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DR E. A. ROTH'S CONTRIBUTION TO ASTRODYNAMICS

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Abstract—This paper presents the major contributions of Dr E. A. Roth, deceased in 1985, from his first studies in ballistic and rocketry, to the analytical theories of the perturbed motion of a satellite and in particular his "stroboscopic method".

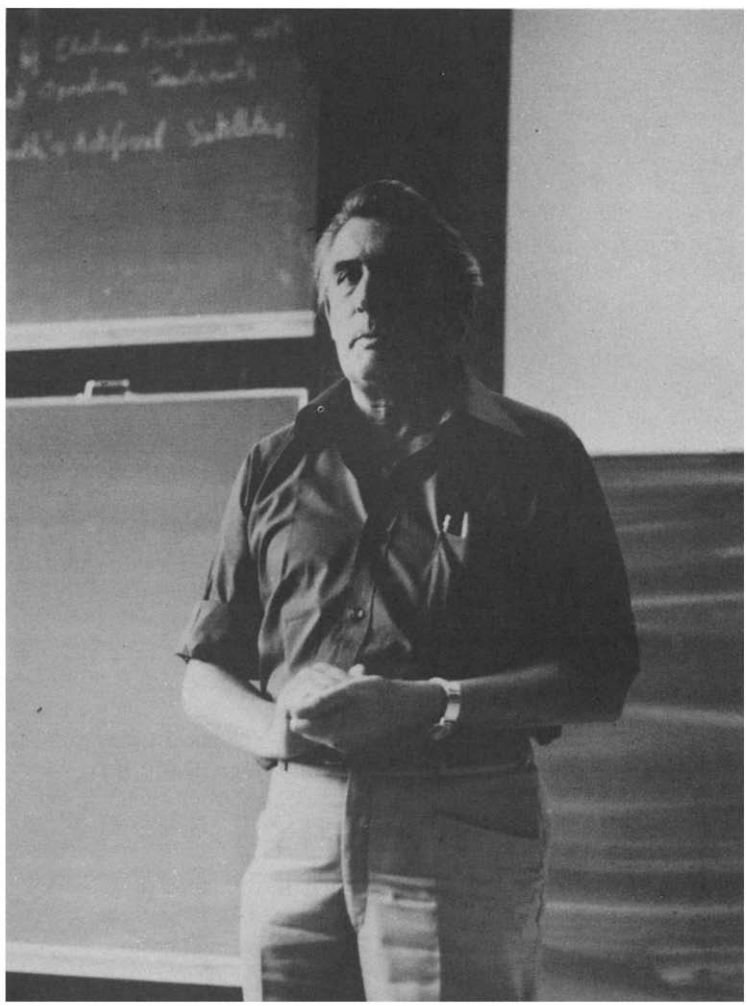

Fig. 1. E. A. Roth (1921–1985).

Dr Roth† (Fig. 1) studied mathematics at the Swiss Federal Institute of Technology in Zürich, where he also obtained his Ph.D in 1953 [2]. His interest in dynamical problems can be traced back to 1949 when he co-authored Professor R. Sänger's book on perturbation method for ballistic [1]. His investigations in ballistic and rocketry allowed him to publish a series of seven papers in *ZAMP* (*Zeitschrift für angewandte Mathematik und Physik*).

Dr Roth joined ESRO/ESA in January 1966, and shortly afterwards was appointed Head of the Section of Theoretical Research. In 1971 he was made Head of the Spacecraft Trajectory Division, and he has

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been Head of the Mission Analysis Office since January 1981.

In all these functions, Dr Roth made major contributions to the successes of the Agency. He played an important role in the conception and design of many ESRO/ESA missions and most of the scientific projects. His practical attitude, combined with a solid theoretical background helped to build his international recognition. Due to his large experience his advice was highly priced.

