Belstead

Progress in the Understanding and Modelling of Destructive Re-entry

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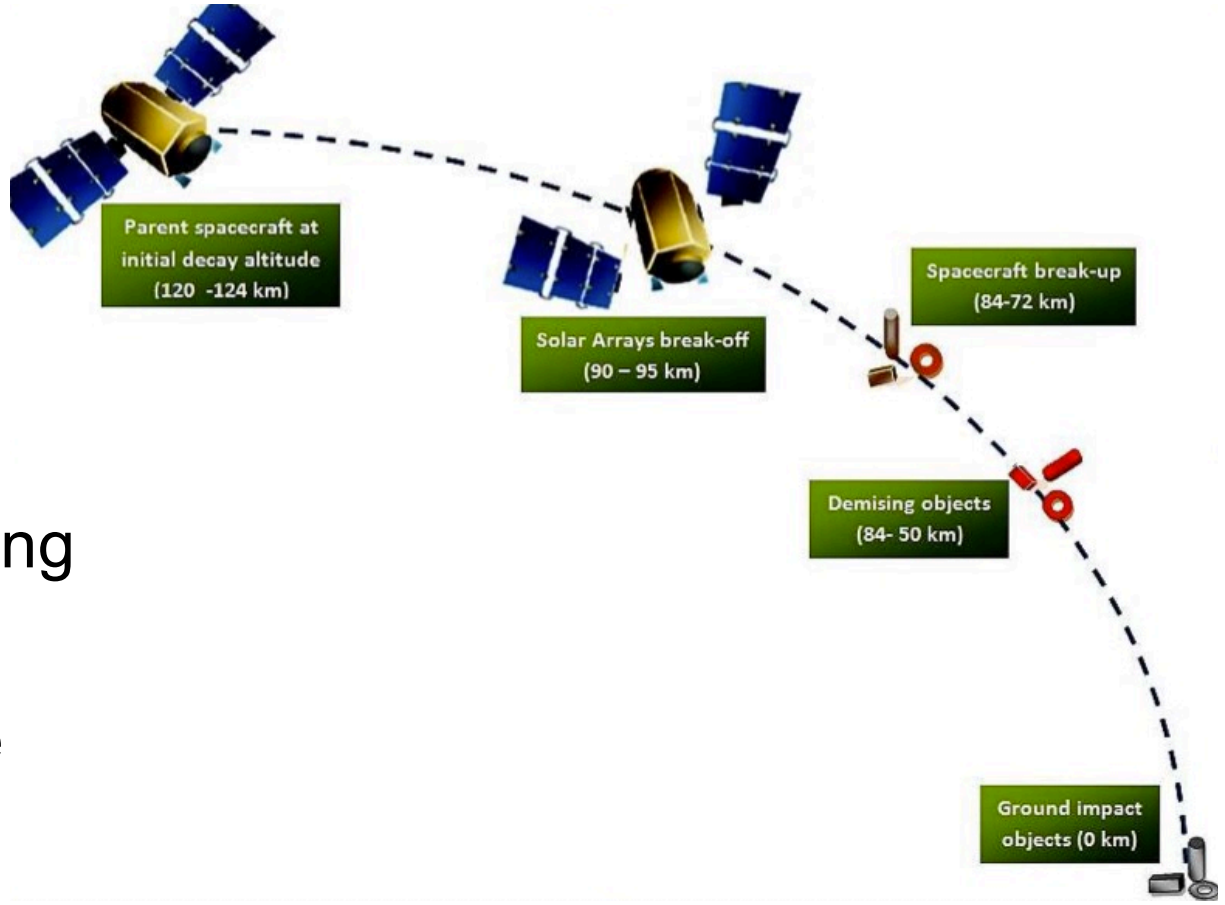
Destructive Re-entry Processes

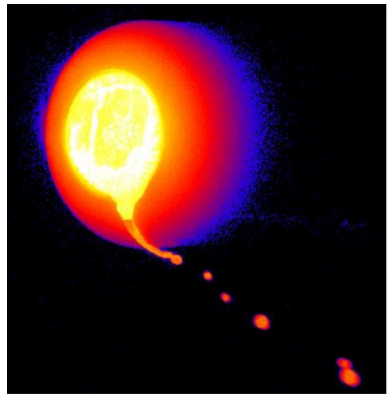
- Initial entry
- Fragmentation
- Aerothermal heating
- Material response
- Uncertainty



