NEW APPROACH OF ORBIT DETERMINATION STRATEGY TO IMPROVE THE STARDUST DYNAMIC MODELS*

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ABSTRACT

Stardust is the first mission that will swing close to a comet (Wild 2) and return the collected cometary material and interstellar dust back to Earth for scientific research. Accurate navigation is vital for successful mission operations as well as science data return.

Since the launch of Stardust in February 1999, the navigation team has encountered considerable difficulty in determining and predicting a consistent estimate of the Stardust orbit. The primary factors contributing to the estimation errors are the mismodelling of nongravitational accelerations due to both the solar radiation pressure and the small $\Delta V's$ (referred to as small forces) that arise owing to the attitude control system (ACS).

Analyses have revealed that during cruise phase, the dominant spacecraft dynamic error source is the small force mismodelling. Stardust is designed with an unbalanced thruster configuration which introduces a ΔV during each attitude control activity. The Limit Duty Cycle (LDC) is the main thruster mode for Stardust mission. It includes deadband at Sun point, deadband walk from Sun to Earth point (DBW2EP), deadband at Earth point, and deadband walk from Earth to Sun point (DBW2SP). Figure 1 illustrates the Stardust orientations during LDC mode and the associated approximate time duration for each attitude.

Based on pre-launch studies the navigation team assumed that the effect of small forces could be treated by a combination of instantaneous impulsive burns and a stochastic acceleration model. This strategy depended on using estimates of the small force determined by an on-board algorithm. Figure 2 shows a typical example of telemetry-derived small forces (using spacecraft on-board equation) in terms of the accumulated total ΔV during LDC mode. However this approach was inadequate due to the deficiencies of the on-board algorithm and shortcomings in the strategy such as the lack of *a priori* knowledge of when to apply the impulse burns, indiscriminate aliasing of the dynamic errors, and the difficulty of incorporating the estimation information to enhance the orbit propagation models.

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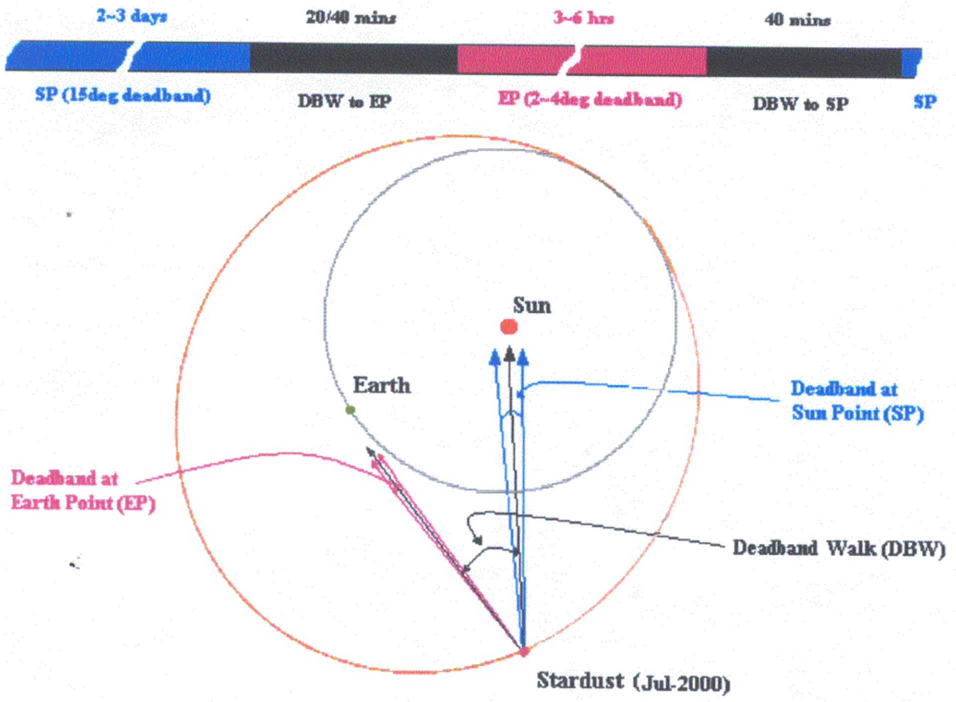

