The GHOST of a Chance for SmallSat's (GH2 Orbital Space Transfer) Vehicle

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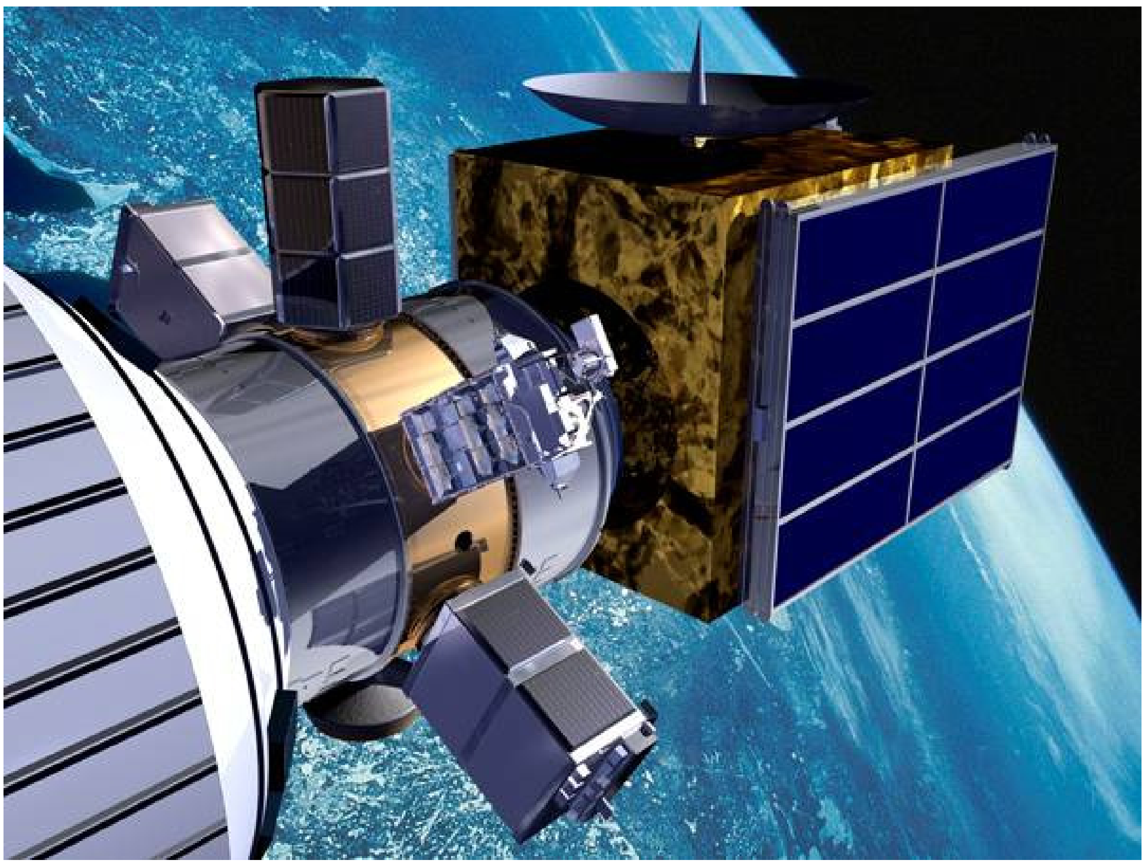

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ABSTRACT

As we enter the era of Small Satellite rideshare, the SmallSat community is faced with a difficult dilemma – the choice between a semi-dedicated launch to LEO on a growing variety of small launchers, or on a rideshare opportunity with an EELV that typically is going to GTO. Each has problems with cost, availability, schedule, weight-margins, etc. Regardless, SmallSat systems have great difficulty getting rides to desired orbits.

GHOST stands for "GH2 Orbital Spacecraft Transfer" Vehicle. This innovative solution is a SmallSat delivery system to allow the EELV to better service the SmallSat community. It is stacked as a third-stage and will provide a combination of - lowering the GTO orbit to LEO, (limited) inclination changes, and/or a constellation-spread for multiple satellites.

United launch Alliance (ULA) is working in conjunction with an industry team to develop the concept of a free-flying GHOST delivery system based upon the ESPA Ring carrier. This system advances the ULA CRYOTE (Cryogenic Test Experiment) concept, which utilizes residual cryo propellants from the EELV upper stage (launches empty to save weight), and adding advanced satellite avionics, a high ISP propulsive module, an advanced power system, and an up/down comm-link, to permit ground-based coaxing of the delivery system into the desired orbits over an extended time period. The GHOST system is intended to be very light and compact in order to reserve as much mission margin for the ESPA-class delivery payloads as possible.

