Autonomous Aerobraking for Mars Orbiters.

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Introduction: Two identified challenges of the Concepts and Approaches for Mars Exploration workshop are the concept for low-cost aeroassist technologies and analyses of trajectories that provide significant efficiencies. One identified cost-reducing technology is autonomous aerobraking [1]. NASA uses aerobraking to reduce the fuel required to deliver an orbiter into its desired final orbit around a target planet or moon that has a significant atmosphere. Instead of using the propulsion system to decelerate the spacecraft, aerobraking decelerates the spacecraft using aerodynamic drag. While flying through the upper atmosphere of the planet or moon multiple times, the spacecraft maintains a periapsis control corridor such that dynamic pressure and thermal loads remain within its design parameters. Aerobraking has been used 4 times by NASA, once at Venus and 3 times at Mars.

Although aerobraking reduces the propellant required to reach the final orbit, this reduction comes at the expense of time (typically 3–6 months), continuous Deep Space Network (DSN) coverage, and a large ground staff. The DSN and ground staff are required to design the maneuvers the spacecraft executes during aerobraking to keep the spacecraft safe and to provide the desired final orbit. The combination of extended time, staff, and continuous DSN coverage results in aerobraking being an expensive operational phase of a mission.

As aerobraking has evolved, the operations have matured to the point where it is believed that many of the operational decisions currently being made by the ground staff can now be made autonomously onboard the spacecraft[2-5]. With the development of autonomous aerobraking, much of the daily operations could be moved to the spacecraft, thus reducing the cost of the aerobraking phase. In addition, because the spacecraft would no longer be tied to the work schedule of the ground (e.g., only perform maneuvers during prime shift and minimize maneuvers during weekends and holidays), autonomous aerobraking also has the potential to reduce risk, as the maneuver could be conducted at the optimal time and executed even if DSN or other required ground elements were unavailable.

The NASA Engineering and Safety Center (NESC) has been supporting the development of Autonomous Aerobraking through its initial phases. In this effort, NASA Langley Research Center, Johns Hopkins University Applied Physics Laboratory, and Jet Propulsion Laboratory have partnered with Phase 1 support from NASA Marshall Space Flight Center, NASA Johnson Space Center, National Institute of Aerospace, and Kinetx, Inc to produce Autonomous Aerobraking Development Software (AADS) that will significantly reduce the cost of a Mars orbiter.[6-9]

Autonomous Aerobraking Development: Aerobraking mission operations involve many activities. These can be broken down into three categories: special, daily, and weekly. The special category consists of walk-in, where the initial atmospheric density characterization is done; end game, where aerobraking is terminated; and contingencies. The daily activities are performed to maintain the spacecraft within the corridor (e.g., upper and lower heat-rate limits, dynamic pressure, or temperature) that was determined by the previous weekly meeting. autonomous aerobraking will replace the ground-based daily activities with onboard processes. Phase 1 was completed in December 2011. It supported model development and preliminary testing of the AADS. AADS incorporates 1) an Ephemeris Estimator, 2) atmospheric density modeling, 3) thermal modeling of the critical elements of the spacecraft, and 4) maneuver strategy. The Ephemeris Estimator will use onboard resources to calculate the current spacecraft orbit after each atmospheric pass. This estimate will be used to determine the next time of periapsis passage, which is the basis for all the aerobraking pass sequences.

The weekly activities, using autonomous aerobraking, will include an evaluation and potential update of the onboard thermal model and atmospheric density estimators. The current weekly aerobraking activities, such as designing the corridor for the next week and setting the criteria for the spacecraft to perform a pop-up maneuver, will remain ground-based even while the spacecraft is using autonomous aerobraking.

The total NESC assessment to provide autonomous aerobraking capability involves four phases. The first phase of this study investigated the technical capability of transferring the processes of aerobraking maneuver decision making (currently performed on the ground through the DSN and an extensive workforce) to an efficient flight software algorithm onboard the spacecraft. Products of Phase 1 included several models and algorithms that were integrated within AADS. An Ephemeris Estimator was developed that used an efficient, easily implemented Runge-Kutta integration scheme, a high order gravity field model, third body gravitational effects, and provided the required accuracy for 7 days. An atmospheric estimator was demonstrated that used traditional atmospheric estimation algorithms that provided periapsis density and density scale height estimates that were adequate for corridor maintenance maneuver calculations. A thermal response algorithm was generated that predicted the maximum temperature of the spacecraft given the periapsis density from the Atmosphere Estimator. The entire system was embedded into two high fidelity simulations that used detailed models of flight subsystems and have vast heritage as simulation tools.

Results of the Phase 1 simulation analysis showed that it is feasible for AADS to provide autonomous aerobraking control of a spacecraft with ephemeris updates less than once per week at all three sampled destinations: Mars, Venus, and Titan. These results have been demonstrated in the presence of atmospheric perturbations and sensor (e.g., inertial measurement unit (IMU)) measurement errors. Longer intervals between ground updates may be possible, as a 14-day ground update interval with atmospheric perturbations at Mars, Venus, and Titan has been demonstrated. This 7-day update cycle meets the goal set for AADS and could significantly reduce the DSN and ground staffing requirements.

Phase 2 is a 12-month phase (January-December 2012) in which rigorous testing of AADS that was developed in Phase 1 is being performed. Models that were developed in Phase 1 will be improved upon with error checking added and uncertainties modeled. Flexibility is added to the functionality of AADS in determining the proper maneuver to execute. Trade studies are being assessed with the Ephemeris Estimator and introducing the option of using AutoNAV, a JPL onboard orbit determination tool that incorporates functionality not currently modeled in AADS such as fault tolerances, orbit safing approaches, and sequence timing information. In addition, additional testing using statistical Monte Carlo approaches and error uncertainties are being performed to more accurately measure the operability of using autonomous aerobraking in a perturbed environment.

It is anticipated that Phase 3 will incorporate all the software required for autonomous aerobraking onto a flight-like processor to determine autonomous aerobraking's computational requirements.

In Phase 4, the autonomous aerobraking software will be installed onto a spacecraft that will use aerobraking, and then autonomous aerobraking will operate during flight in a shadow-mode, where all the steps for autonomous aerobraking are performed, but the commands are not executed. The onboard-determined commands will be compared to the ground decisions.

The ultimate goal of this autonomous aerobraking technology development is to reduce the cost of exploring the solar system using orbiters. Continuing with the current development schedule for autonomous aerobraking, implementation is possible for a Mars orbiter launched in 2018.

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