Figure 1: Spacecraft Attitudes during Limit Duty Cycle Mode

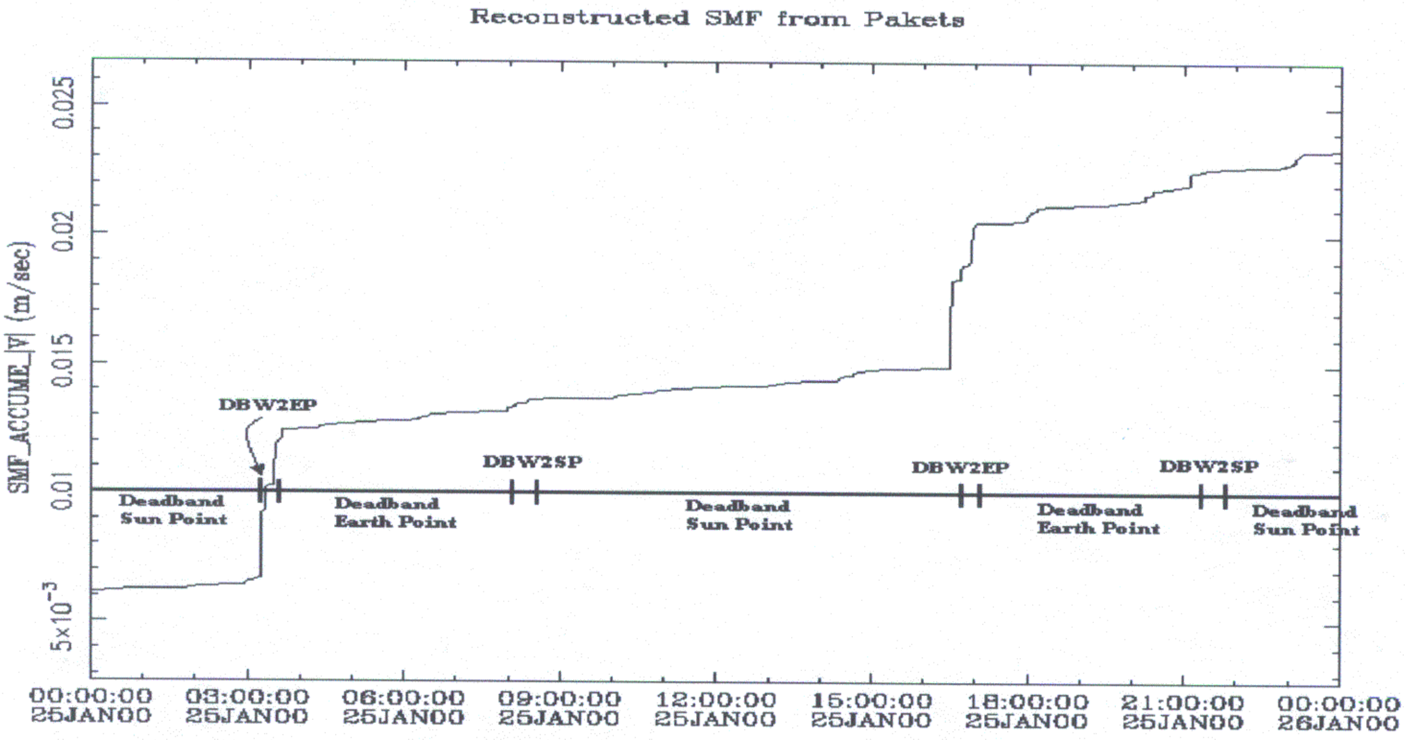

Figure 2: Small Force Accumulated ΔV

This paper describes the estimation strategy to model the small forces, developed as a result of extensive analyses at Jet Propulsion Laboratory (JPL) and Lockheed Martin Astronautics (LMA). The detailed spacecraft (S/C) dynamic models and the evaluation of the dynamic error sources are discussed. A unique filter method has been developed to create a simple and efficient orbit determination (OD) strategy. Not only is it specifically designed to deal with Stardust's dynamic mismodelling but the estimation knowledge also can be used to optimize the orbit propagation models. This filtering strategy decomposes the limit duty cycle into deadband walk, earth-pointing, and sun pointing phases and constructs a characteristic stochastic batch size and level of process noise for each phase. The filter estimates the solar pressure coefficients and stochastic small force scale factors. The scale factor estimates in turn are used as a basis for predicting the effects of small forces for orbit propagation. Figure 3 shows a typical example of stochastic small force scale factor solutions. At times the estimated corrections are almost 40% more than the on-board generated small forces.

