Using Telemetry to Navigate the MarCO cubesats to Mars

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Abstract

The two MarCO "cubesat" spacecraft were launched alongside NASA's InSight in May 2018, operating primarily as a technology demonstrator for small satellites in deep space, with a nominal (but experimental) mission to provide relay support for the primary spacecraft during entry, descent, and landing at Mars. Due to their small size and experimental nature, extensive use of telemetry beyond that commonly used by deep space missions was necessary to complete adequate orbit determination. In particular, telemetry was valuable in two areas: use of wheel speeds during thruster calibrations to improve knowledge of individual thruster force levels, and the use of propellant temperature and pressure data to correctly model small thrusting events on board the vehicle.

Keywords: Navigation, Orbit Determination, Cubesats, Telemetry, Reaction Wheel Speeds, Cold Gas Thrusters

Introduction

NASA's two MarCO (Mars Cube One) spacecraft were launched May 5, 2018, alongside the primary InSight (Interior Exploration using Seismic Investigations, Geodesy and Heat Transport) mission. The six-unit (6U) "cubesats", pictured in figure 1 with marked body axes, were built primarily to demonstrate the viability of these small, inexpensive spacecraft in a deep space environment, with a nominal purpose of providing relay communications during InSight's entry, descent, and landing (EDL)[1]. It is important to distinguish between the primary mission and the nominal purpose; while the spacecraft design was driven by the relay mission, as experimental spacecraft, the MarCO spacecraft were never considered necessary for successful completion of the InSight mission, and MarCO would have been considered successful after demonstrating its viability, even if the EDL mission was never completed. Still, after 6 months in flight, on November 26, 2018, both MarCO spacecraft performed as designed, relaying data back to Earth in real time during InSight's successful landing, providing confirmation of vehicle safety and the first surface picture (figure 2) hours before the Mars Reconnaissance Orbiter (MRO), the prime EDL relay asset, was able to retransmit that data.

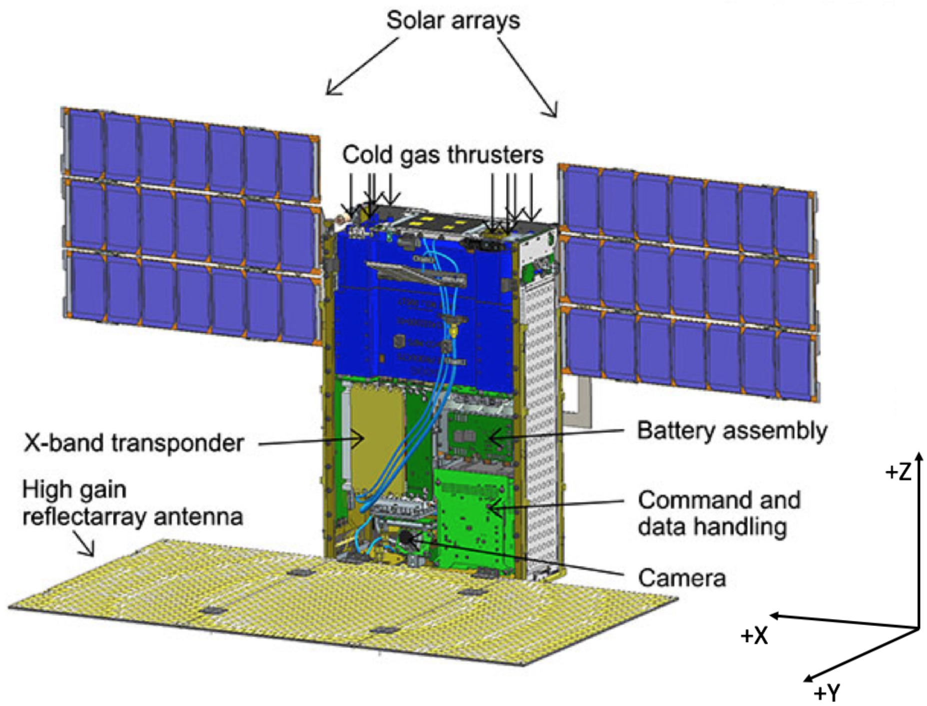

Figure 1: Geometry and Body Axes of MarCO spacecraft

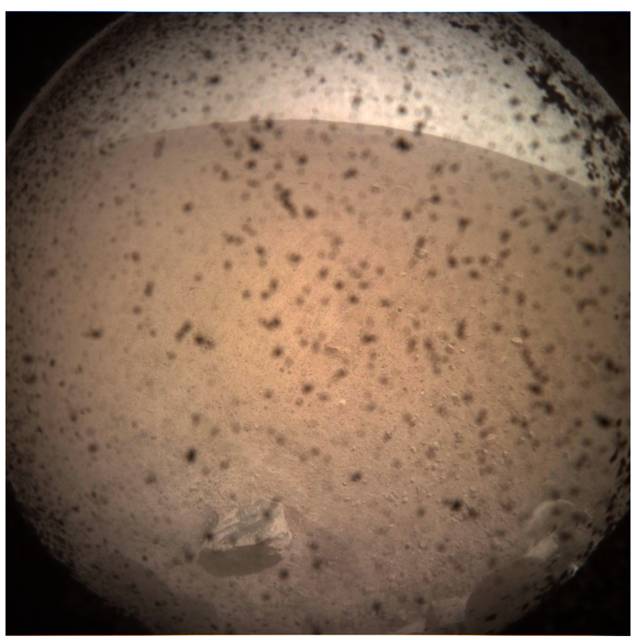

Figure 2: InSight's first surface image, transmitted by MarCO-A

The successful navigation of MarCO-A (Eva) and MarCO-B (Wall-E) was critical to both the technology demonstration and EDL relay missions. First, any technology demonstration necessitated successful navigation, since any subsequent mission would depend on an assurance of navigability. This meant that mission requirements involved demonstrating viable orbit determination (OD) solutions as well as implementation of a trajectory correction maneuver (TCM). Second, a successful relay required that the spacecraft be redirected to appropriate target zones with reasonable knowledge for antenna pointing throughout the flight and EDL.

