**AEROCAPTURE GUIDANCE ALGORITHM DEVELOPMENT AND TESTING.**
J. P. Masciarelli[1], [1]Ball Aerospace & Technologies Corp., 1600 Commerce St, Boulder, CO 80301.

**Introduction:** Aerocapture is an orbit insertion maneuver in which a spacecraft flies through a planetary atmosphere one time using drag force to decelerate and effect a hyperbolic to elliptical orbit change. This is in contrast to the related technique of multi-pass aerobraking which uses drag to circularize the orbit of an already captured spacecraft. Aerocapture employs a feedback Guidance, Navigation, and Control (GN&C) system to deliver the spacecraft into a precise post-atmospheric orbit despite the uncertainties inherent in planetary atmosphere knowledge, entry targeting and aerodynamic predictions. Only small amounts of propellant are required for attitude control and orbit adjustments, thereby providing mass savings of hundreds to thousands of kilograms over conventional all-propulsive techniques.

A key element required for aerocapture is the GN&C system that steers the vehicle through the atmosphere and delivers it into a precise orbit. Through funding provided by NASA's In-Space Propulsion Technology Program, we have demonstrated operation of and aerocapture GN&C system in high-fidelity simulations that include real-time hardware in the loop, thus increasing the Technology Readiness Level (TRL) of aerocapture GN&C. Although some components required for an aerocapture GN&C system have been used in previous space missions, an aerocapture guidance algorithm and true aerocapture maneuver not been demonstrated. The primary focus of this effort was therefore to implement the aerocapture GN&C system in flightworthy software and validate the aerocapture guidance algorithm through hardware-in-the-loop simulations to increase the TRL of the system.

**Algorithm Description:** The Analytic Predictor Corrector (APC) guidance algorithm has been developed to steer the vehicle through the aerocapture maneuver using bank angle control. The algorithm is derived from that developed for the Aeroassist Flight Experiment (AFE) program circa 1989 and has been refined through several aerocapture systems analysis studies for aerocapture at Mars, Titan, Neptune, Venus, and Earth. These efforts have resulted in a mature, flexible, and robust algorithm that is independent of vehicle and mission design parameters, tolerates dispersions and uncertainties in atmosphere density, vehicle mass, aerodynamics, and delivery and knowledge errors. The APC algorithm has shown excellent performance in ground-based simulations of missions to Earth, Titan, Mars, Venus, and Neptune. Three sigma (99.87%) success rates or better have been shown for all destinations using conservative models for atmospheric density profile uncertainty, approach navigation errors, and vehicle aerodynamic property uncertainties. Ball Aerospace has leveraged the prior work, along with our existing flight software development and test benches from other programs, to further mature this aerocapture technology.

**High Fidelity Non-Real Time Simulations:** First, a non-real-time, 6-DOF trajectory simulation was developed for the aerocapture trajectory. The simulation included vehicle dynamics, gravity model, atmosphere model, aerodynamics model, inertial measurement unit (IMU) model, attitude control thruster torque models, and GN&C algorithms (including the APC aerocapture guidance). The simulation used the vehicle and mission parameters from the ST-9 mission. A 2000 case Monte Carlo simulation was performed and results meet the following aerocapture flight performance requirements:

- Aerocapture success rate of 99.7% or higher
- Targeting accuracy (3-sigma) shows that 95% or more of total delta-V required for orbit insertion is provided by aerodynamic drag
- Post-aerocapture orbit plane wedge angle error is less than or equal to 0.5 deg (3-sigma)

**Flight Software and Real-Time Simulation:** Next, a real-time, 6-DOF simulation for the aerocapture trajectory was also developed which included hardware representative of that which could be used on a robotic class interplanetary spacecraft (see Fig. 1). The simulation has demonstrated the guidance software executing on a flight-like computer, interfacing with a simulated IMU and simulated thrusters, with vehicle dynamics provided by an external simulator. Five cases from the non-real-time Monte Carlo simulation, which were the worst cases, were run in the real time simulation environment. The results compare well to those of the non-real-time simulation environment thus verifying the real-time simulation configuration.

**Conclusions:** The results of the above described simulations show the aerocapture maneuver using the APC algorithm can be accomplished reliably and the algorithm is now at TRL-6. With a flightworthy software implementation of the guidance algorithm now completed and tested, this technology is readily available for use in future Mars orbiter missions.

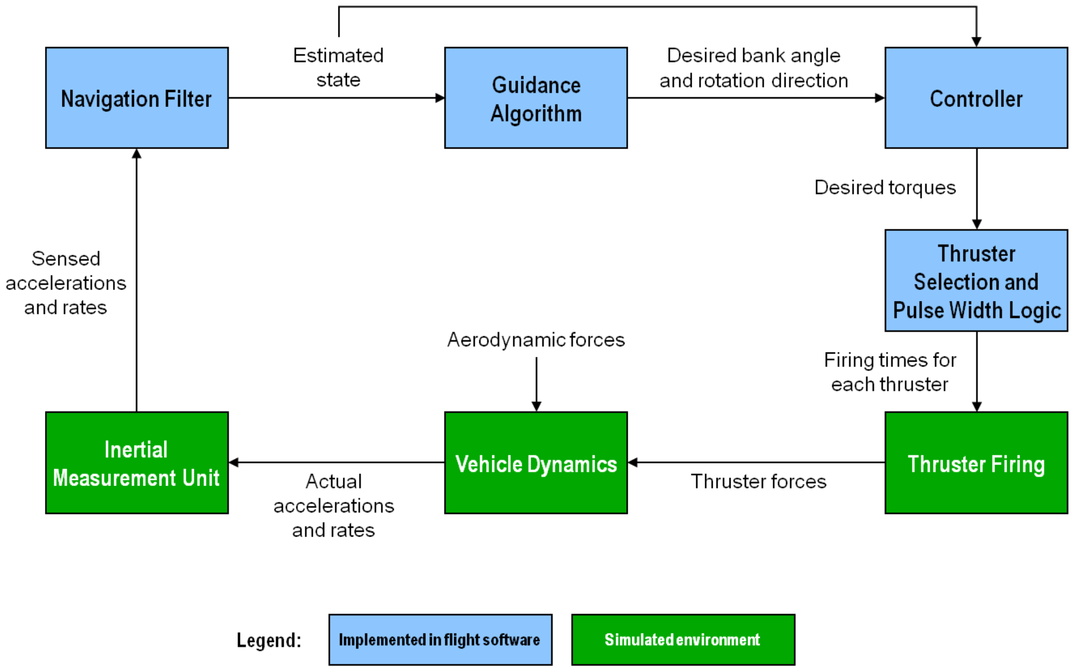


Figure 1. Flightworthy aerocapture GN&C software has been developed and tested in real-time, hardware in the loop simulations.