PUBLICATIONS
of the
ASTRONOMICAL SOCIETY
OF THE PACIFIC

VOLUME 59

1947

RESEARCH WITH ROCKETS

F. ZWICKY

California Institute of Technology, Pasadena, California

Introduction and program.—Somewhat overnight, and to most scientists unexpectedly, a number of devices which were used recently for warfare have become available for fundamental research. Among these devices rockets of all sorts are destined to play a significant role. Presumably, even the best informed can visualize only very dimly how revolutionary this role will be. Some general features of rocket research, however, already begin to delineate themselves. These we shall attempt to describe briefly. As new experiments are planned and their results materialize, further reports will be submitted.

At present, four basic functions of rockets for scientific research suggest themselves.

1. Rockets may be used as test vehicles to roam the earth's atmosphere in its whole extent. The atmosphere thus assumes the character of a vast laboratory within which a multitude of novel experiments may be conducted.

2. Rockets may reach points outside the atmosphere. At these points the radiations, corpuscular and electromagnetic, which come from outer space, will be observable without absorption, scattering, and other secondary disturbances due to the atmosphere. Direct information will thus be gained not only about the true character of these radiations but, by inference, also about the celestial objects from which they emanate. The results to be expected may well be such that present and past astronomy and astrophysics may be considered, figuratively speaking, as having been accomplished by almost totally blind men. Just what will be recorded, for instance, when the stars, nebulae, and other aggregations of matter are observed in radiations now blocked out by the atmosphere, staggers the imagination.

Consider, for instance, what will happen when the total radiation of stars becomes observable. For stars with absolute surface temperatures of 100,000°, 500,000°, and 1,000,000°K the difference between visual and bolometric magnitude is 6.7, 12.0, and 14.2, respectively. Such stars no doubt exist in great numbers as we know from certain O-type stars and from objects like the remnant of the supernova of A.D. 1054 which is the source of the luminescence of the Crab Nebula. The black body radiation, at the three temperatures mentioned, has its maximum intensity in the far ultraviolet at wave lengths 288.4 A, 57.7 A, and 28.8 A, respectively. Such radiations give rise to some entirely unobserved ultraviolet fluorescence in the gaseous clouds surrounding many of the hot stars and to equally interesting ultraviolet interstellar absorption lines. To test new celestial aspects of this kind, it is planned, even before the advent of large and very high-altitude rockets, to launch small secondary rockets to heights of from 500 km to 1000 km, using missiles now available as the primary carriers. It is hoped that these secondary rockets can be equipped with small telescopes, spectrographs, and other instruments designed to record many as yet unobserved phenomena of the types just mentioned. The prediction may thus be ventured, that as long as they are tied to the surface of the earth, the 200-inch telescope, the new powerful Schmidt telescopes, and devices as yet unborn, like the photoelectronic telescope, will be heavily overshadowed by the potentialities of rocket research.

3. Rockets may also be sent far into the extraterrestrial spaces and even to other members of the planetary system. Direct prospecting of those spaces and of planetary objects thus comes within reach. The rockets themselves may serve as "test particles," or they can be used to carry scientific instrumentation with which to record new observations.

4. There exists in addition the more speculative, although not too far distant, prospect of rockets carrying the observers themselves into new unexplored fields.

All of these four possibilities are in the stage of realistic planning, while attempts at the practical application of the first three have already been partially successful, or are in the process of being carried out. A great co-operative effort is well on its way, involving individual scientists, colleges, and agencies of the armed forces and of the government of the United States.

A few special results related to the attempts at launching artificial meteors will be presented here.