While in many ways, navigation of these spacecraft was similar to that for their larger brethren, there were a few distinctions[2]. First consider the implementations of TCMs, using the Vacco-provided cold gas thruster system[3], and the XACT attitude control system delivered by Blue Canyon Technologies[4]. These off-the-shelf parts were simpler than those on larger vehicles, and required some extra work to use successfully. In particular, while most recent three-axis stabilized spacecraft use accelerometers to end maneuvers at a specified accumulated velocity change, MarCO maneuvers were specified as a number of thruster-seconds. Due to varying thrust levels and off-pulsing for attitude control, the mapping of thruster seconds to total velocity change (ΔV) was not obvious, particularly for the first maneuvers. A set of "thruster calibrations" were performed after launch to provide an initial estimate of thruster performance, using a novel approach to integrate reaction wheel telemetry with Doppler data in orbit determination. Continued tracking of detailed maneuver performance as the mission flew was used to further improve accuracy of later maneuvers. The details of this is the focus of the first section of this work.

Second, tracking data was limited due to power constraints on the spacecraft. This is because the amount of power the spacecraft could collect with solar panels was limited by the small form factor and limited available surface area, while the amount of power required to transmit to Earth at a given data rate is independent of spacecraft size. Given sizing and margins, this translated to average tracking passes with two-way Doppler of 1–2 hours, which beyond general operational constraints, also limited the OD capabilities, since during long Doppler passes, the rotational motion of the Earth yields additional information on the velocity perpendicular to the Earth-line. This was mitigated to some extent by both the relative laxity of targeting requirements ($\sim$100 km), as well as the high availability of ΔDOR (Delta differential one-way ranging) measurements by leveraging scheduled opportunities for InSight. However, MarCO-B suffered from large number of small thrusting events due to leaks in the thruster system, and the available tracking data proved insufficient. Instead, due to limited tracking and significant uncertainties, the addition of telemetry data, including event logs, attitude records, and temperature/pressure records, was required for successful orbit determination. This is in contrast with most missions, where telemetry data are usually treated as ancillary, so that Navigation performance is independent of other concerns. The details of this integration and analysis is the topic of the second section of this work.

The MarCO spacecraft succeeded in their mission, successfully relaying InSight EDL data and demonstrating the viability of this class of mission. While the details of the challenges associated with these spacecraft are unlikely to directly apply to future missions, greater flexibility in using and integrating telemetry into Navigation processes will be important due to a cubesat's limited nature.

Thruster Calibrations Using Reaction Wheel Speeds

Each MarCO spacecraft performed TCMs and wheel desaturation maneuvers using a cold gas thruster system provided by Vacco. This system, with eight thrusters on the +Z face of the spacecraft had a specific impulse of approximately 40 seconds, with a propellant tank allowing up to 60 m/sec of ΔV, with 33 m/sec of that allocated to TCMs. The thrusters were arranged as shown in figure 3 with "TCM" thrusters B, C, F, and G directed along with +Z axis for translational motion, and the "ACS" (attitude control system) thrusters A, D, E, and H canted 60° off axis in the ±Y direction for attitude control. A maneuver was implemented by specifying an attitude quaternion, and commanding the thruster system to fire for a set number of millisecond-long thruster pulses, as well as a limiting total wall clock time. The maneuver would shut off after it reached either the wall clock limit or the specified number of thruster pulses. The thruster and ACS system fired the TCM thrusters with duty cycles modulated to maintain the fixed attitude, with occasional firing by the ACS thrusters to further maintain the attitude. Reaction wheels were disabled during maneuvers, with all attitude control handled by the thrusters. Note that the maneuvers began firing assuming nominal thruster performance and spacecraft moments of inertia, with the controller adapting to variations of performance. No feed-forward of controller gains was performed, and no manual updates of thruster or inertia data were performed due to the software architecture making those updates too risky given acceptable performance, so the transient attitude variations were similar for all maneuvers.

Before the first TCM, which was originally scheduled 15 days after launch for MarCO-A, it was desired to understand the in-flight performance of the system. In particular, this meant understanding the thrust level of each TCM thruster, as well as the duty cycles necessary to balance torques and maintain attitude. In order to measure this, a "thruster calibration" was performed over five days, starting three days after launch. During this calibration activity, the thrusters were fired for approximately 10 seconds at three mutually orthogonal attitudes, each of which were 55° from the Earth-line and within the low-gain antenna (LGA) antenna pattern, allowing high precision measurement of the total ΔV on the earth line. Usually for larger spacecraft, these Doppler measurements are sufficient, since the accelerometer cutoff and adaptive pointing controls mean that knowing the ΔV in the spacecraft frame is sufficient to achieve good performance. However, since the controller was not necessarily in steady-state after 10 seconds, and the mapping of ΔV to thruster seconds is dependent on the steady state duty cycles, a more detailed thruster-by-thruster analysis was needed. Note that this section focuses on MarCO-A, because the thruster problems described in the next section complicated the analysis for MarCO-B in a way that yields little improved understanding.

