PADRE: Probabilistic Assessment of Destructive Re-entry

James Beck, Ian Holbrough; Belstead Research,
Jim Merrifield; Fluid Gravity Engineering,
Simone Bianchi, TAS-I, Daniel Briot; Airbus DS,
Martin Spel; R.Tech, Edmondo Minisci; University of Strathclyde,
Pierre Omaly; CNES, Stijn Lemmens; ESA
5th International Space Debris Re-entry Workshop,
Webex, 2nd December 2020
PR00051/D86

Executive Overview

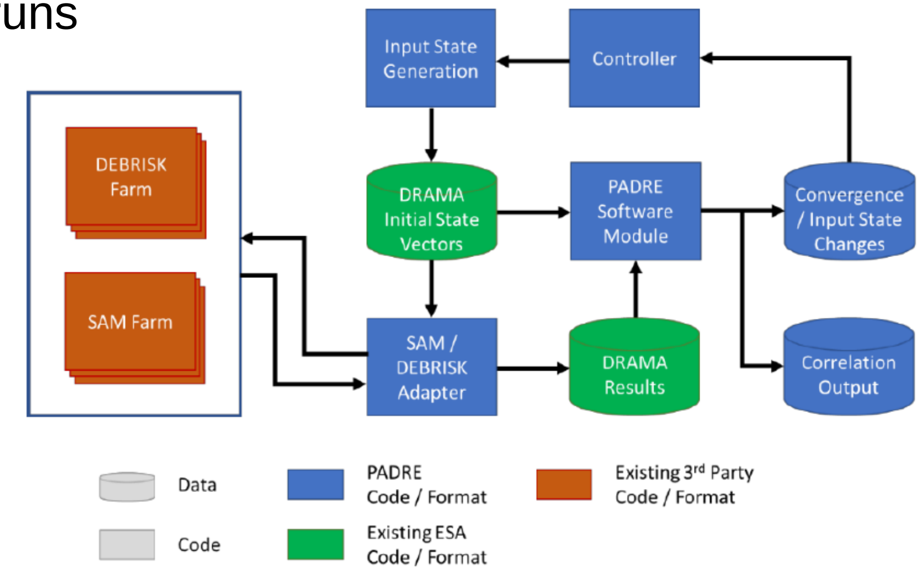
- Probabilistic Assessment of Destructive Re-entry
  - Team blends scientific experts and large system integrators
- Objective: Pragmatic stochastic assessment of casualty risk consistent with research findings
  - Comprehensive assessment of the uncertainties
    - Environmental and modelling
  - Mathematical framework to probabilistically assess re-entry risk
    - Keep focus on physics by restricting output to mass and object number
  - Assessment of capturing design for demise effects
  - Comprehensive test campaign
  - Formulation of risk assessment procedure consistent with current regulatory framework

Uncertainty Modelling

- Complete Uncertainty Model Produced
  - Key sensitivities determined as:
    - **Aerothermodynamic heating (±30%)**
    - **Emissivity (±25%)**
    - **Effective melt temperature (±50K)**
    - **Fragmentation altitude**
- Impact of Engineer Designing the Model
  - Spacecraft modeller selections can dominate uncertainty
    - Much larger than the code-to-code differences
  - Consistent rules required for consistent application
    - **Capture convex heating area (dominates over shape)**
    - **Capture small parts of critical materials (often unmodelled)**
    - **Handling unmodelled masses**

