Summary of VagaLune Orbit

Due to the payload requirements imposed by the Falcon 1e rocket, the VagaLune Project will use an unconventional orbital maneuver to insert the LM into lunar orbit. Historically, lunar missions performed a Hohmann Transfer Orbit (HTO). A HTO provides quick transport from earth orbit into a lunar orbit, via the use of a large orbital transfer rocket. The craft is launched into a Geostationary Transfer Orbit (GTO), then a large thruster is fired propelling the craft towards the moon. While the HTO has worked well in the past, there are several drawbacks to its application in the VagaLune Project. First, the weight associated with the thruster rocket is beyond what the Falcon 1e can carry into orbit. Typically a HTO requires an additional rocket stage attached to the payload to perform the maneuver. NASA's previous lunar explorer mission used an ATK Thikol Star-37 Series Rocket, which with fuel weighs 1147kg. While this is within the payload of heavy lift rockets, it exceeds the total capacity of the Falcon 1e. Beyond the weight issue, the HTO orbit requires precision in the launch, there is only a brief time period every day where the rocket can launch and properly enter the transit corridor to the moon. The last drawback is when the craft approaches the moon, it must fire its thrusters to enter lunar orbit. The HTO maneuver emparts a great deal of momentum to the craft, and if it does not properly fire its rockets to slow down it will not be captured by the moons gravity and be lost to space.

The VagaLune project will incorporate an alternative orbit that does not require a large thruster rocket to propel the spacecraft from earth orbit. In the 1980's Dr. Edward Bellbruno, a mathematician at JPL theorized that it was possible to maneuver a spacecraft between two planetary bodies without the use of a HTO maneuver. His theory rested on the interference of the gravitational forces between 2 bodies. Where the HTO would use brute force to escape the gravity of a particular body, this maneuver would gradually spiral out until the space craft was free. If correctly maneuvered, the craft could enter a region of space called the Weak Stability Boundary (WSB). The WSB is similar in nature to known gradational interference points called Lagrangians. The Lagrangian Points are locations in space between two bodies where the gravitational forces from both bodies counteract. An object in a Lagrangain point will stay fixed in the position indefinitely because the gravitational forces of the two bodies provide equal and opposite forces. The WSB is different for several reasons; the gravitational forces do not completely counteract each other. This means that a spacecraft could maneuver through this region with small thruster maneuvers, and become captured by the gravity of the other body, and enter into orbit. The spacecraft would be launched with a minimal fuel payload and use thrusts to continually expand the orbital radius

Historically, the WSB orbit was considered a technical oddity and lacked feasible applications to space missions. Partly because heavy lift rocket technology existed to deliver large payloads into the transfer orbits, and because the increased time for the transfer made it impractical for human missions. However, with the increased interest in space exploration but with limited budgets the theories behind a WSB orbit are entering the technical spotlight. The first application of the WSB orbit was on the

Japanese Aerospace Exploration Agency (JAXA) Hiten. The mission consisted of two probes, a larger probe that would remain in Earth orbit and serve as a communication relay, and a smaller probe which would expend its fuel and use an HTO to reach the moon. However, after launch the smaller probe failed to communicate, JAXA wanted to reclaim the mission, but the Hiten probe did not have the required fuel to perform an HTO maneuver. JAXA contacted JPL and using Dr. Bellbruno's work a solution was developed to move the Hiten probe from earth to lunar orbit. The probes orbit would move from a stable to an unstable orbit, the probe would begin to continuously expand its orbital radius. This change in orbit would be made every time the spacecraft approached Earth; the orbital characteristics would change to force the spacecraft farther away from Earth on each orbital pass. Eventually the spacecraft would reach a point where its orbit would extend beyond the orbit of the Moon, and begin to fall back towards earth. On the return, if the orbit was properly calculated, the spacecraft would approach the moon and become captured by it. This orbit is called a Ballistic Weak Stability Capture (BWSC). While the ballistic maneuvers are common in the history of space flight, they have some drawbacks for earth moon transfers. First, the spacecraft must extend beyond the orbit of the body it is going to. Secondly, the use of fuel must be rationed, as small thrusts are needed to change the orbit. If the spacecraft runs out of fuel it cannot be recovered.