Some results obtained at the first night firing of a V-2 rocket in the United States.—Soon after their return from Germany in the fall of 1945, some interested technical representatives of the Air Forces learned that a number of German V-2 rockets would be made available for scientific researches under the auspices of the Ordnance Department. Application was therefore made to Major General G. M. Barnes, Office of the Chief of Ordnance, for permission to launch artificial meteors from the V-2 rockets at great heights. Observations of such meteors promise to shed light on problems of supersonic and hypersonic aerodynamics throughout a large range of air densities. Information can also be gained on the physical and chemical characteristics of the outer regions of the earth's atmosphere. Finally, the artificial meteors can be used for a first direct exploration of interplanetary spaces and of the surfaces of various members of the planetary system. We are greatly indebted to General Barnes for his active approval of this pioneering program. For further arrangements General Barnes referred me to Dr. E. H. Krause, head of the Rocket-Sonde Research Section, Naval Research Laboratory. In subsequent discussions it was agreed that some of the V-2 rockets assigned to the Applied Physics Laboratory of the Johns Hopkins University would be launched at night from the White Sands Proving Ground in New Mexico. To eject artificial meteors at sufficiently high speeds, shaped explosive charges were chosen. Dr. J. A. Van Allen of the Applied Physics Laboratory offered to procure these charges which were ultimately handled by Mr. L. J. Paddison of the New Mexico School of Mines at Albuquerque.

Ground tests with the ejection of fast particles from shaped charges on December 16, 1946.—Shaped explosive charges are capable of imparting to fragments of properly chosen metallic inserts velocities of the order of 10 km/sec. On the advice of Colonel C. H. H. Roberts, Ordnance Department, M9 A1 rifle grenades were chosen for the first tests. These contain about 150 grams of a shaped explosive charge of penolite. The conical metal inserts weigh 30 grams and are made of low-carbon steel. Two of these grenades were fired from the ground while a third was launched a few hundred feet into the air and then exploded. The launching point was near the water tank, on a spur of the Organ Mountains at White Sands, while our telescopes and aerial cameras were stationed about 2.5 miles away near the camp at White Sands.

In Plate VI a photograph is reproduced which was taken with the 8-inch F/1 portable Schmidt telescope brought to White Sands from the Palomar Mountain Observatory. From the indicated scale it follows that the shaped charge exploded about 100 meters above the ground (on which the road and water tank are visible). This explosion gave rise to a very bright flash. For later arguments, it is significant to notice that this globular flash appears highly overexposed. A shower of likewise strongly exposed curved lines indicates the trajectories of a great number of luminous fragments of the grenade casing, the shaped charge, and the steel insert. One very fast slug was apparently ejected along the axis of the shaped charge. It gave rise to the straight track on the photograph which in projection has a length of about 150 meters. The actual length cannot be determined, since no stereoscopic pictures were taken. The whole track beyond the shower is very faintly visible on the original photograph. The slug, traveling very fast, obviously encountered terrific resistance in the air, and in slowing down quickly burned up toward the end of its track, which is recorded as a bright club-shaped image. The horizontal strata are cloud banks, which unfortunately obscured the stars, thus making the picture somewhat less dramatic than it might otherwise have been.

In continuation of this first experiment, further tests are planned with various shaped charges and solid inserts of many materials to determine the best combination for the generation of artificial meteors. It is intended to release the charges from planes, antiaircraft shells, high-altitude balloons, and rockets in order to record the artificial meteor tracks at various heights in the atmosphere. The expectation is that, with increasing height and decreasing air density, the tracks will become longer so that with the aid of rapidly interrupting shutters, or other devices to mark time intervals, the speed and the deceleration of the fast-flying particles can be determined.

As the external atmospheric pressure decreases with altitude almost to the vanishing point, the speed of the solid or liquid metal slugs ejected by a shaped charge may be expected to increase. This higher efficiency of the transformation of chemical energy and heat into kinetic energy with decreasing external back pressure is a well-known phenomenon in all jet motors. As far as the author is aware, this effect has never been investigated for shaped charges. Actually, the drag on the terrifically accelerated particles expelled by such a charge must be very great, mainly because of the action of the dynamic rather than the static back pressure, the latter usually being the only one considered in the case of ordinary jets. For use in vacuum, the geometrical shape of explosive charges most suitable for the generation of highest particle velocities will consequently bear some new researches with the promise of gratifying results. The velocities of the ejected particles may well be expected to surpass the velocity of escape from the earth, 11.2 km/sec.

Program of observation of the V-2 rocket on the night of December 17, 1946.—In addition to instrumentation for recording cosmic rays, a timing mechanism was installed to expel and fire three pairs of grenades (shaped charges) at the times $X + 70$ seconds, $X + 80$ seconds, and $X + 90$ seconds, respectively, where X designates the time at which the rocket was to leave the launcher. Four luminous phenomena are to be expected: first, the fiery jet of the V-2 rocket motor; second, the luminous graphite vanes which may reach a maximum temperature of about 2000°C, since, until the cutoff of the propellant, they are immersed in the jet to steer the V-2 on a predetermined path; third, the globular flash of the explosive charges; and fourth, the trails of the luminous ejected particles (artificial meteors), especially the trails of those which diving into the atmosphere are reheated by the friction encountered.

