Probabilistic Assessment of Destructive Re-entry

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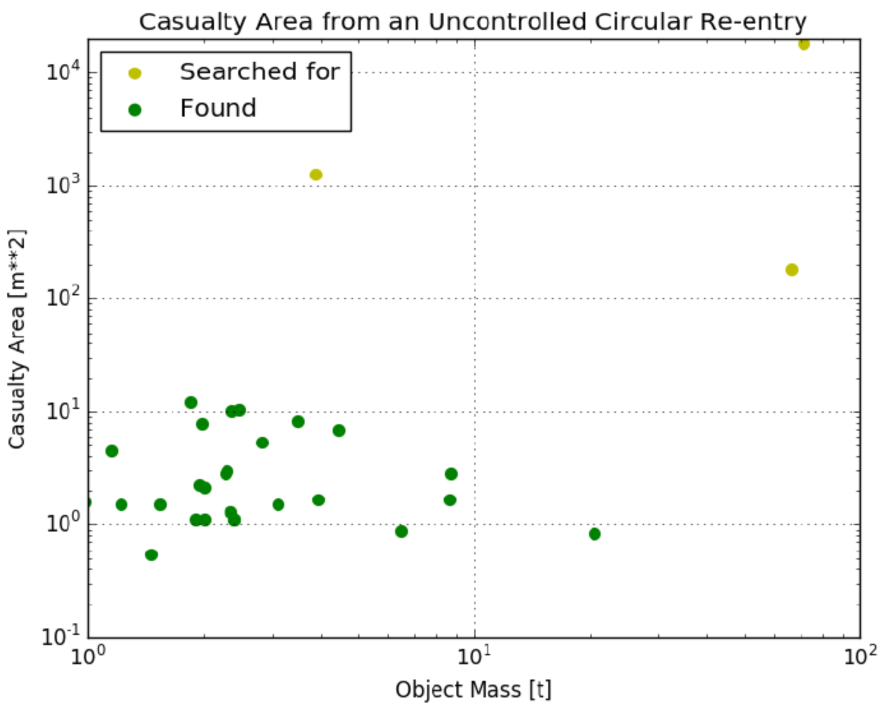
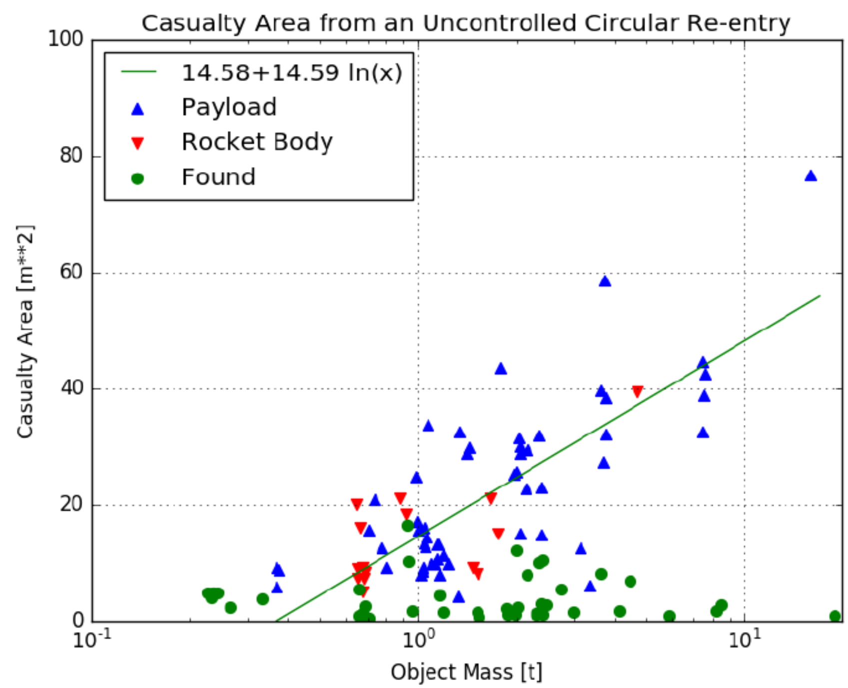
Re-Entry Risk Assessment

