Re-entry predictions of space debris for collision avoidance with air traffic

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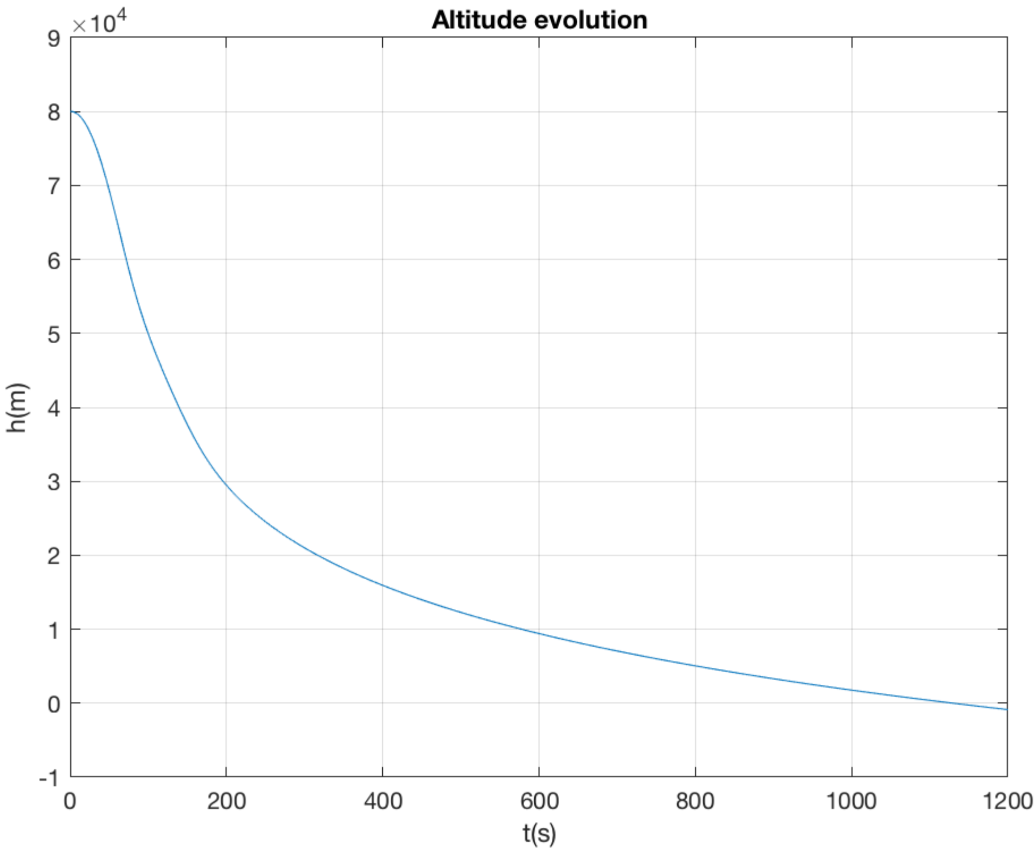
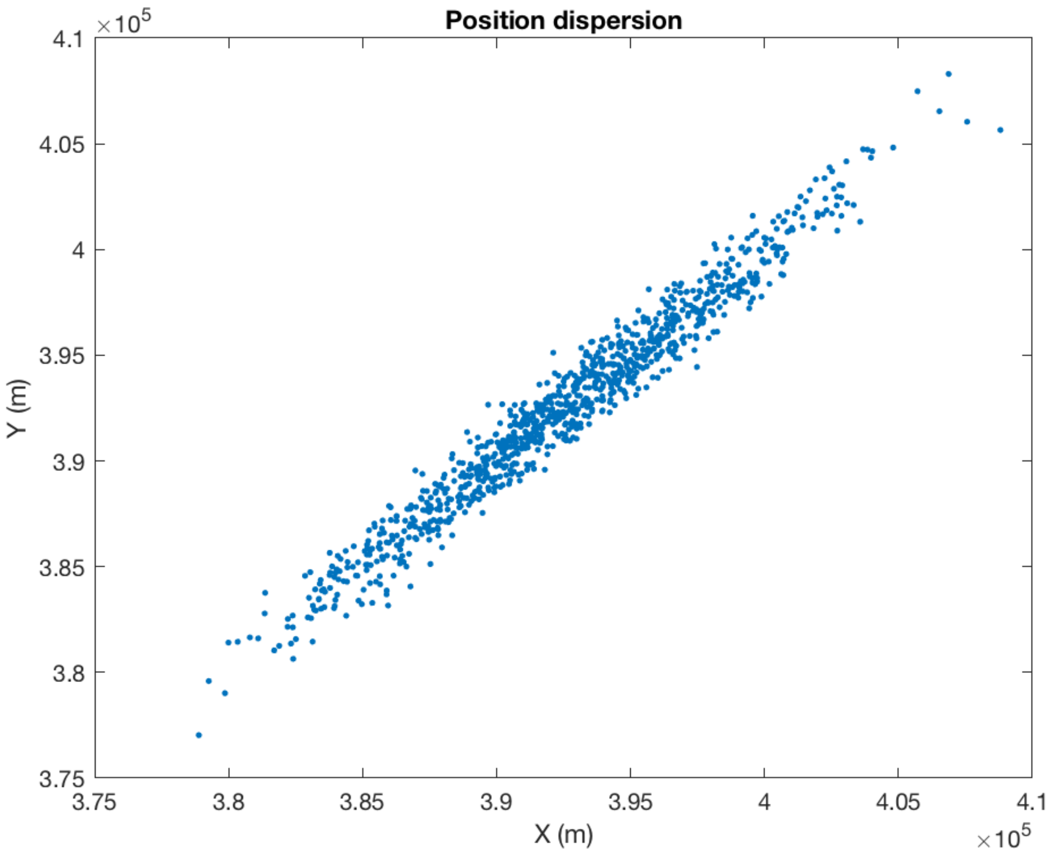
Abstract:

In the past decade, the uncontrolled re-entries of spacecraft and core stages have been quite common, as about 100 satellites and rocket bodies have re-entered the atmosphere each year. However, the re-entry of the core stage of the rocket that launched Tianhe, CZ-5B R/B, in May 2021 attracted a great worldwide attention and concerns as it was the heaviest uncontrolled re-entry since Salyut 7 in 1991. Due to their huge payload, such falling space debris threaten general population. On the other hand, commercial aircraft is a much larger target area because the lethality of each debris object is larger for aircraft, since the relative speed with respect to the aircraft at cruise altitude is much greater than its terminal fall speed prior to Earth impact. Therefore, the need for a safe and efficient integration of Space Vehicle (SV) operations into air traffic system to minimize the risk on human life and to sustain a steady air traffic is evident. For that purpose, the Federal Aviation Administration (FAA) defined in May 2020 a Concept of Operations (ConOps) based on three different Airspace Management Methods to ensure Commercial Space Integration into the National Airspace (NAS). In this paper, a scenario is considered, where a spacecraft experiences dysfunctions of the control mechanisms. Therefore, the re-entry is considered as completely uncontrolled. During such re-entry, predictions are very difficult and are affected by various sources of uncertainty, such as the initial conditions, the ballistic coefficient, the modelling of atmosphere, etc. Therefore, these uncertainties need to be quantified to correctly assess the risk of impact on areas of interest. In this paper Monte Carlo simulation is implemented to propagate uncertainties through a large number of simulations over randomly sampled initial conditions. The paper focuses on the impact of uncertainties in the initial conditions as well as in the ballistic coefficient for the test-case of an Earth atmospheric re-entry. Then the resulting position distribution throughout airspace boundaries is analysed and the impact on Air Traffic is estimated by defining protected airspace areas. As consequence, this work provides a strategy toward more efficient uncontrolled re-entries by combining uncertainty propagation analysis with the FAA's ConOps in the framework of the FAA's Next Generation Air Transportation System (NextGen). To verify the proposed results, the re-entry of the core stage CZ-5B R/B was simulated. The following figures show the typical altitude profile during the uncontrolled re-entry and the position dispersion of the falling debris when reaching a specific airspace level, which need at this point to be cleared with a sufficient advance warning time.


Altitude evolution
$\times 10^4$
9
8
7
6
5
4
3
2
1
0
-1
h(m)
0
200
400
600
800
1000
1200
t(s)


Position dispersion
$\times 10^5$
4.1
4.05
4
3.95
3.9
3.85
3.8
3.75
Y (m)
3.75
3.8
3.85
3.9
3.95
4
4.05
4.1
X (m)
$\times 10^5$

Keywords : Air traffic, Uncontrolled reentry, Monte-Carlo simulation, Reentry predictions, Collisions avoidance

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