Phoenix Launch Vehicle Operations Plan R2020.06.09

1. Technical Approach

1.1 Vehicle Design Overview

- 3-stage, advanced reusable nanolauncher
- 22kg payload to LEO, 11kg to TLI
- Turbopumped aerospike engine, composite tanks
- Lightweight composite structures
- Automated flight termination system
- Airline-like manifesting

- Designed from the beginning for scaled production

PAYLOAD

- Standard Cubesat deployer
- 0.75m fairing accommodates custom payloads
- Spacecraft can be powered on throughout launch

STAGE 3

- High mass fraction, spin stabilized carbon overwrapped solid rocket motor
- TLI/Escape optional

STAGE 2

- Tank and engine design evolved from the Trailblazer sounding rocket
- Proprietary high density nontoxic hypergolic propellant

STAGE 1

- 80kN hypergolic aerospike engine with thrust vector control
- Turbopumped and reusable
- Extensive use of composite materials enable high mass fraction

1.1.1 Propulsion system

1.1.1.1 Liquid Fuel Stages

The first and second stage of Phoenix are powered by a unique storable propellant mixture. Based on high-strength Hydrogen Peroxide and a proprietary fuel blend, the propellants are storable at room temperature, hypergolic and non-toxic. There is no need for cryogenic handling equipment and the extreme personnel protective measures that conventional hypergolic propellants demand.

The hypergolic nature of Phoenix's propellants eliminates the requirement for an ignition system. This characteristic and the propulsion system's deep throttling capability enable reliable engine restart capability.

The first stage uses a clustered-plug nozzle configuration consisting of 8 individual engine modules around an altitude compensating central aerospike. Thrust vector control is provided by differential throttling of the independent engine units. This method eliminates the need for gimbaled engines or other means of active TVC, simplifies propulsion system designand increases system reliability. It also results in a design that has inherent engine-out capability during ascent.

The first stage operates at a sea-level thrust of 80 kilonewtons. During a nominal ascent, the stage burns for 135 seconds before separating and beginning its tossback maneuver followed by freefall and powered landing. The second stage is powered by a single engine operating at 10 kN thrust.

Both liquid fueled stages utilize an electric feed system. Battery-powered pumps reduces the complexity and part count of the propulsion system. It has the additional advantage of permitting each engine to be designed as a completely self-contained unit, which is a benefit for maintenance and hardware replacement in between launches.

Video - Primary propulsion system static test fire (without chamber & nozzle):
https://www.youtube.com/watch?v=zzD55oWcb14

Video - Mobile test stand water flow test:
https://www.youtube.com/watch?v=4Kv5nijSvgY

1.1.1.2 Solid Fuel Stage

The Phoenix third stage employs a solid propellant motor using conventional Ammonium Perchlorate/Aluminum/HTPB. The production motor contains ~150 kg of propellant and burns with an average thrust of 26 kN.

Video - Third Stage subscale motor test:
https://www.youtube.com/watch?v=hOBI4YYZJU4

1.2 Structural Design

The launch vehicle is being designed using composite filament winding for the outer mold as well as propellant tanks. The tankage will be integral with the airframe and form a portion of the outer structure. In order to support landing and reuse, the first stage design employs internal metal structural reinforcement as well as internal aft crumple bearings for the landing system.

The vehicle design features external grid fins and landing legs to support reuse. The fins will be of metallic structure. The hydraulic landing legs will be formed by a metal skeleton with composite overwrap and structural reinforcements.

