



Preliminary DoubleSShot trajectory study

Rev. 20101108

Preface

This is an initial assessment of the DoubleSShot trajectory, based on the preliminary vehicle design parameters. The purpose of this study is to assess, if a vehicle following this outline is likely to be capable of reaching a summit altitude of at least 33km.

This study will follow the lines of previous SugarSShot trajectory studies, but this time actual flight data may be relied on for support of the calculations.

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Vehicle overview

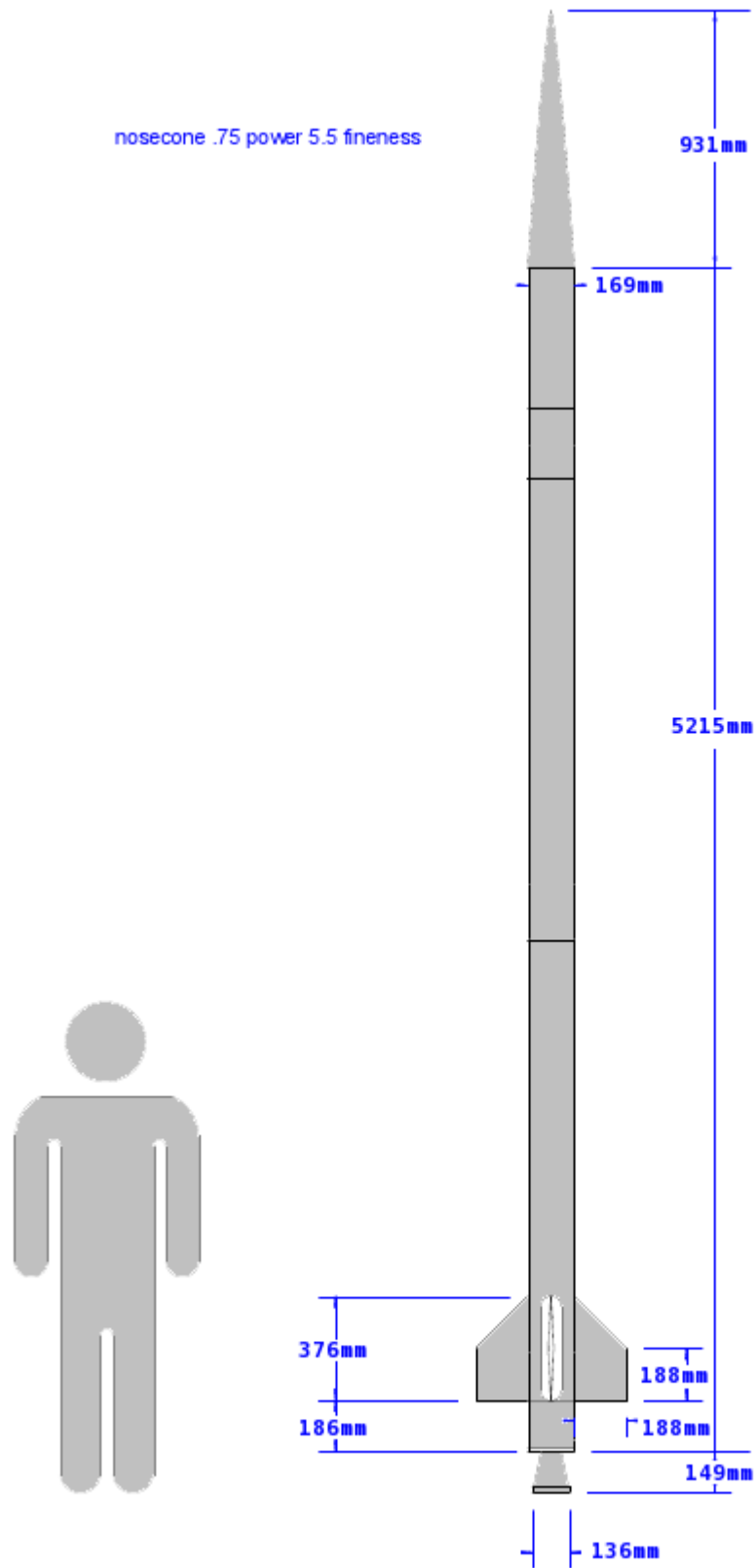
The vehicle layout can be seen below. It has a quite long 37:1 body fineness with a 5.5:1 3/4 power shaped nose cone and 4 clipped delta fins. The fin semi span is approximately 110% of the body diameter. The rocket body has a diameter of 169mm. Basically, the DoubleSShot vehicle is a double sized MiniSShot vehicle, hence its name *DoubleSShot*

The vehicle is powered by a 2 phase motor with each phase targeted to deliver 57500Ns during a 6.7s burn at an ISP of 130s at sea level. With a targeted mass ratio of 72%, this leads to the following overall figures:

- First phase propellant mass: 45.06kg
- Delay grain mass: 1.39kg
- Second phase propellant mass: 45.06kg
- Vehicle dry mass: 34.94kg

The propellant mass for both phases slightly exceed 8 times the 5.5kg of the MiniSShot. This is the consequence of better utilization of the motor chamber because the liner is not expected to scale to double size.

The delay grain is expected to scale with the vehicle, increasing its mass by a factor of 8 compared with MiniSShot.