1.0 SMALLSATS AND DELIVERY OPTIONS

SmallSat missions have a variety of objectives. University S/C desire LEO because of the comm. link margins. Technology S/C, focused on electronics and materials, are interested in GTO orbits to be subjected to the radiation belts. Others are not particular and just want an available ride into space. X-prize S/C have interest in going to Lunar capture and decent. And some science missions want to exit the Earth environs to rendezvous with near-Earth objects.

The difficulty with all these various missions is getting on a launch manifest for a reasonable cost. It's easy to get a dedicated ride so long as you can bear the entire launch cost. But if you want to do a rideshare option, the choices are more limited.

The smaller LEO missions can share rides, depending on weight, with Falcon, Taurus, etc. When your S/C grows to an ESPA class size of 100-200 kg or larger; again the options narrow. The EELVs fly a growing number of ESPA missions, but are typically going to GTO. Getting off the upper stage in the desired orbit can be challenging.

There are some other alternatives like the ESA Jules Verne STV but this is again an expensive dedicated mission. OMVs have been talked about in the past, but nothing has been forth coming.

ULA is proposing a unique OMV type solution called GHOST (or GH2 Orbital Space Transfer) Vehicle. And this is the subject of this paper.

SmallSat Mission/Options

- SmallSat Mission Objectives
  - Leo: Majority are university payloads (easy comm, limited life, self disposal)
  - Middle altitudes polar and equatorial: Technology Missions
  - Lunar demonstrator missions: Xprise type systems
  - Earth-crossing asteroids: Science discovery missions
- Delivery Options include (dedicated and rideshare)
  - Dedicated launcher to LEO with some rideshare cost (SpaceX, Orbital Science, etc.)
  - EELV type launcher that is going to GTO, post primary deployment (**LCROSS**)
  - EELV type launcher with rideshare and evolving LEO separation option (limited delivery)
    - STP-1 Mission 2007 - **Orbital Express** demonstration
  - Space Transfer Vhcl (STV – ESA **Jules Verne**, more capable, more complex, more cost)
  - OMV type systems (usually bi-prop solution, shorter mission duration)
    - NASA concept has been around since 1986
    - Several new entrants, several SBIR's under study
  - GHOST (rideshare using LH2 residuals, thermionic propulsion, longer mission duration)

2.0 GHOST SYSTEM OVERVIEW

The GHOST vehicle is based on the existing ESPA ring structure, see **Figure-1**. It is intended as a free-flyer, separating from the upper stage after the primary S/C has been deployed. GHOST consists of a large dewar or tank placed inside the ring, with avionics and propulsion hosted on 2 or 3 of the ESPA ports outside. The remaining ESPA ports can accommodate deliverable ESPA S/C.

Filling - The GHOST tank launches empty. It is filled on-orbit from residual LH2 from the Centaur upper stage, see **Figure - 2**. This practice saves liftoff weight and eliminates ground handling which minimizes cost. The Centaur routinely has several hundred pounds of residual propellants, depending on the specific mission. The filling of GHOST would have to be done after the Centaur has achieved its disposal orbit. Filling GHOST can be done by reverse settling thrust by the Centaur and opening the nominal LH2 tank vent path to channel the now fluid LH2 into the evacuated GHOST tank. Once the filling is complete the GHOST tank would be sealed and GHOST can be deployed off the upper stage.

CFM – Insulating the GHOST tank to preserve the LH2 is the biggest challenge. Experience from the proceeding CRYOTE (CRYO-Test Experiment) missions (see the CROTE paper in the Space '09 conference proceedings) will provide valuable engineering to optimize the Cryo-Fluid-Management (CFM) systems on GHOST. Currently this is planned as a combination of passive multi-layer insulation (MLI) blankets, composite struts, and minimal contact with "hot" structures. ULA believes that it can achieve the mission duration of 120 days.

Propulsion – the GHOST vehicle relies on mono-prop GH2 boil-off. Using either a solar electric thermal system or an ion propulsion system, GHOST can achieve very high ISP, see **Figure -3**. This is being studied by the BUSEK Corp. under contract with ULA. Combining high ISP, light weight structure, long duration and on-orbit re-targeting – GHOST can move incrementally higher (or lower) to its final destination.

