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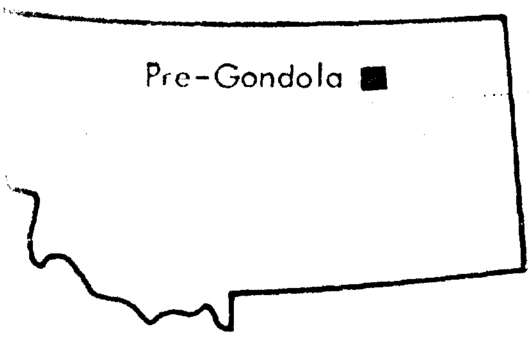
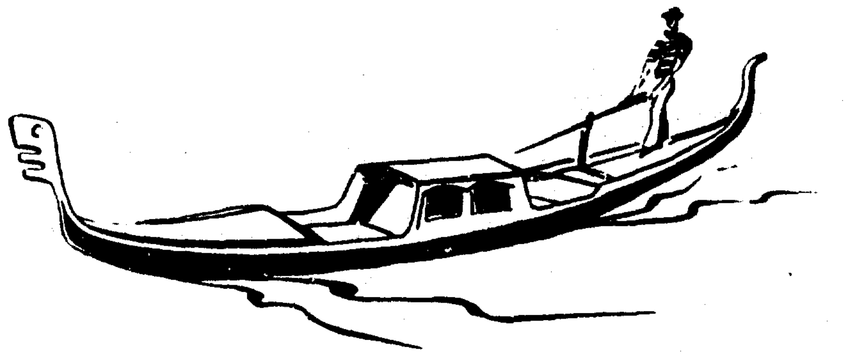


PROJECT
PRE-GONDOLA II



AIRBORNE LIDAR OBSERVATIONS

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View of Pre-GONDOLA II Cloud From CP Area

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ABSTRACT

Lidar (laser radar) observations from an aircraft of the cloud of debris resulting from the Pre-GONDOLA II explosion at Fort Peck, Montana, are described. With the neodymium (near infrared) lidar pointing horizontally at 45° aft of the aircraft beam, the aircraft made a series of flights past the cloud position at a height of approximately 225 meters above ground level and the lidar was fired at intervals of approximately 6 seconds. Since the cloud rapidly became invisible, these flights were positioned with reference to the lidar observations using a Doppler navigation system. From the lidar observations the location, shape, and internal structure (in terms of variations of density) of the cloud at the flight level were determined at five successive times, extending some 37 minutes after the explosion and some 17 kilometers downwind. While this technique is thus shown to be immediately available (with minor improvements) for limited operational application, the developments necessary to realize its full potential are identified and described. In particular, significant improvements in the data handling system are proposed.

ACKNOWLEDGMENT

We particularly wish to acknowledge the very willing cooperation received from Edgerton, Germeshausen and Grier, Inc., both in preparing the aircraft for the experiment and in carrying out the flying experiments, especially in view of the fact that Mr. K. Thompson and his crew came straight to this project from a period of extended flying.

We also wish to acknowledge the assistance and collaboration of Mr. M. Sykos of Lawrence Radiation Laboratory, who acted as Safety Officer.

CONTENTS

I INTRODUCTION

A. Description of Project Pre-GONDOLA II

Project Pre-GONDOLA II was a row-charge cratering experiment in weak, wet clay-shale conducted by the U. S. Army Engineer Nuclear Cratering Group (NCG) as a part of the joint Atomic Energy Commission/Corps of Engineers nuclear excavation research program. The primary purpose of this nominal 140-ton 5-charge row-charge experiment was to gain row-charge cratering experience in a weak, wet medium. In addition, this experiment tested techniques for connecting a row-charge crater to an existing crater and for over-excavating to accept throwout from a follow-on connecting row-charge crater.

Project Pre-GONDOLA II was detonated at Valley County, near the edge of the Fort Peck Reservoir approximately 18 miles south of Glasgow, Montana, at exactly 0800 hours (MDT), 28 June 1967 (see Fig. 1). Coordinates of the center charge were W106° 38' 31", N47° 55' 51". The orientation of the row was along a 11° East of North to 11° West of South alinement extending through the center of Charlie Crater.

The average lip crest to lip crest dimensions after connection to the Charlie Crater were 640 ft x 280 ft. Individual charge yields, depth, spacing, and resulting apparent crater dimensions were as follows:

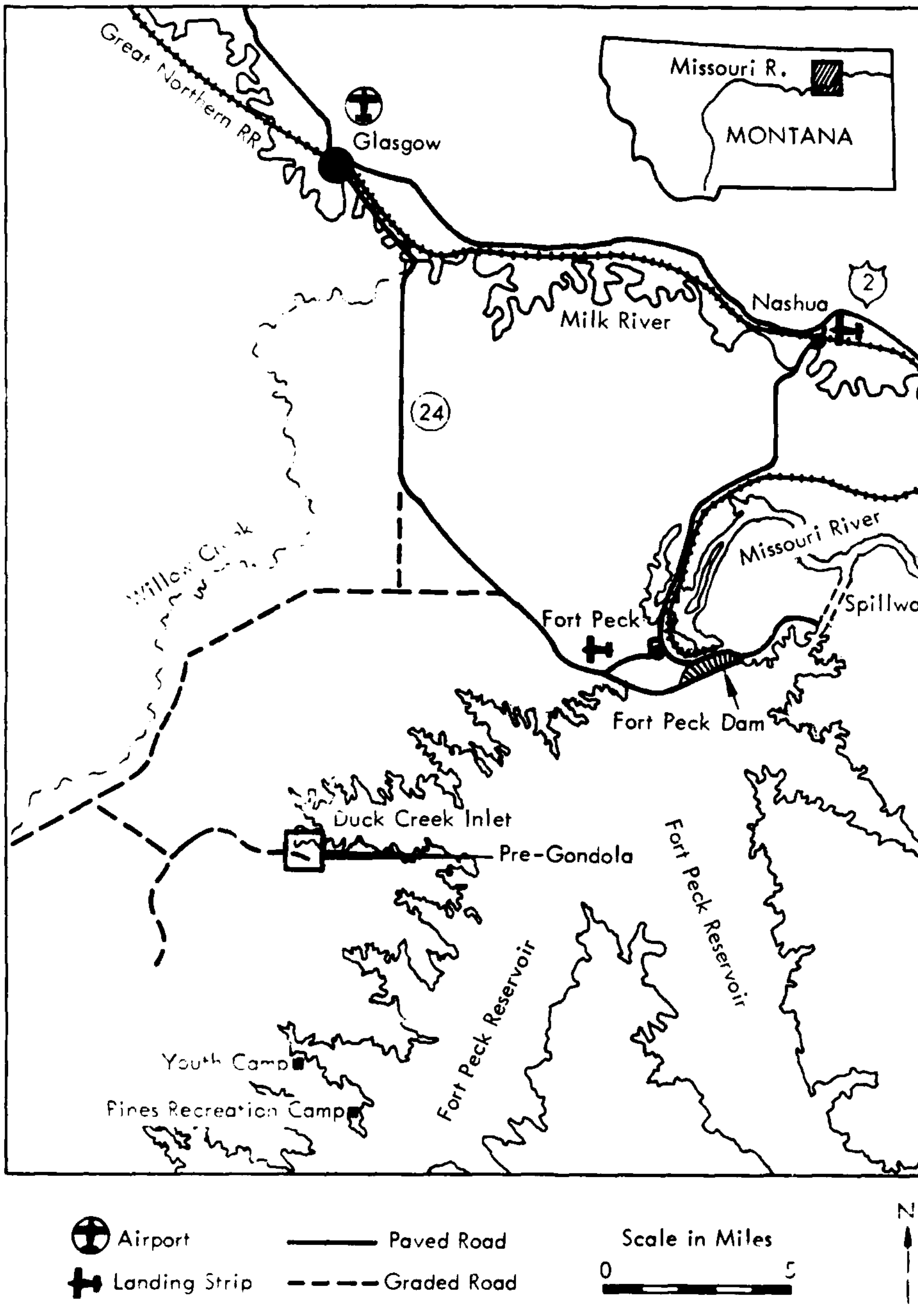

FIG 1 SITE OF PROJECT PRE-GONDOLA II

II PROCEDURE

A. Operational Plan

The operational plan, which had been rehearsed during the test flight of 27 June, called for the initial positioning of the NATS aircraft to the southwest of ground zero. From this position, the aircraft could begin the first run past the cloud immediately after the go-ahead was received from the test director.

The three-man SRI crew aboard the aircraft were employed in the following way. An observer stationed at the lidar sighting telescope controlled the firing of the lidar. He commanded a view of the entire region surrounding the aiming point of the lidar. The lidar return signal was displayed on a Tektronix oscilloscope upon which was mounted a recording camera. The second observer photographed each return signal on Polaroid film, and also monitored the performance of the lidar apparatus. The third observer was stationed at an auxiliary oscilloscope, and visually monitored each lidar return for the presence or absence of a return signal from the cloud. In addition, the Lawrence Radiation Laboratory laser safety coordinator was located adjacent to the lidar sighting station, and could electrically inhibit the firing of the lidar at any time he deemed necessary.

After the detonation, the aircraft was flown on a series of courses, that had been planned previously with regard to wind direction and velocity. (See Fig. 2). The lidar commenced firing well ahead of the estimated position of the cloud, and continued firing until no further cloud returns were received on each run.

