SUBORBITAL DECONVOLUTION OF EJECTA AND STREWN.

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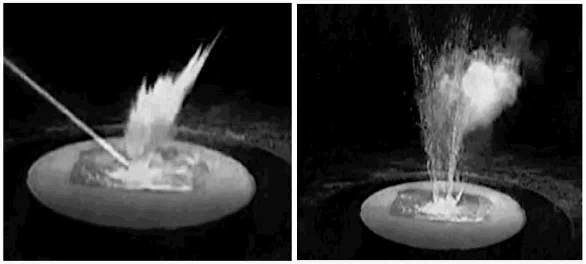
Introduction: Suborbital convolution of ejecta and/or tektites makes correlating with impact structures more difficult, particularly for large ejecta blankets or strewn fields, on rotating planets, and on planets lacking ejecta composition data. Hypervelocity impact tests indicate that volatile target components and other impact conditions may produce plasma jets (from ice) or nearly vertical ejection angles [1], Fig 1.

Figure 1



Oblique Impact: 30 deg, Ice Sheet on Sand, Schultz - Ames VGR

Combined with thin or no atmosphere, weak gravity and planetary rotation, the associated long Time Of Flight (TOF) yield substantial ejected displacement from the impact structure. This equates to A-to-B range with significant central flight angle, measured from the planet's center, ejection A to emplacement B.

Discussion: Growing planetary surface databases and the complexities of ejection variables and suborbital convolution imply a need for optimized analytic, numeric and visualization techniques for planet-wide impact structure/ejecta correlation. Current work looks at options and implications for such techniques, with terrestrial application as one example. Reduction in computational and labor cost is most helpful for impact structure/ejecta correlation processing.

The A-to-B Problem: Strewn or ejecta distribution contains imprinted information with clues as to impact structure location. For a set of ejecta or tektite landing locations with unknown impact structure location, we need to solve launch solution families at each proposed launch point A (possible impact structure) for the entire set of B points (tektites, secondary craters, spall plates, etc.), and then compare with hypervelocity test results for matching ejecta patterns.

A-to-B impact structure/ejecta correlation is computationally costly, with the process involving [individual A-to-B suborbital solution] x [range of TOF values for each A/B pair] x [every B point for each A] x [all proposed A points] x [check vs. various ejecta patterns] x [check vs. incremental azimuths]. Proposed ***A*** points having recognizable features (i.e. directional signature, eccentric or elongate structure, etc.) can be elevated in priority, and may reduce the required ***A*** point set and subsequent process. Incremental TOF also eases data process demand.

Previous workers in tektite studies (for example) use minimum Kinetic Energy trajectories in their analysis [2]. In fact, an infinite number of trajectory solutions exist for as many TOF values, with the singular minimum KE case near the low end of the range of possible TOF values. The distinctly different minimum TOF case is defined by circular orbital velocity at zero altitude about a spherical planet lacking atmosphere, having KE above that required for the suborbital A-to-B problem (in the form of excess velocity).

Also problematic, each landing point ***B*** rotates with the planet over time while the orbit plane is fixed in inertial space once defined by launch location lat/long and launch condition. We consider the set of all surface-fixed landing points ***B*** as a general inertial vector $\underline{\boldsymbol{B}}$ while TOF is unresolved, since $\underline{\boldsymbol{B}}$ has changing direction through 3-space over time. Further, the launch condition parameters of elevation (***EL***), azimuth (***AZ***) and velocity (***VEL***) are typically defined in the non-inertial local topocentric coordinate frame (rotating with the planet), requiring transformation to inertial frame before orbit calculation proceed.

A terrestrial example. A large strewn field of ejecta, tektites, etc. presents the problem of unknown TOF with planetary rotation during loft (offset in longitude is TOF dependent). Although orbital period varies as a simple power function of orbital semi-major axis ($\mathbf{a}^{1.5}$), the different, suborbital TOF varies with both orbit parameters **a** and eccentricity **e,** and must be so treated.