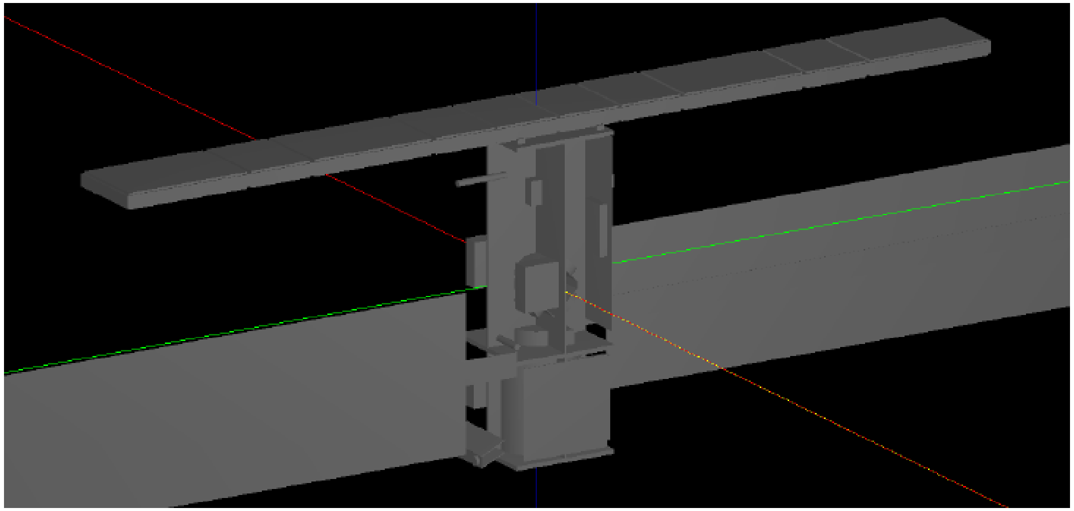
PADRE Software

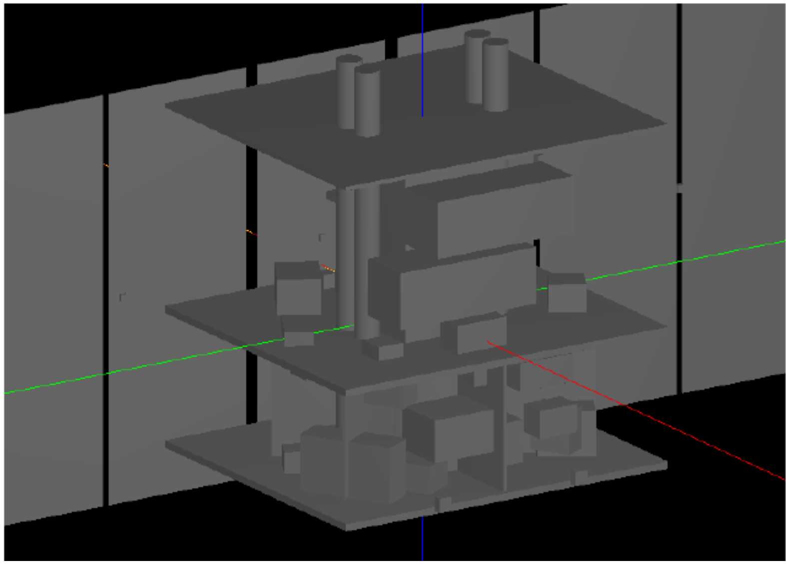
- Stochastic process description of re-entry (Monte-Carlo baseline)
- Designed as a wrapper for current tools
  - Tested on DRAMA, DEBRISK and SAM within this study
- Allows comparison between tools
  - Tools show good agreement statistically
  - Difficult to show from individual runs
- Tool agnostic
  - Adapters can be written
- Service could be provided
  - Simulations performed on cloud