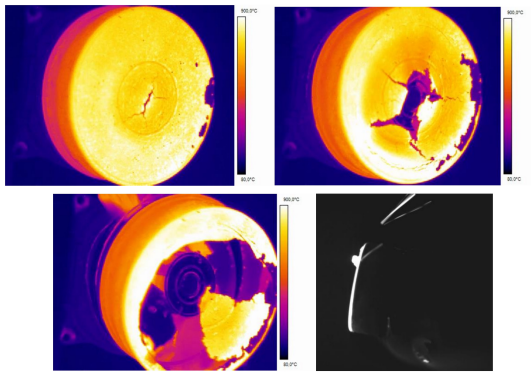
The Old World

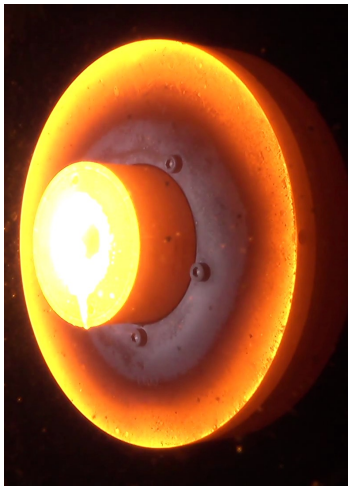
- Old DRAMA/ORSAT Worldview
  - Key dataset is from VAST/VASP tests
  - ‘Catastrophic’ fragmentation at 78km
  - Box-level equipment released cold at this altitude
  - Single simulation; no account for marginal cases
- Old SCARAB Worldview
  - Fragmentation predicted at melt temperature
  - Complete fragment heated as equivalent sphere
  - Unfragmented objects landed
    - Larger fragments, smaller number, less risk
- DRAMA/ORSAT view seen as conservative

The Crisis



- Drivers of Change
  - ESA policy: Refusal of waiver for non-compliant spacecraft
  - Advent of Design-for-demise
- Academic Study no Longer Sufficient
  - Highly simplified analyses
  - Complex geometries, but basic physics
- New Interest in Design Detail
  - Reveals significant deficiencies in the tools
    - Much non-conservatism discovered in the modelling
  - Increases understanding of need for testing
- Demonstration of Utility of Ground Testing





The Need

- Materials and Material Response
  - Generally poorly represented
  - Equivalent metal/material requires significant care
- Fragmentation Processes
  - Least well understood part – very high uncertainty
  - Drives number/size of fragments → Main driver of risk
- Aerothermodynamic Heating
  - Important in fragmentation; drives demise
  - Extremely difficult to get good answer on arbitrary shapes
- Lack of Ground Test Data
- Lack of Flight Data
- Statistical Viewpoint; Likelihoods and Uncertainties

The Response

Test Campaigns

Material testing (metals, composites)
Simple fragmentation testing
Structural joint testing (+D4D)
Equipment testing
(Reaction wheels, CubeSat, Panels, MTQ, Electronics, Battery)
MLI demise testing

Numerical Analysis

Small parts in subsonic shock region
Thermal shock assessment
Glass shear assessment
Uncertainty modelling
(PADRE framework)