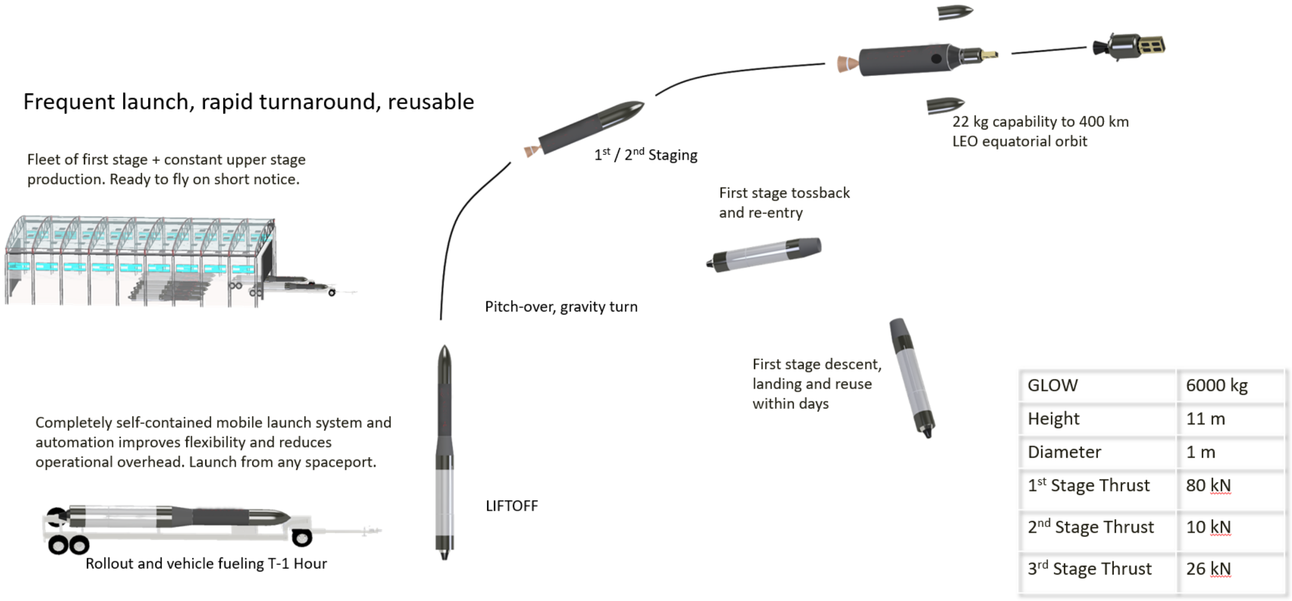
1.3 Automated Flight Termination System

The Phoenix launch vehicle design utilizes an autonomous flight termination system based on the reference design of Kennedy Space Center's Autonomous Flight Termination Unit. See Section 3.5.1 for more details.

1.4 Avionics

Along with several other companies, Phoenix Launch Systems, Inc. applied for a license to NASA's Affordable Vehicle Avionics (Reference Number: TOP2-274). However, NASA was unable to clear the package for release to anyone and recently withdrew it from licensing. Because of that, we have an ongoing project to develop the avionics in-house using the hardware and software codebase that we have been developing for our suborbital launch vehicle.

1.5 Concept of Operations



GLOW	6000 kg
Height	11 m
Diameter	1 m
1st Stage Thrust	80 kN
2nd Stage Thrust	10 kN
3rd Stage Thrust	26 kN

1.5.1 Processing Flow Timeline

Prior to delivery of the payload for integration, in consultation with Phoenix, the customer verifies that the cubesat meets the mechanical and electrical interface requirements of the payload deployer. The customer is responsible for spacecraft testing and ensuring that payloads are in an operable state upon arrival at the processing facility.

Payload Processing Flow:

- T-1 to 2 weeks: Payload is delivered to Phoenix in a "ready to integrate" state
- T-1 to 2 weeks: Payload undergoes powered-on checkout and environmental testing
- T-1 week: Payload/deployer integration, balance testing and launch day rehearsal
- T-3 days to 1 week: Payload deployer with all payloads is shipped to the launch site
- T-3 days: Payload deployer, third stage and fairing are integrated with the Phoenix vehicle
- T-2 days: Launch Readiness Review
- T-0 days: Launch

Launch Vehicle Processing Flow:

- +2 weeks: 1st, 2nd, 3rd stage assembly and qualification complete
- T-2 weeks: Launch date verified
- T-1 to 2 weeks: 1st and 2nd stage integration and checkout
- T-1 week: Partial stack launch day dress rehearsal
- T-3 days to 1 week: Partial stack, 3rd stage, deployer and fairing shipped to launch site
- T-3 days: Payload deployer and third stage integration
- T-3 days: 3rd stage integration is mated to the 2nd stage
- T-3 days: Fairing installation
- T-2 days: Countdown dress rehearsal and end-to-end test
- T-2 days: Launch Readiness Review
- T-1 day: Ordnance and AFTS installation, testing and final safety review
- T-0 days: Launch

1.5.2 Information Flow

Prior to a launch campaign, the customer representative(s) communicate with a dedicated Phoenix Point Of Contact (POC) to plan out prelaunch procedures and technical requirements for mission success. The POC is the focal point within the company for managing the flow of information with the customer as well as outside authorities (e.g. FAA and Air Force).

During a launch campaign, a POC who is also a member or the Mission Management Team serves as coordinator of the information flow between the customer, range and launch team. The customer informs the POC of payload-specific mission requirements while the POC guides the customer through the process of integrating the payload mission into the overall launch campaign. The POC via the MMT also coordinates range support and the services provided by other third parties. Before launch, it is the MMT that convenes representatives from the customer and range along with the launch team to work any final issues and authorize the mission to proceed.

During the countdown, the MMT POC serves as the primary line of communication with the customer.Tthe customer has access to telemetry and two-way communications with the POC. The range likewise has access to data and telemetry and two-way communications with a single, dedicated range safety point of contact on the launch team.

1.6 Approach to Meeting Launch Challenge Goals

Short-notice, on-demand launch and rapid re-launch within days is a fundamental goal for the Phoenix launch system. Operationally responsive space access has been the objective since the system was first conceptualized in 2016.

From its inception, a central design goal for Phoenix has been development of the lowest-cost dedicated nanosatellite launch vehicle in the industry. This dictates a system with minimal infrastructure, ease of maintenance and a launch vehicle with greatly reduced complexity. This has resulted in a concept of operations that, by necessity, requires no fixed ground infrastructure or permanent facilities at the launch site. The lack of dependency on fixed infrastructure and the small size of Phoenix also enables a completely mobile launch architecture.

A key aspect of the launch vehicle that enables rapid launch and re-launch capability is the reliance on extensive use of commonality. The first and second stages share a common propulsion system design which reduces complexity and cost while increasing overall launch reliability. The first stage propulsion system is designed to be modular and allow for easy removal and replacement of individual engines in between flights. Engines can be swapped out for maintenance without limiting Phoenix' ability to re-launch within days.

The operational flow from integration through launch requires minimal equipment. Our mobile spaceport concept requires as few as five ground transport vehicles: 1) 40-foot semi for transportation of the vehicle and launcher and to provide shelter during final pre-launch preparations; 2) One commercial truck for transportation of oxidizer; 3) One commercial truck for transportation of fuel; 4) One vehicle for transportation of the third stage, spacecraft and ordnance to be installed at the launch site; 5) One trailer or RV serving as Launch Control.

Optional systems include a secondary tower for personnel access while the vehicle is vertical, hygiene and crew rest accommodations, emergency medical care station,visitor accommodations and other miscellaneous assets to enhance productivity and safety. The secondary tower is not essential for launch operations. The other optional elements may be supplied by the range or third parties.

Because of our simplified, modular launch vehicle design, small footprint requirements at the launch site and mobile launch infrastructure, Phoenix will be able to provide on-demand launch from multiple locations within days. It is anticipated that turnaround time between launches will be dictated mostly by transportation time from one launch site to another.