Australasian tektites have been shown by ablation morphology to have reentered at ~10 km/s [3], a substantial fraction of Earth's 11.2 km/s escape velocity. TOF in this case may easily be 6 to 15 hours for high ejection angle or "up-spin" easterly launch azimuth [4], or ¼ to ⅝ of Earth's longitude crater-to-strewn. Any well reasoned bounding value for maximum loft time of the AA tektites remains unknown.

Analytical strategy. To reduce cost of solution, the infinite solutions for each A-to-B pair must be reduced to a finite set of integer time increments from minimum TOF through min. TOF + 24 hrs or "next day", and then solved for vector landing location $\underline{\boldsymbol{B}}$(time) = $\boldsymbol{B}_{\mathbf{Launch}} + \boldsymbol{f}_{\mathbf{TOF}}$, where $\boldsymbol{f}_{\mathbf{TOF}}$ is steady polar rotation at constant latitude. At or around next day TOF, the A-to-B solution family turns back nearly upon itself, making longer TOF solutions more computationally intensive and unnecessary [4].

Values of **a** and **e** may be used to tabulate a central flight angle and TOF lookup table for the entire set of different $\boldsymbol{B}$ locations. This reduces iterative requirement depending on required accuracy, but must be repeated on the entire set of $\boldsymbol{B}$ points for each test location of $\boldsymbol{A}$. Solutions for a grid of possible impact structure points $\boldsymbol{A}$ may be scanned by various means for ejection patterns matching hypervelocity testing or simulation, a process enhanced by ever-improving visualization and computational resources [4].

The general A-to-B case. An analytical method involves sensitivities of landing point $\underline{\boldsymbol{B}}$ to the launch parameters $\boldsymbol{EL}$, $\boldsymbol{AZ}$, $\boldsymbol{VEL}$ & launch latitude $\boldsymbol{A_{LAT}}$. $\underline{\boldsymbol{B}}$ may be expressed relative to $\underline{\boldsymbol{A}}$ such that $\underline{\boldsymbol{B}} = [\{\boldsymbol{A_{LAT}}+\Delta_{LAT}\boldsymbol{AB}\}, \{\boldsymbol{A_{LONG}}+\Delta_{LONG}\boldsymbol{AB}+\underline{\ \ }\boldsymbol{f}_{\mathrm{TOF}}\}]$ where the two Δ terms are the relative diplacement of $\underline{\boldsymbol{B}}$ from $\underline{\boldsymbol{A}}$, $\underline{\boldsymbol{B}}$ is defined for $\boldsymbol{A_{LAT}} - \pi/2 \leq \Delta_{LAT}\boldsymbol{AB} \leq \pi/2 - \boldsymbol{A_{LAT}}$ & $\boldsymbol{A_{LONG}} - \pi < \Delta_{LONG}\boldsymbol{AB} \leq \pi - \boldsymbol{A_{LONG}}$, individual $_{\mathrm{A}}$ and $_{\mathrm{B}}$ identifier subscrips omitted.

Conclusion and Visuals: The sensitivities may be resolved with respect to each of $\boldsymbol{AZ}$, $\boldsymbol{EL}$, $\boldsymbol{VEL}$ & $\boldsymbol{A_{LAT}}$, and then calculated over a full domain of both $\Delta_{LAT}\boldsymbol{AB}$ & $\Delta_{LONG}\boldsymbol{AB}$ for $\boldsymbol{A}$ locations pole to equator. While requiring a more comprehensive table due to the 4 dimensions of $\boldsymbol{El}$, $\boldsymbol{AZ}$, $\boldsymbol{VEL}$, & $\boldsymbol{A_{LAT}}$, this method gives reduced solution time after significant up-front derivation effort, and transferability to any simplified planet model when orbit solution parameters of rotation rate $\boldsymbol{\omega}$ and gravitational constant $\boldsymbol{\mu}$ are carried through the derivation appropriately and applied per planet. Transferability between planets offers substantial overall computational benefit.