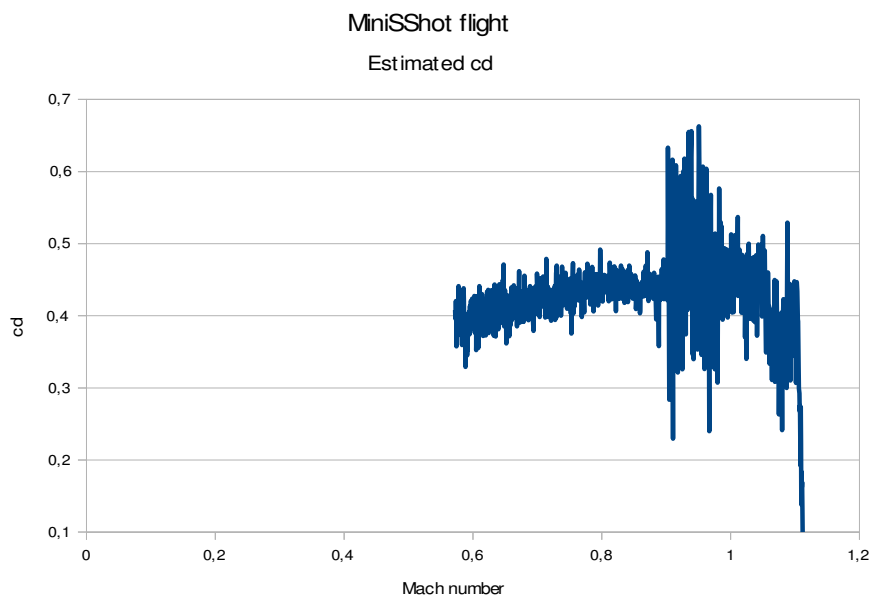
DSS Vehicle for Trajectory Sims
Version 1.0 (2010/10/20)

MiniSShot Revisited

The MiniSShot flight (20100425) was flawed with an anomaly in the second phase ignition. However, good flight data were obtained during the first phase burn and inter phase coast. Due to the similarity of the MiniSShot and DoubleSShot vehicles, vehicle characteristics will be similar.

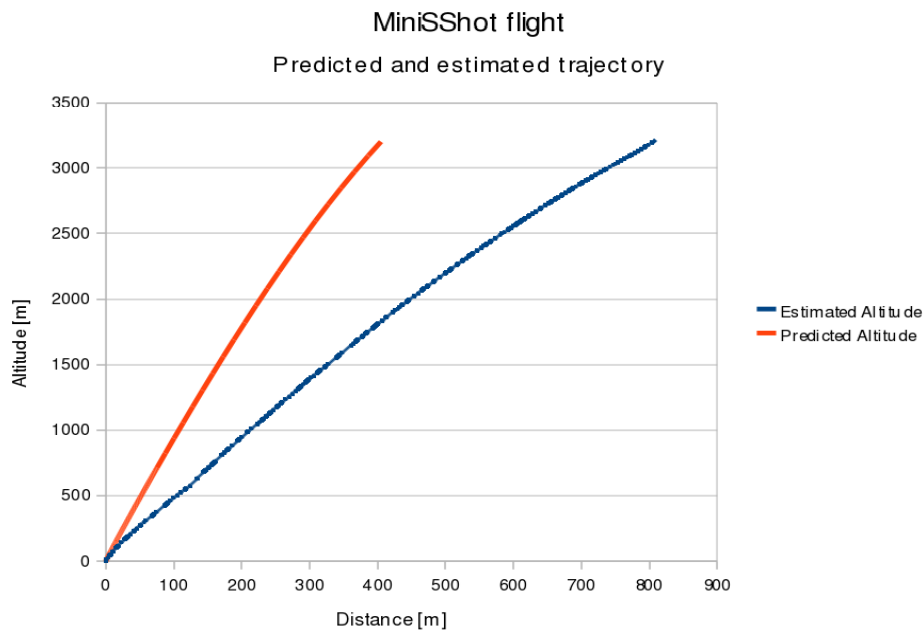
A 2D analysis of the MiniSShot flight data has been performed in order to compare with 2D predictions for the same vehicle.

One of the major questions during the preparation of the MiniSShot vehicle was the effective coefficient of drag. Some features of the vehicle made it somewhat difficult to estimate the c_d value, and furthermore it was unknown how much the delay grain would affect the drag coefficient. Since the MiniSShot flight had a malfunction at the ignition of the second phase, the full answer to these questions cannot be obtained from the flight data – but still, the flight data provides a much better foundation for the drag prediction of the DoubleSShot vehicle.

