The First Shots Into Interplanetary Space

by Fritz Zwicky

ON OCTOBER 16, 1957, at five minutes past 10 o'clock Mountain Standard Time, the first man-made pellets ever to escape from the earth were propelled into interplanetary space from an Aerobee rocket at the Holloman Air Force Base in Alamogordo, New Mexico. The development which led up to this event started in 1945 as part of a comprehensive program proposed for the exploration of extraterrestrial space.

The experiment of October 16 was first suggested in a note by me in the *Publications of the Astronomical Society of the Pacific* (Vol. 58, 260, 1946) on June 3, 1946. It read, in part:

"Properly conducted detonations of shaped charges* can be used to impart to all slugs of matter velocities which, in order of magnitude, are the same as the velocities of detonation of these charges; that is 10 to 15 kilometers per second. If the slugs are launched at the proper moment by shaped charges from rockets at high altitudes, they will be expelled at heights where the atmosphere is so tenuous that the air resistance is very small. *Such particles may be hot and luminous on launching*, or they may become heated by friction with the tenuous air, if their speed is high enough relative to the atmospheric density. These particles will consequently assume the appearance of meteors; thus a multitude of interesting tests present themselves. Some of the particles may have velocities equal or superior to the velocity of a 'close' satellite of the earth (about 8 km/sec), or these velocities may even surpass the speed of escape from the earth (11.2 km/sec). Some of these particles may consequently be launched into satellite orbits of the earth, while others may escape into interplanetary space.

"If artificial meteors are bright enough, photographic observations of them with telescopes of large focal ratios, such as Schmidt telescopes, combined with auxiliary equipment such as objective prisms and gratings, intermittent shutters, and so on, should furnish new data on the physical and chemical properties of the upper atmosphere. Such observations would also give new information on the problem of natural meteors."

Later on, and particularly in my Halley lecture at Oxford, England, in 1948 (see *Observatory* Vol. 68, p. 121-143, 1948) I generalized my program to include the following projects: 1) First throw a small bit of matter into interplanetary space, 2) then a little more, 3) then a shipload of instruments, 4) and then ourselves. 5) Follow up the invasion of interplanetary space by an attempt to reconstruct the solar system so as to make the planets and their satellites habitable by man.

Since 1946 my efforts have been unceasingly directed toward the realization of this five-point program. In the spring of 1946, when I was a member of the Scientific Advisory Board of the U.S. Air Force, I wrote to General G. M. Barnes, then Chief of Army Ordnance, suggesting that one of the V-2 rockets brought from Germany be fired at night, and that artificial meteors be ejected from it by means of shaped charges, such as those used in rifle grenades.

This request was granted and Colonel (now General) H. N. Toftoy made all the necessary arrangements for the firing, which took place at White Sands Proving Grounds, New Mexico, on the night of December 17, 1946. The rocket flew to a height of 117 miles, and valuable scientific data were obtained on the spectral characteristics of the main jet of the rocket, as well as on the luminosity of the hot graphite vanes immersed in the jet for purposes of steering. The shaped charges, however, which should have been ejected from the main rocket and fired at heights of 120,000, 150,000 and

*Explosives that deliver their force in one direction, determined by the actual shape of the charge itself.

180,000 feet did not ignite, apparently because of a malfunctioning in the firing circuit.

This failure proved to have most unfortunate consequences, since several experts subsequently voiced the opinion that the shaped charges would not perform as claimed, and that ground observations with available telescopic equipment would not succeed in recording the tracks of the particles or pellets ejected from the metallic inserts of the shaped charges. Although the firing of October 16, 1957 at Alamogordo finally proved that these experts were mistaken, their earlier objections were heeded by various agencies of the U. S. Government and the Armed Forces, and for ten years it proved impossible to obtain the means and the permission to repeat the fundamental experiment.

