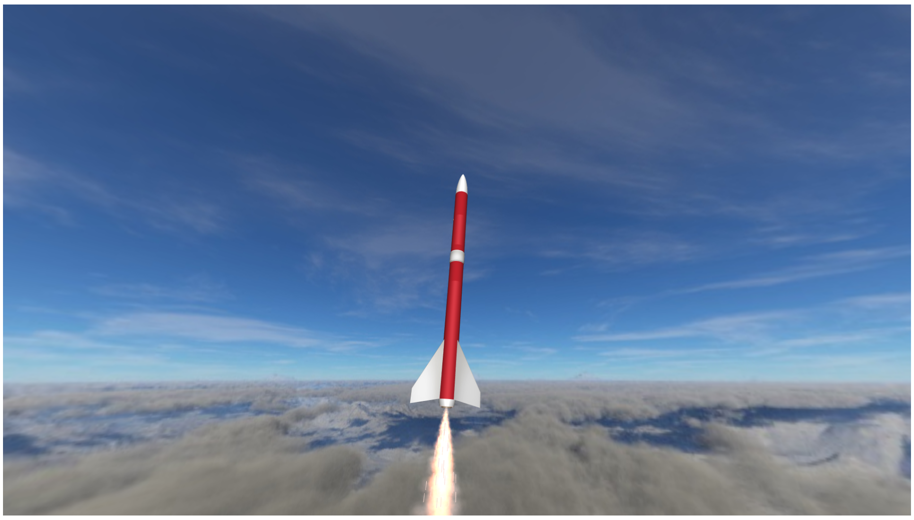
MISSION ANALYSIS

REDSHIFT SOUNDING ROCKET

March 17, 2020



Version 1

Guillaume Araignon
guillaume.arai@gmail.com

Contents

1 Goals **3**
- a Supersonic recoverable rocket . . . 3
- b Hydraulic actuator development . . . 3
- c Sensors payload . . . 3

2 Architecture of the rocket **3**

3 Tools and models **4**
- a Rocket modeled . . . 4
- b Simulation configuration . . . 5

4 Flight envelope **6**

5 Stability **7**
- a Specifications . . . 7
- b Values for the rocket . . . 8

6 Kinematics of the rocket **10**

Abstract

Redshift is a project from engineers and students in the association AeroIPSA, aiming to design, build and launch a supersonic sounding rocket. This paper gives an analysis on the mission: trajectory, stability, and kinematic conditions for the flight to allow proper sizing of the launch site and design of the rocket.

1 Goals

a Supersonic recoverable rocket

The rocket is designed to be recoverable through a parachute opened from a lateral door. To ensure a reliable system locking, the parachute is ejected in a container, which one of its sides is the lateral door closing the compartment. After being ejected, the casing splits in half and releases the parachute.

b Hydraulic actuator development

Next projects could be in need of systems with an important mechanical power, given by pneumatic or hydraulic actuators. This year, we will try and develop a system of gridfins, deployed and maintained in position by hydraulic or pneumatic actuators.

c Sensors payload

Again, to optimize design of future rockets, we will need to take various data from the flight, in particular inertial and vibration data for validating simulation tools, design choices and optimize them. Moreover, a space startup may need to test for a rocket flight some of its systems, this partnership could help us get experience with integration of payloads.

2 Architecture of the rocket

The rocket has a structure in segments, each one is a composite tube with a sandwich structure composed of external layers of carbon fibers / epoxy separated by a honeycomb layer. Each fuselage segment contains a functional subsystem of the rocket, they are linked together by internal aluminium rings. The functional blocks are arranged from the bottom of the rocket:

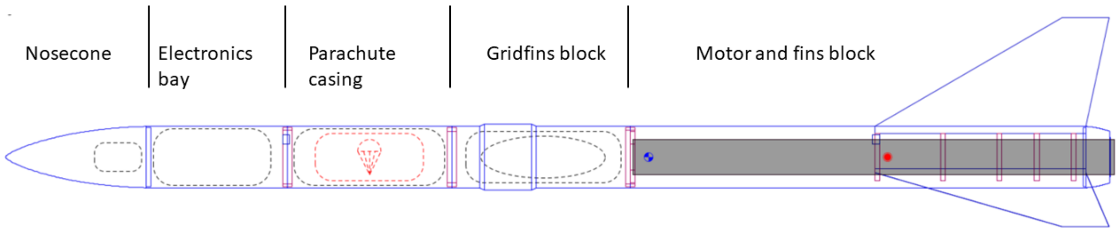


Figure 1

The gridfins are located as close to the bottom of the rocket as possible, to minimise their impact on stability while undeployed. The electronics bay is situated on the top of the rocket to allow for easier disassembling and debugging. The fins are made in a structure similar to the fuselage, a carbon fiber / honeycomb sandwich structure, screwed to the fuselage.

3 Tools and models

a Rocket modeled

The tool used for calculations is OpenRocket, an open source software which allows for basic rocket design and flight simulations. The code calculates aerodynamic properties of the rocket using an extended version of the Barrowman method, allowing valid approximations for supersonic regime. It also takes into account roll and wind perturbations.

To simplify the problem, the fins are modeled as flat plates 6 mm thick, and the undeployed gridfins are modeled as rocket diameter extensions. The modeled used motor is a homemade motor from Opus Aerospace, called RS-76-6G-P. The actual rocket may not be using this particular engine, it will nonetheless use a similar one in terms of dimensions and thrust curve. Here follows the characteristics of this simulated motor.

Simulated rocket dimensions	
Data	Value
Inner diameter of fuselage	125 mm
Outer diameter of fuselage	130 mm
Gridfins model diameter	140 mm
Length of gridins	120 mm
Length of segments	50 to 100 cm
Number of segments	5 (including nose cone)
Total length of rocket	238 cm
Mass of rocket with motor	14.14 kg

Table 1

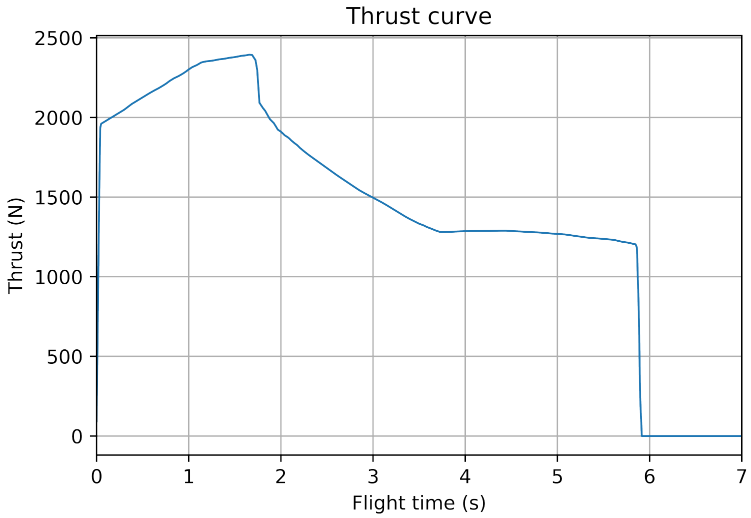


Figure 2

Opus Aerospace RS-76-6G-P	
Data	Value
Diameter	76.2 mm
Length	1050 mm
Launch Mass	6.000 kg
Empty Mass	1.500 kg
Burn Time	5.9 s
Total Impulse	9798 N.s
Max. Thrust	2397 N
Avg. Thrust	1660 N

Table 2

b Simulation configuration

The simulator uses the Extended Barrowman method. This is a semi-empiric method to calculate the aerodynamic coefficients of a flying rocket.
The coordinate systems uses a spherical approximation for Earth by default, which is more than enough for our apogee of only a few thousand meters. Finally, the simulation method is a 6 degrees of freedom simulation using a Runge-Kutta 4 integrator.

The defined direction of the wind is defined as the angle with respect to the direction of the North. 90° means that the wind is blowing from the East in our case.

