LA-UR-97-2273

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Title: Thermal Rocketing and the Laser Geodynamic
Satellite (LAGEOS-1)

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Submitted to: DOE Office of Scientific and Technical Information (OSTI)

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Thermal Rocketing and the Laser Geodynamic Satellite (LAGEOS-1)

Warner A. Miller*

Abstract

This is the final report of a one-year, Laboratory Directed Research and Development (LDRD) project at the Los Alamos National Laboratory. LAGEOS is the most accurately tracked satellite in orbit. It is a totally passive, dense spherical satellite covered with 426 cube corner reflectors. Besides its great utility in measuring the Earth's length of day and polar wobble, this satellite can be used to measure, for the first time, the general relativistic frame-dragging effect. Of the five dominant error sources in such an experiment, the largest one involves surface interaction of thermal forces (thermal rocketing) and its influence on the orbital nodal precession. The project objective was to enhance an already available theoretical model (computer code) developed at Los Alamos based on new optical-spin data obtained at the University of Maryland. The project objective was met and the enhanced code will serve as the new spin-dynamics model for future LAGEOS satellite missions.

Background and Research Objectives

In previous work we undertook a theoretical effort to model the spin dynamics of a LAGEOS-type satellite. It is the knowledge of the state of spin axis of the satellite that allows one to minimize the consequence of the thermal rocketing effect on the rate of nodal precession. In particular, we integrated the spin dynamics equations numerically. These equations included the eddy-current interaction within the satellite with a perfect dipole field. Furthermore, the satellite was assumed to be a perfect sphere of brass (a fair approximation), and its orbit was assumed to be spherical and not precessing. Using this model we were able to qualitatively analyze the spin dynamics through its spin-orbit resonance phase and onto its tidal-locking phase.

Importance to LANL's Science and Technology Base and National R&D Needs

The geodynamic data we obtain from LAGEOS-I and -II is used to determine Universal Time (UT-1) and polar wobble (xp,yp). This data is crucial for real-time

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navigational systems. The analysis of the surface forces on the LAGEOS satellite has solved anomalous orbital dynamics paradoxes in LAGEOS (e.g. the 1-mm delay of LAGEOS's orbit is a result of thermal rocketing).

The goal of the LAGEOS-3 mission is to measure the frame-dragging effect predicted by Einstein's theory of gravity. This effect provides the key mechanism of astrophysical jet alignment in AGNs (Bardeen-Petterson effect).

Scientific Approach and Accomplishments

A new set of observational measurements between 1988 and 1996 were made available in a joint effort with Professor Curie of the University of Maryland. These measurements made it possible to test our enhanced theoretical model with experimental data. Enhancing our model involved four tasks:

- 1) Creating a more realistic model of the Earth's magnetic field by including the tilt of the dipole field.
- 2) Including the tidal precession of the line of nodes of the satellite's orbit ($\sim 126^\circ/\text{yr}$) due to the oblateness of the Earth.
- 3) Starting the calculation using data points from our effort with Professor Currie. This requires one to relate the Euler angles and their time rate of change to R.A and DEC.
- 4) Provide a qualitative argument transcribing the numerical results to the actual satellite geometry. For example, the eddy currents will be greatly reduced due the 426 cylindrical holes drilled into the aluminum shell of the satellite.

These modifications were made and the code results were compared with the glint measurements of Professor Currie in the recent RAU Colloquium 165 on the "Dynamics of Natural & Artificial Celestial Bodies" held in Poznar, Poland. A manuscript comparing the data with observations is currently in preparation. The code results were consistent with the observations made at the University of Maryland. In particular, the drift of the spin axes of LAGEOS-1 toward the North Pole was correctly modeled for the first time. In addition, our code predicts a spin-orbit resonance phase that can dramatically affect the orientation of the satellite.

Our enhanced code is more advanced than any other in the field. It will serve as the new spin-dynamics model for future LAGEOS satellite missions.

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