Figure 4 compares the OD updated small forces (Updt) determined by the stochastic filter with the small forces generated by the on-board algorithm (On-brd). After 17 days the on-board small force is in error by 16%. The plot also compares the predicted small-force models for the same period. This predictions of future small forces activity is critical for predicting the Stardust Earth flyby in January 2001 and in planning maneuvers for this flyby, as well as for the comet encounter and Earth return. The predicted models shown in Figure 4 include a model which was derived using parameters from a stochastic scale factor solution generated before the start of this interval (Updt-Pred) and a predicted model based on a pre-launch assessment of the small force activity (Pred). A comparison of the two predicted models with the actual (Updt) model shows a significant improvement on the predicts derived using the small force solutions. The 'Pred' and 'Updt-Pred' separately show 20% and 5% error with respect to the 'Updt' small forces at the end of the comparison interval.

Stardust is the first comet sample return mission, and it mainly relies on thrusters to maintain and change the spacecraft orientations. This paper has demonstrated a modelling and filtering strategy capable of improving the orbit propagation models noticeably. There is great potential for applying these successful navigation techniques for other deep space missions which are affected by frequent unbalanced forces due to the attitude control activity.

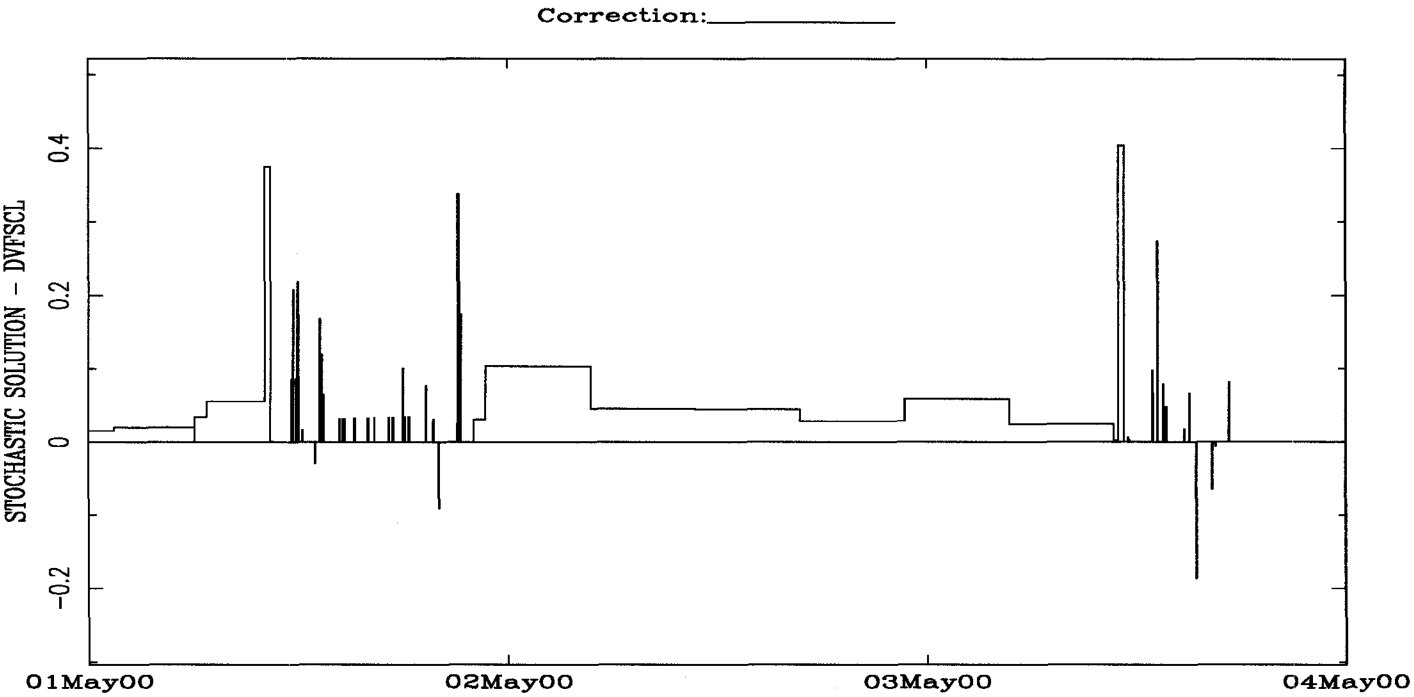

Figure 3: Estimated Small Force Corrections

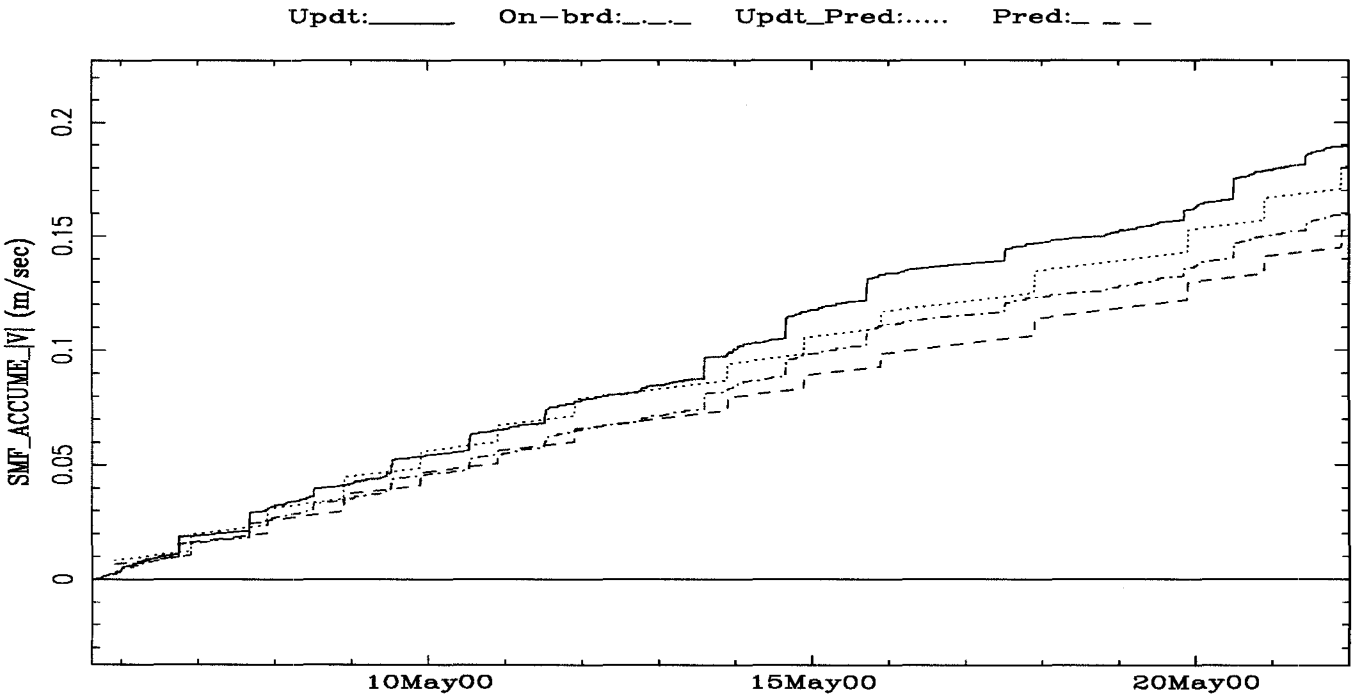

Figure 4: Small Force Comparison