an AGA publication
Aero Geo Astro Corporation

SPACECRAFT TECHNOLOGY

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*a non-profit subsidiary of Aero Geo Astro Corp.

SPARTAN BOOKS

Library of Congress Catalog Card Number 62-21138.

Manufactured by McGregor & Werner, Inc.
Washington 12, D. C.

PREFACE

This textbook is derived, with few changes, from the text material prepared for a one-semester three-credit course in spacecraft technology given during the Spring, 1962, semester to senior engineering students in the Aerospace Engineering Department of Texas A & M College. The course was financed by a grant from the National Aeronautics and Space Administration to Texas A & M College. My services for preparing and teaching the course were provided by a contract between Texas A & M College and the Aero Geo Astro Corporation.

The course was designed primarily for senior engineering students, although it was approved for graduate credit at Texas A & M. The mathematics and physics used in this text are usually completed by engineering students in their sophomore year. The purpose of the course is to give students an over-all view of the space technology field and problems encountered in each area. It is felt that students who have completed this course are better oriented, have a better appreciation of the problems of the people with whom they work, and are better able to communicate with the people working on related problems. An attempt has been made to build the material on a mathematical and physical foundation to give the students an understanding of the difficulties encountered.

The subject matter is divided into nineteen parts. These include a historical review; the significance of space study; space science; space, launch and reentry environments; power supplies; instruments; trajectories and orbits; propulsion; communication; guidance and control; tracking, data acquisition, and data processing; materials and structures; bioastronautics; spacecraft examples; legal and political problems and future plans.

Several guest lecturers participated in the course, and I am grateful for their assistance. The information presented in several sections of this text is adapted from the remarks of these lecturers. The guest lecturers and the subjects on which they spoke are as follows: Professor A. E. Cronk, Trajectories; Dr. Richard H. Davis, Jr., Physiology; Professor Peter

Dehlinger, Gravity Fields; Mr. Albert Ferris, Data Processing; Mr. Emil A. Hellenbrand, Large Booster Structures; Mr. C. R. Morrison, Tracking and Data Acquisition; Professor Vance E. Moyer, Space Environment; Dr. James A. Roman, Bioastronautics; Professor C. H. Samson, Structures; Mr. John Scull, Guidance and Control; Professor R. L. Smith, Jr., Computers; Mr. Garth Sweetnam, Power Supplies and Professor Alymer H. Thompson, Tiros. References used in the preparation of the text are included in the lists of references at the ends of the chapters.

I am grateful for the assistance and encouragement of Professor Cronk and the members of his staff whose cooperation made this book possible. I also wish to thank Mrs. Charlotte Berg who prepared the manuscript for publication.

July 1962 Edward A. Wolff

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SPACECRAFT TECHNOLOGY

HISTORICAL INFORMATION

Before plunging into the engineering problems associated with the effort to investigate and explore space, it is of interest to review some of the history leading up to the present efforts. This chronology is not meant to be exhaustive.

A beginning date for the history of space technology is difficult to establish. One date which has been mentioned is the year 1686, the year in which Sir Isaac Newton described how an earth satellite is placed in orbit. Nearly 200 years later in 1869, Edward Everett Hale published A Brick Moon, which discussed a manned communication and navigation satellite. In 1895 a Russian, Constantino Tsioikovsky, published an article on space travel.

In 1906 an American, Robert R. Goddard, began his early experiments with sky rockets. In 1922 Robert Goddard tested the world's first liquid fuel rocket. In March 1926, he launched the world's first liquid fueled rocket at Auburn, Massachusetts. It went 184 feet in two and one-half seconds. This event has been called the rocket equivalent of Kitty Hawk. In 1928 Fritz Von Opel of Germany tested the first manned rocket car. In 1930 the American Interplanetary Society, forerunner of the American Rocket Society, was founded. In December 1930, Robert Goddard fired an eleven-foot rocket from Roswell, New Mexico, which reached a height of 2,000 feet and a speed of 500 miles per hour.

From 1930 to 1942 rockets were fired periodically in the United States, Germany and Russia. In June 1942, the Germans fired the first V-2 rocket, which reached the height of approximately 4,000 feet. By the end of 1942 the fourth V-2 rocket, which reached a height of 91 miles, had been fired. During World War II over one thousand V-2 rockets were fired toward England. In 1946 the American guided missile effort began to expand. The Army established the guided missiles group in Florida and the Navy fired several V-2 rockets from White Sands.

During 1947 the efforts at White Sands were expanded to include the use of telemetry, high-altitude photography and the parachute recovery of fruit flies and seeds exposed to cosmic rays. The first Aerobee rocket was flown to a height of thirty-seven miles in November 1947. During 1948 the V-2 and Aerobee work was continued, and the first symposium on space medicine was held at the U. S. Air Force School of Aviation Medicine.

During 1949 the firings at White Sands continued, with monkeys being sent aloft in V-2 rockets. In 1949 the first Viking Rocket was launched. It reached an altitude of 51-1/2 miles at a speed of 2250 mph and carried a payload of 464 lbs. of instruments for the measurement of upper air pressure and temperature.

