The Quarter Pounder

A Vehicle to Launch Quarter Pound Payloads to Low Earth Orbit

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Introduction

Attainment of orbit by amateur rocketry enthusiasts is seen as the ultimate goal by many. It represents a capability to explore beyond the confines of Earth's atmosphere and possibly beyond to such places as the Moon, asteroids or other planets. It brings the hope that space exploration and development will become available to the common man.

This is, however, a very difficult goal to accomplish and is beyond the skills of many amateurs. It requires the development of sophisticated rockets as well as sophisticated launch and support infrastructure.

The first difficulty in attaining orbit by amateurs is the very requirements needed to attain orbit. Attaining roughly 17,500 MPH velocity horizontal to the Earth at an altitude of over 100 miles is not easy. It was only about five years ago that the Civilian Space Exploration Team was the first amateur group to reach the altitude of space after nearly a decade of development. Attaining that altitude is only the first part to attaining orbit.

Another difficulty arises due to the complexity of the vehicles required to attain the altitudes and reach the horizontal velocities. The Rocket Equation governs the limits of rocket capability. It specifies the physics that all vehicles attempting to reach orbit must attain. Because of the realities that it imposes on them, orbital vehicles are exclusively multistage vehicles. Amateur orbital vehicles will also be multistage vehicles.

The legal regime governing orbital launch vehicles is yet another difficutly. International laws and treaties impose special requirements due to the danger of harming non-involved individuals and property around the world.

Despite these difficulties, it is the intent to pursue this worthy goal using resources available to amateur rocketry enthusiasts. This paper describes the conceptual design of an amateur launch vehicle capable of attaining orbit for a quarter-pound payload.

Requirements

Orbital Altitudes

It is not possible to attain orbit in the atmosphere. By convention, space starts at 100 kilometers or 62.14 miles. The atmosphere, however, does not suddenly stop at that altitude, but gets progressively thinner. Lower orbits have shorter lifetimes whereas higher orbits have longer lifetimes. To maintain orbits lasting more than one day generally requires an altitude of 100 miles or better.

Orbital Velocities

The equation governing the speed required to maintain a circular orbit about Earth is:

$$V = \sqrt{\frac{\mu}{r}}$$

where:

V = velocity in feet per second
μ = Earth's gravitational constant (1.4076540 x 10^16 ft3-sec-2)
r = radius of orbit from Earth's center in feet

and since the Earth's radius is 3959 miles or 20,903,520 feet, the following table lists several different orbital altitudes and the tangential velocity required:

Orbital Altitude (miles)	Orbital Radius (feet)	Velocity (feet per second)
100	21431520	25628
150	21695520	25472
200	21959520	25318
250	22223520	25168

Therefore, to attain an orbit at 150 miles altitude requires a tangential velocity of 25472 feet per second (or 17367 miles per hour).

Summary

To attain orbit requires that the rocket's payload reach an appropriate altitude and acquire a tangential velocity near 25500 feet per second.

System Description

The following is the description of the vehicular system chosen to meet the orbital requirements for delivering a quarter-pound payload to a circular orbit of 125 miles altitude.

Design Strategies

The following design strategies were chosen as the basis of the design of the Quarter-Pounder vehicle.

Pressure Fed

First, the vehicle is entirely a pressure-fed vehicle. This simplifies many aspects of construction because the development of pumps is difficult. This approach limits the performance of the rocket motors because a trade-off of propellant tank pressure versus rocket combustion chamber pressure is made. Higher pressures results in higher weight and higher rocket performance. However, a lower weight results in lower rocket performance. A combustion pressure of 200 PSI was selected for the first stage and 75 PSI for the upper stages.

High Mass Fraction Vehicle

Second, relatively high vehicle mass is selected to minimize the weight optimization that is necessary to produce a light-weight vehicle. In general, the first stage has a propellant mass fraction of 71.4% or a structural mass fraction of 28.6%. This means that the propellant makes up less than 71.4% of the total lift-off mass and means that the vehicle is relatively heavy as far as modern rockets go.

Six Stages with Duplicated Stages

Rather than try to create a multistage vehicle which is highly optimized for weight, the design chosen is one that uses multiple non-optimized components. Although the first stage is a unique vehicle design, stages 2 through 6 are all identical in construction and capability. Therefore, only two different vehicles must be developed although multiple copies of the upper stage design are used.

Lofted Ascent Trajectory

A lofted ascent trajectory, where the first stage vehicle ascends vertically during its entire flight, was selected. Although non-optimal for attaining orbit, it provides a number of benefits for amateurs. First, it minimizes the locations that the first stage might fall either on burn-out or during a failure. Second, it ensures that the first stage flight is visible and no radar tracking is necessary.