Re-targeting – The value of on-orbit re-targeting is to provide for optimization of the on-board propellant by way of a spiraling trajectory. This requires an up/down communication link via two omni-directional antennas. The comm would be linked to a single ground control center for periodic updates to the GHOST flight computer.

Power - GHOST will require an anticipated 1 kw power source. This can be accomplished via a conventional deployed array system. The sysRAND Corp has an alternative system called the Gamma Battery and is under study contract by ULA. This system would provide the needed power without the cost, risk, and associated control systems for the conventional approach.

GHOST Overview

- ESPA based provides affordable space access
  - Launches empty, avoids expensive ground handling of cryogenics while reducing weight
  - On-orbit transfer of residual LH2 from upper stage into small satellite (~150 lb of LH2)
  - CFM permits long mission durations of up to 120 days
- GH2 mono-propellant transfer stage for small satellites
  - Solar electric thermal (~800) or ion (>3000) propulsion provides high ISP
  - Enables high maneuverability for ESPA-class satellites w/o the upper stage bulk
- Payloads
  - Provides for 3-4 ESPA payloads delivered to desired orbits
- On-Orbit Re-targeting (up/down comm link)
  - Permits incremental multi-burn missions
  - Incremental burns allow optimal orbit maneuvering
  - Contingency operations

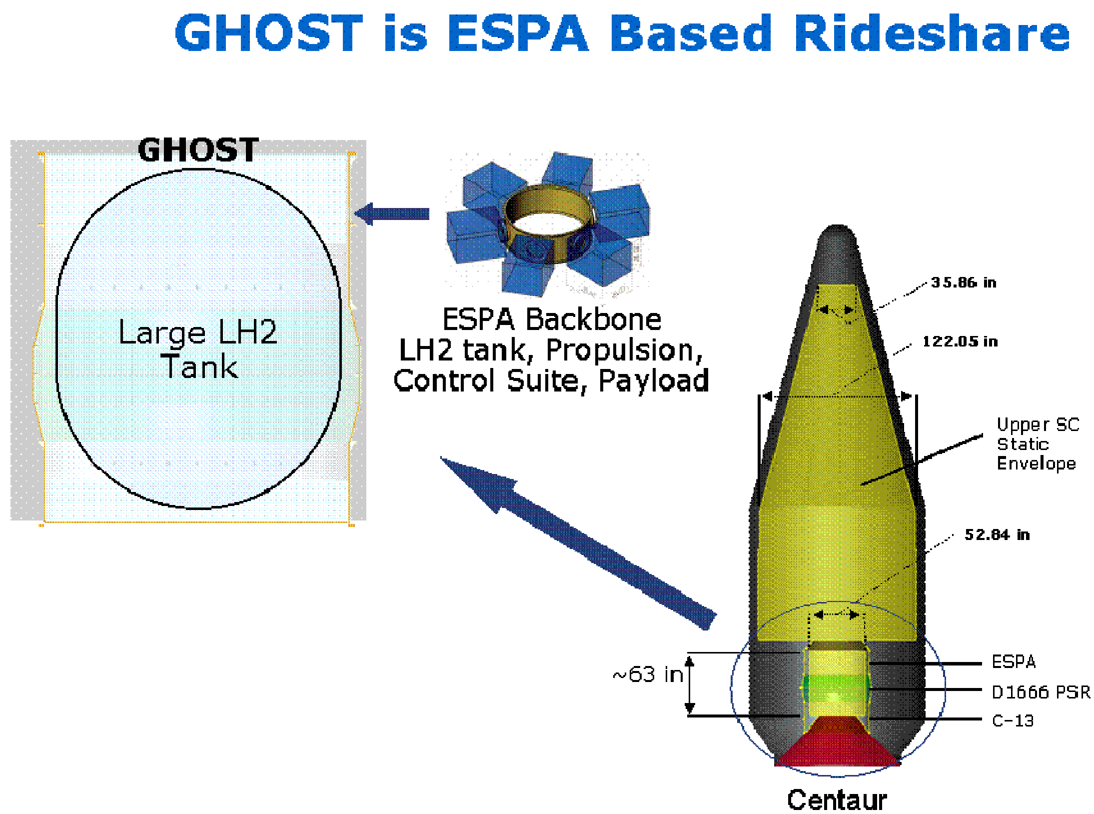
GHOST is ESPA Based Rideshare
GHOST
Large LH2 Tank
ESPA Backbone
LH2 tank, Propulsion,
Control Suite, Payload
35.86 in
122.05 in
Upper SC
Static
Envelope
52.84 in
~63 in
ESPA
D1666 PSR
C-13
Centaur