The ideal application of a WSB assisted orbit would be to keep the spacecraft within the orbit of the target body. However, this maneuver would require either a constant low amount of force, or multiple impulses. The use of multiple impulses would negate the benefit due to the increased fuel requirements. Only recently, has a viable constant force space propulsion system been available. The Ion drive utilizes electromagnetic fields and Xenon gas to produce propulsion. Specifically, the Xenon gas is forced through electromagnetic fields generated in the propulsion unit and the gas is ionized. When the gas is ionized it exits the engine providing thrust. The beauty of the ion drive is that in the drag free environment of space, the small amount of continual thrust can gradually increase the velocity of the spacecraft over time. The ion drive will require some amount of Xenon gas as a propellant, and a constant supply of electricity. Advancements in solar power can provide the required electrical power. Typical Xenon payloads are 70-80kg for a lunar mission. The ion drive has been successfully tested on NASA JPL Deep Space One, and the European Space Agency SMART-1 lunar probe.

The SMART-1 Probe is an important model for the VagaLune project; the probe utilized an internal WSB transfer orbit and an ion drive to propel the spacecraft from a LEO orbit of 200km into a Lunar Orbit with an apogee of 100km. The orbital trajectory for the VagaLune project will be modeled off of the SMART-1 mission. Recent advances in orbital design software and computational algorithms can provide a quick calculation on the orbital parameters. The Hiten probe required extensive manual calculations from the lunar orbit back to the probes position in Earth orbit, and the flight path was computed. The SMART-1 Probe used a commercial piece of software, STK Astrogator, to derive the orbit. Published means exist to generate a WSB transfer orbit starting from a particular LEO with the craft ending in a Lunar orbitThe telemetry generated from the Astrogator software will be downloaded into the VagaLune probe's flight control system prior to launch.

The transfer time for the craft will be approximately one year, at which time the craft will enter into an orbit known as an EL40 orbit around the moon. The EL40 orbit is an elliptical orbit with its perigee at an altitude of 100km. The EL40 was chosen due to the minimal amount of fuel required to insert the craft into the orbit. The WSB assisted orbit can insert a craft into any lunar orbital configuration; however additional conventional rocket fuel must be used to make the insertion maneuver. The EL40 requires a very small amount of fuel to perform the capture maneuver, as the landing approach on the moon requires the use of conventional thrusters fuel conservation is at a premium. Once the craft is in lunar orbit, several system checks will be made to ensure functionality prior to the landing maneuver.

The landing maneuver for the VagaLune project will gather experience from several successful space missions. When the craft is closest to the lunar surface, conventional maneuvering thrusters on the back of the craft will fire to degrade the orbit. Essentially the craft will begin to fall towards the lunar surface. Once the craft is in this decent profile, a laser altimeter based decent control system will take over. Thrusters mounted on the bottom of the lunar module will fire to slow the descent of the craft. The thrusters will slow the descent of the craft to a point where the airbag assisted landing can succeed. The Spirit and Opportunity Mars Exploration Rovers utilized an air bag system to softly land the craft. The payload module of the LM will detach from the thruster and solar panels. Once the module has detached airbags covering the module will inflate, covering the module in large airbags. The craft will fall towards the lunar surface and bounce to a stop. The bottom of the lunar module will be heavily weighted to ensure that the craft will be upright when it comes to a stop. The bags will deflate, then panels will fall down allowing the rover to detach from the LM and drive onto the lunar surface. The rover is independent from the LM, and does not require the LM for communication or power when on the lunar surface. The landing maneuver will render the LM inoperative.