- Drivers for Demisability Assessment
  - Casualty risk limit of 1:10000 per re-entry event
  - Limiting for uncontrolled re-entry for reasonably sized spacecraft
  - Change the design to achieve the limit
- Many Re-entries Historically
  - Over 33000 tons
  - Over 24000 events (mostly uncontrolled)
  - About 50 events directly linked to source objects
  - Only three re-entry events have had searches for debris

Re-Entry Risk Assessment

- Recovery Campaigns
  - The casualty area from large ground objects
  - Simulation does not necessarily match (limited) observations



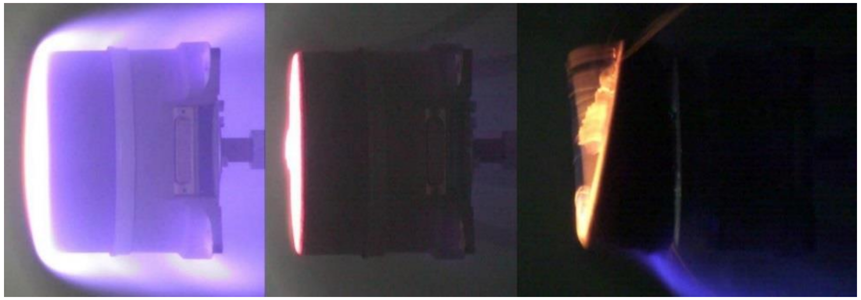


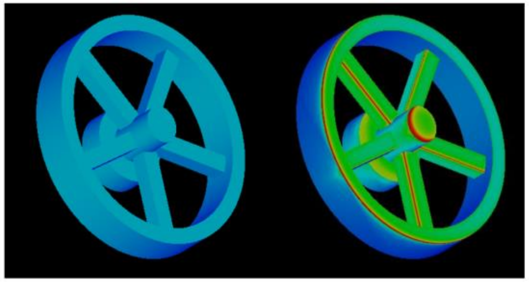
Current Assessment Approach

- Destructive Re-entry Tools are ‘Engineering Level’
  - Range of complexity
    - Object oriented (DRAMA v2, DEBRISK, ORSAT)
    - Spacecraft oriented (SCARAB, PAMPERO)
    - Hybrid (SAM, DRAMA v3)
  - High levels of uncertainties
  - Limited agreement among the methods
  - The majority of the modelling is theoretical
    - Bookwork data with limited capture of phenomenology
    - More recently, some extrapolation from ground tests
- Current Procedure is ‘Single Shot’

Progress in Understanding

- Test Campaigns
  - Material properties
    - CHARDEM / CoDM
    - Ceramics, composites
  - Joint fragmentation phenomenology
    - D4DBB activity
  - Equipment demise
    - ReDSHIFT test campaign
- Theoretical Progress
  - Improved aerothermodynamic heating models
  - Improved material models





Design for Demise (D4D)

- Physics of fragmentation modelling
  - Not captured in *any* current tools
  - Many D4D techniques enhance the fragmentation
  - Understood physically
    - Representation in *all* tools is questionable
    - Impact of technique is difficult to quantify
  - Uncertainties are large
    - Stochastic approach appears to be a good idea
    - Capture the general impact, rather than the detailed physics
- Recent D4D Campaigns have used uncertainties
  - 1000 runs per case is used as standard in SAM campaigns
  - Reduces the impact of single items around demise threshold

PADRE

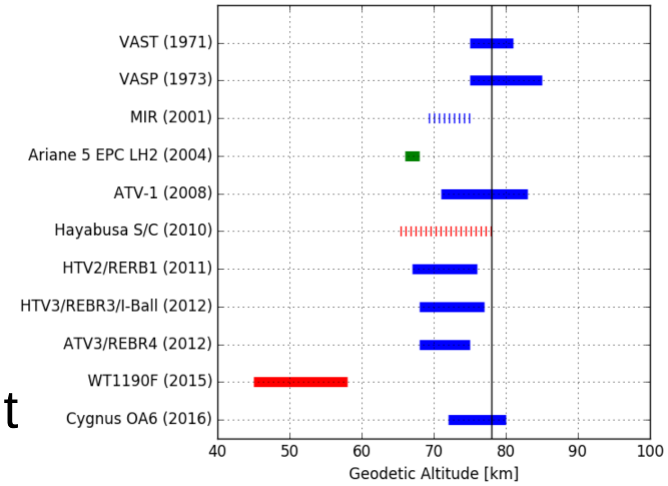
- Probabilistic Assessment of Destructive Re-entry
  - New ESA activity
  - Team blends scientific experts and large system integrators
- Objective: Pragmatic stochastic assessment of casualty risk consistent with research findings
  - Comprehensive assessment of the uncertainties
    - Physics and model representation issues
  - Mathematical framework to probabilistically assess re-entry risk
  - Assessment of capturing design for demise effects
  - Formulation of risk assessment procedure consistent with current regulatory framework

