

B. Prepare a more detailed assessment of the structural separation and demisability of European magneto torquers, when shielded by structural components during early re-entry,

C. Assess feasibility and viability of reaction wheel redesign towards easier demisability or containment of non-demising fragments.
Power – Battery

Appears to be less critical with current technology (Li-Ion)

Proposed way forward:
- Review of current and future technologies: Li-Ion, small cells for most small LEO missions but big cells can be also an option, steel or aluminium case,...
- Check if really an issue: if needed refine re-entry simulation models to confirm/infirm criticality and identify critical parts
- If needed investigate following ways:
  - Case material
  - Cell size and geometry
  - Battery module geometry/assembly
  - Split of battery in several modules
  - Position of battery in satellite (or even external)
SA usually not critical except maybe harness bundle at SADM interface and some small parts in titanium

SADM: compact piece and including SA harness bundle

Proposed way forward:
- Check if really an issue: if needed refine re-entry simulation models to confirm/infirm criticality and identify critical parts
- If needed investigate following ways:
  - Size and geometry: wider SADM would allow spacing of SA harness bundle
  - Materials
  - Increase exposure during re-entry or keep contained
Cylinders made of titanium but thin walls
Power – PCDU

As other electronic boxes, seems to be a critical part

Specificity of PCDU:
- Usually one of the largest electronic box in s/c
- Including power components/parts (potentially bigger): bus bars, magnetic cores and coils, capacitors, relays, other big components

Proposed way forward: see electronic box
Harness seems to be a major contributor to casualty risk

Proposed way forward:
- Check what is the issue: if needed refine re-entry simulation models to identify critical parts (cable electrical conductor and/or insulator, shielding, connectors)
- Investigate following ways:
  - Subdivision/separation of harness/cables in several bundles/cables to improve exposure
  - Material conductor: copper vs aluminum
  - Material insulator and shielding: may play a role in the exposure of conductor to heat flux
D4D – Design for Demise

System Engineering Process

Session 4
ESTEC, 2nd October 2013

Prepared by the D4D / CDF* Team

(*) ESTEC Concurrent Design Facility
Orbital Debris Assessment Report:

- Initial ODAR
- PDR ODAR
- CDR ODAR
- Final ODAR (part of launch approval process)

Contents:

- Spacecraft Description
- Assessment of Spacecraft Debris Released during Normal Operations,
- Assessment of Spacecraft Potential for Explosions and Intentional Breakups,
- Assessment of Spacecraft Potential for On-Orbit Collisions,
- Assessment of Spacecraft Reentry Hazards,
- Assessment of Spacecraft Hazardous Materials,
- Etc.
Orbital Debris Assessment Report:

- **Initial ODAR**
  - Actually needed by project team to understand the debris context for the intended mission profile,
  - Motivates discussion/definition of system requirements,

- **PDR ODAR**
  - Verify compliance of the preliminary design with the system requirements,
  - Granularity of information and confidence of design is low,

- **CDR ODAR**
  - Detailed analysis results could be generated, but might not be required,

- **Final ODAR** (part of launch approval process)
Design 4 Demise

- Active D4D efforts are motivated by critical level in Casualty Risk,
- Debris assessment during reentry needs to be fed back into S/C design process in a series of iterations to arrive at preliminary design,

- Currently the approach is to perform object oriented analysis (DRAMA, ASTOS, DAS, etc.) and apply a “conservative” material assumption on the subsystem modelling, ignoring system level shielding \( \Rightarrow \) Information is too coarse to be useful to D4D,
- Better analysis methodology needed!!?!
D4D Granularity in Phase 0/A
Increasing the Fidelity of Object Oriented Simulations

1. Initial simplified modeling of components/units as individual objects of particular material following main break-up,

2. Replacement of reentry analysis results for certain components/units by higher fidelity results from heritage database/supplier,

3. Adjustment of assumed break-up altitudes to reflect actual shielding conditions of the design.
Summary and Evaluation of Design for Demise Techniques
Summary and Evaluation of Design for Demise Techniques
Design for Demise Techniques

Subsystem Level

Orbit

System Level

Assumptions

- LEO spacecraft
- 500 kg to 4000 kg
- Casualty cross section < 1:10000
- D4D as an alternative to controlled re-entry
Subsystem Level

Alternative Materials
- GLARE
- PEEK

Structures
- Lattice structures

Increase demisability of critical components
- Subsystem housings
- Critical P/L components
- Harness

Containment
- Reduce size and mass of surviving components
GLARE

Glass Laminate Aluminum Reinforced Epoxy

Potential applications:
- spacecraft structure
- radiation and impact shielding

Promising material, Research required for optimisation in material composition and behavior
PEEK

Polyether ether ketone

Potential applications:
• nuts, mechanism parts

Reaction wheels provide high torque,
• Substitution of solid thrusters for thrusters
• replace large units with multiple small units
• new equipment replacing magnetocrystalline...
Propulsion