1.7 Development Schedule and Status

Establish Founding Management	Complete
Test of subscale engine	Complete
Trailblazer preliminary design review	Complete
Trailblazer full-scale engineering model	Complete
Trailblazer engine design completion	Complete
Trailblazer engine manufacturing	Complete
Acquire full in-house propulsion test facilities	In Progress
Launch of Cubesat web store	In Progress
Trailblazer engine test regime	In Progress
Cubesat communication system product launch	In Progress
Phoenix propulsion system development	In Progress
Airframe filament winding technology development	In Progress
Begin Phoenix production facility outfitting	Quarter 1
Begin Trailblazer first vehicle fabrication	Quarter 2
Phoenix second stage vacuum engine test fire	Quarter 3
Trailblazer launch ground systems complete	Quarter 4
Trailblazer first flight	Quarter 4
Trailblazer operation begins, first customer sales	Quarter 5
Phoenix first stage full test fire	Quarter 5
Begin production of first Phoenix vehicle	Quarter 7
Avionics certification	Quarter 10
Flight Safety System USAF certification	Quarter 11
Phoenix first flight	Quarter 12
Phoenix operations begin, first customer	Quarter 15
Company reaches operational profitability	Quarter 16

(Quarter 1 represents the first quarter of operations from the third quarter of 2020)

2. Launch System Capabilities

2. 1 Orbit Insertion Capabilities and Accuracy

The mission of reference for Phoenix specifies the capability to place a 75-kilogram payload into a 400 kilometer circular orbit at a 28.5 degree inclination (Cape Canaveral). An upgraded third stage allows Phoenix to have the capability to place minimum 11 kg into a trans-lunar escape trajectory.

Following first stage separation, guidance and precise trajectory pointing is provided by the second stage. The second stage places the vehicle one a precise path with accurate pointing for an exact orbital insertion. The spin-stabilized third stage provides the final delta-v required to place the payload(s) into the correct orbit.

Orbital Parameter Error	3-Sigma Error
Average altitude	+/- 1%
Inclination	+/- 0.05 degrees
Circular orbit eccentricity	<= 0.0025
Right ascension	+/- 0.05 degrees

2. 2 Performance Calculations

	First stage	Second stage	Third stage	Payload mass (kg)
Propellant (kg)	**4067.00**	**945.00**	**152.00**	**50.00**
Thrust (N)	**80000.00**	**10000.00**	**26390.00**	
Isp (seconds)	**290.00**	**290.00**	**309.00**	

2.3 Payload Accommodation Mass and Volume Envelope

2.3.1 Payload Interfaces

The cubesat deployer provides all interfaces between the payload(s) and vehicle systems. Services provided include power on/off, deploy command and spacecraft/payload prelaunch and ascent health monitoring. This enables payloads to be checked out and verified to be ready for launch after final integration during the countdown. Phoenix does not require payloads to be dormant and isolated from the launch vehicle as is the case with EELV rideshare or spacecraft deployed from ISS. This characteristic greatly increases the mission success rate by ensuring that payloads are healthy and able to operate before committing to launch. In this regard, cubesats flying on Phoenix are treated as primary payloads in the same manner as (for example) a communication satellite on an EELV.

An additional benefit is that cubesats maye be diagnosed in real-time to be non-functional before release and can remain attached to the deployer, thereby reducing orbital debris count.

The mechanical interface with the cubesat deployer follows the cubesat standard so that payloads are able to be delivered to the processing facility and integrated within a matter of days rather than weeks or months. Electrical and telemetry interfaces will likewise be standardized and available publicly so that cubesat developers will be able to design their payloads at the outset to take advantage of those services.

2.3.2 Payload Constraints

The standard envelope inside the Phoenix fairing has a diameter at its base measuring 0.5 meters. The payload fairing and base of the payload deployer are located at the same station along the vehicle's x-axis. Forward of this point, the parabolic fairing tapers to a point with a total fairing length measuring 2 meters.

Inside the fairing, Phoenix can accommodate payloads in the 1-12U cubesat range. Payloads may be in any combination of 1, 2, 3 or 6U sizes. Phoenix can also accommodate certain non-standard cubesat configurations as long as they fit inside the internal envelope.

