Development of software for analysing entry accelerometer data in preparation for the Beagle 2 mission to Mars: towards a publicly available toolkit

Conference or Workshop Item

DEVELOPMENT OF SOFTWARE FOR ANALYSING ENTRY ACCELEROMETER DATA IN PREPARATION FOR THE BEAGLE 2 MISSION TO MARS: TOWARDS A PUBLICLY AVAILABLE TOOLKIT. Paul Withers[1, 2] Brijen Hathi[2], Martin Towner[2], and John Zarnecki[2], [1]Lunar and Planetary Laboratory, University of Arizona, Tucson, AZ 85721, USA, [2]Planetary and Space Sciences Research Institute, The Open University, Milton Keynes, MK7 6AA, Great Britain (withers@lpl.arizona.edu).

Abstract's Abstract: We have tested techniques for turning Beagle 2's entry accelerometer data into a T(z) profile. We reproduced the PDS results for Pathfinder. The PDS trajectory for Pathfinder appears inconsistent with its entry state. Our code is available online.

Introduction: Spacecraft designed to pass through a planetary atmosphere are routinely equipped with an accelerometer. The accelerometer's primary use is operational; its signal being used to control spacecraft events during the challenging period of entry, descent, and landing. Upon further processing, this data can also reveal scientifically useful information on the atmospheric density, pressure, and temperature along the spacecraft path. Developed by Al Seiff's group at NASA-Ames, this technique has been used by Pioneer probes at Venus [1], PAET on Earth [2], Viking and Pathfinder on Mars [3, 4], and Galileo at Jupiter [5]. It will be used on both NASA (MER) and ESA (Beagle 2) Mars landers in the 2003 launch opportunity and by Huygens on Titan. It has also been used to aid the aerobraking of orbiters such as MGS and Mars Odyssey [6]. While the technique is conceptually simple, it is not trivial to implement in practice. Here we report on our early work to develop this technique for eventual analysis of Beagle 2 entry accelerometer data and our trial application to Pathfinder. We also make our computer software available for general use.

Basic Concepts: Using measurements of a spacecraft's aerodynamic acceleration, prior knowledge of the gravitational field, and an initial position and velocity, the spacecraft's trajectory can be reconstructed.

The deceleration of a spacecraft by an atmosphere can then be expressed as:

$$a = {(\rho C_D A V^2)} \big/ {-2m} \qquad (1)$$

where ρ is atmospheric density, C_D is a dimensionless drag coefficient, A is a specified reference area used as a scaling factor for C_D, V is the relative speed between the spacecraft and the atmosphere, m is the mass of the spacecraft, and a is the spacecraft's aerodynamic acceleration. Using the results of the trajectory reconstruction, this equation can be solved for atmospheric density along the trajectory given appropriate values of C_D. C_D is a function of atmospheric chemical composition, pressure and temperature, spacecraft size and shape, and fluid velocity relative to the spacecraft. It can be calculated numerically or via laboratory testing. Given the density, the hydrostatic equation may be solved for atmospheric pressure along the trajectory and an equation of state then solved for atmospheric temperature. We have developed software to carry out both the trajectory and atmospheric structure reconstructions.

Free Software: A version of the IDL software used to reconstruct the trajectory and atmospheric structure is available from "http://www.lpl.arizona.edu/~withers/beagle2/". It is not our most advanced version, since that is not well commented or user-friendly at the present time. Users may specify an entry state and a planet and observe the descent (or skimming off to infinity) of their spacecraft. Users may also specify an entry state and series of acceleration measurements to obtain a trajectory and then the atmospheric structure. We hope that it will be useful to scientists wishing to understand more fully the derivation of atmospheric structure profiles before using those profiles, scientists wanting to verify a published atmospheric structure profile, scientists wishing to derive an atmospheric structure profile from accelerometer data, scientists or engineers performing preliminary studies of an atmospheric entry for mission design, university teachers wanting to liven up classical mechanics classes, and so on. We also hope that user feedback will provide us with many suggestions for improvements and the inevitable bug reports.