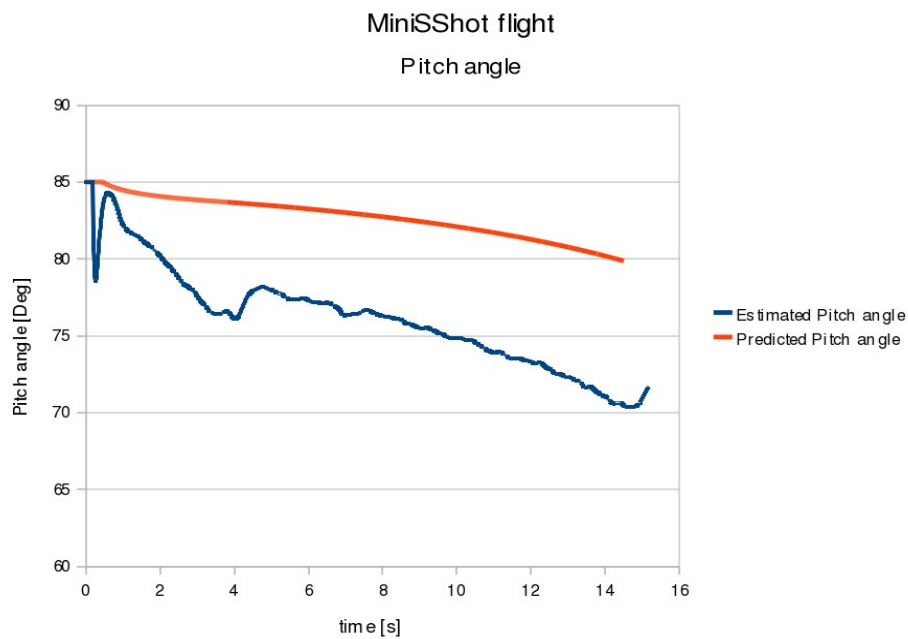


The post calculated coefficient of drag is somewhat lower than expected. The most optimistic estimate (RasAero, power on) is approximately 0.5 in the 0.6-0.8 Mach region. It is clear, that a less conservative approach can be taken when estimating the c_d for the DoubleSShot vehicle.

The trajectory itself is estimated using the longitudinal acceleration and the barometric altitude. While this method has some uncertainties especially on the lateral part of the trajectory, it does provide a good overview of the flight performance.



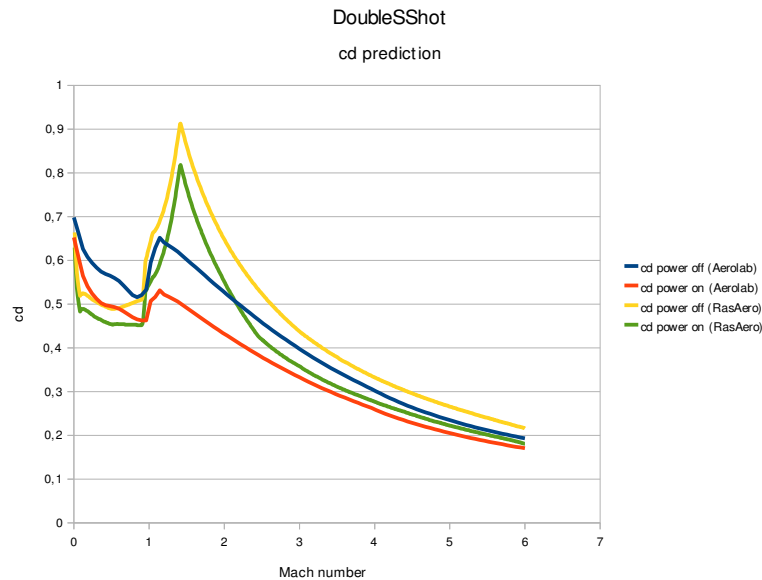
Despite having lower drag than anticipated, the MiniSShot vehicle does not climb to a higher altitude than predicted at phase 2 ignition.



Another view of the same story. It can be seen, that approximately 5 precious degrees are being lost during the first 5 seconds of flight, as a consequence of the vehicle being exposed to surface winds during phase 1 burn. Trajectory predictions using the RasAero software showed nearly no wind sensitivity.

DoubleSShot drag estimates

The estimated drag of the MiniSShot vehicle was overly conservative, and the data obtained from actual flight has been used to trim down the MiniSShot vehicle to better match reality. Some external features, like the camera fairing has been excluded from the model, and there has been a slight adjustment to the surface roughness. The DoubleSShot vehicle has been modeled using the same trimmed down approach, using both RasAero and Aerolab for comparison.



It should be noted that a direct comparison of the drag prediction is not possible, since the two softwares offers different options. The $\frac{3}{4}$ power nosecone is not available in the RasAero software, and there are also other differences – for instance the way surface roughness is specified.

The $\frac{3}{4}$ power nosecone is expected to have lower drag than most other nose shapes at supersonic velocities, as is suggested by the drag models. At transonic velocities, however, the $\frac{3}{4}$ power shape is not superior, and as such, it would be anticipated that RasAero would predict a lower drag in this region. This is not the case, although the RasAero drag prediction in this regime might be caused by the way it treats fin drag, and not the shape of then nose.

The differences in subsonic drag is most likely caused by different surface roughness assumptions.

Performance study

The performance study is based on the following assumptions for the nominal trajectory:

- First phase propellant mass: 45.06 kg.
- Second phase propellant mass: 45.06 kg.
- Delay plug mass: 1.39 kg. Assuming no thrust and being discarded at T+13.7 s.
- Vehicle dry mass: 34.94 kg.
- Motor impulse: 57500 Ns for each phase at sea level.
- Motor burn duration: 6.7s for each phase.
- Specific impulse: 130 s at sea level, *without* altitude compensation.
- Drag coefficient as calculated with Aerolab, assuming power off during delay.