The intention was to use the aircraft's Doppler navigation system to

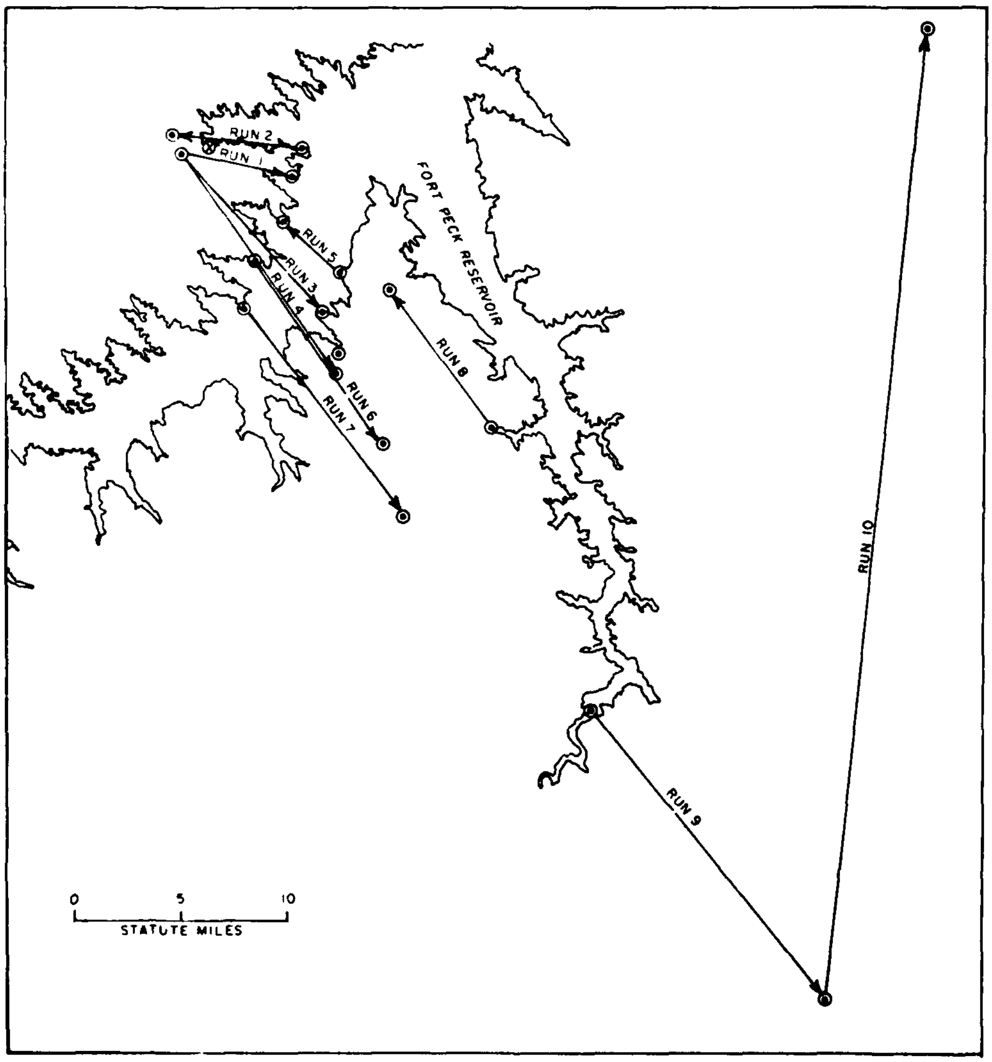

FIG. 2 SUCCESSIVE GROUND TRACKS OF THE AIRCRAFT DURING THE EXPERIMENT

provide a frame-work of reference for making the observations and for providing assistance to the pilot to maintain accurate courses during the observations. Thus, the Doppler plot was started on a recognizable landmark (the Doppler Point) and oriented so that its track was parallel to the expected downwind path of the debris cloud and sufficiently to one side to allow the lidar observations to be made. Each series of lidar observations were to be started at a point along this track, which was called the Lidar Point for the run in question. In this way, it was hoped that a substantial part of the program could be carried out without changing the key Doppler Point. For each pass a new Lidar Point would be selected along the Doppler track in accordance with the experience of the cloud motion, to indicate at what time the lidar shots should begin.

The advantages of this system were that the pilot could position his aircraft at the start of the run on good landmarks. He could then fly the selected tracks with the aid of the Doppler system by maintaining a course that yielded zero drift indications on the Doppler indicator. The Doppler indications of distance along the track then provided an indication of when the lidar observations should begin.

Since it was intended to make observations on both downwind and upwind passes, an identical Doppler positioning scheme was planned for the return upwind passes.

To provide running checks of the Doppler error each Doppler run was to be closed on an identifiable landmark. Since the data recording system had provision for marking any desired "event" (including lidar firings, and recording the coincident Doppler plot position), it was hoped that subsequent analysis would enable all lidar firings to be related rigorously to ground positions.

At the termination of each run, photographs of the lidar returns were examined and compared with a map showing the ground track of the aircraft.* From this information and from the estimated wind data, the size of the cloud and its future position were estimated, and the pre-planned courses were modified as required to properly position the next run with respect to the moving cloud. Repeated runs were made in the manner described above until contact with the cloud was lost.

B. Laser Safety

All lidar observations were made in accordance with the procedures and safety criteria outlined in Annex B of the "Technical Director's Operations Plan for Pre-GONDOLA II."

The safety plan was based on visual surveillance of the volume of space surrounding the lidar path. This volume was monitored by the lidar operator with the aid of a sighting telescope whose optical axis was alined parallel to the lidar beam. The lidar was not fired when aircraft were within the field of view of the sighting telescope, or when the aircraft attitude was such that the lidar beam could strike the ground. In addition, the safety coordinator independently scanned the general area around the lidar beam with binoculars and could inhibit firing of the lidar if he deemed it necessary.

C. Description of the Experimental Equipment

1. Mark V Lidar

The Mark V lidar transmitter consisted of a Q-switched, neodymium-

* The ground track of the aircraft was plotted by the Edgerton, Germeshausen and Grier technical crew from data obtained from the Doppler navigation system.

doped glass laser whose output radiation occurs in the near-infrared portion of the spectrum at a wavelength of 1.06μ. The laser is capable of producing pulsed coherent radiation of 15 nanoseconds duration, with a peak power output of 25 Megawatts. The laser output beam divergence (beamwidth) is approximately 5.6 milliradians. Since the angular resolution of the lidar is determined by the transmitted beam divergence, collimating optics are used to reduce the beam divergence and to produce an output beamwidth of 0.35 milliradians. The corresponding two-dimensional spatial resolution of this beam is 0.35 m at the range of 1 km. The range resolution of the equipment is 2.3 m. The pulse-repetition rate (PRR) of the Mark V lidar is primarily limited by the ambient air temperature, which determines the cooling rate of the laser head. For the temperature encountered during the observations discussed here, the maximum PRR that could be attained was approximately 12 pulses per minute.

The lidar receiver consists of a 6-inch diameter Newtonian reflecting telescope, identical to the transmitter optics. An adjustable field stop at the focal plane limits the receiver acceptance angle to a maximum of 6 milliradians. A multilayered interference filter with a wavelength interval (bandwidth) of 0.01μ is inserted in the receiver optical path to reduce the output noise level produced by solar radiation scattered into the receiver field of view. The dectector consists of an RCA 7102 photomultiplier with an S-1 spectral response. An optical diagram of the lidar is shown in Fig. 3.

A detailed discussion of lidar detection of atmospheric targets and lidar equipment design features is beyond the scope of the present report. These topics are treated extensively in Refs. 1, 2, and 3.