Simulation configuration		
Section	Data	Value
Wind configuration	Average windspeed	3 m/s
	Standard deviation	0.45 m/s
	Turbulence	15 %
	Wind direction	90 °
Launch site	Latitude	52 °N
	Longitude	20 °E
	Altitude	100 m
Launch rod	Length	5000 mm
	Angle	-20 °

Table 3

The angle of the launch rod is defined as the angle from the vertical in the direction of the wind. Negative angles means that the launch rod is oriented downwind. Due to a lack of data about the actual launch site, most of these values of wind and launch site have been chosen arbitrarily.
The decision to simulate a launch downwind is to try and give a worst case for the distance the rocket can reach from the launch ramp. Moreover, the 5 meters-long and 20° inclined launch ramp comes from our former launch campaign specifications.

4 FLIGHT ENVELOPE

Simulated balistic flight with the launch ramp downwind gives the following flight envelope:

Flight envelope	
Apogee altitude	3540 m
Maximum range	3020 m
Time of flight to apogee	20 to 23 s
Total flight time (Nominal dowwind flight)	436 s

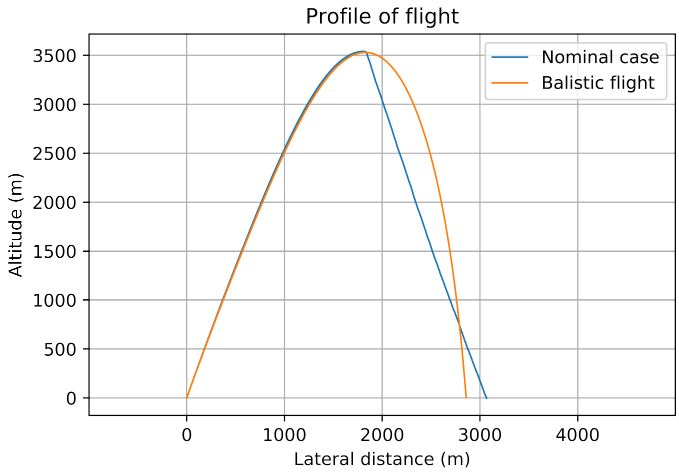


Figure 3: This simulation with a launch downwind gives a maximum range the rocket will reach, for a nominal flight and ballistic (parachute not opened).

5 Stability

a Specifications

Our former launch campaign organizer had specifications about stability to qualify the rocket for flight. As it is flight-proven and worked out by CNES (the French space agency), we will base our study and rocket design on these specifications. All non-constant values will be given between launch ramp clearing and the apogee.

CNES / Planète Sciences specifications		
Data	Min value	Max value
Length / diameter ratio [*N/A*]	10	35
Lift gradient $C_{n\alpha}$ [rad^{-1}]	15	40
Stability margin [*rocket calibers*]	2	6
Stability torque [$rad^{-1} \times$ *rocket calibers*]	40	100

b Values for the rocket

Compliance to the first value is validated, as the rocket will have a length of around 2.3 to 3 meters. With a fixed diameter of 140 mm (taking the diameter given by the gridfins) gives a ratio comprised between 16.2 and 21.

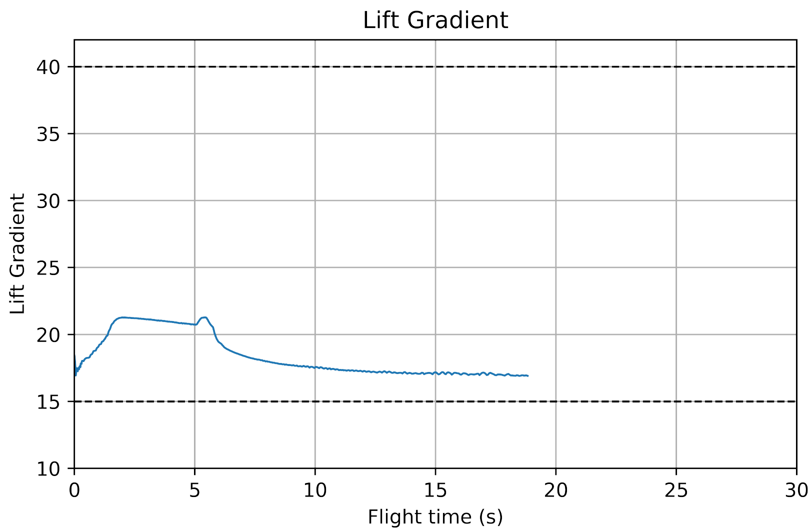


Figure 4: The lift gradient is the lift coefficient with respect to the angle of attack of the rocket, it is therefore given in rad^{-1}. Maximum values during flight are between 16.8 and 21.2.

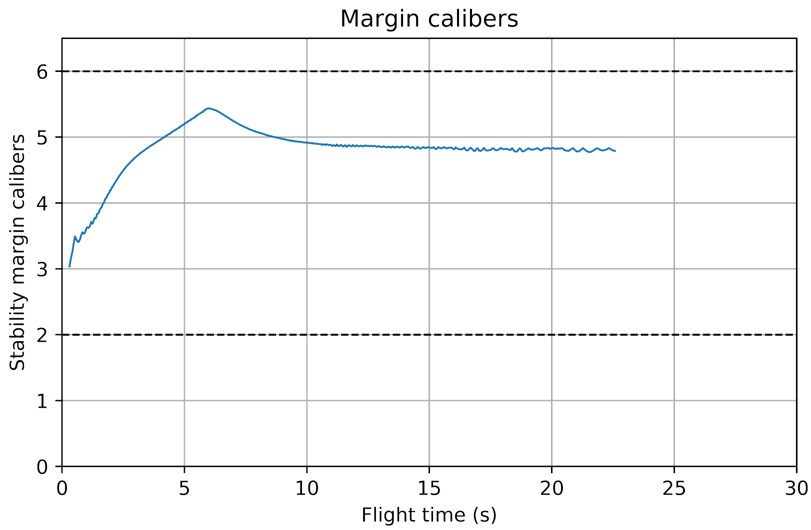


Figure 5: Stability margin is given is rocket diameters, and gives the distance between the centers of pressure and gravity. Extreme values are 3.07 and 5.4.

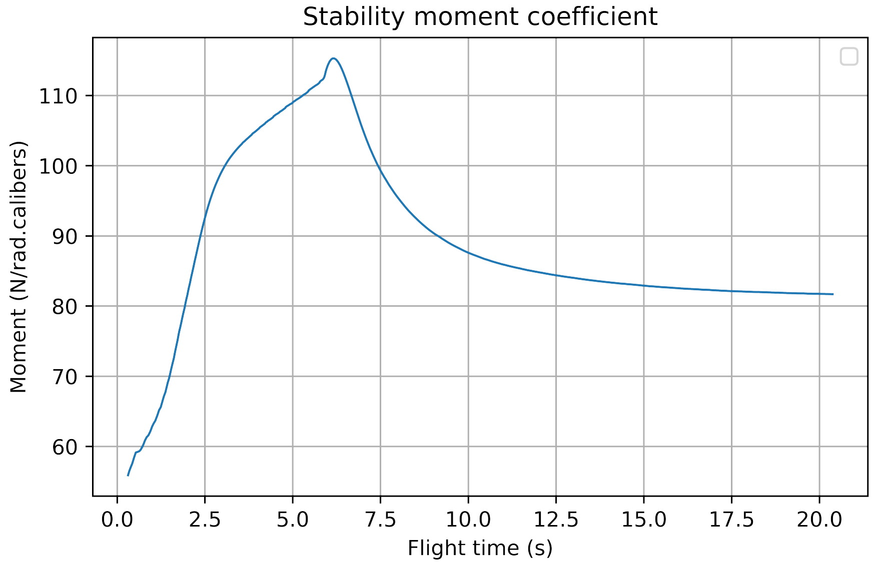


Figure 6: Finally, stability moment is the coefficient of the reacting moment given by the fins to maintain the angle of attack to 0. Maximum moment is for now at around 115.

According to CNES specifications on stability moment coefficient, the current design gives a slightly over-stable rocket in early flight phases. According to these specifications, design changes could be made for the center of gravity to be lowered or fins to be put higher on the rocket.

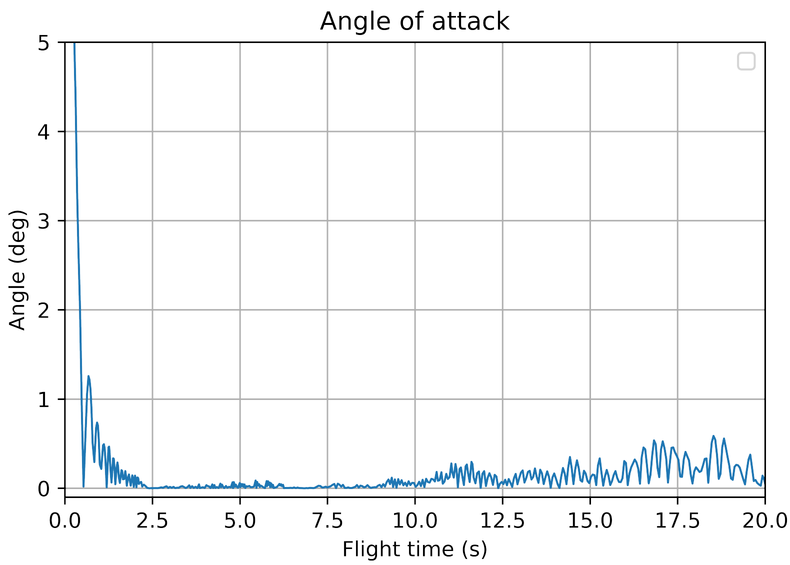


Figure 7

Despite this suposed over-stability of the rocket due to high stability moment coefficient, simulated values for the angle of attack seam to give a stable behaviour. Initial stabilization while leaving the ramps takes less than 2 seconds, and the angle of attack does not exceed 1 for the duration of the flight. Current stability design looks satisfactory.

6 KINEMATICS OF THE ROCKET

This final part gives the forces exerted on the rocket, then kinematic behaviour of the rocket at first, to give data for sizing the most critical parts. The most critical parts for the structure are the thrust plate, fins, parachute system, gridfins and interface rings.

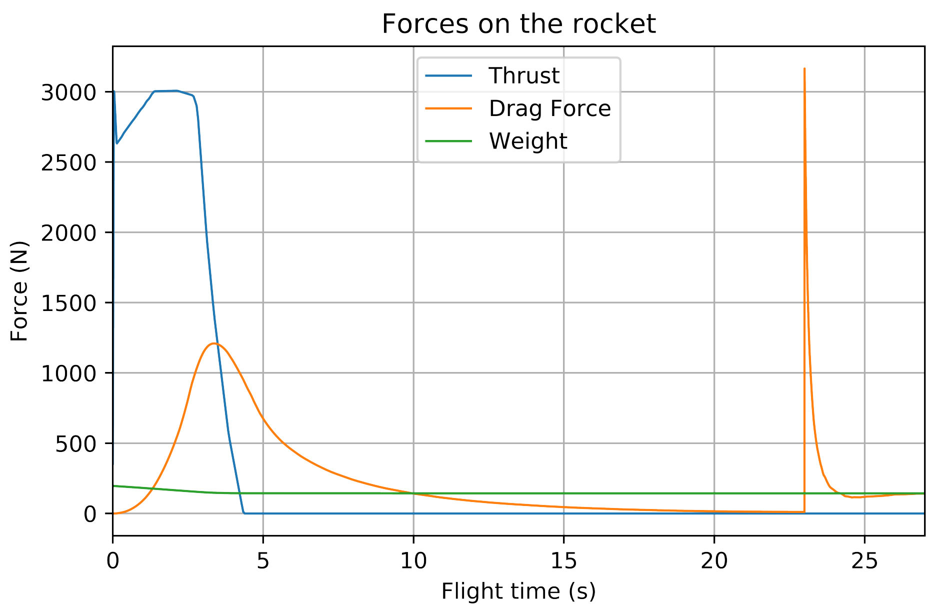


Figure 8

Sizing forces			
Flight phase	Sizing part / subsystem	Data	Value
Boosting phase	Thrust plate and interface rings	Thrust	6000 N
	Fins and gridfins	Drag force	2400 N
Parachute opening	Parachute	Drag Force	6400 N
Parachute fall		Weight	280 N

Table 4: Data above are given with a safety coefficient of 2 with respect to the values found in simulations.