On the night of December 17, 1946, the V-2 rocket left the launcher at $22^h\,12^m\,49^s$ Mountain Standard Time. The rocket made a good flight. The propellant cutoff occurred at $X + 71.5$ seconds, at which time the rocket had reached an altitude of 27 miles and a speed of 5450 ft/sec, according to telemetering data. At that time the trajectory was supposed to have an inclination of 5° to the vertical, according to the presetting of the steering mechanism, but the actual angle was probably somewhat smaller. The rocket apparently reached a maximum altitude of 114 miles flying about 17 miles to the north with a deviation of about 3 to 5 miles to the west. The instrument head which was blasted off the rocket on the down course has not been recovered. More details on the flight will presumably be published in the report of the Naval Research Laboratory. Our telescopes and aerial cameras failed to record the expulsion and ignition of the explosive charges which, according to the time setting, should have occurred at approximate heights of 140,000, 180,000, and 220,000 feet, respectively. Estimates based on the brightness of the globular flashes recorded during the ground tests on the previous night clearly indicate that all of our cameras should have caught these flashes (see Plate VI). We therefore conclude that the timing mechanism went wrong or failed to set off the charges at the predetermined times. Nevertheless our photographs of the flight proved valuable. The following results were obtained:

Direct photographs of the jet of the V-2 rocket and of the luminous graphite steering vanes.—The 8-inch F/1 Schmidt telescope was located 9.6 miles from the launcher and almost exactly to the south. It was elevated to about 61° 56′, as derived from the starry background. The star Σ 485 (BD+61°676, mag. 6.5) is near the center of the photograph reproduced in Plate VII, *A*. The track of the jet is very much overexposed, as is indicated by the image of its multiple reflection from the film (Eastman 103-AE) to the mirror, to the Schmidt plate, back to the mirror, and again to the film. The sudden decrease in brightness when the propellant was cut off is clearly visible, but the luminous graphite vanes were still amazingly bright. The rotation of the rocket around its long axis after the propellant cut-off can be derived from the periodic variation in brightness of the vanes. Since aerial cameras were also stationed by our group at a point 10 miles northeast (azimuth 40°) from the launcher, a stereoscopic analysis of the rocket trajectory is possible. From the curvature of this trajectory the velocity of the rocket may be deduced. This velocity, however, was directly measured on a photograph obtained with a K-24 aerial F/2.5 camera of 7 inches focal length, which was located near the 8-inch Schmidt telescope. In front of this camera a four-bladed propeller shutter was placed which made 85.7 revolutions per minute and which therefore interrupted the photographic trajectory at intervals of 0.175 seconds. Using these time marks, the velocity of the rocket at the time of propellant cutoff was calculated to be 1.05 miles per second as compared with a value of 1.03 miles per second obtained by radio telemetering. With some refinements the telescopic method, in conjunction with accurately timed propeller shutters, is therefore capable of high precision in the determination of flight paths and velocities of projectiles.

Spectroscopic observations of the rocket.—In order to test the suitability of objective gratings for future work on artificial meteors, two of Wood's replica gratings were used to photograph the spectrum of the jet of the V-2 rocket as well as that of the luminous graphite vanes. The gratings are of the "sawtooth" type which give one very strong first order and very weak intensity in the direct image as well as in all other orders. The gratings, which are five by seven inches, have 1440 lines to the inch. One of these gratings was mounted in front of a Wollensak Velostigmat portrait lens of focal length 15.5 inches and a focal ratio F/4.5. This camera was stationed near the White Sands water tank, 6.8 miles from the launcher in a direction 51° west from south. The spectrum of the V-2 from the launcher to a height of about 3.5 miles was photographed on an Eastman-40 plate (unfortunately no panchromatic plate was available at the time). An enlargement of a small part of the picture obtained is reproduced in Plate VII, *B*. In addition to the direct image and the continuous spectra in the first and second orders, three emission bands appear at average wave lengths 4713 A (strong), 4937 A (medium), and 5031 A (weak), respectively. The first two bands presumably must be identified with the λ 4715.2 Swan band of the C_2 molecule and the λ 4935.8 blue band of cyanogen CN. The third band lies near λ 5036.2 of S_2, λ 5031.7 of CO, and λ 5030.8 of N_2. A series of future tests is planned to identify all of the bands with certainty, using larger dispersion (7500 lines to the inch) and a better camera. Attempts will then also be made to obtain absolute spectral intensities of the V-2 jet at all heights up to the propellant cutoff. Such an investigation should make possible the spectral determination of the exhaust temperature of the V-2 jet and its dependence on external atmospheric pressure.