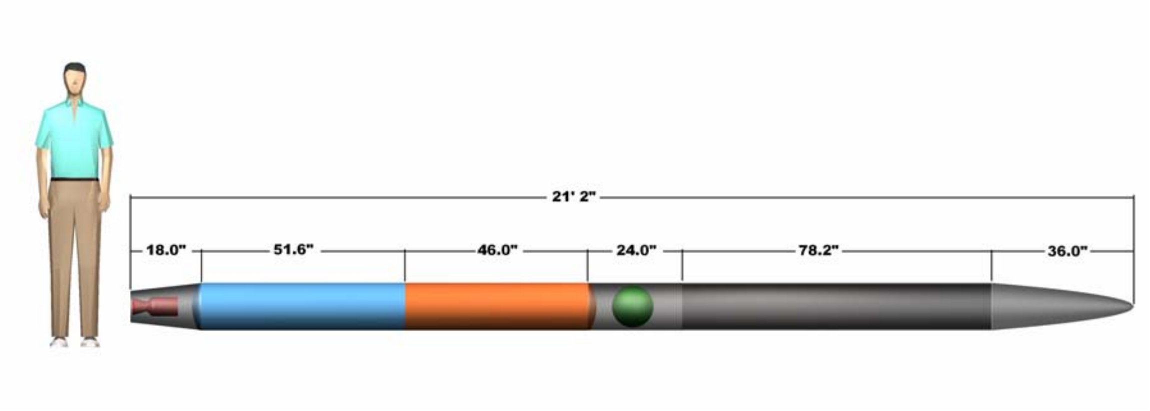
The Quarter Pounder Launch Vehicle

The Quarter Pounder vehicle is a six-stage vehicle utilizing a number of unique strategic approaches to simplifying the attainment of orbit. The following table describes its most abstract characteristics.

Characteristic	Description
Payload	0.25 pounds
Orbit	125 mile circular
Stages	6
Diameter	12 inches
Height	254 inches (21’2”)
Take Off Weight	555.25 pounds
Take-Off Thrust	1300 pounds-force
Fuel	Propane
Oxidizer	Liquid Oxygen
Construction	Aluminum Irrigation Tube
Total delta V	33,105 feet per second

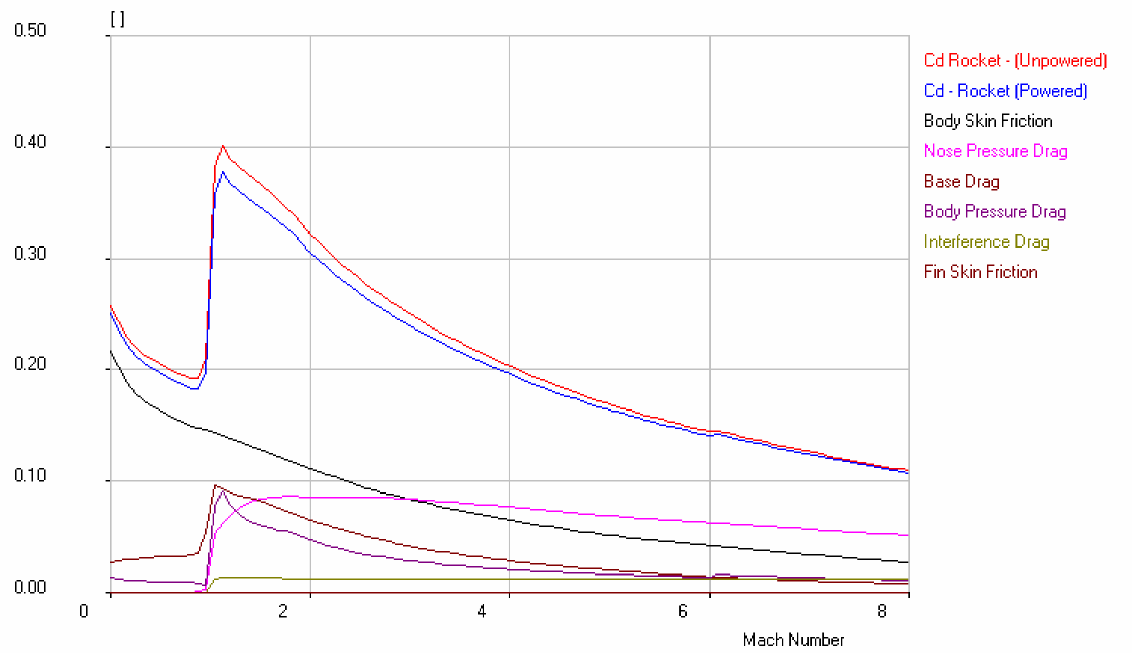
Stage 1

The first stage is a 12-inch diameter pressure-fed rocket with liquid oxygen and propane as the propellants. It is 21 feet 2 inches high including the payload bay and the nosecone. Constructed of welded irrigation tubing, it weighs 140 pounds empty and 490 pounds fully fueled (without upper stages). It has no fins for stabilization and depends on motor gimballing for stabilization and guidance. It uses 24 pounds of helium pressurant at 3000 PSI in a spherical tank for tank pressurization at 250 PSI.