In 1950 a mouse was launched in a V-2 rocket and was photographed by a camera which survived the impact upon reentry. During 1951 the Air Force Missile Test Center was established at Cape Canaveral. During 1952 more animals were rocketed into space by the U. S. and Russia. In 1953 the first Redstone Missile was test-fired by the Army at Cape Canaveral. During 1954 the first American four-stage rocket was launched at Wallops Island, Virginia. During 1955 the first Aerobee high rocket was launched. It reached an altitude of 123 miles with a payload of a hundred and ninety-six pounds. In 1956 the first five-stage solid fuel rocket was launched at Wallops Island and reached a speed of mach fifteen. The first Jupiter C was launched from Cape Canaveral. It reached an altitude of 682 miles in the range of 3,300 miles.

On July 1, 1957, the International Geophysical Year began. This was an 18-month scientific program. In August the first measurements of the earth's magnetic field were made using a balloon-launched rocket. On October 4, 1957, the Soviet Union launched the first earth satellite, Sputnik I. It weighed 184 pounds and was 22.8 inches in diameter. It carried two radio transmitters, which ceased operation on October 27, 1957. The satellite had an initial perigee of 142 miles and an apogee of 188 miles. The weight in orbit was 8,800 pounds. This satellite re-entered the atmosphere on January 4, 1958. On November 3, 1957, Sputnik II was launched. This satellite contained instruments for making scientific measurements and carried a dog.

In January 1958, the first Polaris test vehicle was successfully launched. On January 31, 1958, the first American satellite, Explorer I, was launched. This satellite was 80 inches long and 6 inches in diameter. It weighed 30.8 pounds and carried a payload of 18.13 pounds. It carried a low-powered transmitter which operated until May 23, 1958. Its initial perigee was 224 miles and its apogee 1573 miles. This satellite is expected to stay in orbit for five years. On March 17, 1958, Vanguard I was launched from Cape Canaveral. This was a 6.4 inch spherical satellite which weighed 3.25 pounds and had an initial perigee of 409 miles and an apogee of 2453 miles. It is expected to remain in orbit for 200 years. On March 26, 1958, Explorer III was successfully launched. It reentered the atmosphere on or about June 28, 1958. On May 1, 1958, Dr. James A. Van Allen described the bands of high intensity radiation which have since been named the Van Allen Belts. These were discovered by analysis of data from Explorer I and III. On May 15, 1958, Sputnik III was launched. It weighed 2925 pounds and carried instruments weighing 2134 pounds. The satellite reentered the atmosphere on April 6, 1960. Its radio operated until reentry. In July 1958, Japan fired its first rocket, a two-stage unit which reached an altitude of 30 miles. On July 26, Explorer IV was launched. It reentered the atmosphere on October 23, 1959. On August 27, 1958, the Soviet Union sent two dogs to an altitude of 281 miles and returned them safely.

In August 1958, three nuclear weapons were exploded at an altitude of 300 miles. These explosions, which were part of project Argus, had a yield of 1 kiloton each. Project Argus was an experiment which demonstrated that electrically charged particles will travel in spiral paths about the earth's magnetic lines of force.

On October 11, 1958, the first successful space probe, Pioneer I, was launched from Cape Canaveral. This four-stage rocket weighed 112,000 pounds and was 88 feet long. It reached an altitude of 70,700 miles and a velocity of 23,447 mph. It carried an instrument package weighing 39 pounds. On December 18, 1958, the rocket casing of an Atlas Missile was placed in orbit under Project Score. This rocket had a 150 pound payload which included 35 pounds of communication equipment. The satellite was used to transmit the voice of President Eisenhower. The satellite continued broadcasting until the end of the year, recording and retransmitting voice and teletype messages. On January 2, 1959, the Soviet Union launched its Lunik I rocket which passed within 4,000 miles of the moon. On February 28, 1951, the Air Force fired Discoverer I from Vandenberg Air Force Base, California. On March 3, the Army launched Pioneer I from Cape Canaveral. It is now orbiting about the sun.

On September 12, 1959, the Soviet Union launched Lunik II. This rocket struck the moon on September 13 with a speed of 7,500 mph. On October 4, 1959, the Soviet Union launched Lunik III which passed within 4,500 miles of the moon. The instrumentation package reentered the Earth's atmosphere and burned in April 1960. This cosmic rocket took pictures of 70% of the back side of the moon from a distance of about 40,000 miles.

In February 1960, the Air Force launched Midas I from Cape Canaveral. Midas is a satellite designed to provide early warning of missile launchings by the detection of infrared radiation.

In April 1960, NASA put Tiros I into orbit. Tiros is a weather satellite designed to take pictures of the earth's cloud cover. On April 13, 1960, the Navy placed Transit 1B into orbit from Cape Canaveral. Transit is a navigational satellite designed to provide accurate navigational information to ships. In June 1960, the Navy put two satellites into orbit with a single launching. The Transit 2A and the GREB. On August 12, 1960, NASA put Echo I into orbit, a 100-foot diameter aluminized mylar balloon used as a passive communication satellite. On August 19, the Soviet Union launched the Sputnik V satellite carrying 2 dogs, a rabbit, rats, mice and other animals. This satellite was safely returned to Earth on August 20. On October 4 the Signal Corps launched Courier 1B into orbit. This was a communication satellite containing five tape recorders for storing messages for later transmission back to Earth. On December 1, 1960, the Soviet Union launched another dog-carrying satellite. These animals were not successfully recovered.