In order to get these thruster-by-thruster values, a novel approach was used. High-rate telemetry describing the spacecraft attitude, thruster counts, reaction wheel speeds, and spacecraft body rotation rates were collected throughout the calibration event. Data for MarCO-A's first calibration are shown in figure 4. In theory, this data could be combined in a high-fidelity simulation of the spacecraft attitude and translational motion, and run through a batch filter to estimate the thruster parameters and center of gravity. However, in practice, that kind of integrated rotational/translational filter tool is not available, and previous experience has shown that high-rate measurements are often incompatible with Doppler, due to a mismatch in scale of linearity. This mismatch in

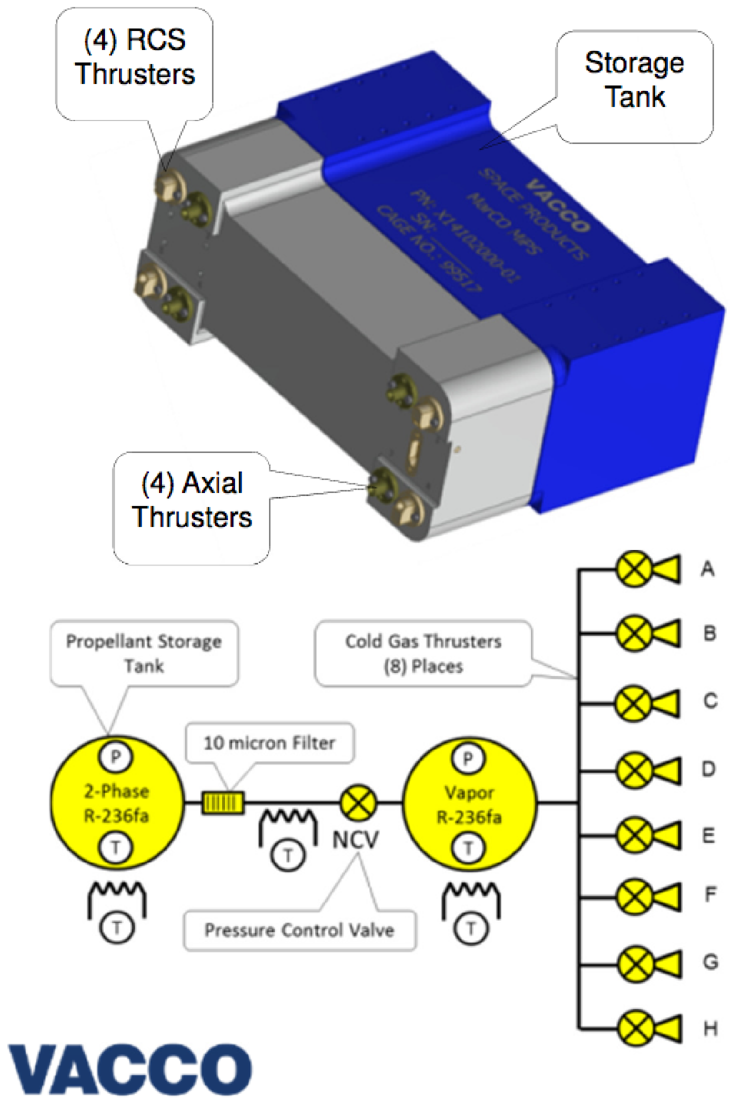

Figure 3: Thruster configuration for MarCO Spacecraft

Table 1: Estimates of MarCO-A Thruster Calibration Forces

Thruster	TCAL-A1 (mN) Force	1σ	TCAL-A2 (mN) Force	1σ	TCAL-A3 (mN) Force	1σ
A	24.1	2.3	45.7	8.7	24.4	9.7
B	11.4	4.0	10.2	3.3	14.7	3.1
C	26.0	3.6	27.9	3.1	21.2	2.8
D	26.4	10.0	29.2	10.0	25.4	10.0
E	22.5	2.4	16.9	8.7	29.4	9.7
F	35.2	7.3	33.7	5.3	35.7	6.1
G	45.2	6.1	52.3	5.2	34.5	5.2
H	25.4	2.7	26.1	9.9	26.1	9.9

scale was apparent in a similar but unrelated problem, using accelerometer data to estimate drag impulse sizes[5], and the solution to that problem informs this problem as well; recognizing that the total effect is what is truly interesting, the accumulated change in angular momentum proves to be just as valuable and easier to integrate with existing orbit determination filters.

Thus, in addition to the traditional Doppler measurements during this time period, shown in figure 5, the total angular momentum of the spacecraft, normalized to an inertial reference frame, was computed before and after the burn, with the difference being the total torque applied by the thrusters during that time period. In particular, restricting the start and end times to when the spacecraft was not rotating, these measurements could be made much more precise and simple to compute, since they would not depend on the noisy body rate data. Modeling the spacecraft attitude and duty cycles from telemetry data, assuming known thruster directions and locations, then the thruster force magnitude and the location of the center of gravity could be estimated as independent parameters, constrained both by accumulated torque and the observed ΔV. The thrust level was allowed to vary between each component, while the center of mass was assumed constant throughout the time period. Estimates for these components are shown in table 1. Note that the a priori uncertainty was 10 mN, so that the non-TCM thrusters were not observable, while the TCM thruster showed significant improvement compared to that a priori or Doppler-only estimates with uncertainties of approximately 7 mN (1σ).

Given these thruster values, the average was computed. These could then be converted to a ratio of ΔV to thruster seconds by assuming a simplified model of the controller. This simplified model seeks to balance the torques while achieving the maximum possible thrust, assuming a maximum possible duty cycle of 90%; this maximum value does not affect the ΔV/thruster second conversion, but does effect the expected wall clock time. Further assuming that the ACS thruster usage is minimal, the total torque at steady state should balance to zero, computed as

$$\tau = \sum (\mathbf{r}_i \times \mathbf{d}_i)\, f_i = 0 \tag{1}$$

where τ is the total torque, $\mathbf{r}_i$ and $\mathbf{d}_i$ are the known thruster location and directions for thruster i in the body frame, and f_i is the per-thruster force to be estimated. As a vector equation, this is a system with three constraints and four degrees of freedom, requiring a further constraint. This comes from the assumption of achieving maximum possible force. A practical method is to assume that two of