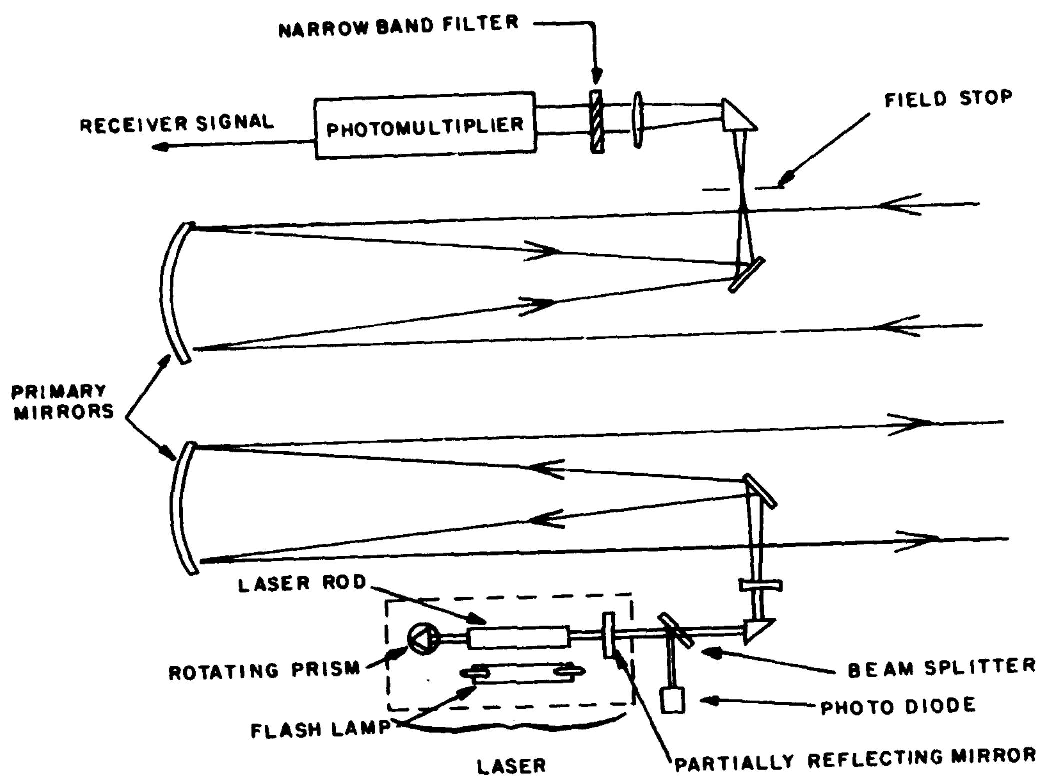

FIG. 3 MARK V LIDAR OPTICAL DIAGRAM

Table I summarizes the pertinent characteristics of the Mark V lidar.

The lidar transmitter and receiver were located on the port side of the aircraft, just aft of the existing electronic equipment rack. The lidar was mounted so that it looked horizontally in a direction 45 degrees aft of the aircraft's beam to the left. (In this way, as shown in Fig. 4, the number of shots traversing the cloud was increased). The remaining units of the lidar were mounted at various locations in the nearby electronic equipment rack. Three cylinders of compressed nitrogen provided energy for the laser Q-switching turbine.*

2. Electronics and Data Recording Equipment

The major electronic components of the lidar and the data recording system are illustrated in block diagram form in Fig. 5. A compressed air-driven turbine rotates the laser Q-switching prism at 500 revolutions per second. Upon receipt of a fire signal, the synchronizing generator triggers the flash lamps in step with a signal from the rotating prism. A capacitor bank charged to approximately 3 kV supplies energy for the laser flash lamps. A photo diode senses the occurrence of the laser pulse and produces a trigger to start the data recording equipment. The output of the photomultiplier in the lidar receiver is fed to a pulse amplifier having a logarithmic transfer function, and then to two Tektronix 453 oscilloscopes. A Polaroid recording camera mounted on one oscilloscope facilitated the initial alinement of the equipment and was used to photograph the lidar return signal. An independent backup system consisting of a manually operated 35-mm recording camera mounted on an auxiliary oscilloscope

*The electric motor-driven air compressor normally associated with the lidar could not be used because of primary power limitations aboard the aircraft.

Table I

MARK V NEODYMIUM LIDAR CHARACTERISTICS

Transmitter

Laser	Neodymium-doped glass
Wavelength	1.06μ
Beamwidth	0.35 Milliradian
Optics	6-inch f/4 Newtonian reflector
Peak Power Output	25 Megawatts
Pulse Length	15 Nanoseconds
Q-switch	Rotating prism

Receiver

Optics	6-inch Newtonian reflector
Field of View	3.0 Milliradians
Pre-Detection Filter Wavelength Interval	0.01μ (100 Å)
Detector	RCA 7102 Photomultiplier (S-1 cathode)
Post-Detection Filter Bandwidth	28 GHz

