SKYWARD EXPERIMENTAL ROCKETRY

a student association from Politecnico di Milano

Stochastic trajectories tool for sounding rocket telecommunication subsystem design

Abstract

The aim of this work is to provide a useful tool to compute the trajectory of a small sounding rocket and show how this kind of simulation can influence the overall system design. In particular it will be presented the interface with the telecommunication subsystem of the Roxanne I-X rocket up to the determination of the link budget. Stochastic simulations will help to robustly determine useful parameters regardless of the scarcity of available data on the whole system.

Stochastic simulation

System model

The sounding rocket flight can be divided in different phases:

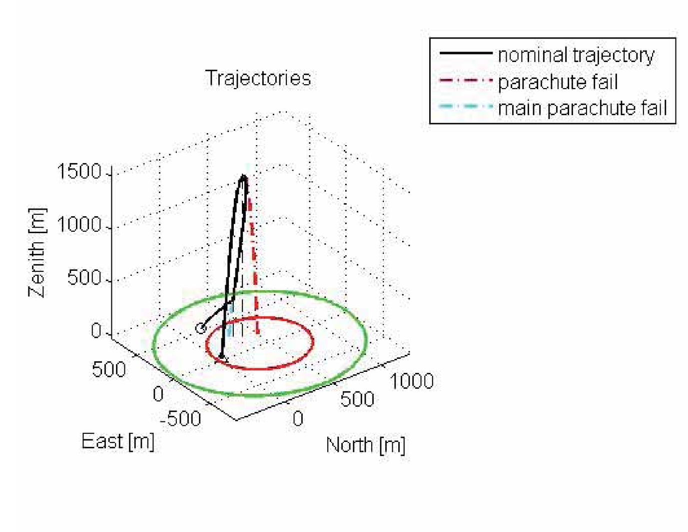
- thrusting phase,
- ballistic phase,
- drogue parachute phase,
- main parachute phase.

For the first two a 6 d.o.f dynamical solver has been implemented. Under the hypothesis of rigid body rocket the translational and rotational dynamics have been addressed in order to reconstruct the trajectory, the velocity profile and the attitude stability.
The aerodynamics coefficients of such a rocket have been computed using Missile Datcom and stored in structures such that at each step the solver can interpolate and determine the coefficient corresponding to the current conditions in terms of mach, angle of attack, angle of sideslip and altitude (air properties). The in-plane aerodynamics has been checked using other methods and software, while the out-of plane behavior is still unchecked. This uncertainties, added to the overall datcom software accuracy, let to the choice of not taking into account the yaw and roll aerodynamics. In a sense this reduced the effective d.o.f of the simulation, since a proper experimental work is needed in order to have the necessary confidence in the model.
The parachute model used is a simplified translational 3 d.o.f where the rocket and the parachute are represented as a single point. The real system is a multy-body flexible system, however due to the lack of experimental data on the parachute it has been decided to reduce the complexity of the model and rely more on a stochastic method to compute the required parameters. Regardless of the simplification, to better reconstruct the phenomena it has been introduced the transient of the parachutes inflation. From the parachute subsystem point of view the apogee altitude, the time needed to reach it and the duration of the drogue phase are necessary to implement a robust deployment electronic system.
One of the main factor that influences the total ground distance covered by the rocket, very important from the ttelecommunication point of view, is the wind. The wind has been modeled using a wind shear method and imposing nominal wind direction and intensity. These parameter will vary in the stochastic simulations.

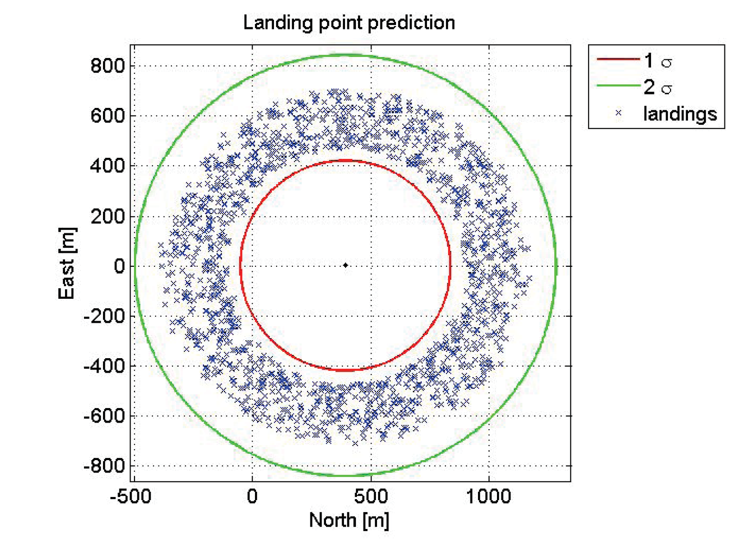
Monte Carlo method

The Monte Carlo method has been devised in order to give more robust data for the design of other subsystems. The parameter that change from one simulation to the other, keeping constant for each one, are related to the thrust (burning time and specific impulse as propellant mass is fixed) and the parachutes drag coefficients. All the aerodynamic forces and wind conditions are also influenced by a random variable during the simulation. This choice increase the computing time but permits to have also a dynamical robustness during each simulation. It is a common behavior that the wind direction and speed changes in time, therefore this method permits to easily take into account the dynamics of the atmosphere without having to devise a very complex algorithm. For the simulations presented, a general wind direction has been identified in order to better represent a pre-launch procedure where some measurements are done in-situ.
The parameters of which has been computed mean and variance are:

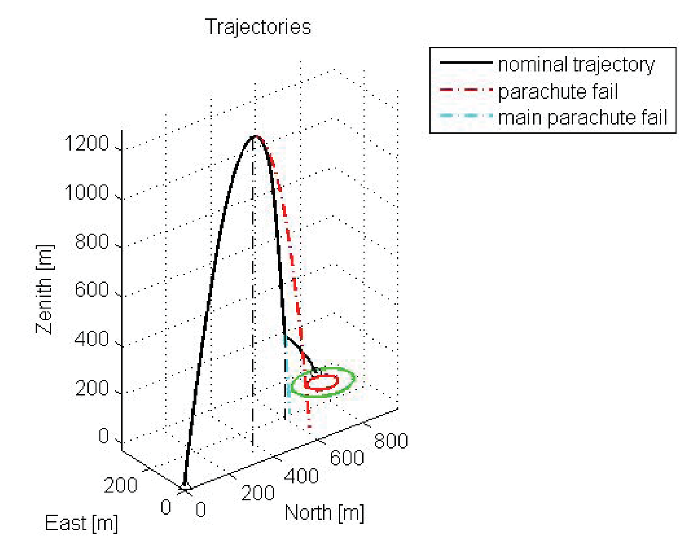
- apogee position and time needed to reach it,
- main parachute deployment location and time delay,
- landing point in the best case and with partial or total parachutes failures,
- velocity of impact of such landing points.



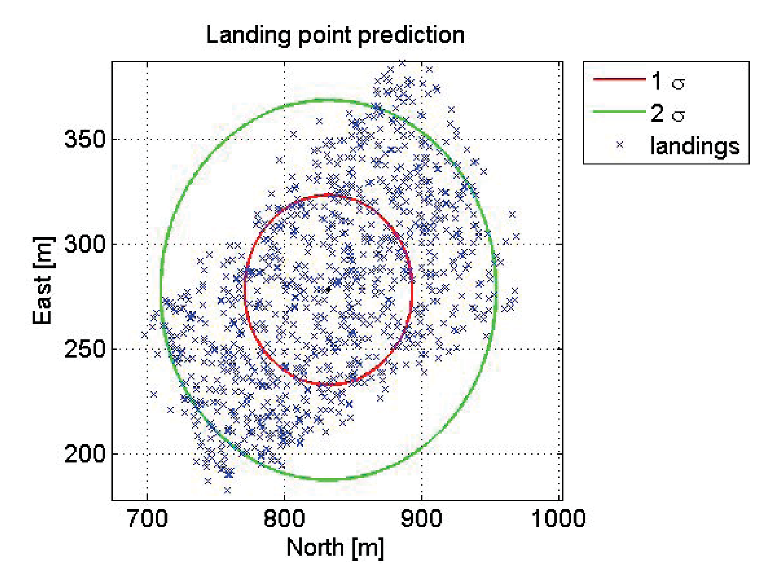
trajectoy with no preferencial wind direction



main parachute landing point with no preferencial wind direction



trajectoy with preferencial wind direction



main parachute landing point with preferencial wind direction

Telecommunication subsystem

Design

Rocksanne I-X implements a wireless comunication system made basically of a pair of RTX module (ZigBee) operating at 2.4 GHz, each one connected to an specifically developed antenna: one at the ground station and one flying attached to the rocket. In order to design and valuate the link performance it has been used a mix of software and algorithm to model the system. This is the common CAE approach.

The design goal for the telecommunication subsystem were to

- obtain a strong, and stable signal between the rocket and the ground,
- receive data in real-time from sensors in order to follow the path of the rocket.

The parameters involved in this calculation are:

- the distance from the two stations,
- the features of the radio modules,
- the antenna radiation pattern,
- the propagation quality.

Since the launch requires quasi-perfect condition (no rain, fog etc.) it has been assumed to have no atmospheric losses in our simulations. Standard ZigBee features was taken into account:

- +17 dBm of output power
- -106 dBm of receiver sensibility

Ground antenna

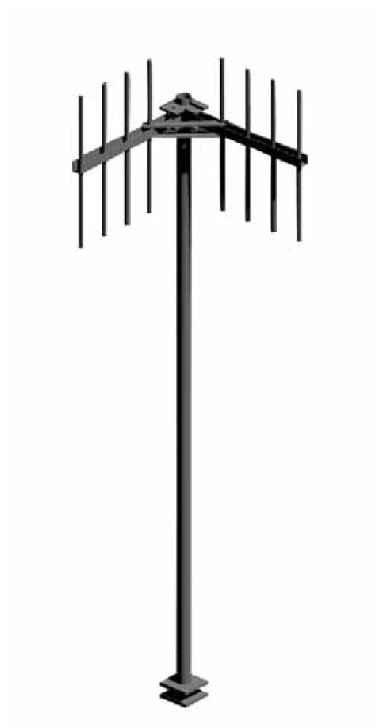
The ground antenna has a 90 degrees corner reflector with a simple dipole, providing a gain higher than 10 dB for the main direction. Creating a FEM model with another software and computing it's electromagnetical properties, it has been extracted the radiation pattern. Through the simulations it has been found that tilting the antenna from ground at about 45 degrees increase the overall link margin.

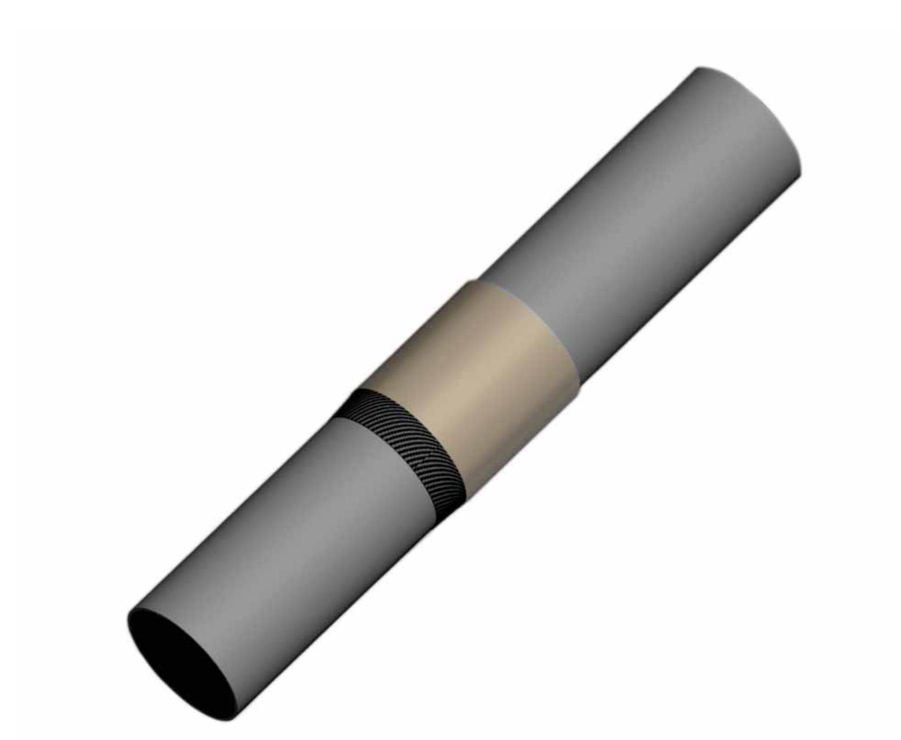
Patch-array antenna

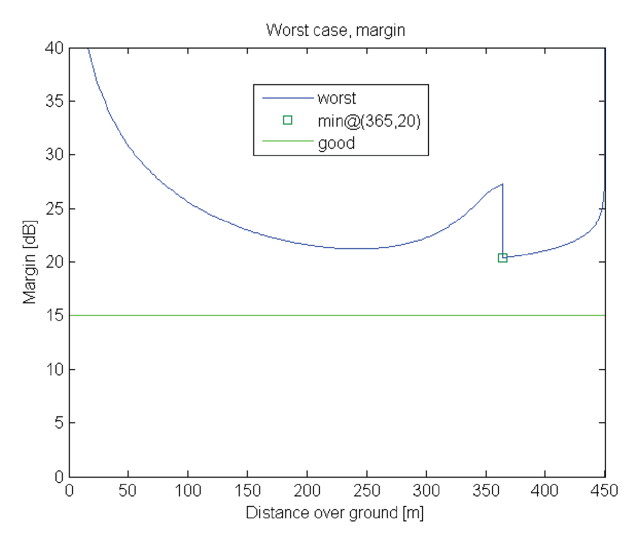
The on-board antenna has a microstrip patch array wrapped around the cylindrical fuselague under a teflon coverage. This antenna include also a GPS antenna, but this is not covered in this poster. A full-wave simulation of the entire array in these case was too expensive, hence it has been chosen to simulate only one of the four patch in the array and then, using antenna theory, it has been computed a total radiation pattern. The increase in gain due to the array effect and the loss due to disalignment from patch caused by the rocket spin on the roll axis have been neglected.

Results & Conclusion

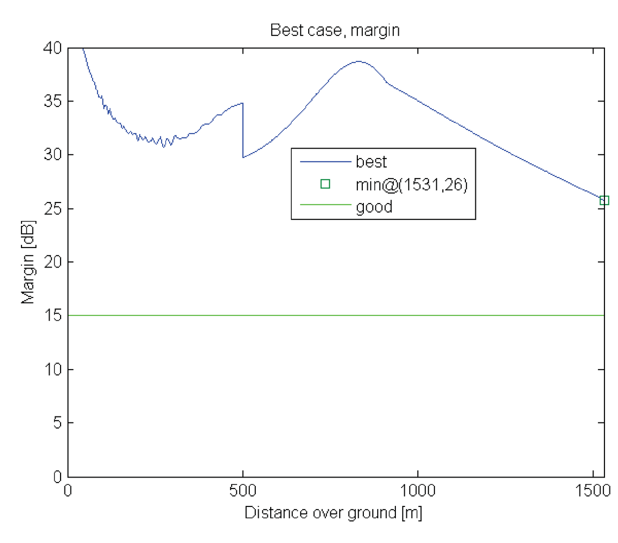
The method here presented has given reasonable and robust results, therefore it will represent the basis of development for future works. The data robustness permits to conclude that the telecommunication subsystem performance are in accord with its design. Simulations shows that the Margin is above the limit also in case of a strong wind.


ground antenna


on board antenna



margin with 3 m/s wind (worst case)



margin with no wind (best case)

Future work

Future works will be oriented on increasing the reliability of the parachute model and to better correlate trajectory dispersion and off-limits areas with the wind in order to prepare the best launch procedures obtainable. The dispersions can be reduced enormously with experimental data, but this do not depend on the presented tool, moreover the interpretation of data computed with this tool can be useful to choose which experimental activity should be preferred in order to reduce costs.

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References

[1] Box, Simon, Christopher M. Bishop, and Hugh Hunt. "Stochastic Six-Degree-of-Freedom Flight Simulator for Passively Controlled High-Power Rockets." Journal of Aerospace Engineering 24.1 (2010): 31-45.

[2] Giorgio Guglieri, "Introduction to Parachute Subsonic Aerodynamics" Politecnico di Torino

[3] Chusilp, Pawat, Weerawut Charubhun, and Navapan Nutkumhang. "A Comparative Study on 6-DOF Trajectory Simulation of a Short Range Rocket using Aerodynamic Coefficients from Experiments and Missile DATCOM."

[4] R. Munson, "Conformal microstrip antennas and microstrip phased arrays" IEEE Transactions on antennas and propagation , January 1974.

[5] David M.Pozar " Microwave Engineering" , 3rd ed., Wiley, 1997