The Navy authorities, however, made possible some ground-testing of the jets from shaped charges at Inyokern, China Lake, California. Some results were reported in *Ordnance*, the journal of the Army Ordnance (July-August, 1947). These results showed, in particular, that the transportable 8-inch Palomar Schmidt telescope was quite powerful enough to photograph, at distances of hundreds of kilometers, the jets extruded from small shaped charges. The cameras, equipped with either objective gratings or prisms, also gave much information on the spectral characteristics of the jets, and consequently on the reactions within the jet and the chemical nature of its surroundings. Furthermore, it was learned that the shaped charges and the inserts should be geometrically as symmetrical as possible if fast jets containing only a few pellets—rather than a spray of particles—were to be achieved.

In this connection, my associates at the Aerojet Engineering Corporation in Azusa, Calif., and I developed a most useful liquid explosive, consisting essentially of nitromenthane CH_3NO_2, doped with a small amount of an amine, such as diethyl amine $(C_2H_5)_2NH$. This explosive, commercially known as Jet-X, is naturally more uniform than a solid explosive, and through its use as a shaped charge most efficient extruded particle jets have been obtained. During the preliminary ground tests it was also found that, with various configurations, pellets with speeds of 12 kilometers per second or more could be achieved, which is quite sufficient to have these pellets escape from the earth's gravitational field if they are launched at sufficiently great heights.

In elaboration of the idea that jets of fast particles should be *hot and luminous on launching*, Joseph F. Cuneo—patent attorney and industrial chemist of Covina, Calif.—and I developed a series of alloys for the inserts of shaped charges which, on detonation, are ejected in the form of ultrafast hot and self-luminous pellets. Some of these inserts which produce self-luminous artificial meteors are:

a) An easily oxidizable insert, containing metals such as aluminum, magnesium and lithium. These metals would partly oxidize and generate much heat while reducing H_2O, CO, CO_2 gases which are generated in the explosion of the shaped charge. As a result, hot and luminous particles or liquid droplets are expelled which are visible in a vacuum.

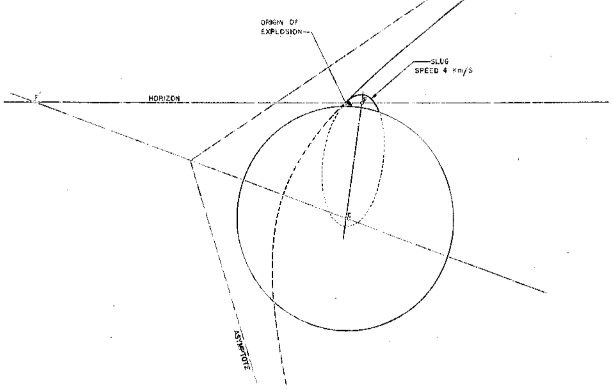
b) A second type of heating may be achieved by surrounding the pellets, oxidizable or not, with a reactive material producing much heat on ignition by the detonation of the shaped charge.

c) The most effective method of producing exceedingly hot particles, however, is to use what we call "coruscatives" or "heat explosives" for the inserts. These are combinations of solid or liquid reagents which react fast, generate much heat and produce solid reaction products. Upon ignition, then, coruscatives develop little or no gas, and so they do not fly apart as conventional explosives do. One of the well known combinations of reagents which constitutes a coruscative is iron oxide (Fe_2O_3) plus aluminum, forming the welding mixture known as thermit. On ignition, this mixture reacts and produces iron and aluminum oxide, with a resulting temperature of about 4000 degrees centigrade.