Physical Uncertainties

- Environment
  - Atmospheric density / space weather
  - High altitude winds
- Aerothermodynamics
  - Aerodynamic forces / moments
  - Aerothermodynamic heating
- Material Response
  - Emissivity, catalysis, conductivity (thermal contact quality)
  - Composites, ceramics ablation response
- Fragmentation Processes
  - Force transmission in heating vehicle and effect of spin

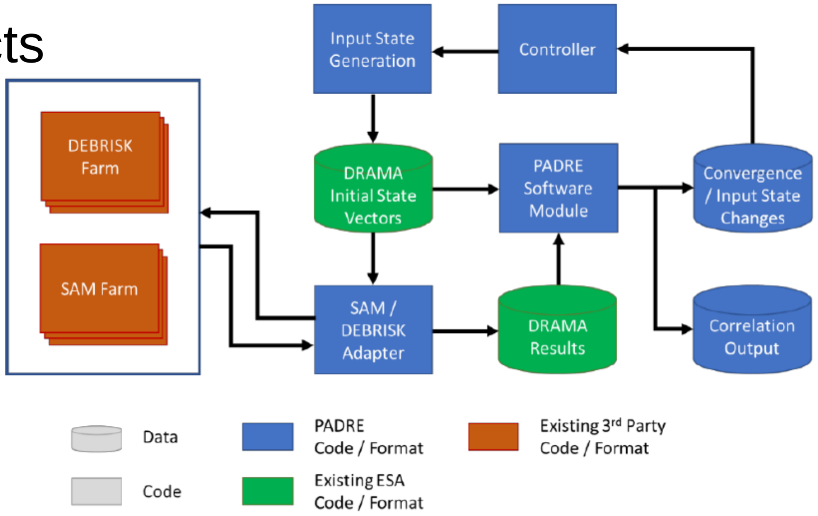
Model Representation Uncertainties

- Spacecraft Fragmentation
  - Break-up altitude
  - Fragmentation process
    - Joint failure criteria, melt failure
    - Fragment number per component
- Aerothermodynamics
  - Complex shapes, rarefied flows
  - Shielding of components, heating in separated/cavity flows
- Component Representation
  - Shape and material approximations
  - Consistent rules required for consistent application



Stochastic Model

- Stochastic process description of re-entry
- Different statistical methods to be investigated
  - Trajectory uncertainties, break-up uncertainties
  - Likelihood of fragment survival; distributions of landing site
- Designed as a wrapper for current tools
  - Will be tested on DRAMA, DEBRISK and SAM within this study
  - Designed to capture hybrid aspects
  - 6dof, predictive fragmentation



Test Cases

- Full Range of Test Cases
  - Uncontrolled, semi-controlled, controlled and interplanetary entry
  - Four baseline spacecraft (2 TAS-I, 2 ADS) to be used
  - Step through the design phases, simulate knowledge levels
- Three Trajectory Codes to be Used
  - DRAMA (baseline), DEBRISK, SAM (full discrepancy analysis)
  - Necessary convergence of statistics to be derived

Procedural Representation

- Statistical risk estimation procedure to be developed
  - Estimation for complete spacecraft and D4D features
  - Accounts for uncertainty limits in early development stages
- Some ideal principles for the procedure
  - Simplicity – guide a general engineer through “experts world”
  - Consistency – set of (simple) rules for inclusion of break-up criteria, D4D techniques, representation of critical equipment
  - Accuracy – requirements for simulation numbers/convergence
  - Tool Independence – tuning of the model to achieve consistent results using different breakup tools (may be unachievable)
  - Consensus – with many stakeholders in the team, consensus over the procedure is a key goal