An Inexpensive Rocket Technique for Obtaining Low Level Wind Profiles[1,2,3]

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ABSTRACT

An inexpensive, reusable, cold propellant (no fire) rocket has been adapted so a continuous smoke stream is emitted from the instant of launching to an altitude of 1200 ft. The smoke column is photographed simultaneously at 10-sec intervals by two cameras located 2000 ft from the launch site and at right angles to each other. Results are presented in terms of north–south and east–west components of the wind speed at any desired altitude to 1200 ft. A brief cost analysis is presented as evidence that the rocket technique is quite inexpensive relative to other systems in use today.

1. Introduction

Relatively few good techniques are available for obtaining low level wind profiles. Towers instrumented with anemometers have been used occasionally to determine the low level wind profile to 1200 ft. Lack of mobility, cost of installation, hazards to aviation, and the sheltering effects of the tower on the instrumentation are the biggest drawbacks to the widespread use of such towers.

Another time-proven technique involves the release and tracking of pilot balloons. Such a technique allows one to compute the integrated wind velocity in successive layers of the atmosphere, the thickness of each layer depending upon the sampling interval, rate of rise of the balloon, skill of the operators, etc. When using the theodolite method, it usually takes 10 min or longer to complete observations for each wind profile. It is impossible to obtain an instantaneous profile using a pilot balloon. The balloon integrates not only in space but also in time so that resultant profile is at best only a smoothed profile of the wind field. In strong wind situations, the balloon may drift away so rapidly from the point of release that observations cannot be taken. Also, a profile obtained using a pilot balloon is not truly vertical over a single point on the earth, but rather a spatially integrated profile since the balloon moves with the wind.

In short, the conventional techniques are impractical and uneconomical when it is important to obtain low level wind profiles that are truly vertical and nearly instantaneous, especially if such profiles are needed at many individual locations.

2. Background

A problem necessitating the use of truly vertical wind soundings arose associated with a study of lake breezes. The problem was to obtain wind profiles at four to six stations located inland from the western shore of Lake Erie as nearly simultaneously as possible. It was hoped that whatever technique was developed for use on the land might be useful over the water as well, where wind profiles have been even more difficult to obtain. The height of the profiles would, in general, need be only 1200 ft, since the lake breeze rarely reaches higher altitudes in this particular area.

Several new ideas were considered which could replace conventional wind measurement techniques for obtaining low level wind soundings. The most promising of these ideas was the release of a vertical smoke column by an ascending rocket and subsequent photography of that smoke column. Simultaneously, and independent of the development described herein, Tolefson and Henry (1961) developed the same basic technique for wind determinations from 5000 to 50,000 ft, and more recently a low level adaptation has been reported from Australia by Cooke (1962). The rocket produced smoke column could be evaluated at short time intervals giving a nearly instantaneous wind profile which would be truly vertical over a given point. It is significant to note that a profile obtained from such a rocket could not be compared with a pilot balloon profile because the rocket profile is a short period time integration whereas the pilot balloon profile is usually a longer period time integration plus a spatial integration. To make the smoke rocket idea practical, three major components had to be either developed or adapted for this need.