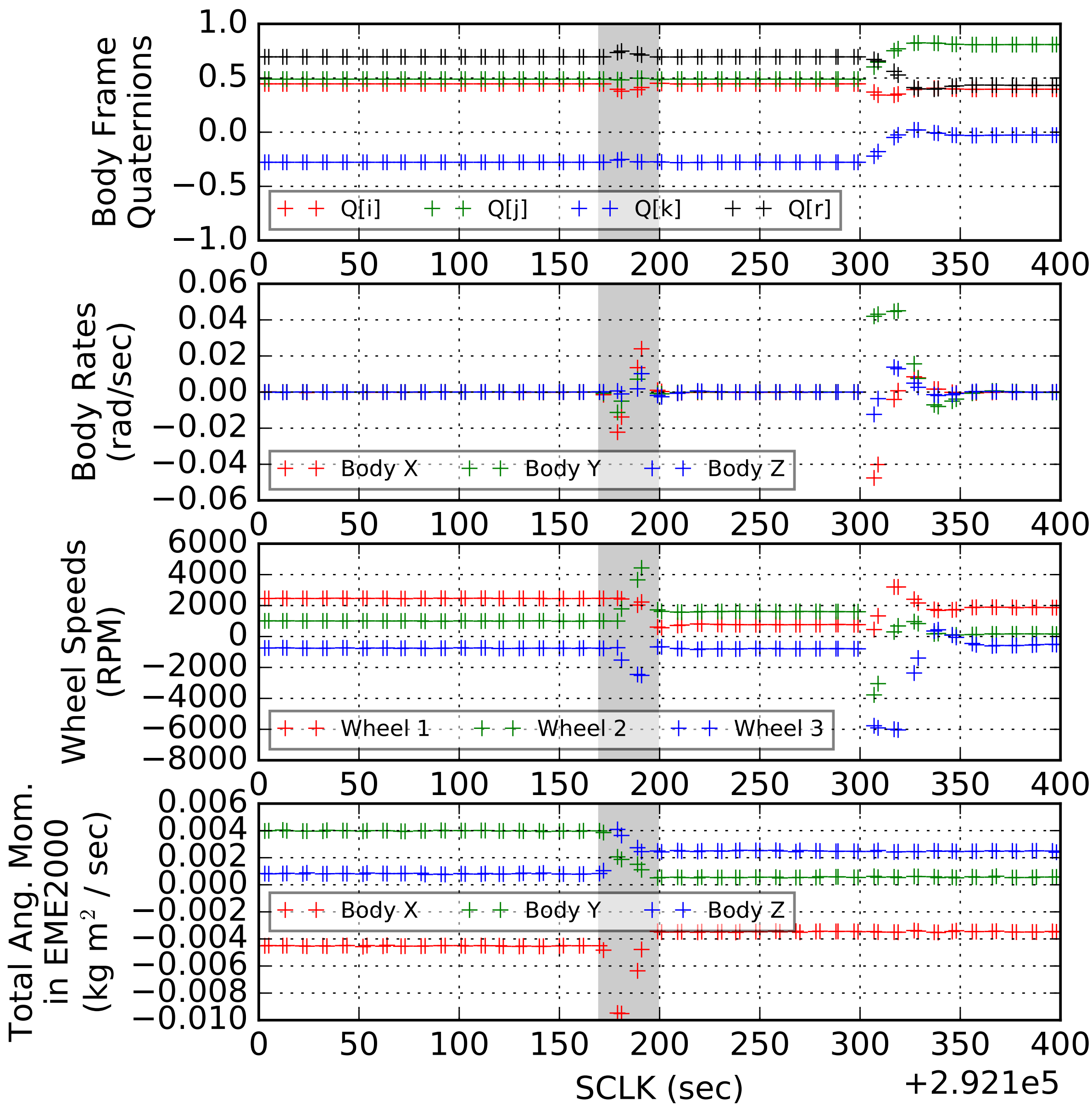

Figure 4: Telemetry from first MarCO-A Thruster Calibration

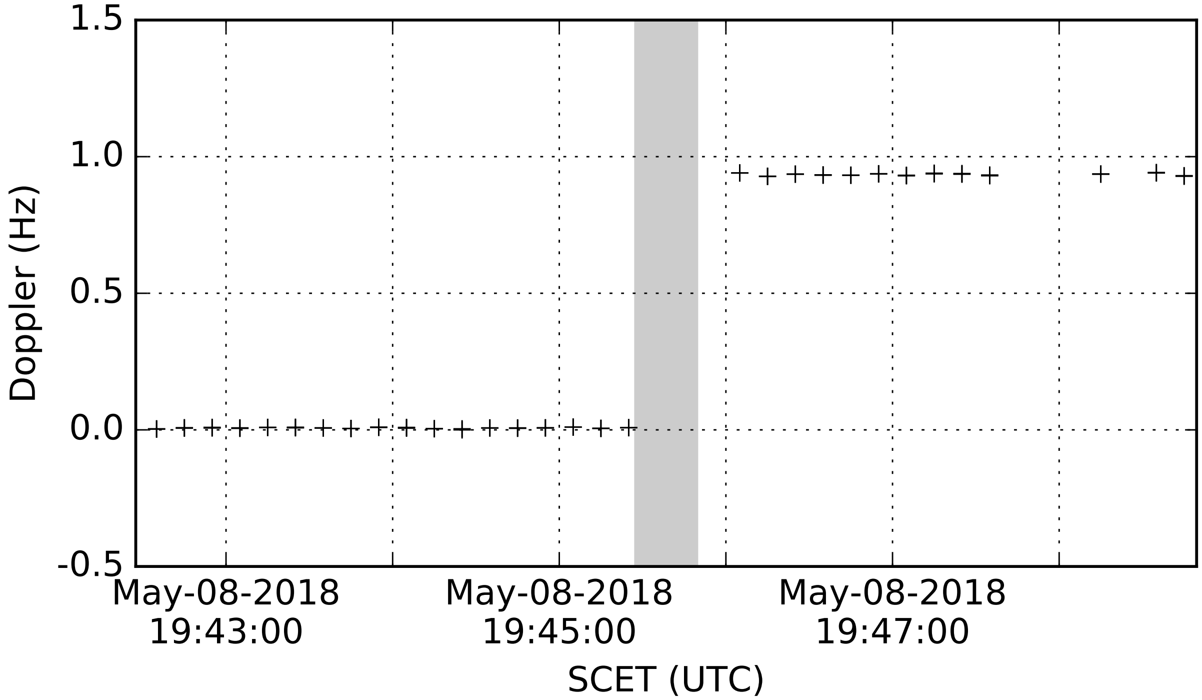

Figure 5: Doppler signature of first MarCO-A Thruster Calibration

Table 2: MarCO-A Thrust and Duty Cycle design values after Thruster Calibration

Thruster	**Force (mN)**	**Duty Cycle**
B	12	90%
C	25	90%
F	35	26.4%
G	44	50.3%

the thrusters are firing at the maximum achievable rate, and computing the necessary forces for the other two to satisfy the equation. Only one of these solutions will be viable, while the others will include duty cycles above the allowed level. For MarCO-A, thrusters B and C were assumed to run at full duty cycle, with thrusters F and G off-pulsing to maintain torque. Ultimately this led to the computed duty cycles in table 2, and a ratio of ΔV to thruster seconds of 1.99 mm/sec^2.

After the first full-length maneuver, the mapping between thruster counts and ΔV could be computed from data. The primary difference was that the use of ACS thrusters allowed thrusters F and G to be used more effectively, increasing their duty cycle. Throughout the mission, the total ΔV estimated using radiometric tracking data and the recorded thruster seconds were