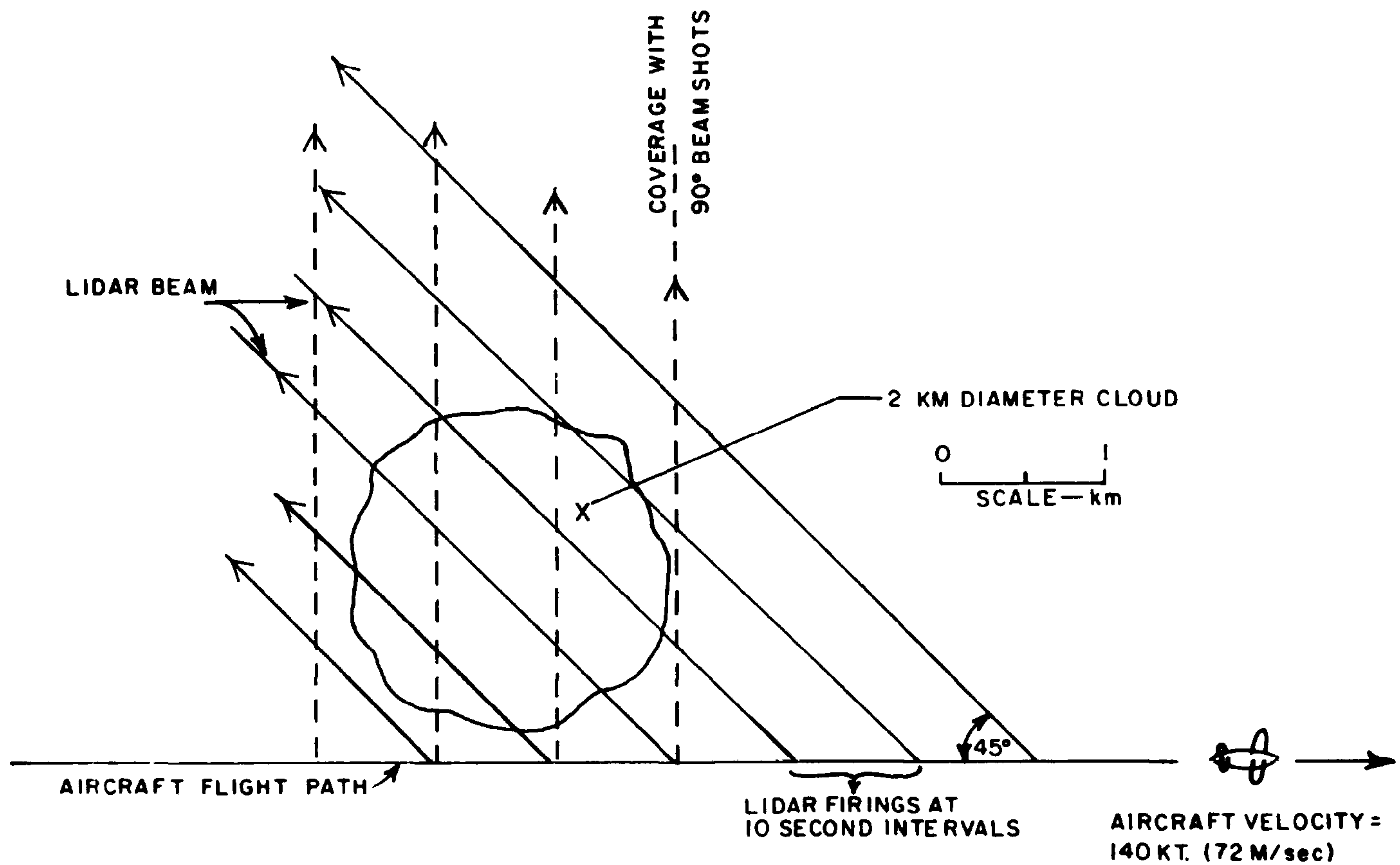

FIG. 4 PLAN VIEW OF SCANNING SCHEME-AIRBORNE LIDAR

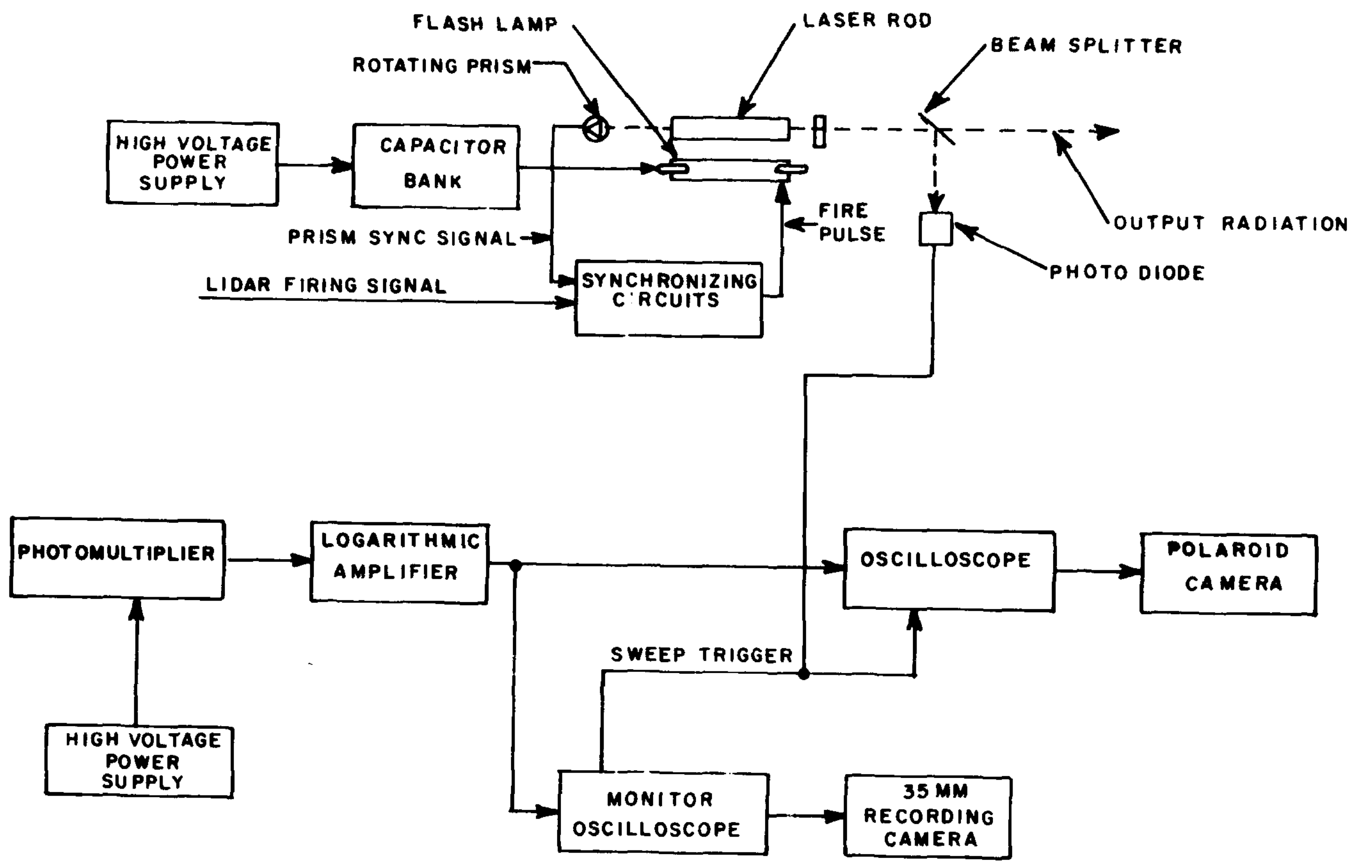

FIG. 5 BLOCK DIAGRAM OF THE MARK V LIDAR ELECTRONICS

was used to photograph each trace. A telephone system was installed to facilitate communication between the three-man lidar team and the safety coordinator. An audio tape recorder connected to the telephone line was used to record various equipment settings, as well as a running commentary on the progress of the experiment. In addition, the observer stationed at the lidar sighting telescope had access to the aircraft's normal intercommunication system.