Generally speaking, a flame-type spectrum should be observed in a rocket jet. There are, however, some features which are not present in an ordinary flame. For instance, there is the great speed with which the jet moves. During the expansion through the nozzle of the jet motor, the duration of which is of the order of a microsecond, the various reaction products may not reach thermal equilibrium concentrations. That is, these concentrations may be "frozen" at a higher temperature corresponding to a point upstream in the nozzle. Also, as the rocket passes into the tenuous region of the atmosphere, the gases in the jet such as CO and H_2 will be less subject to afterburning because of lack of external oxygen. A series of phenomena not occurring in usual flames may therefore make their appearance.

The second grating was mounted in front of a K-24 camera with tube extension. This camera has a focal length of 20 inches and an effective focal ratio of F/5.6. The camera was mounted at the northeast station previously mentioned and was directed toward a point about 140,000 feet above the launcher, at which point the first pair of shaped charges was expected to explode. The picture obtained consequently shows the spectrum of the jet as well as that of the luminous graphite rudders. Since a panchromatic film (Tri X Pan) was used, a number of red emission bands were photographed, notably the red CN band at λ 6191.7 superimposed on the red Swan C_2 band at λ 6191.2. Unfortunately, the lines of the grating were oblique to the trajectory of the V-2 and the definition is poor. The spectrum of the graphite rudders beyond the propellant cutoff shows a remarkable feature inasmuch as, somewhat unexpectedly, the red band at λ 6187 appears in emission superimposed on the continuous spectrum of the hot graphite plates. This means that either C_2 or CN molecules evaporate from the graphite vanes and emit their characteristic bands. This opens up an interesting field for observation of the rate of evaporation of hot carbon and other substances high up in the atmosphere as well as the possibility of investigating the emission of certain forbidden lines if advantage is taken of the long mean free path in the tenuous upper atmosphere.

Our plans for the immediate future are as follows:

a) The suitability of shaped charges for our purposes will be tested further. Experiments are planned concerning the most favorable size and shape of these charges. Inserts of various materials will be tried. The dependence of the speed of the ejected particles on the detonation speed of the explosives will be analyzed and the influence of decreasing back pressure will be investigated. Finally, a qualitative and quantitative theory of shaped charges awaits formulation.

b) Secondary rockets will be launched from large mother carriers in order to reach great heights.

c) The shaped charges will be released and exploded at ever increasing heights. For this purpose, planes, antiaircraft shells, small balloons, large primary, and smaller secondary rockets will be used to carry the shaped charges aloft to heights from a few kilometers to several hundreds of kilometers.

Obviously the new field of research just described will need the co-operation of many observers for its full exploitation. Amateur astronomers are therefore invited to participate in the experiments. Both photographic records with powerful cameras of large focal ratios and visual observations can contribute much toward the successful realization of our program.

Thanks are due to the many collaborators from the California Institute of Technology, from several Western observatories, and from the Aerojet Engineering Corporation, as well as to officers and scientists in the service of the Army.

In conclusion, it should perhaps be mentioned that the most distant photograph of the V-2 jet was obtained by Sam Levitz of the *Arizona Daily Star*. At Palomar Mountain, where G. F. W. Mulders and B. H. Rule were ready at the 18-inch Schmidt telescope, no positive result was obtained because of clouds at the eastern horizon.

