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Chapter 9

THE SCIENTIFIC FOUNDATIONS OF SPACE FLIGHT IN NEWTON'S "PRINCIPIA" (1687)*

(On the occasion of the 300th anniversary of the first publication of "Principia")

Mieczyław Subotowicz†

In 1987 we celebrated the 30th anniversary of the Space Era. In October 1957 the first flight of Russian Sputnik was realized—the first artificial satellite of the Earth. In this connection the names of many important scientists, engineers, and technicians who contributed to the realization of the first flights of artificial satellites are mentioned, e.g. K. Tsiolkovsky, R. Goddard, R. Esnault-Peltrie, H. Oberth, W. Hohmann, A. Szternfeld, W. von Braun, S. P. Korolyev, and many others—scientists and engineers.

In this connection, I would like to present a few remarks on the contribution of I. Newton (1687) to the fundamental laws and fundamental ideas formulation concerning the possibility and realization of the reactive (jet) propulsion or rocket propulsion, and that of artificial satellites and spaceflight. This is also connected with the celebration of the 300th anniversary of the publication of the distinguished Isaac Newton's book: *Principia Mathematica Philosophiae Naturalis* [1].

ROCKET PROPULSION

In the book mentioned above [1], Newton formulated three principles of dynamics. We shall be interested mainly with the third principle of dynamics, the well known action-and-reaction principle. In it is also contained the principle of rocket propulsion. As the principle of the momentum conservation follows from the action-and-reaction principle, both principles of the description of rocket flight are given clearly and precisely by I. Newton for the first time: At that time, the second half of the XVIIth century rockets were known mainly as fireworks, and had been used at least for about the last 400 years. But nobody analyzed the principle of rocket motion scientifically as the reaction of mass thrown out of the nozzle of the

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rocket on the remaining body and fuel of the rocket. This was done by I. Newton for the first time.

HOW TO ESTABLISH AN ARTIFICIAL SATELLITE OF A CELESTIAL BODY

An important part of Newton's book [1] contains the analysis of the motion of planets around the Sun. I would like to keep my attention on the second book and its important part: "The system of the world." After a short discussion of the history of the growing understanding of the structure of the solar planetary system by Chaldeans, Egyptians, Greeks, and Romans, the book deals with the principle of circular motion in free space. The force responsible for the circular motion of celestial bodies is called "a centripetal force, as it is a force which is directed towards some center; and, as it regards more particularly a body in that center, we call it circumsolar, circumterrestrial or circumjovial, and so in respect to other central bodies."

To explain how to understand "that by means of centripetal forces the planets may be retained in certain orbits . . . we [must] consider the motions of projectiles." "For a stone that is projected, by the pressure of its own weight, is forced out of the rectilinear path, which by the initial [velocity] alone it should have pursued, and made to describe a curved line in the air; and through that crooked way is at last brought down to the ground; and, the greater the velocity with which it is projected, the further is goes before it falls to the Earth. We may therefore suppose the velocity to be so increased, that it would describe an arc 1, 2, 5, 10, 1000 miles before it arrived at the Earth, until at last, exceeding the limits of the Earth, it should pass into space without touching it." This is the first scientific formulation of the possibility of how to launch artificial satellites of the Earth. Isaac Newton accepts that "there is no air about the Earth, or at least it is endowed with little or no power of resisting."

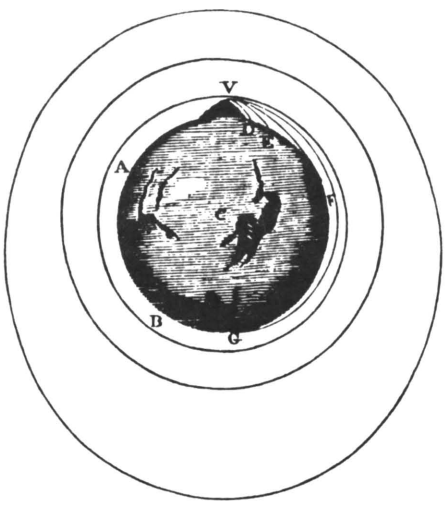

Figure 1 This figure taken from Newton's book proves the possibility of launching an artificial satellite.

In Figure 1 "AFS represents the surface of the Earth, C its center; VD, VE, VF the curved lines which a body would describe if projected in a horizontal direction from the top of a mountain successively with more and more velocity." . . "for the same reasons the body projected with less velocity describes, the lesser the arc, VD, and with a greater velocity, the greater the arc, VE, and, augmenting the velocity it goes further and further to F and G; if the velocity was still more and more augmented, it would reach, at last, quite beyond the circumference of the Earth, and return to the mountain from which it was projected." . . . . "Its velocity, when it returns to the mountain, will be no less than it was at first; and retaining the same velocity, it will describe the same curve over and over, by the same law."

> . . . But if we now imagine bodies to be projected in the directions of lines parallel to the horizon from greater heights, as of 5, 10, 100, 1000, or more miles, or rather as many semi-diameters of the Earth, those bodies, according to their velocity, and the different force of gravity in different heights, will describe arcs either concentric with the Earth, or variously eccentric, and go on revolving through the heavens in those orbits just as the planets do in their orbits.

As we see, in Newton's text, it contains an exact indication of the possibility of establishing artificial satellites of the Earth, moving along closed trajectories, circular or elliptic ones (eccentric orbits). Gravity determines the trajectory of the body. This force plays the role of the centripetal force necessary to move the body around the central (large) body. This centripetal force is directed to the center of the central body. It decreases inversely as the square of the distance from the center of the central body (Earth, Sun, Jupiter, or other planets).

REFERENCE

1. Isaac Newton: Mathematical Principles of Natural Philosophy and His System of the World, Translation into English by Andrew Motte in 1729, revised by Florian Cajori, vol. 2: The System of the World. University of California Press, Berkeley and Los Angeles, 1962 (fifth printing).