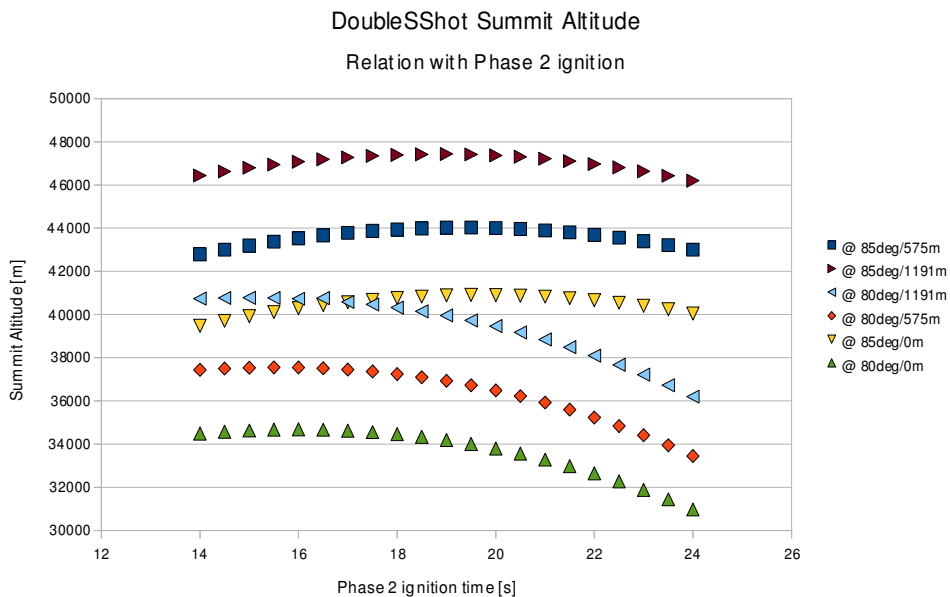
For simplicity, altitude compensation for the thrust is not being considered due to the fact that the same nozzle is being used during both burns, and can not be optimal during the entire flight. An attempt to deal with the effects of is covered separately.

There are six sets of calculations for the purpose of selecting the best possible Phase 2 ignition time :

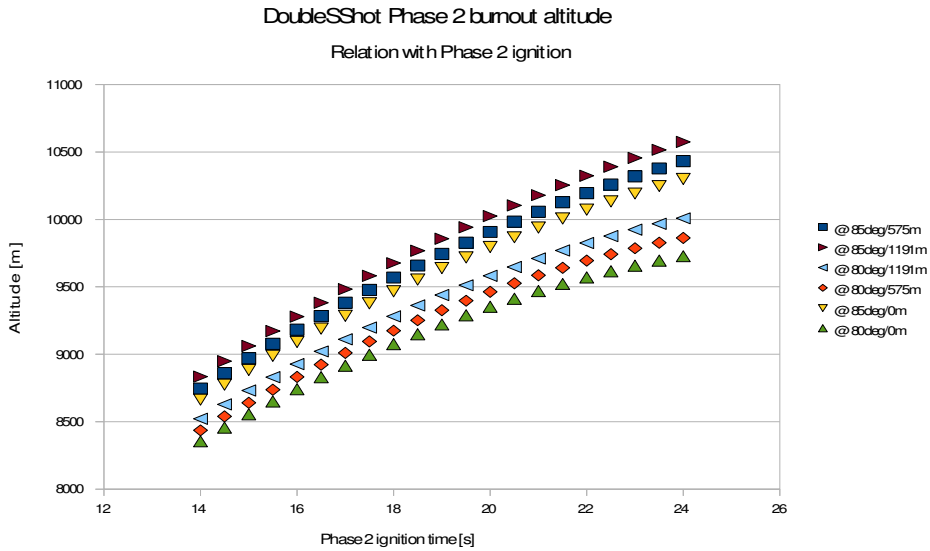
- Launch site at sea level, 575m elevation or 1191m elevation.
- Launch tower tilted 80 or 85 degrees from horizontal.

The 575m launch site elevation approximately corresponds to the FAR site, while the 1191m roughly corresponds to the Black Rock Desert.

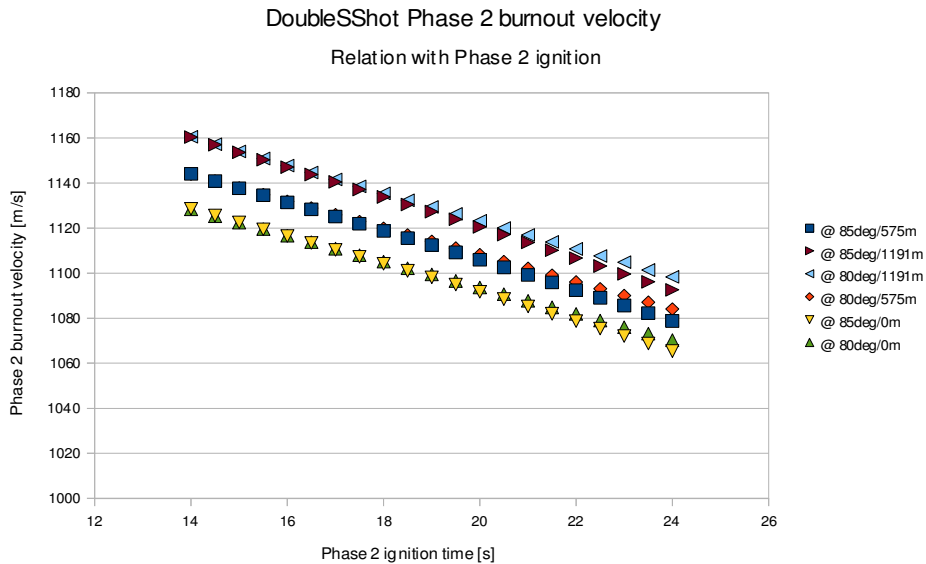
The launch tower at 85 degrees corresponds to best practice no wind condition, while the 80 degree condition is a first order approximation to reflect the influence of surface winds.



