Spacex's Intentions on Landing Humans on Mars in 2022

Mars Transfer

In 2022, SpaceX intends to land humans on Mars using its new rocket, BFR, and interplanetary spaceship, BFS. In order to prepare for this mission, an unmanned BFS will fly to Mars in 2020, validating life support, EDL, and in-situ propellant production systems critical to the success of the 2022 manned mission.

In order to simulate a worst-case life support requirement, BFS will be launched on a longer transfer duration trajectory than a typical manned BFS mission. This longer trajectory, in addition to ensuring BFS can withstand a longer than expected period of interplanetary flight, will also reduce delta-V requirements, allowing more fuel to be saved for Mars EDL. Increasing fuel margins for EDL help ensure experiments critical to the 2022 manned mission, like the Sabatier reactor that will produce liquid methane fuel for BFS's return to Earth, will reach the surface safely.

To determine an optimal launch date in the 2020 transfer window, departures beginning April 1, 2020 and extending until [date] and arrivals beginning September 28, 2020 and ending [date] were consider. Additionally, trajectories were constrained to require no more than 500 and no less than 45 days of transfer time between Earth and Mars.

From the resulting porkchop plot, shown in Figure 1, a nominal human mission in the 2020 window would depart 100 days after April 1, on July 10, 2020, and arrive at Mars 90 days after September 28, on December 27, 2020. These dates were selected to give a nominal time of flight of 170 days while minimizing delta-V required for the interplanetary transfer.

For the 2020 test launch, this trajectory will be modified to arrive instead 120 days after the beginning of the transfer window, on January 26, 2021. The launch date of July 10, 2020 will not be changed from the nominal manned trajectory. This transfer will result in a hyperbolic excess velocity of 2.9012 km/s and a C3 of 13.7455 km2/s2. The time of flight for this trajectory will be 200 days, which will allow verification of life support systems at an acceptable margin above a nominal trajectory. Table 1 shows these values as compared to those of a nominal manned flight in 2020. Lambert's solver returns a tm of 1 for both the nominal manned and unmanned test trajectories, indicating that both are short-way transfers.

J2 Perturbation

J2 perturbation is caused by the asphericity of the Earth. The Earth, as with most rotating bodies, has a bulge around its equator which creates gravitational effects on satellites in orbit. This effect manifests in a gradual shift of the longitude of the ascending node and argument of periapsis of an orbit. This is shown in the attached Matlab graphs, where the longitude of the ascending node of orbit A1 can be seen to linearly decrease over the course of four days. This is different than a two-body assumption, where the longitude of the ascending node would remain constant over time.

The rates of change of both the longitude of the ascending node and the argument of periapsis vary depending on other orbital elements. The graphs of both rates of change show that the rate of apsidal and nodal regression approach zero as inclination approaches 90°. This is clear in the graph of nodal regression but is obscured in the apsidal rotation graph by a spike. Orbits B3, B4, and B5 cross 0° argument of periapsis as a result of their orbital perturbations – this causes their rates of apsidal rotation to jump by ±90°/day (a 360° change divided by four days). In the same way, the B1 orbit crosses 0° longitude of ascending node in the nodal regression graph, creating a 90° spike.

J2 perturbation is important to consider for any satellite that needs to keep a precise orbit for a long period of time. Satellites will need to use station-keeping fuel to reposition themselves to counteract the effects of J2 perturbations. This will limit the satellite's lifetime, as station-keeping fuel will eventually run out. In addition, station-keeping maneuvers need to be considered in the satellite's delta-V budget, to ensure that it can reach its operational orbit and still have enough fuel for station-keeping for the satellite's desired lifetime.

We use the two-body assumption in class because it allows us to avoid modelling the asphericity of the Earth. This allows us to consider the Earth's gravity as a constant force acting between the center of mass of our spacecraft and the center of the Earth. While considering the J2 perturbation yields more accurate orbital predictions, it will also require modelling of the Earth's gravity will make problems much more difficult to evaluate by hand.