tracked, as shown in table 3. These could then be used to fine tune parameters to get viable maneuvers. Note however, how the last five maneuver segments saw a significant increase in the per-thruster acceleration. During the last segment of TCM-A2, a significant leak in the valve from the tank to the plenum was observed, meaning that the plenum pressure could not be appropriately regulated, leading to the larger forces apparent in this data.

Table 3: MarCO-A ΔV and Thruster Count Ratios

TCM	**ΔV (mm/sec)**	**Thruster Time (sec)**	**Ratio (mm/sec^2)**
TCAL-A1	67.4	30.01	2.247
TCAL-A2	58.9	30.07	1.959
TCAL-A3	54.6	30.03	1.817
TCM-A1x	495.3	253.68	1.953
TCM-A1a	481.2	257.13	1.871
TCM-A1b1	961.0	504.60	1.905
TCM-A1b2	914.5	504.58	1.812
TCM-A1b3	431.6	254.95	1.693
TCM-A1b4	468.6	255.39	1.835
TCM-A1b5	508.2	254.76	1.995
TCM-A1c1	477.2	256.20	1.863
TCM-A1c2	502.3	254.64	1.973
TCM-A1c3	532.0	256.31	2.076
TCM-A1c4	548.9	255.32	2.150
TCM-A1d1	1926.1	972.22	1.981
TCM-A1d2	340.5	194.41	1.752
TCM-A1d3	178.4	90.65	1.968
TCM-A1e	269.8	147.41	1.831
TCM-A2a	247.7	130.30	1.901
TCM-A2b	266.7	130.27	2.047
TCM-A2c	295.7	80.50	3.673
TCM-A3a	215.3	55.77	3.861
TCM-A3b	215.3	51.36	4.192
TCM-A3c	242.2	51.70	4.684
TCM-A3d	242.2	61.74	3.922