Figure - 1

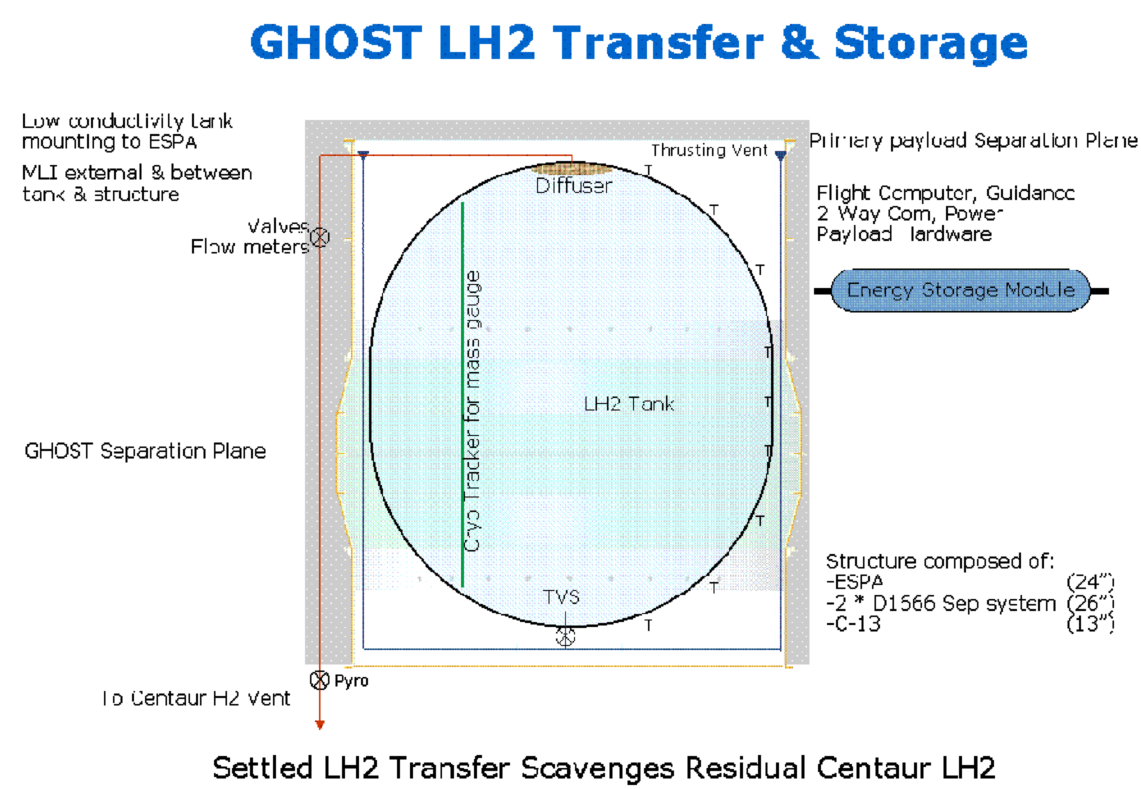
GHOST LH2 Transfer & Storage
Low conductivity tank
mounting to ESPA
MLI external & between
tank & structure
Valves
Flow meters
GHOST Separation Plane
To Centaur H2 Vent
Pyro
Thrusting Vent
Diffuser
Cryo Tracker for mass gauge
LH2 Tank
TVS
Primary payload Separation Plane
Flight Computer, Guidance
2 Way Com, Power
Payload Hardware
Energy Storage Module
Structure composed of:
-ESPA (24")
-2 * D1566 Sep system (26")
-C-13 (13")
Settled LH2 Transfer Scavenges Residual Centaur LH2