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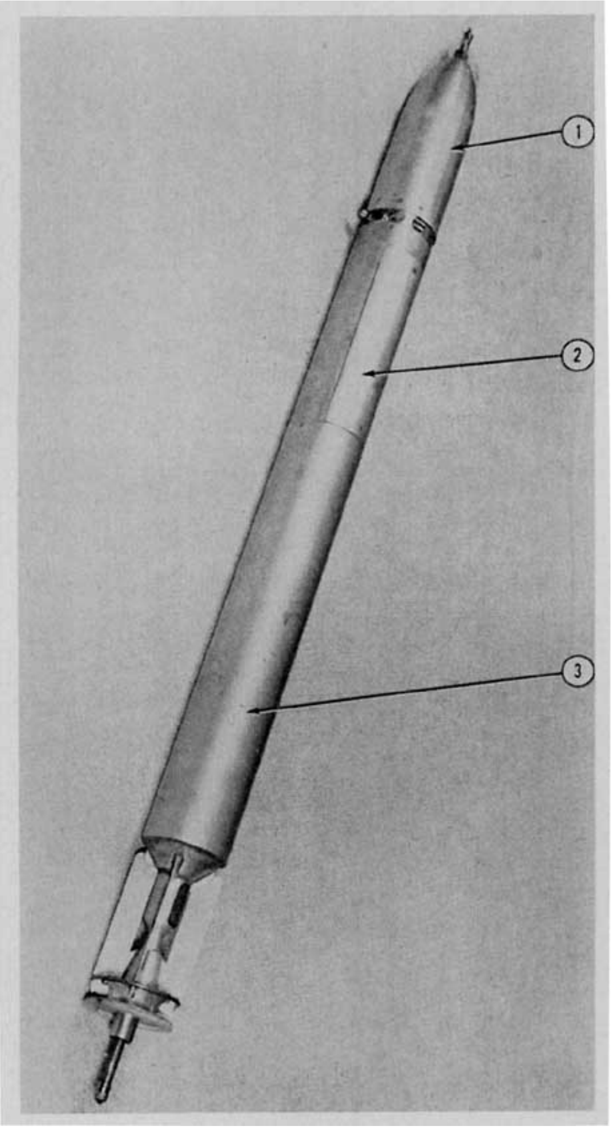

FIG. 1. The Cricket Rocket: 1) the payload section, 2) parachute and timer section, 3) propellant tank and nozzle assembly.

The first and most important component was an economical, reliable, and safe low level sounding rocket. Fortunately, a rocket that fulfilled these requirements had been developed by Texaco Experiment Incorporated of Richmond, Va. This rocket is known as the Cricket, so named for Cold Rocket Instrument Carrying Kit.

The second major component necessary was a smoke ejection system which could be used as a payload for the Cricket rocket. A system satisfying this need has been developed by the Meteorological Laboratories at The University of Michigan.

The photographic equipment constituted the third major component of the system. Although a number of cameras and types of film were available for such usage, the most efficient technique had to be determined by experimentation.

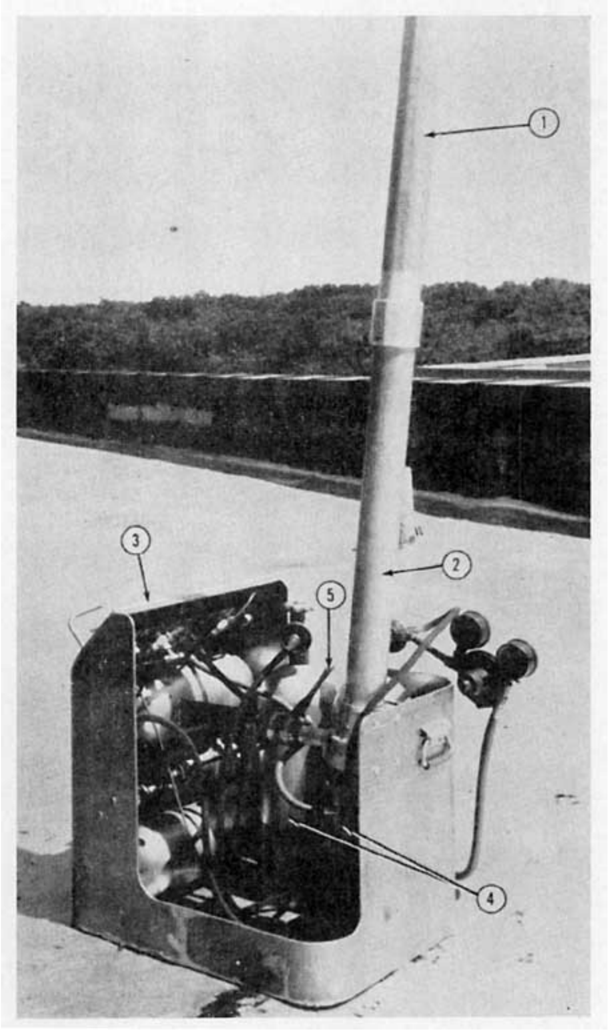

FIG. 2. The Cricket Launcher: 1) 10-ft launch tube, 2) breech tube 3) control panel, 4) CO_2 tanks, 5) launch release valve.