A 70-mm view camera was installed near the lidar. A photograph was automatically taken at every firing of the region surrounding the lidar field of view.

3. Aircraft Equipment

Data concerning the travel of the aircraft over the ground was obtained from the Doppler radar navigation system (AN/APN-183) aboard the aircraft. The instantaneous coordinates* of the aircraft were printed on paper tape at every firing of the lidar.

Additional navigational data were printed in tabular form by a teletype unit associated with the aircraft digital computer system. The data (which included altitude, groundspeed, magnetic heading, drift angle, wind speed, and direction) were printed out at every firing of the lidar.

*Referenced to a rectangular coordinate system that included a known starting and ending point for each run.

III RESULTS

A. Program Summary

The modifications to the NATS aircraft required for this experiment were accomplished by E. G. and G. at the aircraft's home base.

The major modifications were:

(1) Construction of a mount for the lidar transmitter and receiver

(2) Construction of viewing ports for the lidar at an existing escape hatch

(3) Provision of 110 volt, 60-Hz power

(4) Provision of a power distribution panel

(5) Provision of mounting arrangements for the other components of the lidar system.

On 7 June, the NATS aircraft (a Martin 404) arrived at San Francisco International Airport for a trial installation of the lidar equipment. The equipment was installed during the day. On the following morning, the lidar was alined and checked for proper operation. A test flight in the local areas was conducted in the afternoon to verify the proper operation of the equipment under actual operating conditions. At this time, a careful check was made to determine if operation of the lidar would produce electrical transients capable of interfering with the proper operation of other equipment aboard the aircraft. Also, the operation of the lidar was monitored to verify that operation of the aircraft's electrical and electronic equipment would not produce spurious triggering of the lidar. All equipment aboard the aircraft performed properly, and no interference of either kind was observed. A number of runs were made past several small cumulus clouds to simulate the cloud tracking operation. The purpose of these runs was to obtain an appreciation of the time scale involved in tracking relatively small clouds with a fast moving aircraft. A secondary purpose was to obtain lidar data that was later used to optimize the various settings of the lidar equipment. The duration of the test flight was approximately 2.5 hours. On 9 June the lidar equipment was removed, and the aircraft returned to its home base.

The original schedule was such that the aircraft would be available at Glasgow, Montana, for several days before the shot. A number of test flights had been planned during which time the lidar tracking and plotting technique could be optimized. Because of higher priority commitments of the aircraft, it became necessary to delay the installation of the lidar until the morning of 27 June. The SRI crew, with the equipment, met the aircraft at Twin Falls, Idaho.* The installation was completed during the flight from Twin Falls to Glasgow. A test flight was made in the late afternoon of 27 June but was necessarily limited to checking out the equipment and establishing an initial plan of operation of a minimum nature.

All equipment functioned properly. The duration of the test flight was approximately one hour.

In the actual observational flight on the morning of the 28th, some difficulties arose in connection with the proper positioning of the aircraft; also, because of insufficient time, it had not been possible to put the 70-mm view camera in effective operation. A malfunction occurred in the digital computer that resulted in loss of the data normally printed out on the teletype unit. The main problem was at the interface between the aircraft

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*The lidar was involved in another project there.

crew and the lidar crews. This resulted inevitably from the from the lack of preparation and practice caused by the curtailment of the test flight period. Again, shortcomings in the intercommunication system between the crews could not be rectified in the time available. The experimental method described in Section II-A was followed, and the cloud was successfully observed by lidar during five of the first six runs. Contact with the cloud was lost after run six (approximately 38 minutes after detonation) and the remaining four runs failed to re-establish contact with the cloud.

The lidar equipment operated without malfunction during the entire flight. The duration of the observational flight was approximately two hours.

A preliminary reduction of the data was accomplished after the flight, and an informal letter report describing the experiment and the preliminary results were submitted on the evening of 28 June.

The following day, the aircraft stopped at Twin Falls on its return trip, where the lidar equipment was removed.

An Interim Data Report was submitted on 24 July 1967.

B. Data Summary

TABLE II. Summary of lidar data obtained in this experiment

Run No.	Start Time (MDT)	End Time (MDT)	Number of Shots Fired	Number of Shots Traversing Cloud
1	0804:43	0805:42	7	1
2	0808:35	0809:56	9	-
3	0812:24	0814:33	9	6
4	0822:15	0826:05	23	6
5	0829:22	0830:16	8	6
6	0835:10	0838:20	24	6
7	0847:00	0850:26	28	-
8	0856:00	0900:00	21	-
9	0913:00	0916:45	41	-
10	0920:00	0926:00	46	-
			Total 216	

The primary data for this report consisted of the 216 lidar returns recorded on Polaroid film along with the ground coordinates of the aircraft corresponding to each lidar shot.

IV ANALYSIS, DISCUSSION, AND INTERPRETATION

A. General Remarks

After the detonation, which occurred at 0800 MDT, the main series of runs were made at an altitude of approximately 225 meters above the terrain in such a way that on each run, a succession of lidar shots probed a horizontal plane intersecting the cloud. Each run was intended to provide optimum viewing of the cloud as it was displaced by the wind. On each run, the lidar was fired at regular intervals (at a rate of approximately 10 per minute), starting from a point well ahead of the cloud's estimated position and continuing until no further echoes were recorded.