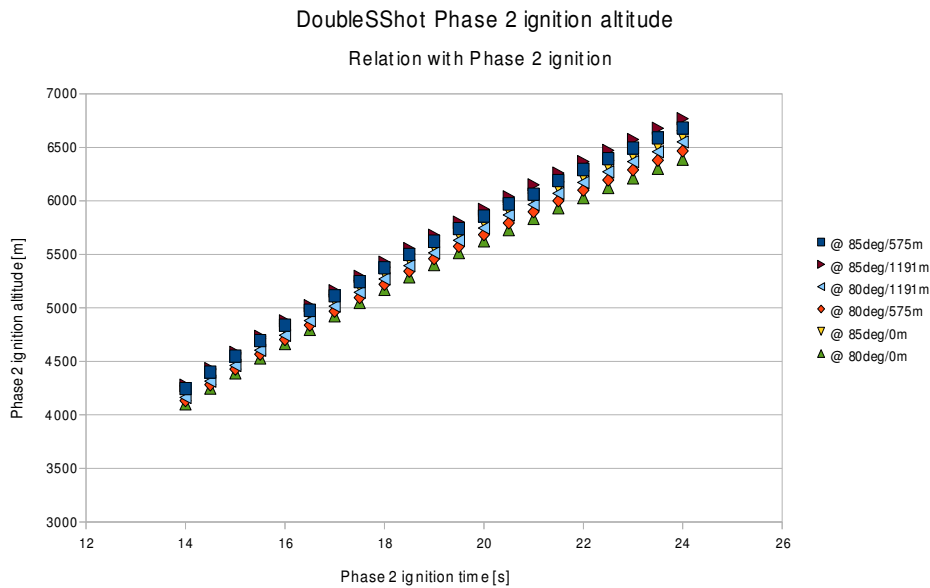
The predicted summit altitude for the different scenarios, with respect to phase 2 ignition time. It is clear, that the target of 33km is within reach, but the general "optimal" point of phase 2 ignition must be governed by the wind influenced trajectories, as this is where the goal may be missed. T+16s seems to be the best overall choice for the 80 degree cases, and will even allow for some ignition delay without any major negative impact on the altitude. For the 85 degree case, optimum might be closer to 19 seconds, but since the target of 33km is safely reached anyway, it will be better to focus on the wind influenced trajectories.



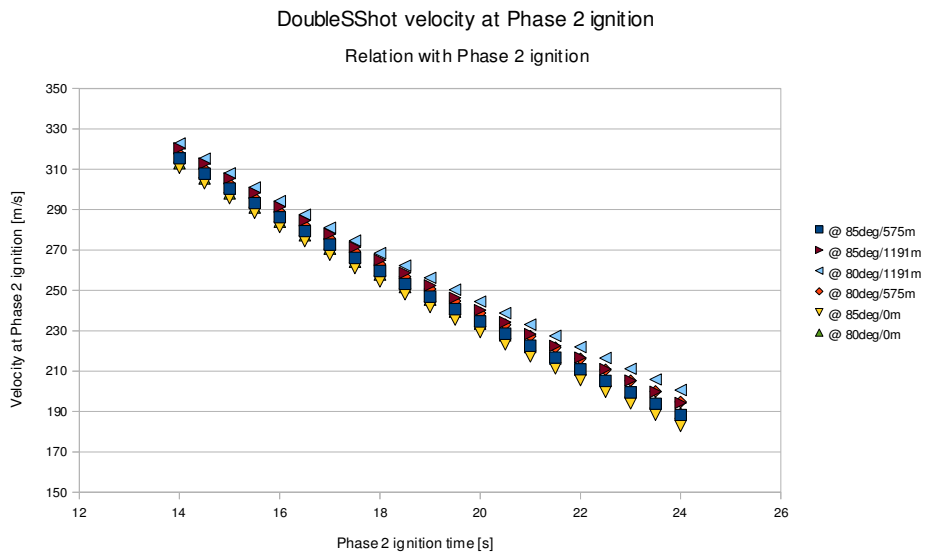
Burnout altitude of phase 2 will be at roughly 9000m for a T+16s phase 2 ignition.



Phase 2 burnout velocity is primarily depending on the launch site altitude, and will be in the order of 1100m/s.