3. The rocket system

The rocket system consists of two separate units, the rocket and the launcher with its associated equipment. The rocket is divided into three major sections as shown in Fig. 1. Section (1) is the payload container, section (2) holds the parachute and timer mechanism, and section (3) contains the propellant tank and nozzle assembly. Fig. 2 is an illustration of the launching equipment which consists of (1) a 10-ft launch tube, (2) a breech tube, (3) a control panel, (4) pressurized CO_2 launch tanks, and (5) a launch release valve.

A cold type propellant (no fire) is used by the rocket in such a manner that the thrust is obtained in two separate stages. In the first stage of launching, the rocket is essentially shot out of the launch tube. In the second stage the rocket is accelerated by the release of a propellant mixture being ejected from its propulsion nozzle. The propellant mixture consists of liquid acetone and liquid CO_2 at a pressure of 600 psi. A nozzle plug is placed in the propulsion nozzle prior to launching to keep the propellant in the rocket while the rocket is in the launch tube. The launch tanks are charged with gaseous CO_2 to a pressure of 350 psi. The rocket is then ready for launching.

When the launch release valve is opened, gas pressure is exerted on the nozzle plug of the rocket and the rocket experiences an upward thrust accelerating to a speed of about 100 ft sec^{-1} as it leaves the launch tube. The rocket's stabilizing fins unfold as the rocket leaves the launch tube, permitting the nozzle plug to be released. The second stage is then initated and the rocket accelerates, due to the rapid ejection of the acetone and CO_2. This thrust lasts for approximately 2 sec, at which time the rocket has attained a speed of almost 350 ft sec^{-1} when carrying a payload of 1.5 lb. The rocket then coasts to a height of 1300–1600 ft.

An improved version of the rocket is now available which is slightly longer than the earlier models and operates at higher pressures. The rocket described in this paper produced a flight apogee of 3000 ft with a $\frac{1}{2}$ lb payload. The improved rocket produces a flight apogee of approximately 4000 ft with a $\frac{3}{4}$ lb payload. Using the smoke producing payload discussed here, wind profiles should be obtainable to at least 2000 ft.

The time required for the rocket to achieve peak altitude is about 10 sec with a 1.5 lb payload. A timer mechanism opens the parachute compartment at some preset time after launch. This time may be set from 2–30 sec, depending upon the particular application being made by the rocket user. When the parachute opens, the rocket descends slowly to the earth usually without damage to itself or to any surrounding objects. Thus the rocket may be reused again and again as long as no major structural damage occurs.

4. The smoke ejection system

Several smoke producing payloads were available, but few were suitable for rocket use because of a number of stringent requirements. These requirements can be listed as follows:

a) the smoke producing payload had to be limited to 2.55 inches in diameter, about 6 inches in length, and 1.5 lb in weight;
b) the smoke emission had to start as soon as possible after the rocket was launched, and be continuous for at least 10 sec;
c) the smoke producing reaction should not be exothermic;
d) the smoke producing reaction should yield a maximum amount of smoke per gram of reagent;
e) the rocket system was to be reusable, hence the smoke ejection system had to be suitable for repeated operations.