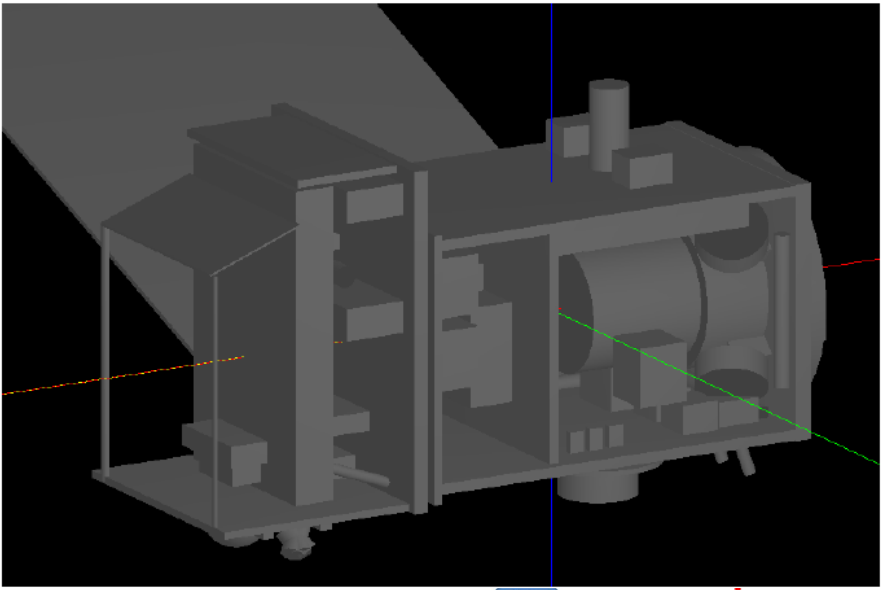


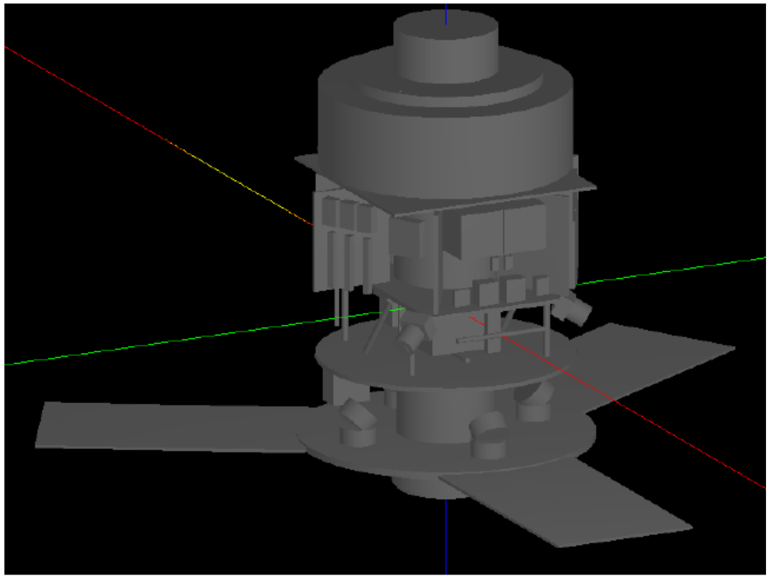
Test Cases Overview

- Full Range of Test Cases
  - Uncontrolled, semi-controlled, controlled and interplanetary entry
  - Four baseline spacecraft (2 TAS-I, 2 ADS) used
  - Step through the design phases (0/A/B), simulate knowledge levels
- Three Trajectory Codes Used
  - DRAMA (baseline), DEBRISK, SAM (full discrepancy analysis)
- Huge Number of Simulations
  - 16 test cases; Phase 0/A/B simulations; 3 re-entry codes
    - 9 sub-cases per test case
  - Each sub-case has a minimum of 2000 spacecraft simulations
    - Between 100 and 200 components per simulation
    - Order 550,000 spacecraft simulations
    - Order 90 million component simulations