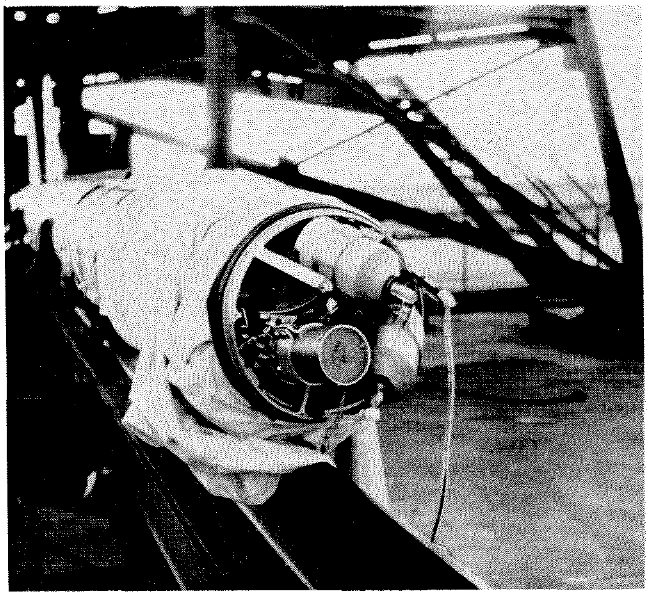
During the past few years we have successfully developed a number of compressed powder coruscatives which have been used to form conically-shaped inserts for shaped charges. Particles composed of the hot reaction products of these coruscatives retain their high temperatures for many minutes. When they are ejected at high altitudes, with speeds of 10/km sec or greater, they should therefore be visible up to thousands of kilometers above the surface of the earth.

On the basis of the results achieved with shaped charges, Captain W. C. Fortune of the U. S. Navy got interested in the project of launching artificial meteors at high altitudes. In 1955 he arranged for a series of tests from balloons, which led to additional valuable knowledge of how to conduct ultimate experiments with artificial meteors.

The first of these ultimate experiments came about in



Ultrafast pellets ejected at 14 km/sec, from 200 km height, and at a 45° angle, follow the hyperbolic trajectory with foci C and F′ until they are bent into elliptical orbits around the sun. The heavier slug, ejected at 4 km/sec, describes the elliptical trajectory with foci C and F and falls back to the earth. Debris from the casing falls at a short distance from the explosion.



Three shaped charges, pointed in different firing directions, mounted in the top part of the instrument head of an Aerobee rocket.

a most casual way. Dr. Maurice Dubin, of the Geophysical Research Directorate of the U. S. Air Force, had been visiting Pasadena off and on since 1954 and had interested himself in the artificial satellite project. Someday he hoped to make room for the shaped charges in the instrument head of one of the many Aerobee sounding rockets which were being fired for other scientific projects, such as cosmic ray studies, the study of the processes in aurorae, and the analysis of the physicochemical properties of the upper atmosphere.

The first chance came late in the summer of 1957, when Dr. Dubin informed Cuneo and me, as well as two other experts on shaped charges—Drs. T. C. Poulter of Stanford University and John S. Rinehart of the Smithsonian Astrophysical Observatory in Cambridge, Mass.—that around October 15 an Aerobee rocket would be fired in whose tip some extra space would be available to install three small shaped charges.

Dr. Poulter's group conducted some experiments to show that the three charges, if properly mounted and connected to the same detonator, could be fired without interfering too much with one another—an interference which, of course, could endanger the formation of really well-defined fast particle jets.

Dr. Poulter's preference was a very narrow conical, or practically cylindrical, insert in his shaped charge. This configuration is known to produce the fastest jets so far achieved, reaching velocities of ejection of up to 30 kilometers a second. These cones, however, produce high velocities at the expense of mass in the jet, which often is entirely gaseous. Dr. Poulter chose aluminum as the material for his insert, relying on the low-density diatomic and monoatomic oxygen in the high atmosphere to oxidize his jet in part, while the high speed of the latter also produces some luminosity because of frictional heating. In addition, there is some oxidation of the aluminum from the more easily reducible oxides of the explosive gases accelerating the aluminum insert—which makes the particles hot and luminous even in a vacuum.

Dr. Rinehart also chose an aluminum cone which, however, was cuplike and massive—about one centimeter thick. From such a cone, more massive but slower pellets can be expected than from Poulter's narrow-angle cone and thin inserts. Solid cast explosives were used for both Poulter's and Rinehart's cones.