During 1961 over 50 satellites were launched. These included the manned spacecraft Vostok I and Vostok II launched on April 12 and August 6th respectively. Also launched were Discover, Transit, Tiros, Midas, and Oscal satellites.

Early in 1962 Ranger and Tiros satellites were orbited and on February 20, 1962, the first United States manned spacecraft was orbited.

Two manned sub-orbital flights were successfully carried out by the U. S. in May and July 1961, supporting and augmenting much of the scientific data compiled from unmanned flights.

Multiple payloads and piggy back launch techniques have increased the tempo for information gathering and documentation.

Manned orbital flights in 1962 have been the fruit of careful planning and the natural evolution from worldwide scientific effort. The information gained from U. S. manned spacecraft, weather, navigation, and communications satellites has been made available to the scientific community.

The increasing pace of space activity has invited participation by many countries and the population of satellites and spacecraft is steadily increasing.

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Chapter 2

THE SIGNIFICANCE OF SPACE ACTIVITY

With the ability to penetrate the immediate surroundings of the Earth's surface has come the realization that there are many scientific problems and many applications of scientific knowledge which can now be effectively pursued.

All of our early knowledge of the universe came from measurements at optical wavelengths (0.3 to 0.7 microns). More recent radio astronomy work has extended the measurement to wavelengths from 1 to 30 centimeters. Now we have the opportunity to make observations and conduct experiments at great distances from the Earth's surface and at wavelengths which were not previously available due to the effects of the intervening atmosphere. The elimination of the Earth-bound restriction also permits the direct observation of other bodies in the solar system by human beings and instruments located on or near those bodies. A new and challenging field has been opened to the scientists and engineers.

The present space program includes a manned space flight program to explore and study the solar system. It includes astronautical and geophysical satellites and sounding rockets designed to facilitate research on the universe and our planet. It also includes meterological, communication and geodetic satellites designed to make use of our knowledge to advance technology on Earth. The material which follows includes a discussion of some of the scientific questions being asked by space scientists today, a review of the experimental work which has been done and which is presently planned for answering these questions, and a more detailed discussion of space technology—the engineering problems involved in the study and use of space. One subject being studied is the Earth's surface.

Measurements of the Earth from satellites will provide information on the plastic properties of the Earth and on the nature of the seasonal variations in the rotation of the Earth. Geodetic satellites will be used to tie together separate, widely spaced geodetic nets that are too distant to be accurately connected using Earth-based triangulation. Geodetic satellites will also be used for an accurate detailed determination of the fine structure of the Earth's gravitational field.

One field being studied by space scientists is the nature of the environment surrounding the Earth. This study is of particular importance to the engineers who must design and construct the equipment which will operate in that environment. The tools being used to study the regions above the Earth's surface includes balloons, rocket probes, and orbiting satellites.

Conventional meteorological sounding techniques provide data on less than one-fifth of the Earth's atmosphere with the result that large storms have remained undetected for several days in desert, ocean, and polar areas. The use of several properly distributed meteorological satellites will provide the capability of prompt monitoring of all storms.

There are several questions of interest concerning the upper atmosphere. Scientists are interested in the density of electrons, the different types of gas molecules and atoms, and the positive and negative ions and radicals. They are interested in the nature and quantity of particles received from outside. They are interested in the motions of these particles (the temperature and diffusion, collision, and recombination rates). They are interested in the mass motions of these particles (turbulence and winds). They are interested in the chemical and electronic state of the particles (degree of exitation and ionization). They are interested in radiation received and generated. The manner in which these quantities vary with geographical position, altitude, and time are also of interest.

Satellites and rockets have already been used to answer some of these questions. X-rays and auroral particles have been detected in the upper atmosphere by the use of rockets. The solar ultra-violet spectrum has been photographed from rockets. The electron density in the ionosphere has been measured. Pressure, temperature, and composition profiles have been measured from the Earth's surface to tens of thousands of kilometers. Cosmic rays have been studied and the Van Allen Belts of charged particles have been discovered and studied with satellites. The shape of the Earth has been studied by analyzing the orbits of satellites.

Satellites are being utilized to look down on the Earth from above, as is done with the meteorological satellites which photograph cloud cover and the top side sounder used to examine the ionosphere from above. Satellites offer the ability to look around the Earth as they travel to obtain information on variations with position. Satellites also offer the ability to look out into space without the encumbrance of an intervening atmosphere, as is done with the orbiting astronomical observatory. Figure 1 shows the transmission of the atmosphere.

One of the first practical applications of Earth satellites is their utilization for communications. They promise to be of use for telephone, TV, and data transmission as supplements to existing transoceanic cables and radio links.