The aircraft maintained a true airspeed of approximately 155 knots, giving a downwind ground speed of 165 knots and an upwind ground speed of 145 knots. At these speeds, lidar shots were made at approximately 552 meter intervals along the track on downwind runs and at intervals of 485 meters on upwind runs. Difficulties were experienced in positioning the aircraft and the runs made were badly located with respect to the cloud; in addition, the runs were made at overlong intervals in some cases. (It should be recalled that the cloud became barely perceptible to the eye shortly after the detonation and was quite invisible by about minute 15).

The top of the cloud did not appear to rise above 250 meters or so above ground level and rapidly became quite tenuous as it moved at a velocity subsequently measured at 148 degrees (T), 7.0 meters per second.

The furthest distance of dust detection was 6.7 km at 29 minutes, 55 seconds after detonation. At this time the cloud was some 13.8 km from ground zero. The greatest distance from ground zero at which the cloud was observed was 16.5 km at minute 37.

Extensive searching failed to re-establish contact with the cloud after Run 6 (the last return being obtained at minute 37:36). By this time the cloud had become very diffuse, but it is probable that some further tracking could have been achieved had the aircraft positioning been fully effective.

B. Cloud Position and Shape

Figure 6 shows the successive locations of the cloud as it was displaced by the wind. The aircraft tracks are shown, each identified by the run number; along each track the position at which the lidar was fired is indicated. (Only significant lidar shots are so indicated). The position of the lidar points has been adjusted on the basis of the measured wind displacement to give the optimum representation of the shape of the cloud at mid-time (centered on the position indicated with a square).

The orientation of the major axis of the cloud is in good agreement with the orientation of the Pre-GONDOLA II crater, and does not appear to change significantly with time. The shape of the observed portion of the cloud does not change rapidly with time; this characteristic agrees fairly well with the behavior of Pre-GONDOLA I Delta event, where an approximately circular cloud was tracked for 10 minutes. Meaningful conclusions concerning cloud size and growth cannot be presented because of the limited sampling of only a portion of the cloud. However, it is interesting to note that the size of the observed portion of the cloud did not appear to increase as rapidly as the Pre-GONDOLA I Delta Cloud[4]. For example, in the time interval between 0814:08 and 0837:23 (see Fig. 6) the cloud size increased by a factor of 1.3. During the Pre-GONDOLA I Delta event, in the time interval from three minutes to ten minutes after the detonation, the cloud size increased

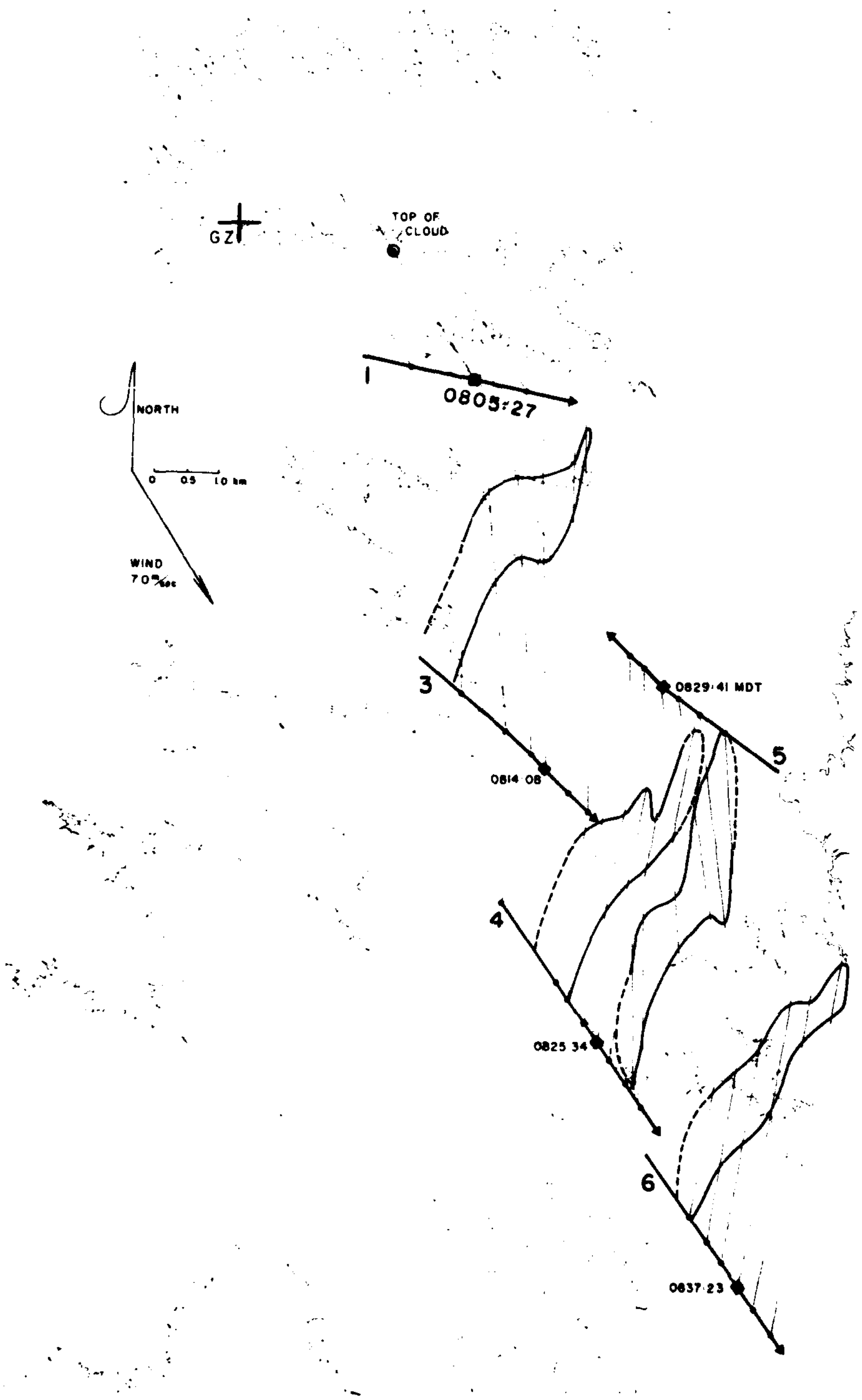

FIG. 6 SUCCESSIVE LOCATIONS OF THE CLOUD

by a factor of 2.4.