The size and weight restrictions ruled out the use of any oil fog techniques. Restrictions on reaction temperature and controlled emission made it difficult to use Berger's mixture.[4] White phosphorus, although one of the best smoke producers, was too dangerous because of its inflammable nature. The smoke producing technique which fitted the above requirements most closely was one which involved the hydrolysis of titanium tetrachloride due to the water vapor in the air. The production of smoke depends on the following generalized equation

$$TiCl_4+2H_2O \rightarrow \underline{TiO_2}+4HCl,$$

which produces titanium dioxide (TiO_2) as a white powder. This reaction was deemed suitable for use in the smoke ejection system because there was no high temperature of reaction, TiO_2 was a fine powder with little tendency toward settling, and since titanium tetrachloride was a liquid, it could be easily transferred into the rocket, dispensed and atomized into a fine spray.

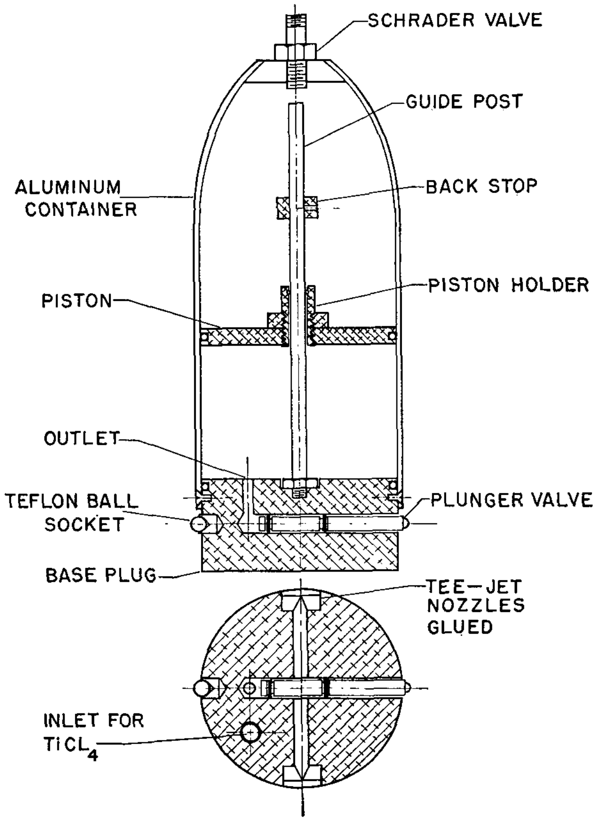

Fig. 3. Schematic drawing of the smoke ejection system.

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[4] Berger's mixture produces a white, long-lasting smoke from the following reaction:

$$2Al+C_2Cl_6+3ZnO \rightarrow \underline{3ZnCl_2}+Al_2O_3+2C.$$

Once titantium tetrachloride was chosen as the smoke producing agent, the design requirements were governed mainly by the characteristics of this liquid which acts as a mild acid. These design requirements are enumerated as follows:

a) $TiCl_4$ is a mildly corrosive liquid which necessitates the use of a relatively inert container;
b) because $TiCl_4$ reacts with moisture, it must be shielded from the air until the rocket is launched;
c) $TiCl_4$ must be atomized as it is dispensed into the atmosphere, so a maximum of smoke can be produced in a short period of time.

The smoke ejection system is made principally of aluminum which reacts very little with the titanium tetrachloride. The major components of this system are sketched in Fig. 3. The $TiCl_4$ is placed between the piston and the base plug just prior to launching. The plunger valve presses against the launch tube so it is held shut until the rocket leaves the launch tube. The space above the piston is charged with gaseous CO_2 to 90 psi through the Schrader valve. The CO_2 provides the required ejection pressure necessary for atomization by the tee-jet spray nozzles. As soon as the rocket leaves the launch tube, the pressure inside the container pushes the plunger valve open and ejects the $TiCl_4$ through the spray nozzles. During the early part of the flight, the liquid $TiCl_4$ is pressed against the base plug and the tee-jet spray nozzles due to the rocket's acceleration. However, as the rocket begins to coast, the liquid tends to move away from the base causing the ejection of $TiCl_4$ to cease. A piston, such as the one shown in Fig. 3, which moves continuously toward the base plug maintains a continuous ejection of $TiCl_4$ until the piston reaches the base plug. After the rocket returns to the earth, the payload section is washed with methyl alcohol so no reaction takes place between the $TiCl_4$ and the aluminum casing.