2.4 Ascent Environments and Loads

Flight Event	**Axial Load (g's)**	**Lateral Load (g's)**
Launch/First Stage Ignition	From -1.0 to 2.0	1.50
Stage 1 Engine Resonance	2.0	1.50
Wind Gust	2.0	2.50
Stage 1 Max Acceleration	5.0	2.00
Stage 2 Ignition	From -1.0 to 5.0	1.50
Stage 2 Engine Resonance	3.0	2.50
Stage 2 Max Acceleration	5.0	2.00
Stage 3 Ignition	From -1.0 to 5.0	2.00
Stage 3 Max Acceleration	14.6	1.00
Envelope	From -1.0 to 14.6	2.50
Maximum free molecular flow heating	1200W/m^2	
Acoustic environment (OASPL)	130dB	
Max Q	30kPa	*Tentative

2.5 Launch Operations, Range Integration and Dependencies

The Phoenix mobile launch capability is designed to operate without placing dependencies on a hosting launch range. However, there are provisions for sharing data and telemetry with the range. There is a secure communications interface that the launch decision authority, range safety and emergency services may monitor during the course of launch operations. Two-way communications are available with those parties to ensure successful and safe launch operations.

A typical launch flow follows the processing flow outlined in section 1.5.1. The entire mobile spaceport, vehicle elements and payload arrive at the launch site between 3 to 7 days before launch. Those four days are spent establishing the local presence, connecting utilities, communications checks and making sure that all ground infrastructure is in readiness.

T-3 days is devoted to final integration and checkout tasks. A final launch rehearsal and the Launch Readiness Review takes place two days before launch. Hazardous and safety-critical operations to load ordnance and conduct checkout of the flight termination system is conducted the day before launch.

On launch day, or prior if circumstances dictate, the propellants are loaded aboard the vehicle before the start of countdown operations. The countdown lasts approximately 2 hours. The countdown is almost entirely automated except for arming the ordnance and flight termination system. Each critical step receives a go/no-go status and the ability for human intervention to call a halt to operations.

Cleanup and breakdown of the launch system takes up to two days post-launch, followed by departure leaving no footprint behind.

3 Launch Site Requirements

3.1 Commodities

The Phoenix launch system requires three commodities: high-strength Hydrogen Peroxide, the proprietary fuel blend and Helium pressurizing and purge gas. All of the commodities will be transported to the launch site by Phoenix and Phoenix does not rely on any supplies from the launch range.

Fuel and oxidizer will be transported on separate vehicles under HAZMAT safety provisions. The fuel is blended and packaged from constituent chemical components at company facilities which is also where the oxidizer is concentrated and packaged. Helium is procured from commercial gas supply companies.

At locations where a generator is required, an additional supply of fuel will be necessary. This will also be procured by Phoenix from local suppliers if not supplied by the launch range.

3.2 Utilities

Because the entire Phoenix launch system is designed to be completely self-contained and mobile, no range-provided utilities are required for operations, although it is desirable. This includes electrical, water and communications. Where utilities are available and it is more cost-effective, the system will have the capability to interface with and utilize those services.

3.3 Facilities

3.3.1 Payload Processing Facility

During a nominal launch campaign, almost all of the payload processing will be conducted at Phoenix's corporate facility. Final integration and checkout takes place at the launch site inside the Phoenix transport vehicle which also serves as the launch site processing facility. During a rapid-response launch, all integration and checkout can take place within the mobile facility.

3.3.2 Vehicle Checkout and Integration Facility and Launch Pad

Phoenix is transported to the launch site inside an enclosed, environmentally-controlled truck. It is transported mounted on its vertical erector and umbilical tower. At the launch site, the 3rd stage, payload and fairing are integrated with the partial vehicle stack inside this truck. Prior to launch, the truck is opened and the vehicle raised to vertical to rest on the ground attached to the launch stand that is part of the erector. The launcher is designed so that it may be leveled for situations where it is either resting on a concrete pad that is not level or needs to rest on the ground.

