Trajectory Simulation of Meteors Assuming Mass Loss and Fragmentation

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Introduction and Objective

- Program used to simulate atmospheric flight trajectories of entry capsules [1]
- Includes models of atmospheres of different planetary destinations – Earth, Mars, Venus, Jupiter, Saturn, Uranus, Titan, ...
- Solves 3-degrees of freedom (3DoF) equations for a single body treated as a point mass
- Also supports 6-DoF trajectory simulation and Monte Carlo analyses
- Uses Fehlberg-Runge-Kutta (4th-5th order) time integration with automatic step size control
- Includes rotating spheroidal planet with gravitational field having a J2 harmonic
- Includes a variety of engineering aerodynamic and heat flux models
- Capable of specifying events – heatshield jettison, parachute deployment, etc. – at predefined altitudes or Mach number
- Has material thermal response models of typical aerospace materials integrated

Modify trajectory simulation tool, Traj, to make it suitable for meteor entries including mass loss & fragmentation

Trajectory Simulation Process with Meteor Physics Equations

Entry State (r > 0) (including Entry Altitude, Entry Angle, Geographic Location, Meteor Shape, Size, and Mass)

Heat Flux Environment (Convective and Radiative Heat Flux, Model, Heat, Cooling and Melting)

Mass Loss (Ablation, Sublimation and Melting)

Meteor Trapeze (Tabulated or New: Using: Atmospheric Model, Surface Properties, trajectory, etc.)


Basic Assumptions:
- Hyperbolic excess velocity: 15.0 km/s
- Altitude at entry: 95.0 km
- Relative velocity at entry: 19.0 km/s
- Relative entry angle: -18.5 deg
- Relative heading angle: -76.6 deg
- Geographic latitude at entry: 54.5 deg
- Oblate rotating Earth
- Gravitational model includes J2 term
- US-1976 atmospheric model

Meteoroid Assumptions:
- Shape: Sphere
- Density of meteoric material: 3300 kg/m³
- Aerodynamic model: Sphere
- Sensitivity study to entry mass, heat transfer coefficient, heat of ablation, and fragmentation

Heat Transfer Coefficient, \( C_H \), Model

\[
C_H(z) = \left[a + b(z - c)^{-1/2}\right] \exp\left(\frac{z - c}{T}\right)
\]

- Curve fit expressions are to be used for \( z > 15.5 \) km
- \( C_H \) for different velocities and diameters obtained through linear interpolation

An example “quality of fit” plot generated with curve fit.

Sensitivity study to entry mass, heat transfer coefficient, heat of ablation, and fragmentation

Test Case: Chelyabinsk [3]

Basic Plots for Variable \( C_H \) and Double Fragmentation (Case 2_D)

Conclusions, Future Work and References

- Traj, an established trajectory simulation tool successfully modified for meteor entries
- Improvements include:
  - Simple mass loss equation of meteor physics
  - Time-varying heat transfer coefficient based on detailed flow computations
  - Ability to specify fragmentation events
  - Updated version of Traj tested against Chelyabinsk observations
  - Traj can now be used to establish sensitivity of trajectories to various meteor parameters
  - Leaves open the issue of verification/validation of Traj and additional test cases are needed
  - Could tektites [4] be used as additional test cases?
  - Advantages of simulating tektite entries into Earth’s atmosphere
  - Exo-atmospheric shapes are definitely spherical
  - Small sizes and (sub)orbital entry velocities
  - Problem is dominated by convective heating and melting
  - Melted shapes are aerodynamically stable
  - Chemical composition of australite tektites is statistically well defined
  - Serve as a good foundation for the tougher meteor entry problem

References: