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Location of space debris by infrasound

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After an exhausted stage has separated from a rocket it comes back to the dense atmosphere. It burns and divides into many pieces moving separately. Ballisticians can calculate an approximate trace of a falling stage and outline a supposed area where the debris can fall (target ellipse). Such ellipses are usually rather big in sizes (something like 60 x 100 km).

For safety reasons all local inhabitants should be evacuated from a target area during rocket's launch. One of problems is that the ballistician can not compute the traces and areas exactly. There were many cases when debris had fallen outside the areas. Rescue teams must check such cases to make changes in rockets. The largest pieces can contain remains of toxic rocket fuel and therefore must be found and deactivated.

That is why the problem of debris location is of significant importance for overland fall areas. It is more or less solved in Kazakhstan where large fragments of 1st stages can be seen in the Steppe but it is very difficult to find fragments of 2nd stages in Altai, Tomsk region and Komi republic (taiga, mountains, swamps).

The rocket debris produces strong infrasonic shock waves during their reentry. Since 2009 the Kola Branch of Geophysical Survey of RAS participates in joint project with Khrunichev Space Center concerning with infrasound debris location. We have developed mobile infrasound arrays consisting of 3 microphones, analog-to-digit converter, GPS and notebook. The aperture is about 200 m, deployment time is less than 1 hour. Currently we have 4 such arrays, one of them is wireless and consists of 3 units comprising a microphone, GPS and radio-transmitter. We have made several field measurements by 3 or 4 such arrays placed around target ellipses of falling rocket stages in Kazakhstan ("Soyuz" rocket 1st stage), Altai and Tomsk region ("Proton" rocket 2nd stages). If was found that a typical 2nd stage divides into hundreds of pieces and each one generates a shock wave. This is a complicated problem to associate signals registered by different arrays.

We developed an approach based on modeling of realistic fragment trajectories. We assume that until some time t0 all stage is moving along the predicted theoretical trajectory. At the time t0 (disintegration) the pieces receive different ballistic coefficients and random increments of velocity. We continue the trajectory (solving 2nd order differential equation) using the coordinates at t0 and velocities with random increments as initial conditions and with different ballistic coefficients. Thus we obtain a 'pipe' of trajectories each one can in principle occur in reality. For each trajectory of the pipe we compute theoretical times and azimuths of shock wave arrivals to the arrays. If they are in agreement with the measured arrivals we consider that the trajectory has occurred in reality and its end is the landing place of a rocket fragment.

The experiment of "Soyuz" 1st stage location in Kazakhstan has shown that errors of such location are less than 2 km that is acceptable to use the method in practice.