Maximum kinematic values		
Flight phase	Data	Value
Boosting phase	Acceleration	150 m/s^2
	Velocity	410 m/s
Parachute opening	Acceleration	220 m/s^2

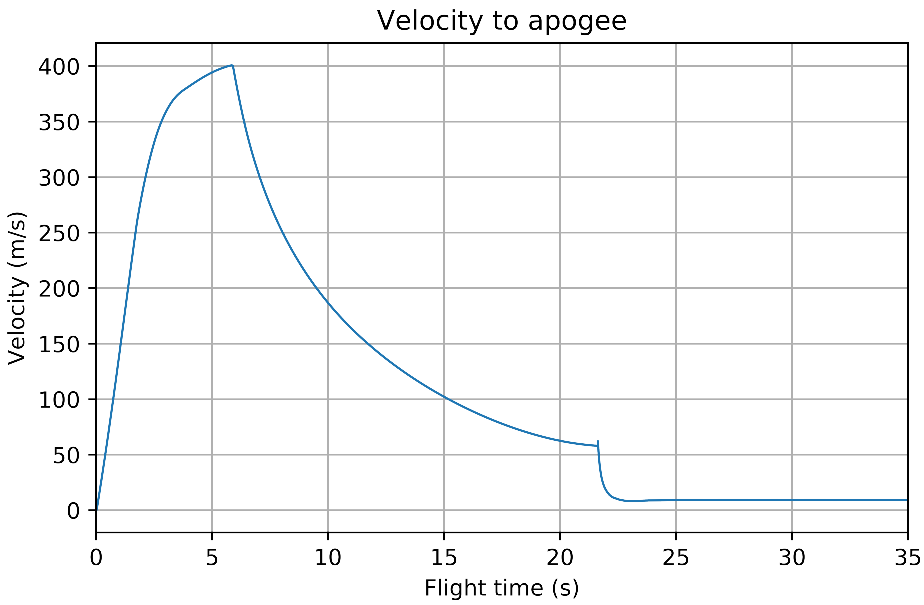


Figure 9

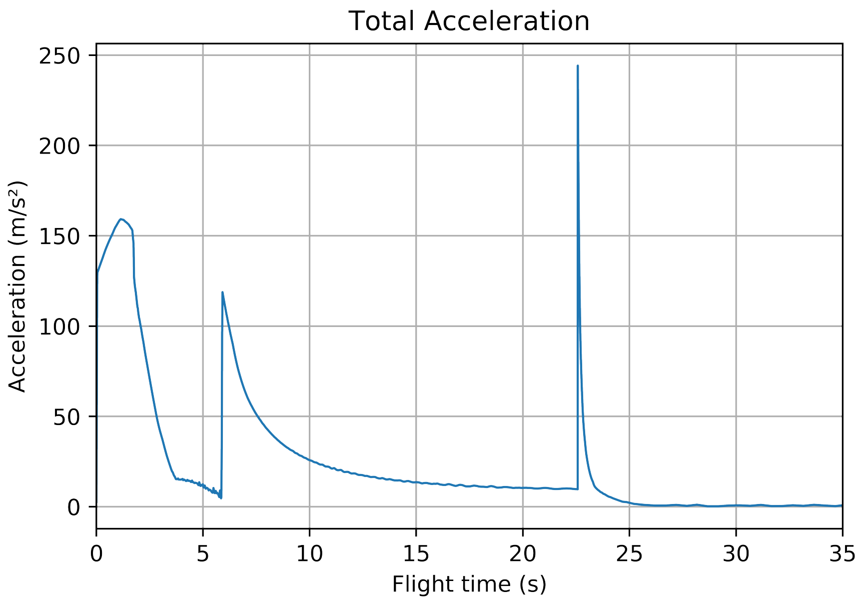


Figure 10