5. The photographic system

Two cameras mounted on tripods at right angles to each other are necessary to obtain an instantaneous photographic record of the smoke trail. Two types of cameras have been tried for this purpose.

The first type was a 4×5 inch press camera with a focal length of 5.3 inches (135 mm). The lens and the photographic film were kept exactly vertical while the principal axis of the lens was displaced upwards relative to the center of the film. This facilitated photographing to a higher altitude, but it tended to increase the third

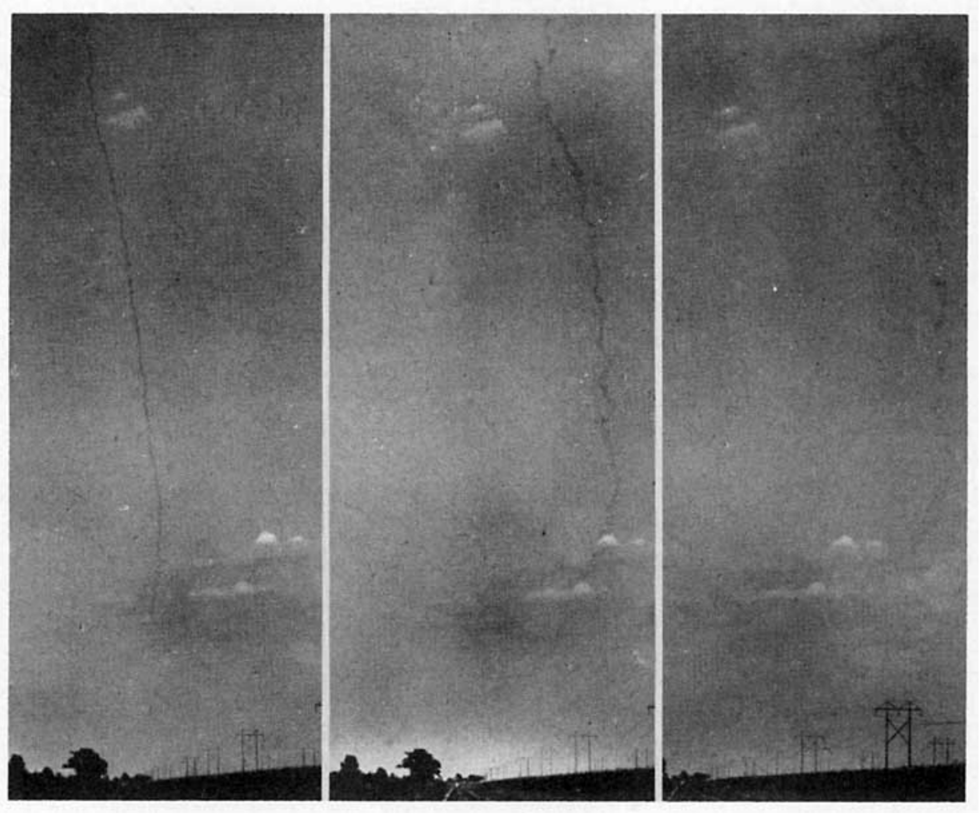

FIG. 4. Photographs of the rocket smoke trail, 16 September 1961. Camera facing east. a) 0 sec, b) 10 sec, c) 20 sec.

order aberrations caused by obliquity or skewness. An experimental evaluation revealed that the distortion produced in this camera was hardly perceptible in spite of the oblique pictures which were being taken.

The second type tried was a 35-mm camera with an attached automatic film advance mechanism. The negatives from this camera have to be enlarged considerably and have no particular advantage as compared with the press camera.