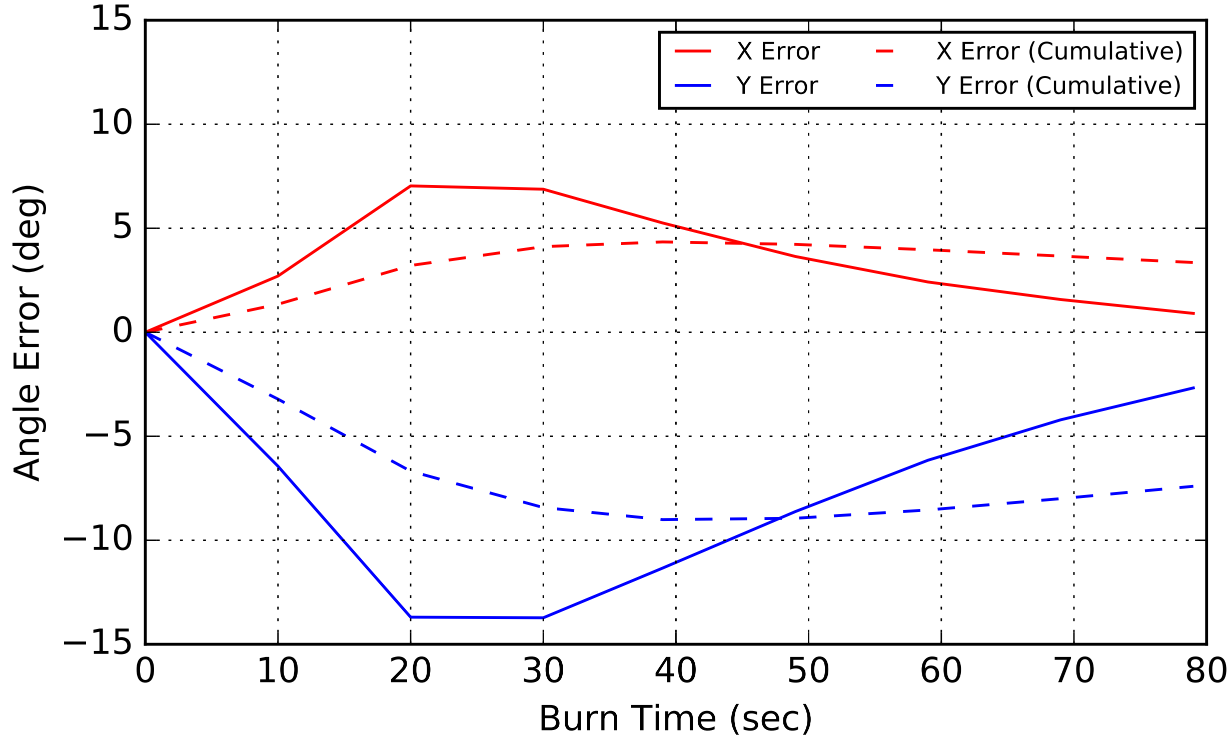

Figure 6: Burn attitude offsets for sample MarCO-A TCM

Additionally, the pointing errors of the maneuvers were computed. The off-pointing in the spacecraft X and Y directions, shown in figure 6 showed a significant "nod" in the +Y direction that reached a maximum of 15° and averaged to a 7° bias during a typical 75 second burn[1]. During the initial maneuvers, these errors were not included in the design, but later maneuvers included offsets in the design quaternions so that the "true" pointing would be in the desired direction. Note that because it was a large time-dependent variation, shorter burns had to include larger offsets. These pointing errors stayed consistent to within 1° for the mission, and between both spacecraft.

Blowdown and leak force estimation

The MarCO-B spacecraft was launched with a known leak in the pressure control valve between the propellant tank and the thruster plenum, and the level of this leak could change after actuating that valve. What would have been a minor issue became more significant due to a second leak that occurred in thruster D, an ACS thruster canted to allow significant torques on the spacecraft. Either leak in isolation would have been simple to deal with, but the combination meant that there was a constant thrust with a significant lever arm, and thus significant torque, being applied to the spacecraft, mostly about the body X axis. This problem became apparent after the first

[1]This level of off-pointing also triggered a fault protection mode that limited individual burn events to 78 seconds

thruster calibration for MarCO-B was attempted, on 15 May 2018. In order to minimize angular momentum accumulation due to solar pressure on the solar panels and high gain antennae, while maintaining power collection, the spacecraft spent most time in “solar rotisserie” mode, pointing the +Y axis towards the sun and rotating about that sun line with a 15 minute period. In theory, this rotation would cause the torques to largely cancel out, but when the plenum pressure became too high, the thruster torque could saturate the reaction wheels before completing a rotation, leading to a desaturation burn, or a shut down of the ACS system, causing tumbling and a thruster-based despin.

In order to mitigate the possibility of these “wild rides”, a sequence of slow blowdowns, or SBLO events were commanded to occur every 45 minutes. These events involved slewing the spacecraft to a team-selected attitude, and opening the four TCM thrusters to release all the gas in the plenum that had accumulated since the last SBLO in a controlled direction and with minimal induced torques. Thus, while the SBLOs would incur some translational accelerations, the cycles of desaturation maneuvers and ACS loss of control could be avoided. However, while these SBLOs proved mostly effective[2] at maintaining spacecraft health and attitude, they did make the job of navigation more challenging. With limited tracking, slow dynamics, and ground system that was not prepared to communicate the implementation of these ad hoc solutions, estimating many small impulses proved difficult, with far more degrees of freedom to estimate than could be constrained with the given observables.

The typical velocity change for each SBLO would be ~0.1 mm/sec in a “low” leak regime, ~1 mm/sec in a “medium” leak regime, and ~5 mm/sec in a “high” leak regime. The cumulative effect of these on the trajectory, particularly in the earliest days of the mission after the leak first occurred, when the high leak rate dominated, was strong and needed to be included in the OD modeling. In addition, the continuous leak out of thruster D needed to be estimated as well. Initial efforts attempted to reconstruct these forces through the use of two continuous accelerations. The slow leak was estimated as a force in the sun direction with weekly variations. The SBLOs were modeled as continuous accelerations as well, with the understanding that jumps in the Doppler would occur when an SBLO occurred in pass, but that a good fit would achieve an average residual of zero even with significant slopes and jumps within those residuals, as shown in figure 7. These continuous accelerations would need to change direction over different time periods, accounting for the different force levels and commanded attitudes seen during and between Doppler passes. This approach proved problematic in three ways. First, it was difficult to know the correct a priori values for the accelerations, leading to low confidence and wide variations in the resulting solutions. Second, there were a large number of estimable variables with wide a priori uncertainties, and not enough data to fit them appropriately. Finally, the process of setting up these accelerations was also tedious and prone to error, making OD solutions difficult to produce given the low available staffing.

An alternative approach was required to find a priori values and understand the forces. Up to that point, only radiometric tracking data were used, as is typical for navigation to prevent reliance on data that may not always be available. However, given the nature of the challenge, it became more necessary to utilize all available information, including telemetry. First, all the available telemetry was explored to determine what information was available and useful. Pressure data and wheel

[2]A few momentum desaturation cycles were triggered by high leak rates following maneuvers