Aerodynamics

Based on aerodynamic modeling, the following graph illustrates the coefficient of drag throughout the flight.



Drag Coefficients at 0.0deg. Angle of attack vs. Mach Number
Reference Area = 113.10in²

The first stage contains no guidance system, relying on control signals from the upper stages to ensure its flight trajectory.

Motor

The motor is either a regeneratively or ablatively-cooled rocket motor which produces 1300 pounds-force of thrust. It has a specific impulse of 242 seconds at sea-level and 282 seconds in a vacuum and a thrust:weight ratio of 50:1. It has an expansion ratio of 3:1. The propellant burns for a total duration of 66 seconds with a burn-out altitude of 23 miles and a peak altitude of 93 miles after coasting. The motor thrusts the vehicle up to 4700 feet per second maximum.

Tanks

The oxidizer tank contains 241 pounds of liquid oxygen. The fuel tank contains 110 pounds of propane.

The tanks are constructed from 0.090” thick 12” diameter aluminum tube. Endcaps are welded and a single cap serves as a common bulkhead between the propane and the liquid oxygen. Feed-through pipes bring pressurant and control signals through the tanks.

Control

The system uses two electrical lead screws to provide gimbal control over the motor. A battery system provides the power for this stage. There is no roll control envisioned in this system.

Pressurization

A single spherical 3000 PSI helium tank provides pressurization. It is 11 inches in diameter. A primary regulator brings the pressure down to 800 PSI where a secondary regulator brings the pressure down to 250 PSI ensuring that each of the oxidizer and fuel tanks are properly pressurized.

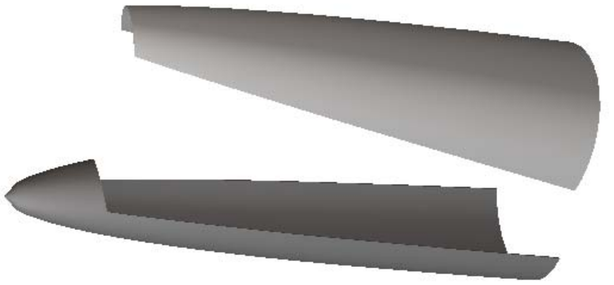
Payload Bay

The upper stages are contained inside of the payload bay section which is 78.2 inches long. It is constructed from 12 inch diameter 0.064 inch thick aluminum tube. The payload bay also has optical windows for the thermopile-based horizon detectors used by the navigation system to ensure a vertical flight.

Nose Cone

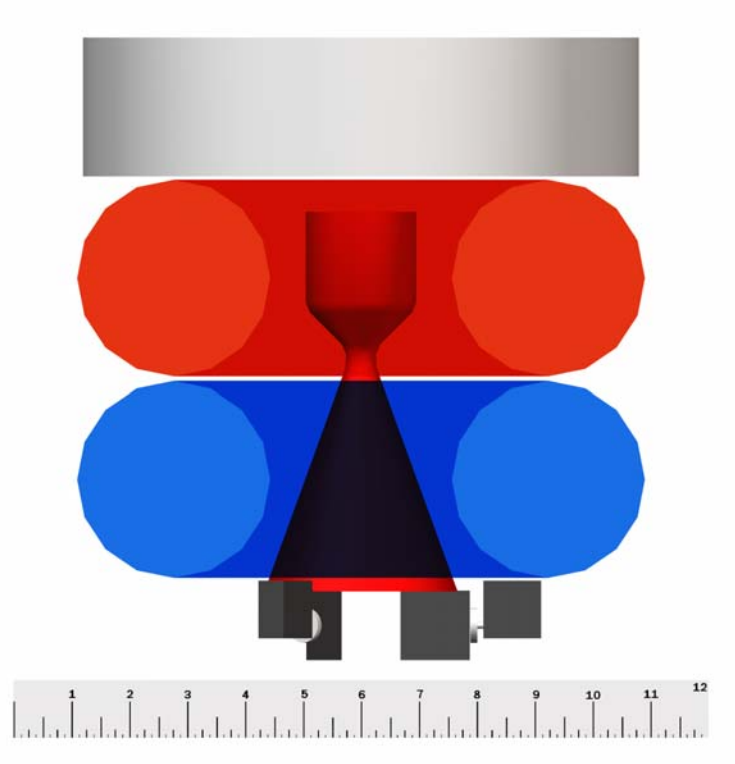
The 36 inches long by 12 inches diameter nose cone has a ½-power shape to minimize drag. It is produced from composite material and weighs less than 4 pounds. It contains a pitot tube to provide dynamic pressure information to the guidance system.

