FUEL DISTRIBUTION ESTIMATE VIA SPIN PERIOD TO PRECESSION PERIOD RATIO FOR THE ADVANCED COMPOSITION EXPLORER

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Abstract: Beginning in September 2013, fuel tank temperature telemetry from the Advanced Composition Explorer (ACE) satellite suggested one of the four tanks onboard had minimal propellant remaining. In November 2014, temperature telemetry from a second tank began to suggest that it too contained minimal propellant. The fuel imbalance suggested by this telemetry was contrary to pre-launch mission expectations of the propulsion system performance. In order to minimize the maneuver underperformance that began in May 2014, which was ascribed to pressurant from the empty tanks mixing with fuel from the remaining tanks, a closure of the fuel line latch valves was considered. Before conducting the closure, mathematical models of ACE were developed and an analysis of sun sensor data was performed to determine the nature of the fuel imbalance. Specifically, the spin period to precession period ratio was used to estimate the remaining mass and distribution of fuel within the propulsion system. First, numerical models of the ACE fuel tanks were developed to calculate the spacecraft moments of inertia for any given fuel amount and distribution. Next, the ideal gas law was applied to develop possible pre-launch fuel distribution scenarios. A mathematical simulation of a non-axisymmetric spin-stabilized spacecraft was then built to relate moments of inertia to the rotational dynamics of the system. A Fast Fourier Transform (FFT) of output from this dynamics simulation was employed to relate calculated moments of inertia to spin and precession periods. The fuel tank models and the rotational dynamics model were then combined to determine spin period to precession period ratios over the life of the mission for the fuel distribution scenarios under consideration. The resulting lifetime modeled ratios were compared to the history of actual spin period to precession period ratio derived from the effect of post-maneuver nutation angle on sun sensor measurements. A Monte Carlo analysis was performed to resolve measurement errors in ACE dry moments of inertia and fuel tanks locations, to estimate the fuel distribution, and to assess the impact of each of these factors on fuel mass estimates. The error ranges considered were constrained by measurement uncertainty. This novel analysis of spin and precession periods indicates that at the time of launch, propellant was distributed unevenly between the two pairs of fuel tanks, with one pair having approximately 20% more propellant than the other pair. Furthermore, this analysis indicates the pair of tanks with less fuel expelled all of its propellant by 2014 and that approximately 46 kg of propellant remains in the other two tanks, an amount that closely matches the operational fuel accounting estimate. In addition to these results, this paper also presents an explanation of how the initial fuel distribution could have been imbalanced, which centers on the fact that the while the fuel lines from the four tanks are interconnected, the pressurant lines for one pair are isolated from those for the other pair. After the completion of this analysis, the ACE mission successfully closed the latch valves in March 2015 and has since experienced nominal maneuver performance.

Keywords: *Fuel Distribution, Moments of Inertia, Precession, Spin, Nutation.*