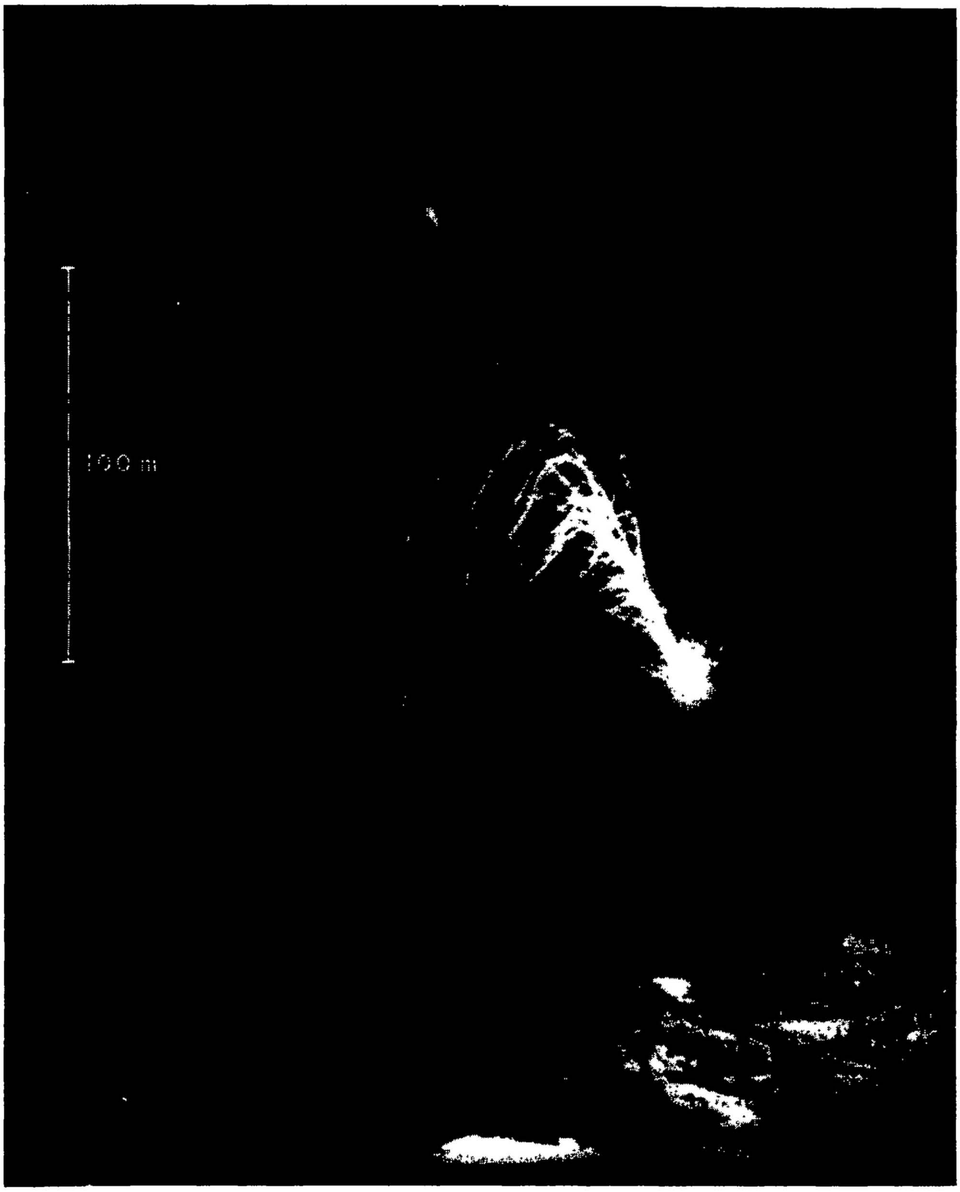
DESCRIPTION OF PLATE VII

A) This photograph of a part of the V-2 rocket trajectory was obtained on December 17, 1946, with the 8-inch Schmidt telescope. The rocket left the ground at $X = 22^h\ 12^m\ 49^s$ Mountain Standard Time. The start of the trajectory on the photograph is at $X + 57.5$ seconds. The propellant cutoff is clearly indicated by the break in intensity at $X + 71.5$ seconds and the point where the trajectory outlined by the luminous graphite rudders leaves the field is at $X + 79.4$ seconds. The straight streak on the left is the multiply reflected image of the trajectory (reversed in direction). On it the point of propellant cutoff is still clearer. The reflected image is a nuisance in some respects, although in the present case where the direct images are too overexposed for absolute luminosity determinations, the spurious image with its reduced intensity may be useful.

