Introduction

On April 23, 1965 the first *Molniya-1* spacecraft was launched by former Soviet Union, [1]. After that many others were launched until 2004. These satellites were initially designed for Russian communication networks and their orbits form a class of special orbits around Earth: the *Molniya orbits*. Let us call generically *Molniya satellite* a object orbiting along a Molniya type orbit.

The main dynamical features of Molniya orbits are:

- *period of approximatively* 12 *hours*
- *eccentricity* $e \geq 0.7$
- *inclination* $i \approx 63.43\,\mathrm{deg}$
- *argument of perigee* $\omega = 270\,\mathrm{deg}$

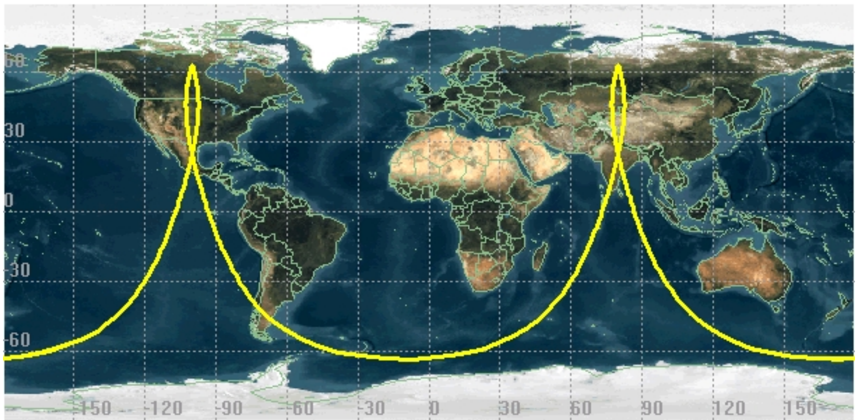

Figure 1: Sub satellite ground track of a Molniya satellite.

Why did they choose such orbital elements? The territory to cover was, and still is, enormous and is located at a high latitude, thus a high eccentricity and a quite stable apogee above the region of interest are needed. A constellation of at least three Molniya satellites provide a continuous coverage. The value of the inclination used is close to the *critical inclination* value; in this way the oblateness of our planet does not induce a precession of the line of apsides, therefore apogee and perigee are almost frozen because $\omega = 270\,\text{deg}$ is a stable position. Finally the time interval between two passages through the ascending node must be half of sidereal day to ensure that the ground track repeats every 24 hours.

These orbits are particularly interesting from a dynamical point of view. The orbital period of a Molniya satellite is commensurable with the Earth's rotation period: each day a Molniya satellite revolves around the Earth two times. The consequence is a $2:1$ *tesseral resonance*[1] whose effects couple with the critical inclination resonance effects. Moreover, a Molniya satellite undergoes several perturbations. The low value of the altitude of the perigee gives a non-negligible atmospheric drag, which deeply affects the evolution of the semi-major axis. Besides, the satellite spends the most of the time at high altitudes, thus the lunisolar effects play a fundamental role on timescale larger than a satellite orbital period.

Some Molniya satellites launched before 1974 experienced a quick decay, but the satellites launched after 1974 did not. Molniya orbits are considered quite chaotic, that is, the dynamical evolution strongly depends on the initial conditions. Sometimes the chaotic growth of the eccentricity leads to quite low value of the perigee altitude, and, if the perigee altitude decrease below a certain value, the satellite decays. Moreover, the satellite operative lifetime is heavily influenced by the available propellant reserves: a Molniya satellite needs frequent station-keeping maneuvers [5]. The propellant typically exhausted in two years; sometimes it was possible to extend the lifetime of a few years.

The purpose of this thesis is to investigate the long-term effects caused by the lunisolar perturbation on a Molniya satellite dynamics. The work will be structured as follows. Ch. 1 is a short presentation of the mathematical theoretical tools that are useful to deal with the specific problem of a Molniya satellite. Ch. 2 contains an overview of the Molniya orbits. Some previous results found in the literature are also presented. In the second part of Ch. 2 the analytical doubly-averaged model for a Molniya satellite is built, up to the third order expansions of the lunisolar disturbing functions. Ch. 3 exhibits some numerical investigations on the doubly-averaged lunisolar model in order to identify the dominant perturbing terms. The main *resonant* terms, selected in Ch. 3, are studied as isolated resonances in Ch. 4. The aim of Ch. 4 is to identify a possible resonances overlapping region in the proximity of the Molniya orbital environment. Finally, Ch. 5 provides an overview of the main results obtained so far, and offers some further investigations which may be the topic of future works. All the numerical results are achieved by using *Mathematica*.

[1] It is called *mean motion resonance* in [24], but it does not arise from a commensurability between mean motions. For this reason, we will call it tesseral resonance throughout the discussion.