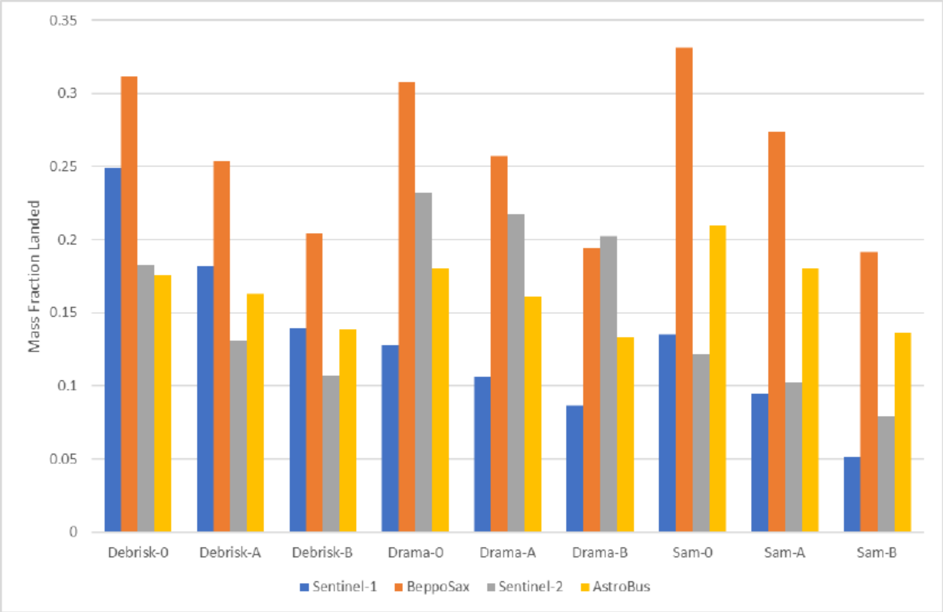


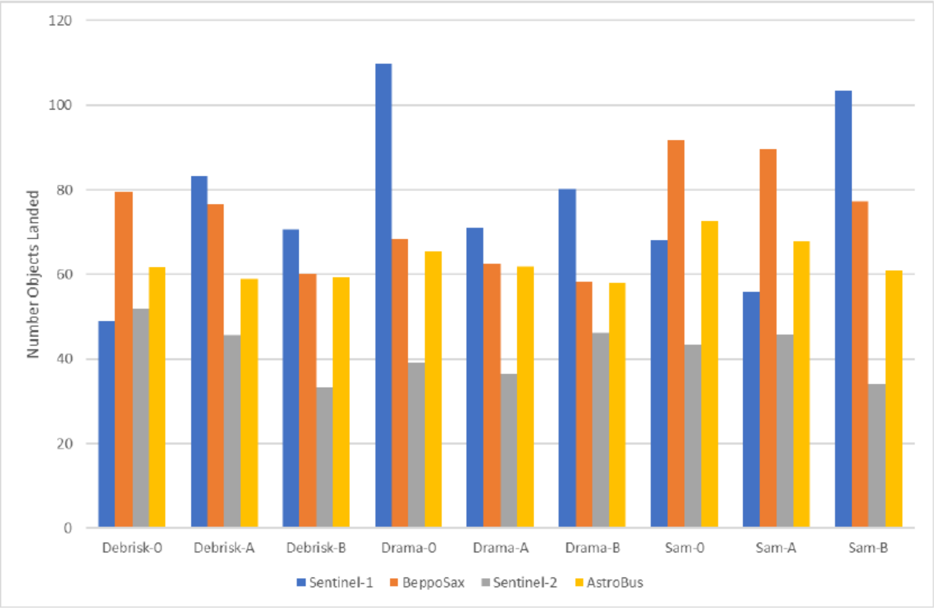




Results Overview

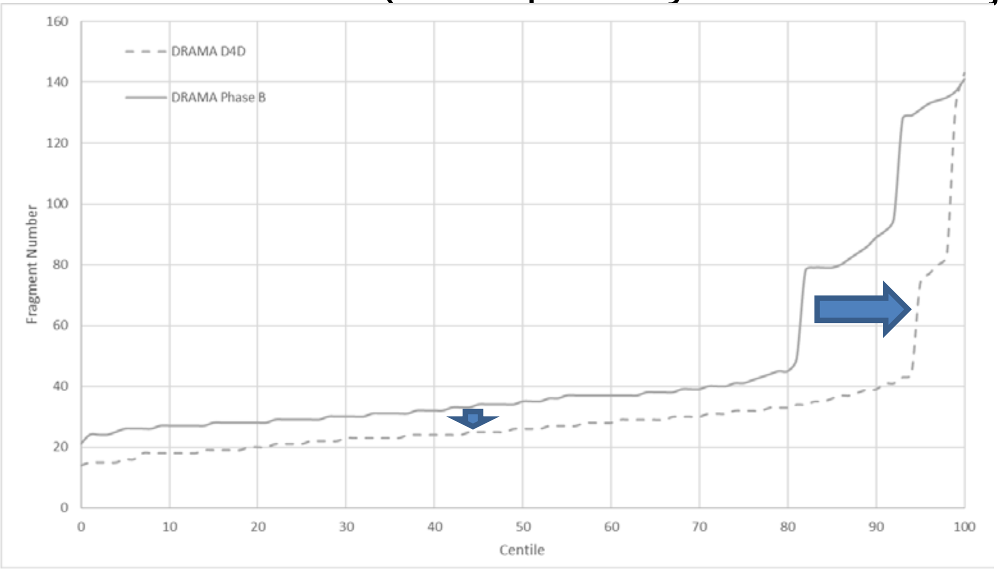
- Landed Mass / Landed Fragment Count (Uncontrolled re-entry)
  - Mean mass landed from 5-30% of spacecraft mass
  - Mean fragment numbers mainly in 30-80 range
- Modelling Impact
  - Generally consistent results across the three re-entry tools
  - Spacecraft models are key to the results; key uncertainty source





Design-for-Demise

- Component level and system level techniques applied
  - Usually material change
  - Component level techniques generally successful
- Identification of spacecraft on which system level D4D is effective
  - Effective in two cases (more demise of partially demisable objects)
  - Ineffective in two cases (fewer partially demisable objects)



Lessons Learnt

- Identification of low probability, high impact events
  - Battery cell survival at low heating
- Consistent results between tools (DRAMA/SAM/DEBRISK)
  - Identical spacecraft models used for each tool
  - Not identifiable from a single run; but clear statistically
- Demonstrates criticality of consistent modelling
  - Rule based approach required
  - Procedure developed to complement DIVE
    - **Simplicity** – no requirement for involvement of experts
    - **Consistency** – set of (simple) rules for inclusion of break-up criteria, D4D techniques, representation of critical equipment
    - **Consensus** – agreement from modellers, designers, regulators
- **Statistical Approach Recommended for Future Assessments**