Figure - 2

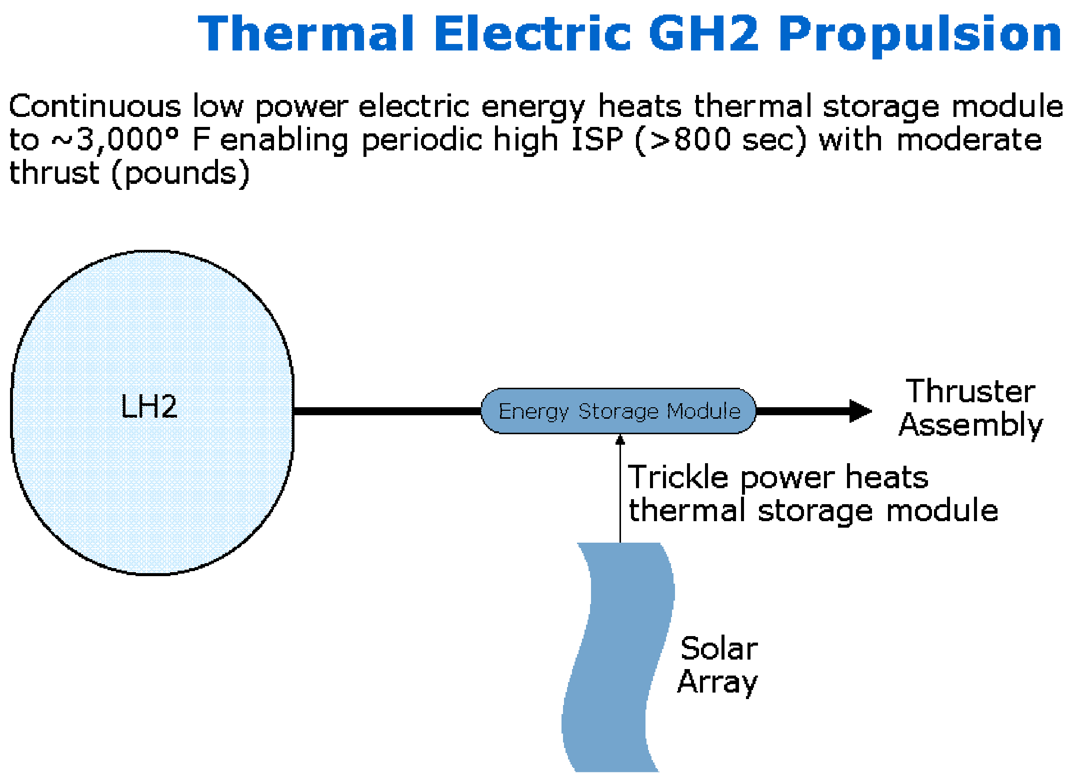

Figure – 3

3.0 WHY DO WE NEED GHOST?

GHOST is a highly efficient, light weight solution to the problem of delivery for ESPA class S/C to a variety of orbits. By discarding the upper stage, it is free to maneuver independently with a minimum mass in both structure and propellant. The long-duration and use of re-targeting provides high propellant optimization.

GHOST can provide a unique solution not achievable with conventional LEO launch systems. It is potentially lower in cost as a "rideshare" opportunity. It can raise or lower the orbit from a GTO starting position.

GHOST can service a wide variety of customer desires. GHOST can achieve LEO or GSO delivery. It can deliver a constellation series to a desired orbit plane and can make multiple plane deliveries for missions such as CLAIRIO. GHOST can perform Earth escape missions to service: Lunar Capture, Lagrange Points, and Near-Earth Object Rendezvous. Missions such as the Solar Probe+ are possible.

Why GHOST?

- High mission maneuverability
  - High impulse & thrust solar-electric thermal GH2 propulsion
  - Allows independent orbit delivery of rideshare payloads
- Rideshare provides affordable launch of GHOST
  - Scavenged upper stage residual LH2 propellant, minimized GSE support
- LH2 transfer using advanced CFM technologies
  - To be flight proven on CRYOTE demo missions
  - First flight demonstrates performance objectives and on-orbit re-targeting
- On-orbit ops permits long-duration orbit adjustments
  - 120 day missions allows multi-burn tailored/incremental orbit adjustments
  - Altitude and limited plain changes possible
  - Wide variety of delivery missions supports broad customer base
    - LEO, GSO
    - Constellations in a single plane or multiple plane
    - Earth escape: to Lunar, Lagrange pts, or near-earth asteroids & beyond

4.0 GHOST PROPULSTION

GHOST uses boil-off from scavenged LH2 propellant. H2 gas does provide a high ISP, if it can be utilized in the way just described. More conventional propellant systems such as N2H4 provide high direct insertion thrust. However, given a long-duration, the GH2 system delivers a higher change in velocity overall, See **Figure – 4**.