The nosecone splits at altitude to provide a clear exit for the payload. Springs force the leaves apart and cause them to be ejected at altitude.



Upper Stages

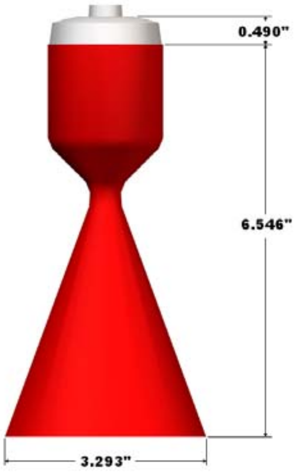
The 5 upper stages are all based on a single design vehicle. Together, these five vehicles provide nearly all of the tangential velocity required for orbit. Each stage weighs three pounds empty and contains 10 pounds of propellant. Each has a single 25 pound-force thrust motor which operates at 75 PSI combustion chamber pressure. Each one contains a full guidance system as well as all of the necessary control capabilities needed. They utilize thrust vectoring vanes to provide roll, pitch and yaw control.



Stage 3 in cross section

Motor

The motor produces 25 pounds-force of thrust. It is produced from electroformed nickel. All aspects of this motor are produced from electroformed components to the greatest possibility in order to reduce weight. It has a 50:1 nozzle expansion ratio which produces at least 310 seconds of specific impulse in a vacuum. The motor has its own lightweight electrical igniter to allow starting in flight.



Tanks

Two electroformed toroidal tanks provide storage for the propellants. The propellants are liquid oxygen and propane. The tanks are identical and each hold up to 183 cubin inches of propellant.

Pressurization

The pressurization system depends on the self-pressurization properties of the propellants. Since each propellant has a vapor pressure greater than the combustion chamber pressure at room temperature, they will be able to pressurize the chamber for combustion without additional pressurization. Since each tank wraps around the combustion chamber, they will be irradiated with infra-red energy, adding additional heat to them during flight. This is necessary since they cool as they expand to gases and their vapor pressure is lowered. By careful design, the proper amount of heat insolation is ensured.

Control

Full yaw, pitch and roll control is provided by three control vanes in the nozzle exhaust. Small servos control these vanes.

Guidance and Navigation

A Guidance, Navigation and Control (GNC) system is contained in the enclosure at the forward end of the vehicle. Six thermopile optical horizon sensors are used for reference in conjunction with MEMs gyroscopes and accelerometers to integrate and propagate the orientation and position.

Control Computer

The control computer is a single-chip microcontroller which accepts as inputs voltages from several sources. It combines the inertial data, pressure data and horizon sensor data to integrate and estimate the current position, orientation and flight characteristics. It provides multiple outputs for controlling the servos on this stage as well as any other stages it may be controlling.

Power Supply

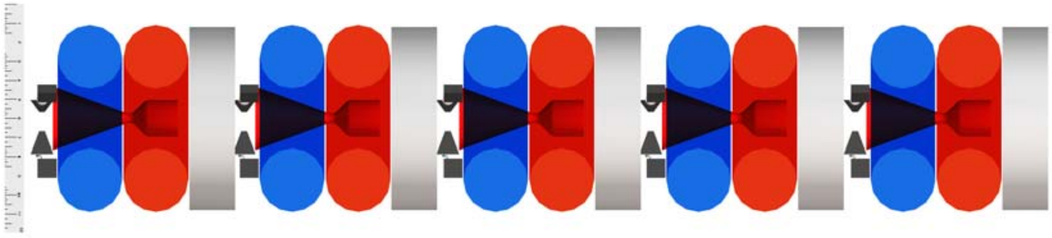
Power is supplied from hearing aid batteries.

Data Control and Communications

Flight and other data is stored in the internal control computer for download at a future time. A small radio of 200 mW allows the data to be transmitted to a ground station at a slower rate.