3.3.3 Launch Control

The Launch Control Center and all necessary consoles are contained within a dedicated vehicle (an RV suffices). It has full integration, checkout and launch capability without the need for any range-supplied facilities. Operational software is a combination of COTS software (e.g. LabView) and custom software based on a modernized and streamlined version of the Ground Operations Aerospace Language.

3.4 Safety

Operational safety requirements and procedures are currently being developed in accordance with MIL-STD and NASA-STD recommendations and rules. See Section 5 for a list of referenced standards and guidelines. At the launch site, emergency medical, fire and security assets will be in place per local, state and federal ordinances and range requirements. Phoenix will provide these services to complement what is provided by the range or to support the requirements entirely when range support is not available.

3.5 Range Requirements

3.5.1 Flight Termination

Due to the high development and operational costs, autonomous flight termination is the only viable path for Phoenix's low-cost model and is a necessity for a fully mobile launch system.

Phoenix has executed a license with NASA's Kennedy Space Center and acquired its Autonomous Flight Termination Unit reference package including software code, hardware designs and test plans. Currently, hardware is being procured and the PCB's are in the manufacturing phase. We have a software build and test environment and are completing software development and certification plans. For qualification, the Phoenix AFTU will fly on one or more suborbital vehicles in the 1st and 2nd quarter of 2019 to verify the ability to maintain accurate vehicle state information and respond appropriately to real and simulated flight conditions.

3.5.2 Telemetry

Telemetry during ascent will be provided by dual space-to-ground (e.g. TDRSS) and UHF communications links during the first stage portion of flight. Later phases of ascent will rely on space-to-ground communications. The satellite radio is currently in development. UHF communications will be provided by COTS systems.

4 Safety, Reliability and Operational Procedures Guidance

- MIL-STD-882E SYSTEM SAFETY
- MIL-STD-1540C Test Requirements For Launch, Upper Stage, And Space Vehicles
- MIL-STD-1833) Test Requirements ForGSE And Software Supporting Space Vehicles
- MIL-HDBK-338B ELECTRONIC RELIABILITY DESIGN HANDBOOK
- TR-2004(8583)-1 Test Reqs For Launch, Upper-Stage, And Space Vehicles. Aerospace Corp.
- AFSPCOM MANUAL 91-710 RANGE SAFETY USER REQUIREMENTS
- AEROSPACE REPORT NO. TOR-2009(8591)-13 Space Vehicle FMECA Guide
- Reliability Analysis Center CRTA-FMECA Failure Mode, Effects and Criticality Analysis
- MIL-STD-1629A PROCEDURES FOR FMECA
- Flight Assurance Procedure (FAP) 322-209 Standard for Performing FMEA andCIL
- NASA Fault Tree Handbook With Aerospace Applications
- NASA-STD-8719.17 NASA Requirements for Ground-Based Pressure Vessels and Pressurized SystemsNASA-STD-8739.10 EEE Parts Assurance Standard

- NASA-STD-8719.13 NASA SOFTWARE SAFETY STANDARD
- NASA-GB-8719.13 NASA Software Safety Guidebook
- NASA-STD-8719 Safety Standard for Explosives, Propellants, and Pyrotechnics
- NASA-STD-8719 NASA ELV Payload Safety Requirements
- NASA-STD-7002 Payload Test Requirements
- NASA-STD-5001 Structural Design and Test Factors of Safety for Spaceflight Hardware
- NASA-STD-5002 Load Analyses of Spacecraft and Payloads
- NASA-STD-5005 Standard for The Design and Fabrication of Ground Support Equipment

Phoenix Launch Systems is strictly following the guidance from the FAA Office of Commercial Space Transportation found here: https://www.faa.gov/about/office_org/headquarters_offices/ast/licenses_permits/launch_reentry/