Numerous publications and contributions to international meetings give evidence of his extensive work in celestial mechanics. He was regularly invited to participate in the *Oberwolfach Conference on Celestial Mechanics* (proceedings of his communications in [4, 5, 9, 10, 14]). At the annual *Congress of the International Astronautical Federation* he was chairman of the session on Natural Trajectories of the Symposium on Astrodynamics and member of the Astrodynamics Committee.

His favourite field of interest was analytical theories for the perturbed motion of a satellite. Since the early days of ESRO fast methods for orbit computation were needed for general mission studies as well as for launch windows and lifetime analyses. Among the first satellites launched by ESRO two of them, namely HEOS-1 and -2, were to be placed on a highly eccentric orbit ($e = 0.9$). Due to the lunisolar perturbation on the eccentricity influencing the perigee height, such an orbit is rather unstable and initial conditions have to be selected in order to guarantee that the perigee will not drop below the Earth surface during the satellite's operational lifetime. This imposes a constraint on the launch window and leads to estimate the satellite's orbit history for a grid of launch dates and hours. In order to keep computing time in reasonable limits, Dr Roth developed a semi-analytical scheme, called the stroboscopic method, for fast propagation of satellite orbits.

In the stroboscopic method, the perturbations are integrated analytically along one revolution on the basis of the initial osculatory state at a particular point on the orbit (the perigee for eccentric orbits). This procedure is then repeated for many revolutions. Since the orbital state is provided only once per revolution, a kind of stroboscopic view of the trajectory is obtained.

This method, first published in an ESRO report [3], was constantly refined (see, for example [5]) and used for lifetime and launch window estimations of the ESRO/ESA scientific satellites HEOS-1, HEOS-2 [4], COSB, ISEE-2 and EXOSAT.

During the emergency operations for GEOS-1, which was inserted into a non-nominal orbit on 20 April 1977, the stroboscopic method allowed to gain quickly an overview over the numerous options.

Anticipating the need of including new types of perturbations for orbit computation of planetary orbiters, Dr Roth investigated the extension of the stroboscopic method to third-body perturbations of a Moon orbiter [14], to the perturbation of a Galilean orbiter by the oblateness of Jupiter [10] and by other Galilean moons [15].

More recently, the stroboscopic method was extended to higher order in the treatment of the gravitational potential [12, 13]. For including circular or equatorial orbits, the method was also applied to equinoctial elements [16, 18]. Dr Roth's last paper, presented at the *36th IAF Congress* [20], deals with a more refined treatment of the air drag perturbation for the equinoctial version of the stroboscopic method.

For spacecraft cruising in a heliocentric orbit, Dr Roth investigated the perturbation due to the asteroid ring [6] and the radiation pressure [7].

Dr Roth participated actively in the mission definition phase of new ESRO/ESA scientific projects.

For the project SOREL of a heliocentric probe aimed at experimentally testing the General Relativity theory, Dr Roth published not less than six papers (see, for instance [8]).

For analyzing the scientific merit of proposed orbits for scientific satellites, Dr Roth developed fast analytical ways for evaluating the relation of the orbit with the terrestrial and planetary environment described by mathematical models [11].

Purely computational aspects were not neglected by Dr Roth and he showed much interest in modern computer languages, software design and advanced fields like artificial intelligence. One of his ideas was to build an expert system acting as a front-end to a formula manipulation program which would automatically develop a tailor-made analytical theory for a given application.

Dr Roth was fully aware of the problem of the crowding of the geostationary orbit [17], the safety hazard of space debris [19] and the importance of accurate satellite decay prediction [9]. In September 1985, he organized a workshop at ESOC on Re-entry of Space Debris, which his illness unfortunately prevented him from attending. The proceedings of this workshop, published in ESA SP-246, is dedicated to his memory.

Dr Roth helped many young people entering the space field, and post-graduates often found inspiration as Visiting Scientists within his group. He also lectured regularly on spaceflight dynamics at the Technische Hochschule Darmstadt.

With his death on 4th October 1985, we lost an esteemed friend and colleague, a man of great experience and an enthusiastic supporter of space activities, who was always willing to help with his much-valued expertise.

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