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USING ONBOARD TELEMETRY FOR MAVEN ORBIT DETERMINATION

Try Lam,[*] Nikolas Trawny,[†] and Clifford Lee[‡]

Determination of the spacecraft state has been traditional done using radiometric tracking data before and after the atmosphere drag pass. This paper describes our approach and results to include onboard telemetry measurements in addition to radiometric observables to refine the reconstructed trajectory estimate for the Mars Atmosphere and Volatile Evolution Mission (MAVEN). Uncertainties in the Mars atmosphere models, combined with non-continuous tracking degrade navigation accuracy, making MAVEN a key candidate for using onboard telemetry data to help complement its orbit determination process.

EXTENDED ABSTRACT

The Mars Atmosphere and Volatile Evolution Mission (MAVEN), part of the NASA Mars Scout program, is set to launch in 2013 and will explore the planets upper atmosphere, ionosphere and interactions with the sun and solar wind. During the mission's science phase, the spacecraft will spend approximately 1 year orbiting Mars in an elliptical orbit with a period of 4.5 hours. During each periapsis pass at altitudes between 125 to 150 km, the Mars atmosphere will impart significant drag ΔV on the spacecraft. Uncertainties in current Mars atmosphere models, combined with non-continuous deep space network (DSN) tracking noticeably degrade navigation accuracy, making MAVEN a key candidate for using onboard telemetry data to help complement its orbit determination process (Reference 1). Onboard telemetry has recently received growing interest for use in applications such as atmosphere reconstruction and autonomous aerobraking (see, e.g., work by Tolson et al, Jah et al., and OShaughnessy et al.). This paper describes our approach and results to include onboard telemetry measurements in addition to the traditional radiometric observables to refine the reconstructed trajectory estimate and subsequent trajectory prediction. This effort is intended to be an extension of the batch orbit determination (OD) software, MONTE, currently in use at the Jet Propulsion Laboratory (JPL).

MAVEN differs from previous Mars aerobraking missions in many aspects, such as orbital period, available tracking data, and requirements. Although MAVEN will not be aerobraking, it will encounter drag ΔVs at periapsis much higher than that of MRO's science orbit (but significantly lower than that of MRO's aerobraking orbits). The nominal MAVEN science orbit will have drag

[*] Jet Propulsion Laboratory, California Institute of Technology, M/S 264-820, 4800 Oak Grove Dr., Pasadena, CA 91109, 818.354.6901, try.lam@jpl.nasa.gov.
[†] Jet Propulsion Laboratory, California Institute of Technology, M/S 301-121, 4800 Oak Grove Dr., Pasadena, CA 91109, 818.343.8685, nikolas.trawny@jpl.nasa.gov.
[‡] Jet Propulsion Laboratory, California Institute of Technology, M/S 230-104, 4800 Oak Grove Dr., Pasadena, CA 91109, 818.343.8685, clifford.lee@jpl.nasa.gov.

ΔVs of a few millimeters (3-9 mm/s) per second per orbit, with a varying periapsis altitude designed to maintain a density between 0.05 and 0.15 kg/m^3. The science phase will also include five so-called deep dips, during which periapsis altitude is reduced to achieve densities between 2 and 3.5 kg/m^3. During deep dips the drag effect can be more than 10 times larger (80-180 mm/s) than during the nominal science orbit. Unfortunately, MAVEN's periapsis altitude and orbit inclination of 75 degrees are sufficiently different from previous Mars missions so that only few data points exist to characterize atmospheric density in this regime. Furthermore, MAVEN will nominally only have one 5-hour DSN Doppler tracking pass per day (two 5-hour HGA 2-way Doppler passes and five 5-hour LGA 2-way Doppler passes per week). This is in stark contrast to previous Mars aerobraking missions, that had continuous Doppler coverage. The 5-hour window of 2-way Doppler tracking covers over a full orbit (orbit period is 4.5 hours), thus allowing to accurately reconstruct atmospheric density of one periapsis pass per day. During the 8-day "Deep-Dip" period of the mission the tracking will be near continuous. In practice there will be gaps in the 2-way Doppler due to station hand-overs, occultations, orbit or pointing geometry, and around periapsis (12 minutes prior and 22 minutes after periapsis passage). In total, MAVEN will have less tracking data than previous Mars missions, and will suffer from large atmospheric modeling uncertainties.

The key OD requirements during the science phase are (1) to predict the periapsis uncertainty to less than 20 seconds of periapsis passage time, and (2) to reconstruct position knowledge to within 3 km (3-σ). For the nominal tracking scenario with one tracking pass per day, the expected reconstruction uncertainty meets the 3 km requirement. However, there are some worst case contingency tracking scenarios where the requirements cannot be met.

Using onboard telemetry data (acceleration and torque) for OD on MAVEN will help with the reconstruction and prediction requirements. The accelerometer data will be provided at 1 Hz. Accelerometer measurements are subject to scale-factor errors, (time-varying) biases, and noise. We chose to process acceleration magnitude instead of the full acceleration vector, since it limits sensitivity to attitude errors, and reduces the number of measurements to process. The accelerometer magnitude computed value is given by the equation

$$a_{comp} = s \mid \mathbf{a} \mid + b \tag{1}$$

where s is a scale factor, $\mathbf{a}$ is the measured non-gravitational acceleration vector defined as total acceleration of the spacecraft minus the total gravitational acceleration,

$$\mathbf{a} = \mathbf{a}_{total} - \mathbf{a}_{grav} \tag{2}$$

and b is the accelerometer bias.

The wheel speeds of the Reaction Wheel Assemblies (RWAs) are combined with S/C rotational velocity, APP gimbal rates, and inertias to compute the S/C angular momentum. Numerical differentiation then yields an inferred measurement of the external torque acting on the S/C. In contrast to angular momentum, the expected external torque can be computed solely from the S/C trajectory and attitude, without having to integrate an additional dynamic state. The torque measurement, as computed from telemetry during pre-processing is given by

$$\mathbf{T}_{msr} = \mathbf{I}_{s/c}\dot{\omega}_{s/c} + \mathbf{I}_{RWA}\dot{\omega}_{RWA} \times (\mathbf{I}_{s/c}\omega_{s/c} + \mathbf{I}_{RWA}\omega_{RWA}) \tag{3}$$

The computed measurement of the torque, computed from S/C trajectory, attitude, and maneuver data, is defined as

$$\mathbf{T}_{comp} = \mathbf{T}_{aero} + \mathbf{T}_{SRP} + \mathbf{T}_{gg} + \mathbf{T}_{finiteburn} \tag{4}$$

where $\mathbf{T}_{aero}$ is the aerodynamic torque, $\mathbf{T}_{SRP}$ is the solar radiation pressure torque, $\mathbf{T}_{gg}$ is the gravity gradient torque, and $\mathbf{T}_{finiteburn}$ is torque due to thruster firings (finite burns).

The successful demonstration of using telemetry data to improve the accuracy of ground based orbit determination will help to reduce cost (DSN tracking time) and increase performance of future JPL missions. In addition, it presents an important stepping stone to autonomous onboard aerobraking and aerocapture.

REFERENCES

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