Cuneo and I used a 1.5-millimeter-thick aluminum cone of 60° apex angle, and about seven centimeters in diameter, to back a compressed cone of a special fast reactive coruscative cone of the same configuration, but of about 3 to 4 mm thickness. From this type of configuration, an exceedingly hot jet of massive particles may be expected, consisting of slags of aluminum oxide and other refractory-like compounds, retaining their heat well and radiating it away at a high temperature relatively slowly, so that long trajectories become observable. The explosive used for our shaped charge was the putty-like composition called C_3, furnished by the Air Force.

All three groups were on location at the Holloman Air Force Base to install their charges themselves. The charges, during the upwards flight of the Aerobee rocket, were all pointing downward, but in three different directions. Since the main section of the instrument head carried other types of instruments, the tip of the rocket, in the shape of a dunce's cap, had to be detached, kicked off and turned over in free flight away from the rocket, in order to direct the ejection of the artificial meteors in directions above the horizontal plane. The kick-off mechanism and the timer for firing the shaped charges were installed by the crew of the Geophysical Research Directorate of the U. S. Air Force, under the direction of Dr. Maurice Dubin, and according to his designs.

The sequence of events was as follows:

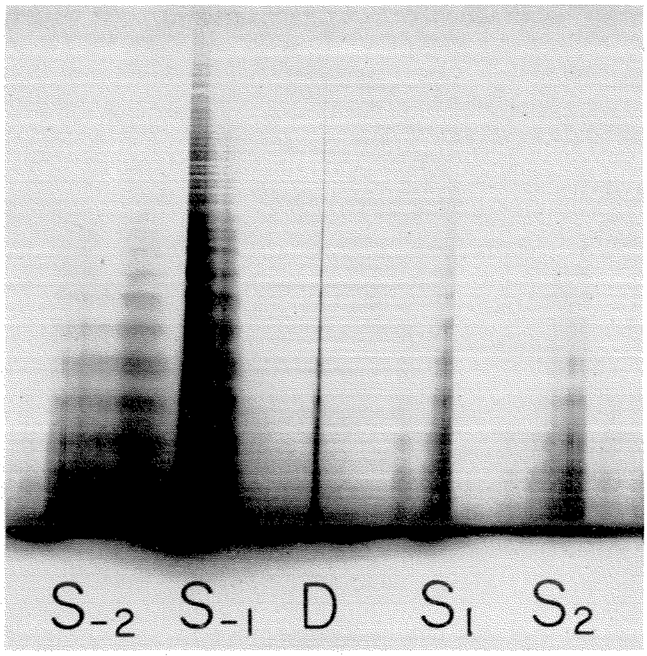
The Aerobee rocket was launched from its tower at Holloman Air Force Base at about 10:05 MST. Propellant burnout was 45 seconds later, and the tip of the rocket, with the shaped charges, was kicked off 55 seconds after launching. The tip coasted for another 36 seconds and slowly turned over. The charges, then, were fired 91 seconds after launching of the rocket, and the artificial meteors were ejected at a height of about 85 kilometers.

A very bright green flash was observed by all, but only some experienced observers saw one of the fast jets streaking off toward the north north east. The brightness of the initial flash, as seen from the ground, was about minus tenth visual astronomical magnitude. This flash was also observed from Palomar Mountain by my assistant, Howard S. Gates. At this distance of exactly 1,000 kilometers the flash appeared to be of minus fifth to minus sixth magnitude.