Reconstruction of Mars Pathfinder Trajectory: To test the validity of our reconstruction software, we reproduced the analysis of the Mars Pathfinder accelerometer data [4, 7]. Most of the information necessary to do so is available on PDS volume MPAM_0001. This volume does not provide any information on C_D. Without information on C_D, it is not possible to reconstruct the atmosphere structure. However, figure 3 of Magalhaes et al shows C_D as a function of altitude as appropriate for their reconstruction [4]. Lacking any other knowledge of the dependence of C_D on spacecraft attitude or speed or atmospheric conditions, we used a crudely scanned and digitized version of this figure as our aerodynamic database. This will be an important source of error, but we were still able to obtain good results. We have reservations about the initial conditions stated in Magalhaes et al and in the PDS volume written by the same authors. Its latitude and longitude at an altitude of about 200 km is quoted with uncertainties of about 0.04 degrees. Figure 2 of Magalhaes et al shows an entry latitude and longitude about 1 degree different from that quoted in the text. Magalhaes et al have shifted the trajectory somewhat to reproduce the well-constrained landed position, but state that the entry latitude and longitude remain within the quoted uncertainties. The trajectory as detailed by the PDS extends from the ground to about 150 km and appears to match Figure 2 of Magalhaes et al at these lower altitudes. Using these initial conditions, we obtained a trajectory that was systematically different from the PDS trajectory between 0 and 150 km altitude by about 1 degree in latitude and longitude. Using alternative initial conditions from Spencer et al at about 140 km altitude [7], our trajectory reconstruction differs systematically from that of the PDS by only 0.04 degrees in latitude and longitude. Our reconstructed altitudes differ from those of the PDS by less than 1% throughout the trajectory. We note that these results are obtained with a poor aerodynamic database, but discussions with Tim Schofield of the Pathfinder ASI/MET team, though helpful, have failed to resolve our confusion. For now, we will use the Spencer et al initial conditions until we understand the discrepancies within Magalhaes et al [4]. Hence our reconstruction of the trajectory differs from that of the PDS by hundredths of a degree in latitude and longitude and about one percent in altitude, with both a systematic offset and one that grows with time. We attribute the systematic offset to differences in entry state and the PDS's shift to match the landed position. We attribute the growing offset to the accumulation of uncertainties that are minimised in the PDS reconstruction by additional constraints, such as altitude and descent velocity near landing from radar data not available to us.

Reconstruction of Mars Pathfinder Temperature Profile: The primary scientific result from an entry accelerometer is a vertical profile of temperature with much higher vertical resolution than possible with any other measurement technique. Using the crude parameterisation of C_D mentioned above, we reproduce the PDS density profile to within a few percent. Note from equation 1 above that uncertainties in C_D translate linearly into uncertainties in density. Our reproduction of the pressure results is slightly better and our temperature results, shown in Figure 1, match to within a few K above 40 km and within ten K below that, which we consider to be a good result. In Figure 1, "PDS Atmosphere" refers to the results of Magalhaes et al and "Mine" refers to our results. A glance at figure 3 of Magalhaes et al shows that this decrease in accuracy below 40 km is to be expected given the complexity in the curve of C_D that we have tried to scan and digitise.

Ongoing work: Having verified our software, we are using it to study the effects of uncertainties and errors on the future scientific results of the Beagle 2 entry accelerometer. Knowledge of how instrument digitization, instrument sampling rate, any systematic offset, and uncertainties in entry position, velocity and aerodynamic properties affect the accuracy of the trajectory and atmospheric structure reconstructions will help focus the Beagle 2 project's efforts on those areas where improvement in them is most profitable.

Conclusions: We have made an initial version of our toolkit for reconstructing trajectories and atmospheric structure profiles from entry accelerometer data publicly available. The toolkit will be used to prepare for the landing of Beagle 2 on Mars. It has been verified on Mars Pathfinder and suggests some discrepancies in the published work on the Pathfinder reconstruction. We hope to receive feedback on the publicly available toolkit that will help us improve it.

References:

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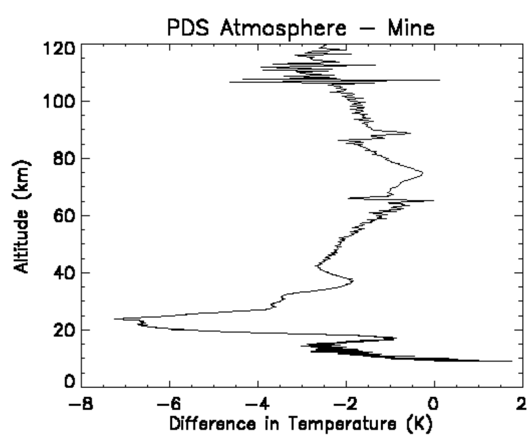

Figure 1