Typically hydrazine or cold gas propulsion systems

- Aluminum instead of Titanium or CRES tanks
  
  High potential for tank demisability vs. new development with remaining unknowns such as propellant compatibility and manufacturing issues

- Destructive devices for tanks

  generic device which can be applicable for various tank types
AOCS

Reaction wheels and magnetorquers provide highest casualty risk

- Substitution with alternative actuator technologies, e.g. RCS thrusters or electric propulsion
- Replace large magnetorquers with multiple small magnetorquers
- New equipment development: replacing core materials of magnetorquer

New development, Effectiveness of new reaction wheels and magnetorquers needs to be verified by improved simulation tools

unattractive due to propellant penalty, or mass and cost
loss of effectiveness
Power and Electronics

Li-Ion batteries might pose a risk
  • Al case instead of stainless steel
  • restructuring of Aluminum housing
  • battery splitting into modules
Solar array drive mechanism
  • relocate outside to expose cable bundle to more heat
PCDU and electronics boxes
  • containment, increased heat exposure or lowering of kinetic impact energy < 15 J for bus bars, magnetic cores (e.g. ferrite), coils, ceramics, and CFRP which may pose a risk

Benefits need to be quantified and evaluated with regard to the degree of detail in the re-entry simulation

• Refinement of re-entry simulation models for critical components
Payloads

Challenges:
- Uniqueness and payload design requirements limiting D4D techniques
  - high performance
  - thermal and physical stability
  - mission-determined mass, volume and location of instruments

Potential D4D Techniques:
- Material Replacements
- Containment
- Optimised area-to-mass ratio
- active break-up between P/L and P/F
Harness

Power harness
- improve heat exposure by subdivision of harness bundles in several cables
- Aluminum instead of Copper conductors
- integration of demisable harness in demisable S/C structure
Structures

lattice structures
Inclination change
EOL disposal manoeuvre
Change of attitude motion

Inclination
- unlikely to be adjusted for a given mission

EOL Disposal Maneuvre
- Lower perigee
- additional delta-v required

Attitude Motion
Inclination

- unlikely to be adjusted for a given mission
EOL Disposal Maneuvre

- Lower perigee
- additional delta-v required
Attitude Motion
System Level

Inner spacecraft structure
Spacecraft configuration
Containment
Active spacecraft break-up
S/C Inner Structure

- Avoid H-shape as well as central cone or tube
- Open struts structure instead of closed panels around demise-critical components
- Increase inner heat exposure

mass penalty vs. increased heat exposure

Relocating equipment

- Move e.g. batteries, boxes, reaction wheels, magnetorquers outside the satellite
Relocating equipment

- Move e.g. batteries, electronic boxes, reaction wheels, magnetorquers outside the S/C
- Increased need for radiation shielding, mechanical and thermal stability on component level
- External dimensions are limited by the launcher fairing volume

Demisability vs. vulnerability
Containment on System Level

- Box, e.g. made of Titanium that includes all survival-critical components
- Attachment of P/L and critical components to harness
- Light but temperature resisting net around critical components

- Mass penalty
- Uncertain in reliability
- New development

weakening of structural integrity over time
- Corrosive liquid exposure
- After passivation uptake mechanism activated, or Paraffin acts as barrier
Active S/C Break-up at High Altitudes

Applications:
- between PLM and SVM
- to remove outer panel and increase heat exposure for inner components

Implementations:
- Before or during passivation: weakening of structure, e.g. corrosive liquids
- After passivation: active break-up mechanisms, e.g. frangibolts or Paraffin actuators

Remaining unknowns w.r.t. technology and safety
Increased reliability and safety compared to pyrotechnics
Mass penalty
Titanium that is non-critical
Conclusions

Demisability needs to be traded against vulnerability regarding
  • launch
  • radiation
  • space debris impact

and against a controlled re-entry
in terms of
  • cost
  • schedule
  • benefit
Long-term solutions

net
material research
Short-term solutions

active S/C break-up
Summary and Evaluation of Design for Demise Techniques
D4D – Design for Demise

Systems

Session 4
ESTEC, 2nd October 2013

Prepared by the D4D / CDF* Team

(*) ESTEC Concurrent Design Facility
Next steps

1. Close *open actions*
   a. Answer webcast questions not covered during the sessions

2. Update the draft statement of work of the TRP activity “Multi-disciplinary assessment of Design for Demise techniques”
   a. Iterate with CDF team members

3. ITT to be released before end of year
1. Many thanks to the all webcast viewers!!!

2. Although we did not have a real-time interaction, your input has been very valuable!

3. We believe webcasting the sessions to industry has been very positive
   a. Advice for future studies?
1. This has been a challenging but very interesting CDF MiCRA study:
   a. The subject is wide and intrinsically complex and it is difficult to derive general conclusions

2. ...but some very interesting results have been achieved ⇒ they show areas that require further study

Many thanks to all team members!!!