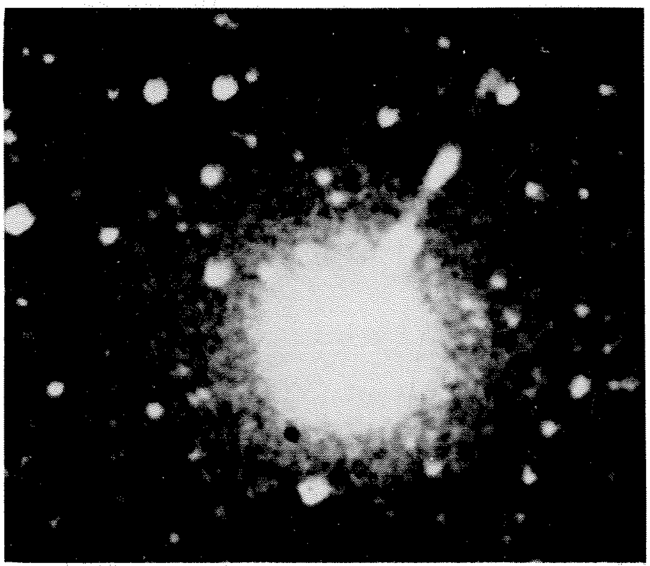
On most of the photographs taken with the super Schmidts on Sacramento Peak, about 30 miles east of Alamogordo, and with the cameras stationed in the Alamogordo valley, the flash appears as a bright blotch, while two sharp short trajectories of two of the artificial meteors emerge from its center. The brighter of these tracks appears with clearly marked interruptions on the photograph (below) taken by one of the super Schmidts with its fast interrupting shutter.

The evaluation of all the available data showed that the speed of the pellet of closely bunched particles in the brighter jet was at least 15 km/sec and that two jets went clearly upward, away from the earth. Since the pressure remaining at 85 km is roughly one millionth of the pressure on the ground, a fast particle one millimeter thick would have lost less than one hundredth of its kinetic energy in traversing the remaining atmosphere. Since the particles, from the analysis of the brightness of their trajectories, were clearly more massive than that, and since they possessed almost twice the kinetic energy necessary for escape from the earth, it is certain that they got away from the gravitational pull of the earth to become tiny satellites of the sun, describing orbits around the sun, which, except for effects of light pressure and loss of mass by evaporation, must be essentially elliptical.

The firing was being photographed from the Palomar Observatory by Dr. M. L. Humason, using the 48-inch Schmidt telescope, and by Howard S. Gates with the 18-inch Schmidt. On the 48-inch Schmidt plate there appears a long, peculiar and slightly curved track originating approximately, but not quite exactly, in the point of explosion of the shaped charges. The origin of this track is still in doubt. It is, however, possible that it can be explained as being due to one of the *slow* slugs ejected from any shaped charges fitted by a solid insert. Indeed, it should be remembered that three types of particles were ejected in the experiment: (a) the fast particles travelling with velocities greater than the velocity of escape from the earth (11.2 km/sec), (b) the slow and heavier slugs with speeds of 3 to 5 km/sec, and (c) the debris from the casing used to hold the explosives. Both the heavy slugs and the particles of the debris might have been sprayed over an area the size of the American continent or greater.



Spectrum of track of ultrafast particle of copper photographed with 3" lens and echelette grating. D is the direct track, S_{-2}, S_{-1} and S_1, S_2 are, respectively, the strong and the weak first and second orders in the spectrum.


One of the ultrafast luminous pellets emerging from the flash of the coruscative explosion. In this photograph, made with a super Schmidt camera equipped with an interrupting shutter operated at 1800 cycles per minute, the distances between the interruptions of the track allow calculation of the speed of the pellet.

As a result of this experiment, made possible by the whole-hearted cooperation of Dr. Maurice Dubin, of the U.S. Air Force, we can now maintain that:

1. Small man-made projectiles were launched away from the earth for the first time, never to return.

2. The initial tracks of these artificial meteors could easily be photographed with ordinary cameras at a distance of 100 kilometers and it would be possible to record them with large telescopes at many thousands of kilometers.

3. The firings proved that coruscative inserts can be ignited by detonative shear ignition in the relative vacuum at the height of 85 kilometers, and that ignition does not depend on the jets hitting an oxidizing atmosphere.

4. As to the usefulness of the continuation of the Holloman experiment—such experiments will give information on the density of the atmosphere hundreds of kilometers above the earth's surface, on its state of chemical composition and decomposition, on the number and character of the excited states of molecules, atoms and ions in the ionosphere, on the origin of the aurorae, on the electric and magnetic fields far from the earth's surface, on certain characteristics of the moon's surface—and they will pave the way for direct experimentation with all the planets and their satellites in the solar system.