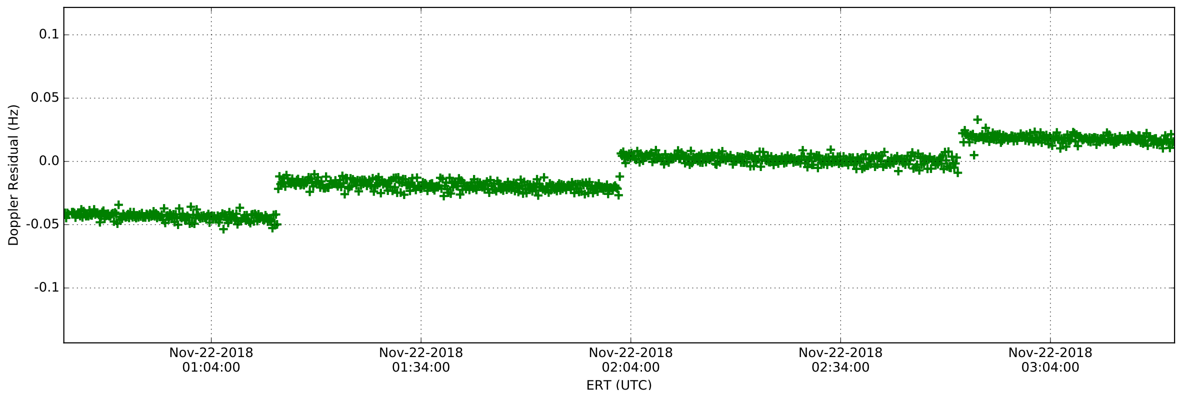

Figure 7: Signature of uncorrected MarCO-B SBLO in Doppler

speeds, in a technique similar to that used for thruster calibrations, were first used to determine the force of the leaking thruster. Estimating SBLOs took a different approach. Records of each SBLO were stored in event records (EVRs), which could then be combined with reconstructed quaternions and temperature and pressure data to get approximate a priori ΔV vecors, for which small corrections could be estimated rather than the large corrections in the telemetry-free case.

The estimation of the leak rate relied on the accumulation of momentum, as measured by wheel speeds rotated into an inertial frame, in the rotisserie mode period between each SBLO. This is a fraction of the total torque applied by the thruster, since a majority of the torque was perpendicular to the rotation vector. However, with knowledge of the reconstructed quaternions, the start and end pressure, and an assumption of linear pressure buildup (since pressure data were not recorded throughout), the total accumulated torque in EME2000 as a function of a single parameter, the area of the leaking area could be computed as

$$\Delta\ell = \sum_i C_i \left(\mathbf{r}_4 \times \mathbf{d}_4\right) \left(P_0 + \frac{P_f - P_0}{t_f - t_0}(t_i - t_0)\right) A \tag{2}$$

where C_i is the rotation matrix at time i, P_0 and P_f are the pressures at times t_0 and t_f, t_i is the time of each measurement, and A is the estimable leak area. Solving for A across a large number of measurements produced an estimate of a 0.015 mm diameter leaking area, for an approximate force of 2 μN at the higher leak rate. Ultimately this yielded an a priori acceleration in the sun direction of 0.1 to 1.0 μN, which was then used to appropriately constrain the orbit determination solution and achieve reasonable and consistent orbit determination results. This analysis was not explicitly performed after the initial analysis, since the approximate acceleration was sufficient to get reliable results from that point forward.

Developing better solutions for the SBLO impulses began by finding the correct times for the events. The spacecraft downlinks event records that specify the spacecraft clock (SCLK) time of the events. Because this clock could be unreliable, it was correlated with SBLOs that occurred during Doppler passes, and thus could be known to occur within a few seconds of a given Earth receive time, and with the known light time, correlated with a well known spacecraft event time (SCET) in UTC. The downlinked telemetry also regularly included reconstructed attitude quaternions, giving the direction of the force at each SBLO. Finally, the magnitude could be computed by observing the temperature and pressure of the plenum before and after an SBLO. Given that the plenum has a known fixed volume, the mass of gas in the plenum could be computed using the ideal gas law

$$PV = \frac{m}{M}T \tag{3}$$

where P is pressure, V is volume, m is mass, T is temperature, and M is the molar mass of the propellant. Then, assuming a known exit velocity (i.e. specific impulse, I_{sp}) and spacecraft mass ($m_{s/c}$), then the ΔV could be computed from telemetry as

$$\Delta V = \left(\frac{P_2}{T_2} - \frac{P_1}{T_1}\right)\frac{V}{M}\frac{gI_{sp}}{m_{s/c}}. \tag{4}$$

This ignores the effects of the plenum refilling during the SBLO, but this rate was assumed to be small, and also depended on assumptions of spacecraft mass and specific impulse. However, all of these values are known to well within 10%, so that the associated uncertainties would be much smaller than the original telemetry-free estimates. These were then modeled in the trajectory, and estimated with a ±10% (1σ) uncertainty in magnitude, and small (0.1 mm/sec) off-axis terms in daily batches to account for variations.

However, this dependency on telemetry was problematic when that telemetry was not reliably retrieved. It should be noted that three components (event records, attitude, and pressure data) were independent and any of them might be missing. Event records could be interpolated between known points; if a gap longer than the known time period was observed, fake records would be generated and SBLO entries for use in the filter would be added. Because the attitude was commanded, when reconstructed data was unavailable, the commanded attitude could be assumed from other telemetry points recording those commands. However, this was haphazard due the ambiguities of how attitudes were defined in software, so it was preferable to retrieve the true reconstructed attitude where possible. Finally, if the pressure data were not available, then the ΔV was assumed to be within reasonable limits, with a nominal of 0.5 mm/sec and with large uncertainties of ±0.5 mm/sec (1σ), boundaries which would reasonably include all observed values. In these cases the estimate could become negative, which was indicative of a poor fit and could be corrected.

In order to overcome the problems of limited telemetry availability, the spacecraft team began placing a higher priority on this data, saving the quaternions and pressure data in the seconds before and after an SBLO as part of the "beacon" data that gets recorded automatically and downlinked at high priority. Once this change occurred the data were usually available quickly. Often though, the EVRs indicating an SBLO were the least likely to be available; previously, EVRs were more likely to exist than pressure records, so the approximate interpolation described previously was sufficient. Instead, on board sequence delays meant that it was common for interpolated SBLO time to drift by minutes from the actual times, so that unreasonably small pressure drops were observed, and incorrect a priori values were included in the simulation. As a response, the EVR time interpolation was updated to look for sharp drops in the pressure data, and infer that these were the true SBLO SCLK values when EVRs where unavailable.