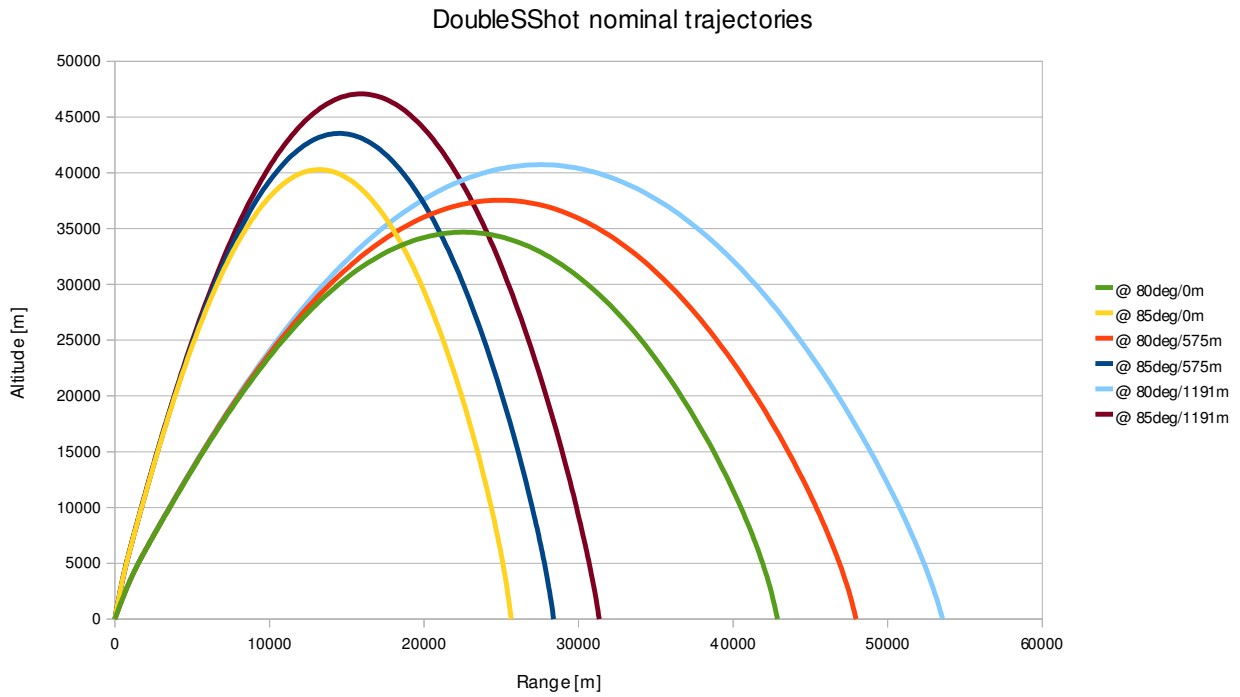
The altitude of phase 2 ignition will be in the order of 4600m for a T+16s phase 2 ignition.



The velocity at phase 2 ignition will be in the order of 290m/s for a T+16s phase 2 ignition.

Delaying the ignition a few seconds will not be critical, but in order to avoid wind influence of the second phase burn, it will be better to fire phase 2 early than late.

The overall conclusion is to fire phase 2 at T+16s, to minimize the risk of failing the objective due to surface and altitude winds, while maintaining a fair margin under no wind conditions.

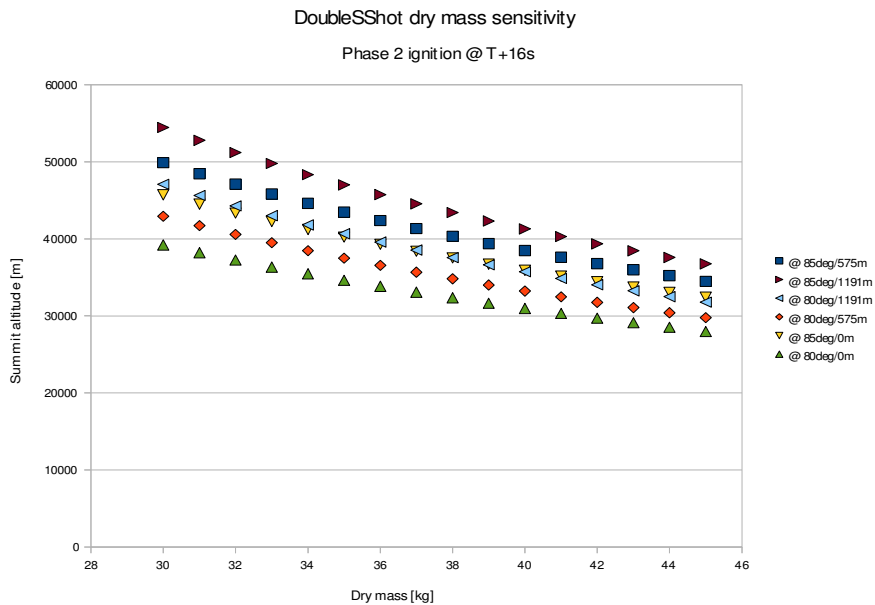


An overview of the trajectories for the nominal vehicle for the 6 cases considered. Trajectories are shown purely ballistic, since at this point, the details of the recovery are not yet available.