Upper Stage Stacking

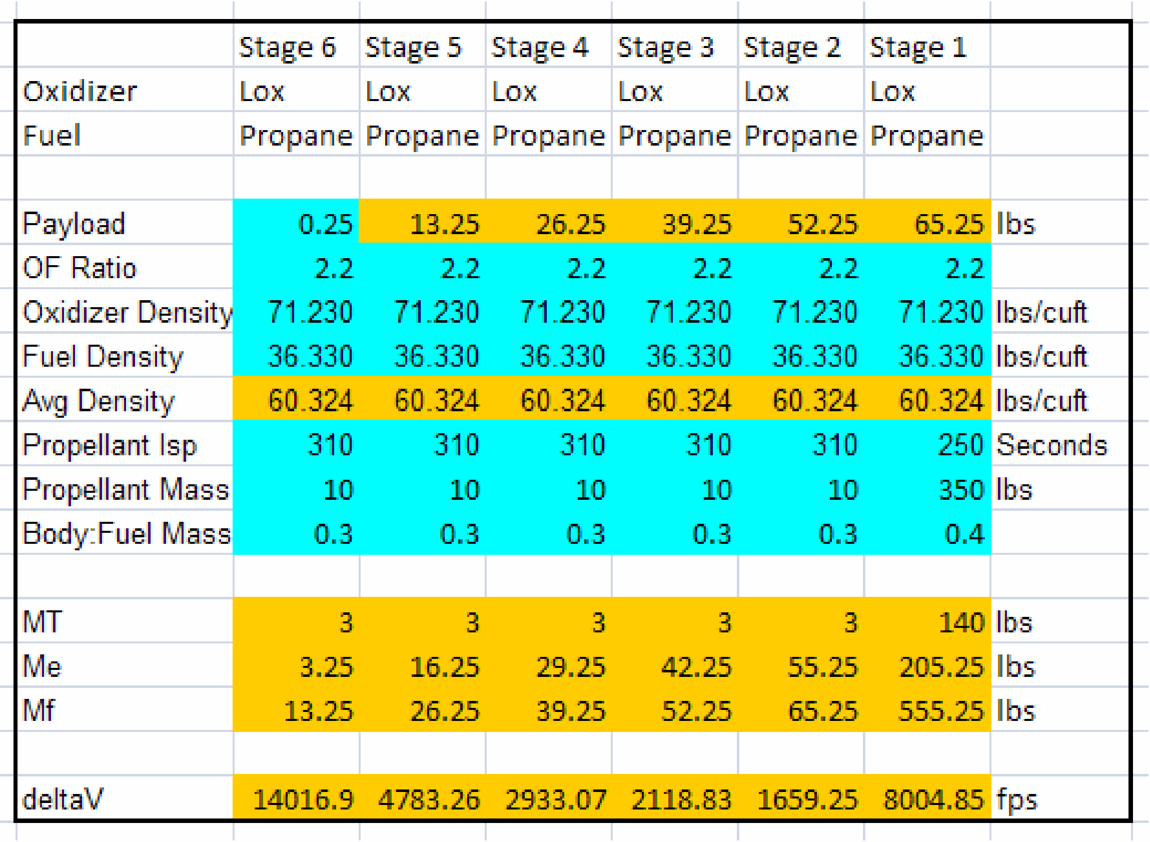
The upper stage modules are stacked and carried inside of Stage 1's payload pay. They are ejected after Stage 1 burnout when the aerodynamic forces have reduced sufficiently.



Stacked Stages

System Characteristics

The following diagram shows the weight and performance expected from each stage.



	Stage 6	Stage 5	Stage 4	Stage 3	Stage 2	Stage 1	
Oxidizer	Lox	Lox	Lox	Lox	Lox	Lox	
Fuel	Propane	Propane	Propane	Propane	Propane	Propane	
Payload	0.25	13.25	26.25	39.25	52.25	65.25	lbs
OF Ratio	2.2	2.2	2.2	2.2	2.2	2.2	
Oxidizer Density	71.230	71.230	71.230	71.230	71.230	71.230	lbs/cuft
Fuel Density	36.330	36.330	36.330	36.330	36.330	36.330	lbs/cuft
Avg Density	60.324	60.324	60.324	60.324	60.324	60.324	lbs/cuft
Propellant Isp	310	310	310	310	310	250	Seconds
Propellant Mass	10	10	10	10	10	350	lbs
Body:Fuel Mass	0.3	0.3	0.3	0.3	0.3	0.4	
MT	3	3	3	3	3	140	lbs
Me	3.25	16.25	29.25	42.25	55.25	205.25	lbs
Mf	13.25	26.25	39.25	52.25	65.25	555.25	lbs
deltaV	14016.9	4783.26	2933.07	2118.83	1659.25	8004.85	fps