The first pair of shaped charges was supposed to go off at $X + 70$ seconds, just before the propellant cutoff, but no trace of any flash appears. Since this flash should have been much brighter than the small luminous graphite vanes, it is assumed that the timing mechanism failed to explode the charges.

The total exposure was 25 seconds on an Eastman 103-AE spectroscopic film. The star somewhat to the left of the center is Σ 485 ($\alpha = 4^h\ 3^m\!.4$, $\delta = +62^\circ\ 12'$, 1950.0).

B) The spectrum of the V-2 jet was obtained on an Eastman 40 plate with an F/4.5 camera of 15.5 inches focal length and an objective replica grating of 1440 lines per inch by R. W. Wood. The black horizontal lines are images of lights on the ground. At the left are the lights of cars approaching the launcher. Above the launcher is the direct image of the jet of the V-2. This image is very bright at first because of the low speed of the rocket, thinning out as the rocket gains speed. The trajectory curves toward the left in response to the programmatic steering of the rocket with the aid of the graphite rudders immersed in the jet. The first-order spectrum of light from the control-blockhouse merges with the second-order spectrum of the jet. Emission bands at 4713 A, 4937 A, and 5031 A are clearly visible in the second-order spectrum. The continuous spectrum indicates that there is very little blue light in the jet.