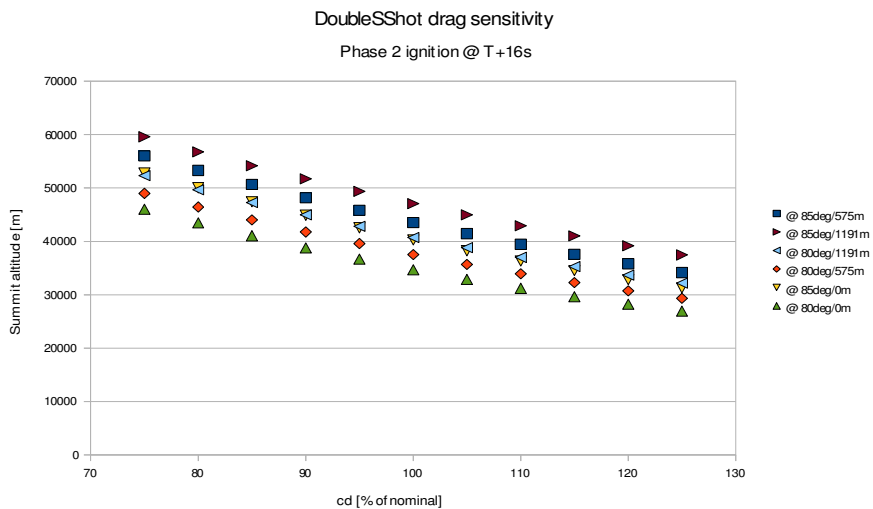
Sensitivities

The sensitivities of the nominal trajectory against dry mass, cd, thrust, launch angle and altitude compensation is being calculated. The assumptions are as stated for the nominal trajectory with the exception of the parameter being investigated. The timing of the phase 2 ignition is fixed at T+16 seconds.

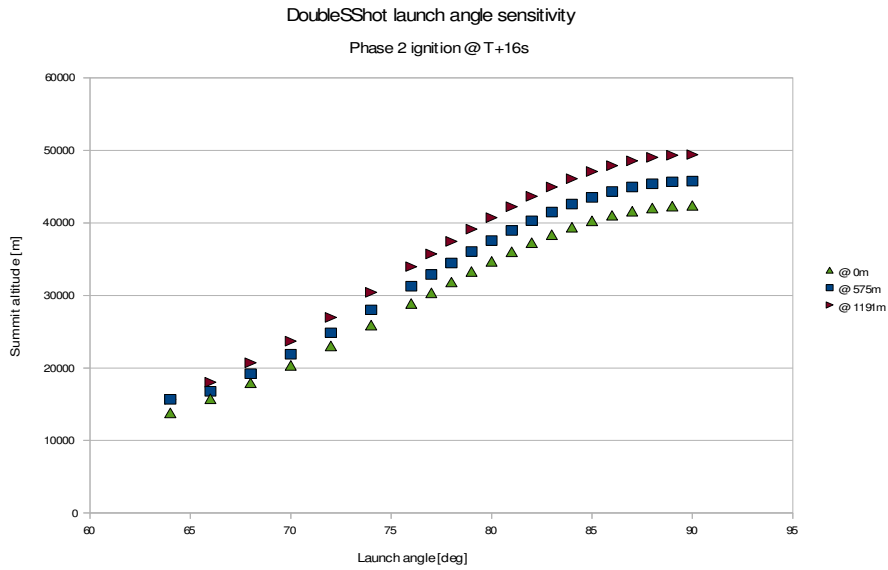
As with the nominal trajectory, calculations are being made for the same 6 cases: launch at sea level, at 575m or at 1191m - at 80 or 85 degrees from horizontal.



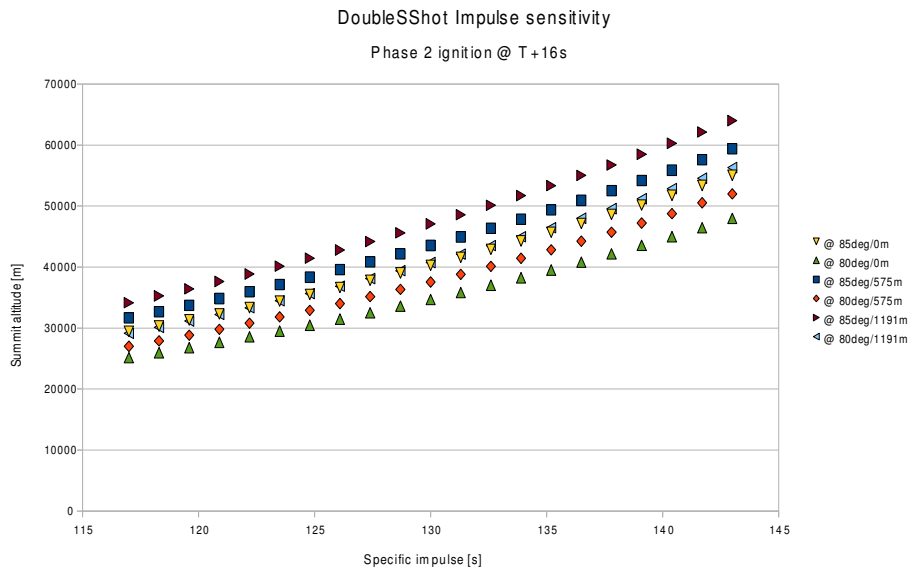
Sensitivity of the summit altitude against dry mass. There is a roughly linear relation, and every mass reduction possible will increase the achievable altitude.