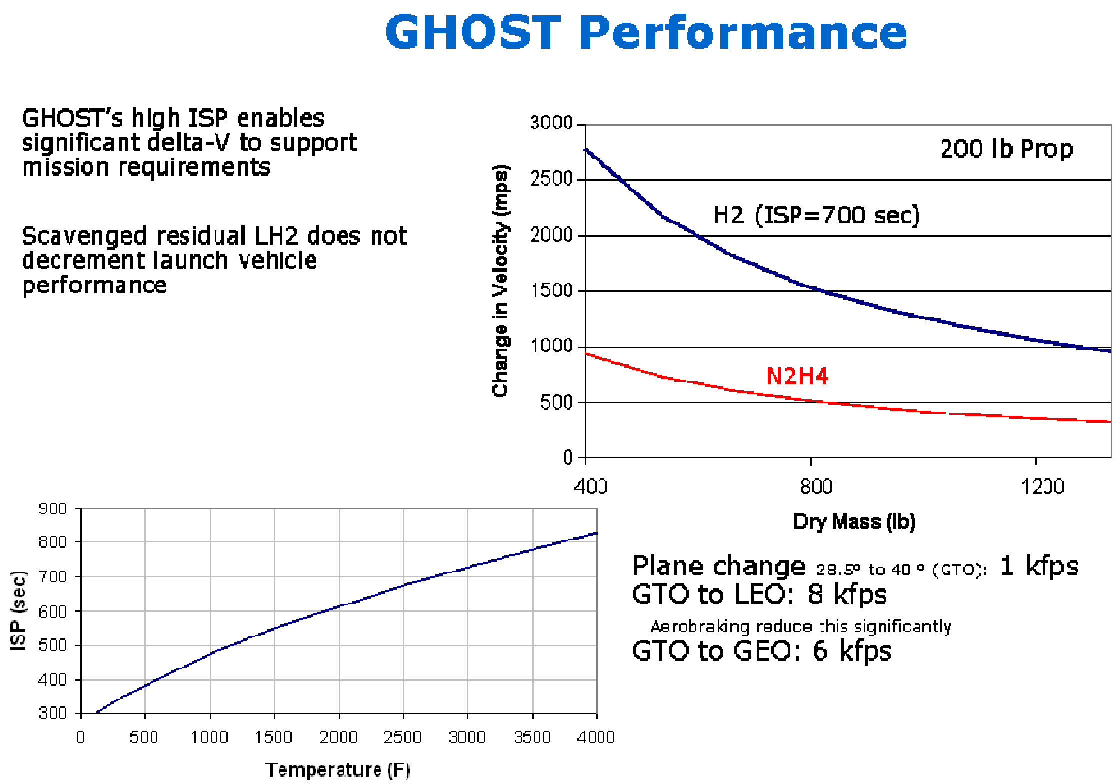

Figure – 4

6.0 GHOST DEVELOPMENT

GHOST is a concept at this time. There are elements that need to be developed to make all the pieces fit. Much of GHOST is predicated on successful CRYOTE mission results factored back into the GHOST engineering model. A notional flow of development is given below to show how GHOST can be made into a deliverable system. It is possible for GHOST to be available to fly as early as 2013.

GHOST Development

- Cryo-fluid management (CFM) is critical enabling technology
  - Fluid transfer, pressure control, thermal isolation, liquid acquisition, mass gauge, vapor cooling
  - CRYOTE provides first space demonstration of integrated long duration cryogenic propulsion system
  - CFM technologies applicable to all aspects of space-based cryogens
    - Space-depots, In-space earth departure stages, Earth return stage, Lunar delivery stage
- 2009 GHOST conceptual design and performance
  - Propulsion System Trades
  - Avionics Assessment
  - Power System trades
- 2010 development
  - Develop full scale, flight like prototype
  - Demonstration (thermal propulsion, chill-down, fluid transfer, storage, safety)
  - Define launch opportunities and ride share payloads
- 2011 development
  - Flight hardware Construction
  - Integration with Atlas launch vehicle and rideshare payloads
- 2012 first flight
  - Full system demonstration (CFM and H2 propulsion)
  - Delivery of rideshare payloads to their unique orbits
- 2013 operational system