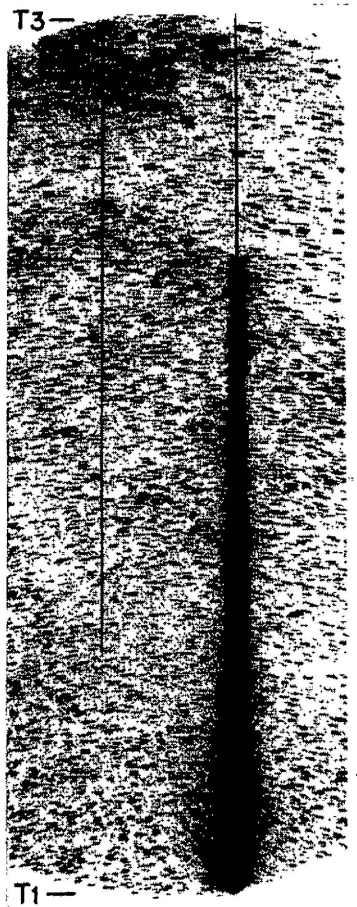


X7.8

SHAPED CHARGE WITH CONICAL STEEL INSERT EXPLODING IN THE AIR

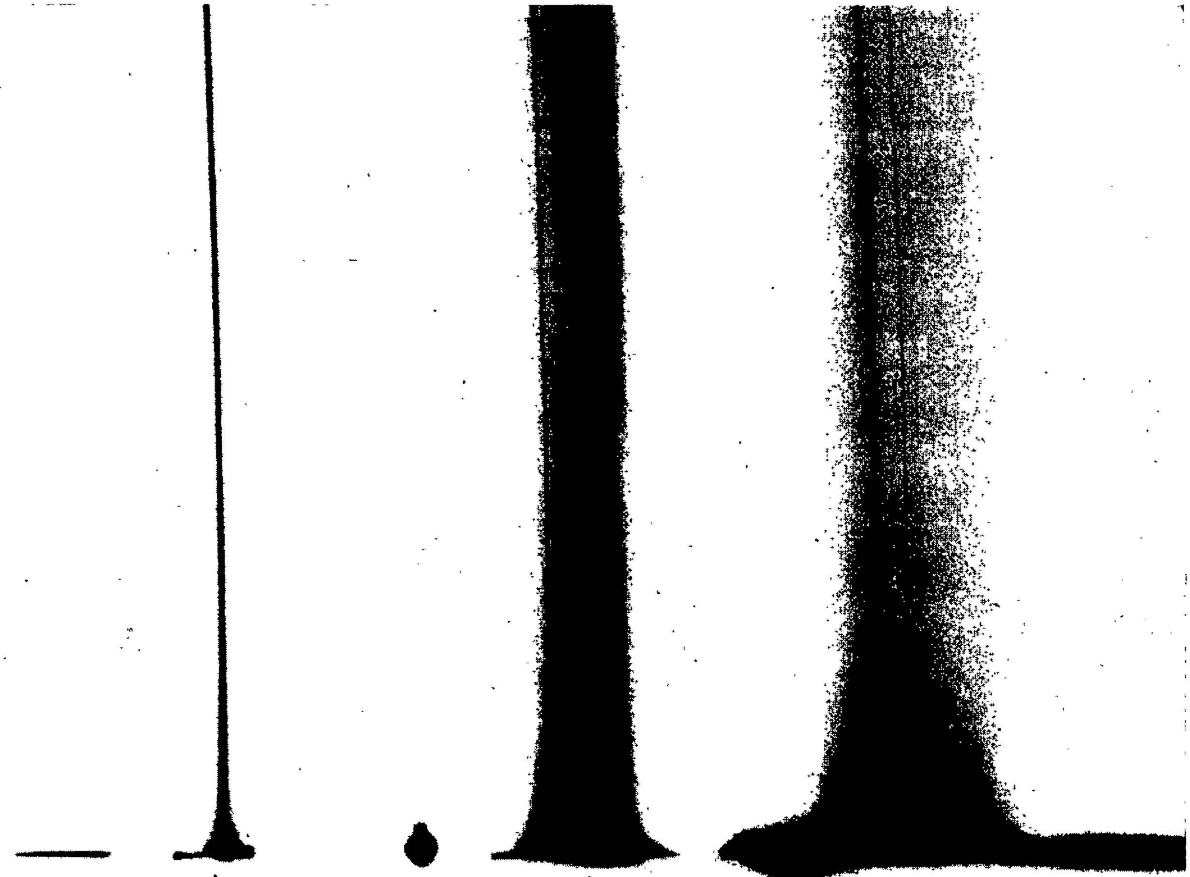
The ridge beneath the flash is an eastern spur of the Organ Mountains near the White Sands Proving Ground. The water tank of the Proving Ground and the road leading to it are visible at the bottom of the picture, which was taken from a distance of about 4.0 km at 10:00 P.M. on December 16, 1946. The sky was overcast so that although the exposure was twenty seconds, no stars are visible.

A



X 1.3

B



a b c d e f

X 3.1

V-2 ROCKET

A) Direct photograph of a part of the V-2 rocket trajectory. $T_1 = X + 57.5$ sec; $T_2 = X + 71.5$ sec; $T_3 = X + 79.4$ sec; where $X =$ time of launching.

B) Objective grating spectrum of V-2 jet: (*a*) lights of cars on road; (*b*) launcher on ground and direct image of jet; (*c*) blockhouse; (*d*) first-order spectrum of jet; (*e*) first-order spectrum of blockhouse; (*f*) second-order spectrum of jet. The three emission features in order of intensity and wave length are at 4713 A, 4937 A, and 5031 A.

	Greenwich Civil Time
First contact	$11^h\ 11^m\ 34^s$
Maximum eclipse	12 12 45
Fourth contact	13 19 14

The first and last contacts were well observed and are believed to be accurate within 2 or 3 seconds. The time of maximum eclipse cannot be greatly in error; two minutes later it had definitely passed. At its minimum size the crescent appeared to be a thin line without breadth, about 45 degrees long.

It was estimated that first contact was 10^s past before the observer was conscious of it. The recorded time of first contact is therefore 10^s earlier than that observed. The air temperature at the station was 5° C.

RESEARCH WITH ROCKETS

A CORRECTION

F. Zwicky
California Institute of Technology

In my article, "Research with Rockets," in the April number of these *Publications,*[1] Plate VI shows a photograph of a shaped charge exploding in mid-air, which contains a most unfortunate spurious feature. I refer to the straight track with the bright upper end which in fact is nothing else but the internally and multiply reflected image within the telescope of the flash of the shaped explosive charge and of the jet emanating from it. Photographs of jets unmarred by the reflected image will be published in other places. One such photograph is to appear in the *Army Ordnance Journal,* July-August issue, as a part of an article on "Artificial Meteors" written by me.

June 9, 1947.

---

[1] *Pub. A.S.P.*, **59**, 64, 1947.