The selection and use of suitable film, filters, and exposure times are the most important factors involved in obtaining optimum photographic results. Kodachrome film with a red filter has given good results. However, infrared film with a K-25 filter has shown promise for future studies.

Photographs are taken by cameramen who are in constant communication with the launch site through the use of two-way radios. By referring to a stop watch, a communications man located at the launch site directs the cameramen when to take the pictures. In a more sophisticated system, an electric timer would transmit the signal at appropriate time intervals, and the received radiosignals would be amplified to operate the camera shutters by electric solenoids.

6. Analysis of data

The analysis of data is accomplished in a very simple manner, assuming no lens defects or distortions. The photographs are taken at a distance of 2000 ft from the launch site at intervals of 10 sec. An example of such photographs is shown in Fig. 4. The plume movement between two consecutive photographs was 100–200 ft. It was assumed that the error due to the movement of the plume along the axis of the camera was negligible. The 4×5 inch negatives were enlarged to 7.5×9.5 inch positives. The relation between actual object size and the size on the positive photograph was established by knowing the magnification factor from the negative to the positive, the focal length, and the object distance.

A transparent overlay was superimposed on each of the positive photographs and the position of the smoke trail was traced in each case. Fig. 5 shows a typical overlay with the successive smoke trails traced on it. Knowing the position of the smoke trails relative to each other, it was possible to obtain a 10-sec average wind speed component at any altitude to 1200 ft. Fig. 6 shows the final profiles for two successive 10-sec intervals.

Different methods of analysis may be utilized if other needs arise. Should single level readings be desired without the use of photographic techniques, then a calibrated telescope could be employed. This technique has been used successfully at Woomera Range, in Australia (Cooke, 1962). Photographs taken at either faster or slower time intervals would be another variation of the analysis technique. The exact method of data analysis depends upon the use that is to be made of the wind profile obtained from the smoke trails. Regardless of which method is selected, all are considerably easier to evaluate mathematically than the double theodolite pilot balloon method.

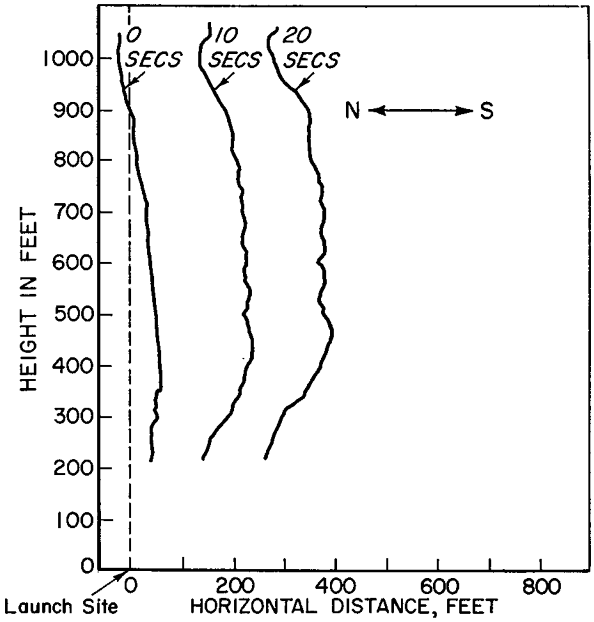

Fig. 5. Overlay composite of the smoke trails from the photographs of 16 September 1961.