Flight Test Feasibility

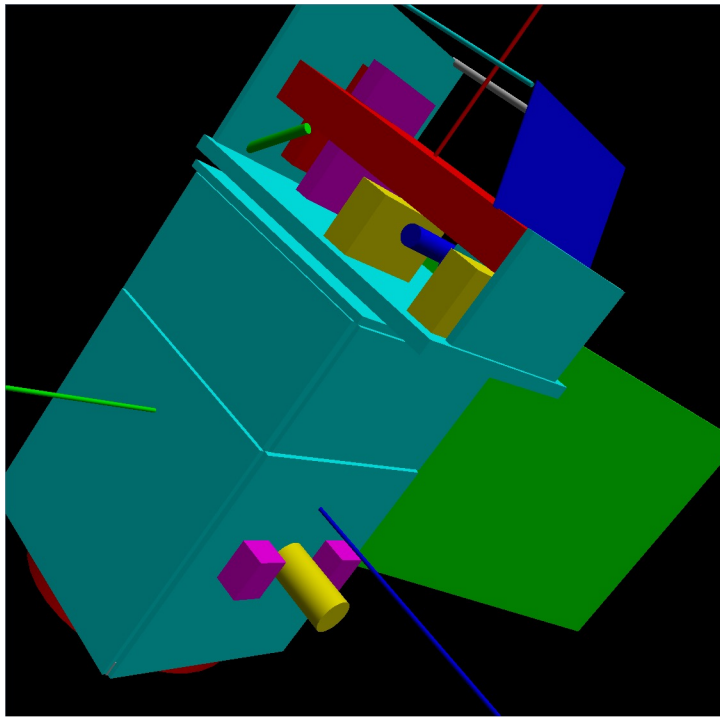
Modelling Improvements

Component-based representation
(SAMj, now DRAMA)
Standards and guidelines
(DIVE, standard models)
Local length scale aerothermodynamics
Metal material modelling
(emissivity, Cp, catalycity)
Insulator modelling (HBI, SBI)
Fragmentation/Joints modelling
(inserts, mass loss)

And this is limited to BRL involvement…

The Impact

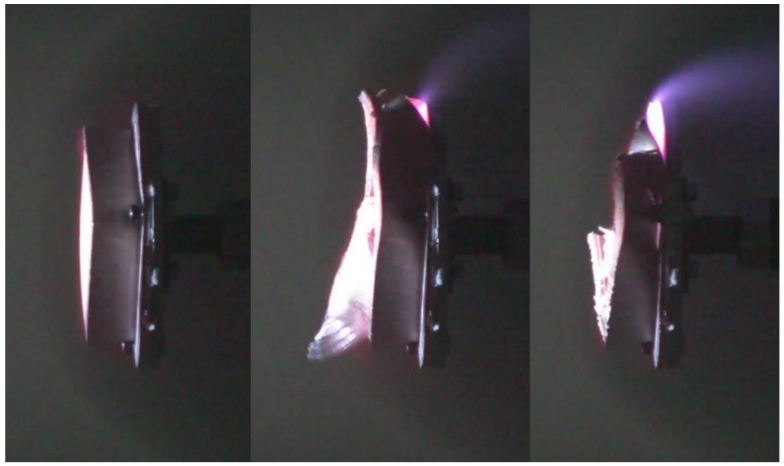
- Shift in Study Types
  - Large Studies
    - PADRE probabilistic framework
      - Uses thousands of simulations of complete spacecraft per configuration analysed
      - Full statistical assessment
  - Comparative Studies
    - SAMj and DRAMA
    - Common input format (excel-based)
      - Direct comparison
    - SAMj Viewer of excel input
      - Simplifies model construction



The Impact

- Shift in Modelling Standards
  - Higher Number of Critical Parts Assessed
    - Include all potentially critical parts
  - Component Based Fragmentation
    - Failure primarily at weak parts – joints
  - Impact observed in PADRE study
    - Land a larger number of smaller objects
  - Modelling approach implemented into DIVE guidelines
- Consistency in Modelling Standards
  - Guidelines
  - Move towards database of standard equipment models

Recent SAMj Upgrades



- Fragmentation Phenomenology
  - Mass loss model
    - Based on test aluminium failure
    - Small fraction for other metals
- Heat Balance Integral
  - Simplified model to allow for conduction
  - Consistent fidelity with standard bulk heating model
  - Designed for use with glasses and composites

- Complex Shapes
  - What is the impacting area at the ground?
  - SAMj has a new convex hull model to close gaps/holes

The Future

- Aerothermodynamic Heating to Complex Shapes
  - Still a major research topic
  - What happens to attached small parts (bolts, pipes)?
- Material Behaviour
  - Final demise – when is a composite no longer a risk?
  - Variation of behaviour of composites?
  - Glass shear demise process
- Fragmentation Phenomenology
  - Still highly uncertain; more hypothesis than understood process
- Flight Experiment Data
  - Improved knowledge means we might be able to use it well!