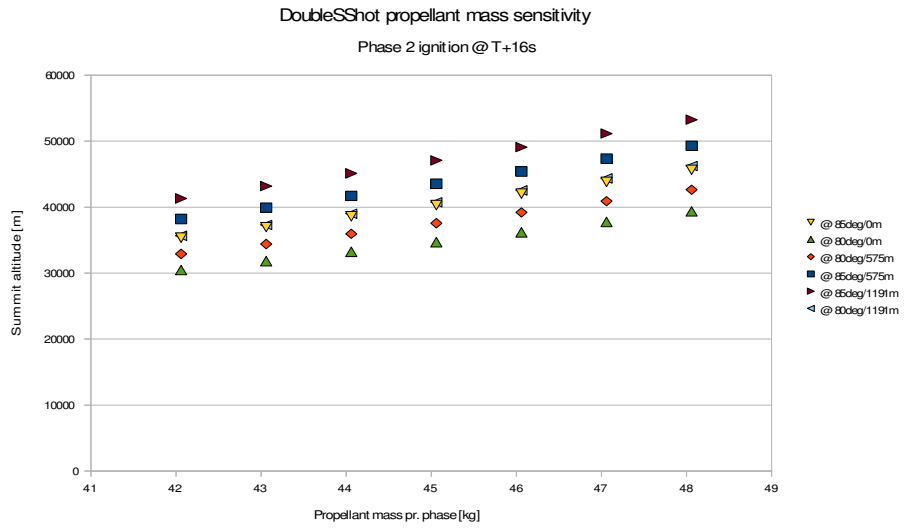
Sensitivity against cd. Note that the cd scaling is constant throughout the velocity regimes – deviations from nominal at a certain velocity regime will have less impact. The reduction in achievable altitude increases almost linearly with the cd.



Sensitivity against launch angle. Loosing 5 degrees to the wind gets expensive when the nominal launch angle drops below 85 degrees.



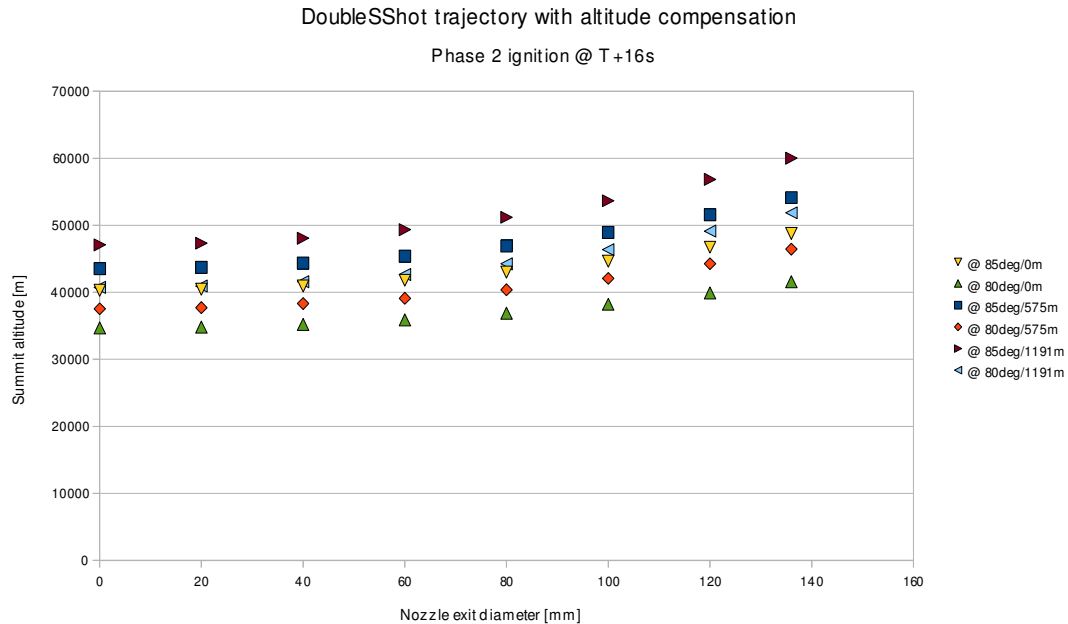
Sensitivity against (sea level) specific impulse. Note that both phases are assumed to have the same specific impulse for simplicity. The numbers *do not account* for any altitude compensation.



Sensitivity against variation in propellant mass. Note that both phases still have the same propellant mass.

Altitude compensation

Altitude compensation is difficult to cover due to the fact that the same rocket motor with the same nozzle covers the altitude range from ground up to approximately 9km. Furthermore, the nozzle exit pressure is not yet known.



The altitude compensation on the trajectory will be estimated assuming that the exhaust expands to 1 atmosphere at the nozzle exit while delivering a specific impulse of 130s at sea level. The thrust gain at altitude will be calculated for different nozzle exit diameters to deal with the fact that the altitude compensation will depend on the exit pressure. It would be more realistic to base the simulations on the real exit pressure, but this is not facilitated by the simulator.