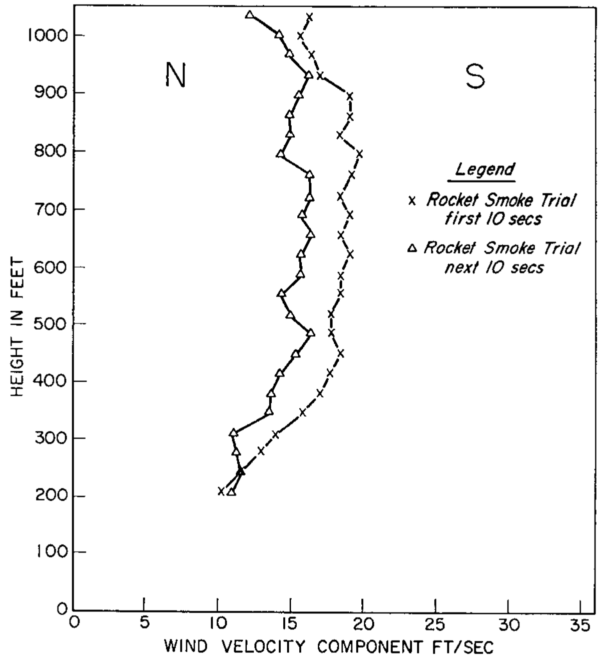

Fig. 6. Wind profiles obtained from the overlay composite of the smoke trails, 16 September 1961.

7. Cost estimate for the rocket system

Probably the greatest advantage of the system proposed in this paper in comparison with other rocket systems is the economical cost of operation. The reason the Cricket rocket system is so economical is that the component parts are reusable. The exact cost per flight will vary depending upon the usage, the terrain in which the rocket lands, the effect of the $TiCl_4$ on the aluminum parts, etc.

The simplest launcher for the Cricket costs about $400.00, although more sophisticated launchers may be purchased. The rockets cost $30.00 each, but are used again and again unless a major section is damaged. Based upon a minimum of six flights per rocket, the cost per flight is estimated at $15.00. This cost includes the initial price of the rocket, the cost of fabrication of the smoke ejection system, the CO_2, acetone, and $TiCl_4$. A damaged rocket can be repaired and put back into operation through the purchase of replacement parts.

Photographic and communications equipment constitute an additional cost which varies in accordance with the precision required. Because such equipment is already a part of many groups' basic field instrumentation, the costs are not estimated here.

The minimum personnel required includes a launcher operator, a communications man, a rocket retriever, and two cameramen. Extra men can be used to assist in preparing the rocket and the launcher for firing and also as communications men at the camera sites. On the other hand, a fully mechanized operation would require only two men, one man to launch the rocket and trigger the cameras automatically, and the second man to retrieve the rocket.

8. Summary

A rocket technique has been described which can be used to obtain wind profiles to 1200 feet above the earth's surface. Its main advantages are as follows:

a) *mobility*—The wind profile can be obtained at several locations during the same day by merely transferring the launcher and two cameras with tripods.

b) *adaptability*—The technique can be used on flat or hilly terrain, and possibly even in metropolitan areas. It is also possible that the technique can be adapted for limited use over water.

c) *rapid analysis*—By using press cameras equipped with polaroid film and taking double exposures, it is possible that a wind profile at 50-ft intervals to 600 ft could be abstracted within 2 min of firing the rocket by use of a simple calibrated overlay. Such profiles could provide much fuller, and up-to-the-minute wind information for correcting the wind loading of non-radio-controlled rockets than is currently available.

d) *low initial cost*—Operating expense is also relatively low.

e) *small hazard to life and surroundings*—No fire or explosives are used. There is small likelihood of serious exposure to toxic agents.

f) *truly vertical profile*—The wind profile obtained is essentially that directly over the launching site, rather than a spatially integrated profile depending on the angular trajectory of a balloon.

There are some disadvantages in the use of a smoke trail released by a rocket. They are:

a) the operation is limited to daytime operation unless searchlights are used to illuminate the smoke trail;

b) the use of titanium tetrachloride limits the smoke technique to fair weather days when no rain or low clouds are present;

c) current techniques require a minimum of five men, but automation can reduce this to two men.

At this point the advantages outweigh the disadvantages, especially since many of the other techniques for obtaining wind profiles are as severely limited as the rocket technique. Thus the rocket technique of obtaining low level wind profiles has a place today in the field of micrometeorology.

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