Once these data were included in the orbit determination solution, the results were much more consistent arc to arc, and predicted the future trajectory significantly better. It was also a straight-forward approach; when telemetry were downloaded, processing and inclusion in the OD filter

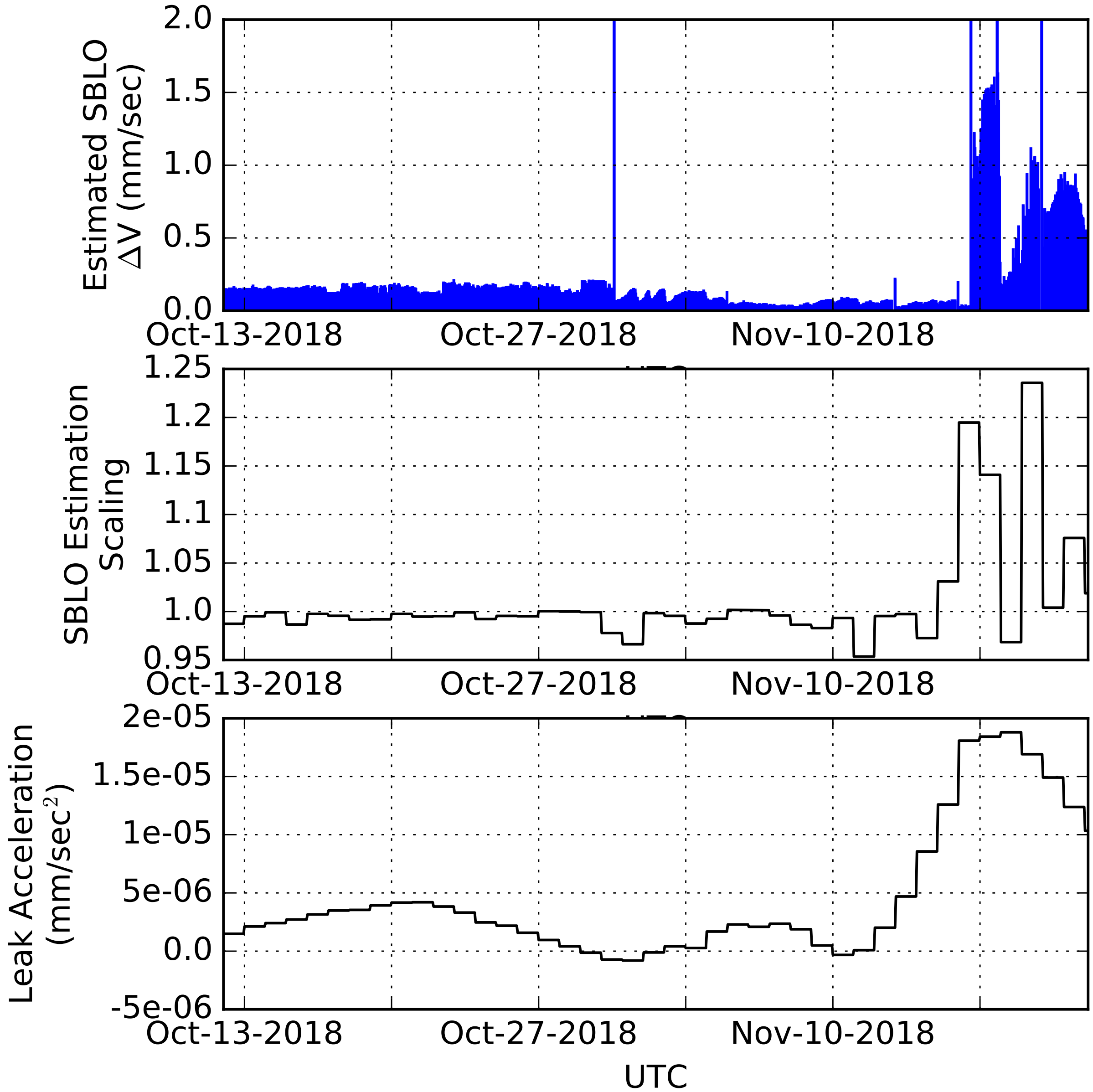

Figure 8: Estimated MarCO-B SBLO and leak parameters

could be done automatically, with only significant manual interventions being required to revise the SCLK/SCET offsets by correlating observed Doppler shifts with recorded SCLK times. Figure 8 shows the estimates of the forces. The first chart shows the SBLO ΔV for a period in late cruise in the body fixed frame. The second chart shows how they are scaled from the a priori values, demonstrating that the ideal gas approximation was quite good, with the largest variations occurring at higher pressures where some recharging of the plenum during the SBLO or liquefication in the plenum could occur. Finally, the last subchart shows the estimated leak acceleration in the sun direction, which while aliased with solar radiation pressure, maintains reasonable values using this approach. Ultimately, these techniques allowed the small two-person, part-time Navigation team to perform the relay mission with precision and reasonable workloads, demonstrating the effectiveness of the approach.

Conclusion

The success of the MarCO mission depended on many things, but the ability to integrate a wide variety of telemetry points into orbit determination proved critical in ways that were not planned before launch, particularly for MarCO-B. The availability of that telemetry, the willingness of navigators to process and understand that telemetry, and the cooperation of the spacecraft team in retrieving the most critical data proved a strong substitute for the increased ground station time and larger teams of more traditional missions.

Future interplanetary cubesat missions are all likely to share some of these characteristics, including small teams, limited radio time, informal ground system tools, and experimental payloads/systems. They also are less likely to benefit from the generous ΔDOR schedule the MarCO spacecraft enjoyed due to their proximity to InSight. With these systems, operations teams should be prepared for unexpected problems, and without the aid of large teams and the option of increased radio time, understanding and using all available data can be a powerful mitigation. Given this, it is highly recommended that navigators for small experimental missions familiarize themselves with the available telemetry, and cultivate relationships to make the best use of that data.

Acknowledgments

This work was carried out at the Jet Propulsion Laboratory, California Institute Technology, under a contract with the National Aeronautics and Space Administration.

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