Visualization. In *Fig. 2*, an azimuth-constrained launch solution set correlates well with an oblique hypervelocity impact test plume for launch location "A" having an observed axial scar feature; populating the Australasian strewn field in effect antipodally. The energy space plot has unit Earth escape KE (dashed grey arc), with vertical being up and downrange to the right in all 3 panes. Red vectors 1 & 2 are μ-tektites, more disrupted (more heated) melt with scale ≤ 1 mm.

Figure 2.

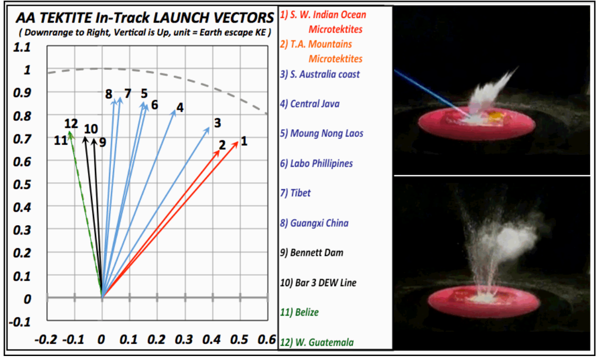


Fig. 3 shows a single orbit solution, with TOF ~8.5 hrs for a ~10 km/sec "up-spin" directed mid-latitude launch point $\underline{\boldsymbol{A}}$. Increasingly complicated families of single solutions for individual A-to-B pairs and then sets of A-to-B pairs pose progressively greater visualization challenges due to their highly detailed and geometrically complex 3-D data, and due to the general time-dependent nature of suborbital trajectories. View is looking down from North pole, Prime Meridian to the right and 90° East longitude being up in the frame.

Figure 3

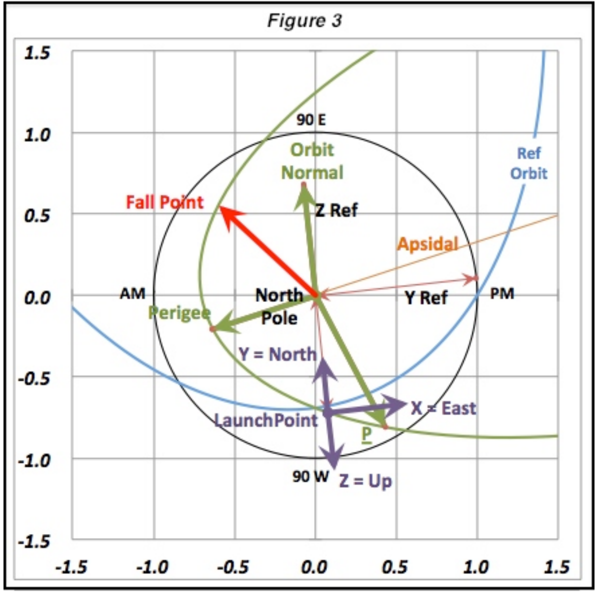


Figure 4

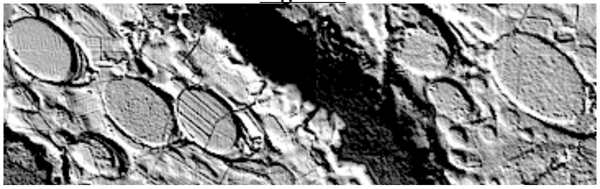


Fig. 4 A suspect ejecta blanket imaged with LIDAR, showing a portion of 45,000+ co-aligned sand bed voids scaling from 100 meters to several kilometers, aligned systematically by latitude, with robust adherance to only 6 different archetype ovoid shapes.

The greater the number of proximal and distal ejecta features that show correlative alignment to a given suspect geologic feature, the higher that feature should rise in priority for A-to-B Suborbital Deconvolution.

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References: [1] F. Sommer et al., (2012) *Meteoritics & Planet. Sci. 48, p33*. [2] J. Wasson (2015) *Lunar & Planet. Sci. Conference*, abstract #2879. [3] D. R. Chapman & H. K. Larson, (1962) NASA Tech Note D-1556. [4] T.H.S. Harris & H. Povenmire (2015) *LPSC 2015* abstract #1291.