C. Cloud Displacement and Wind Velocity

The successive locations of the cloud along the mean path Fig. 6 are plotted as a function of time and shown in Fig. 7. The displacement is seen to be remarkably regular at the height of the observations (approximately 225 meters above the surface) and corresponds to a wind velocity of 7.0 meters per second from 328 degrees (T).

It is also interesting that the trajectory of the cloud in Fig. 6 does not originate at ground zero. This is probably partly due to the uncertainty in determining the mean path and the position of the cloud relative to the mean path was anomalous in its early stages (due to different wind directions at the lower level), apparent erroneous motions along the mean path would result from the plotting procedure employed in Fig. 7.

D. Cloud Density

Contours of relative echo intensity for Runs 3, 4, 5, and 6 are shown in Fig. 8, 9, 10, and 11 respectively. These contours indicate, on a logarithmic scale, the relative density of the debris within the cloud, as well as can be inferred from the available data. Various attempts were made to relate echo intensity, area of the cross section, and time along the lines of the analyses made of the Pre-GONDOLA I data. The limited nature of the present data, however, did not permit meaningful interpretation to be made. The restricted data rate of the experiment was inappropriate for the small scale of the size and structure of the Pre-GONDOLA II cloud. The resolution of the data along the lidar path is on the order of 100 meters but in the direction of the aircraft's motion the resolution falls to 350 to 400 meters.

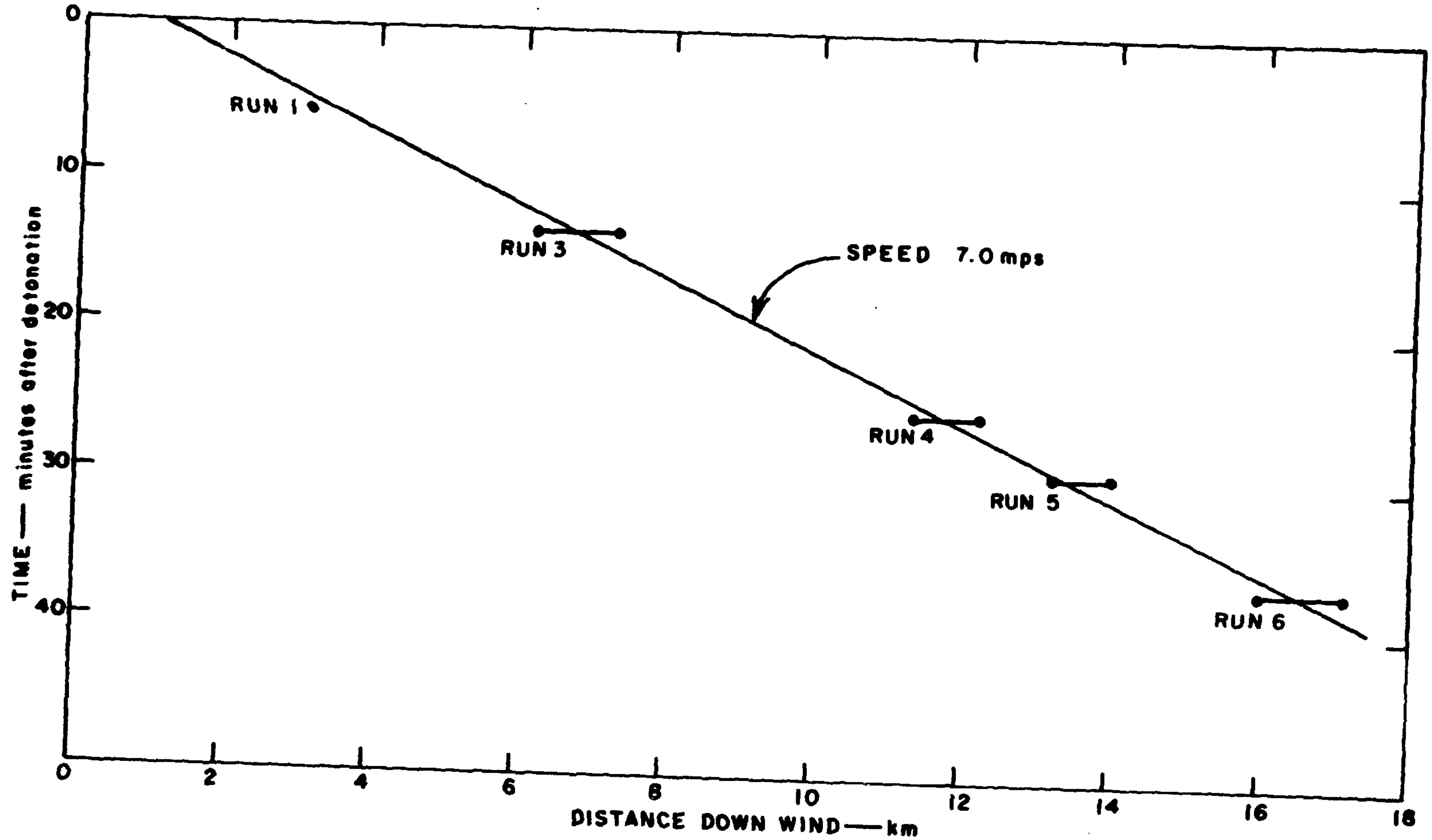

FIG. 7 CLOUD DISPLACEMENT ALONG MEAN PATH — 148°T

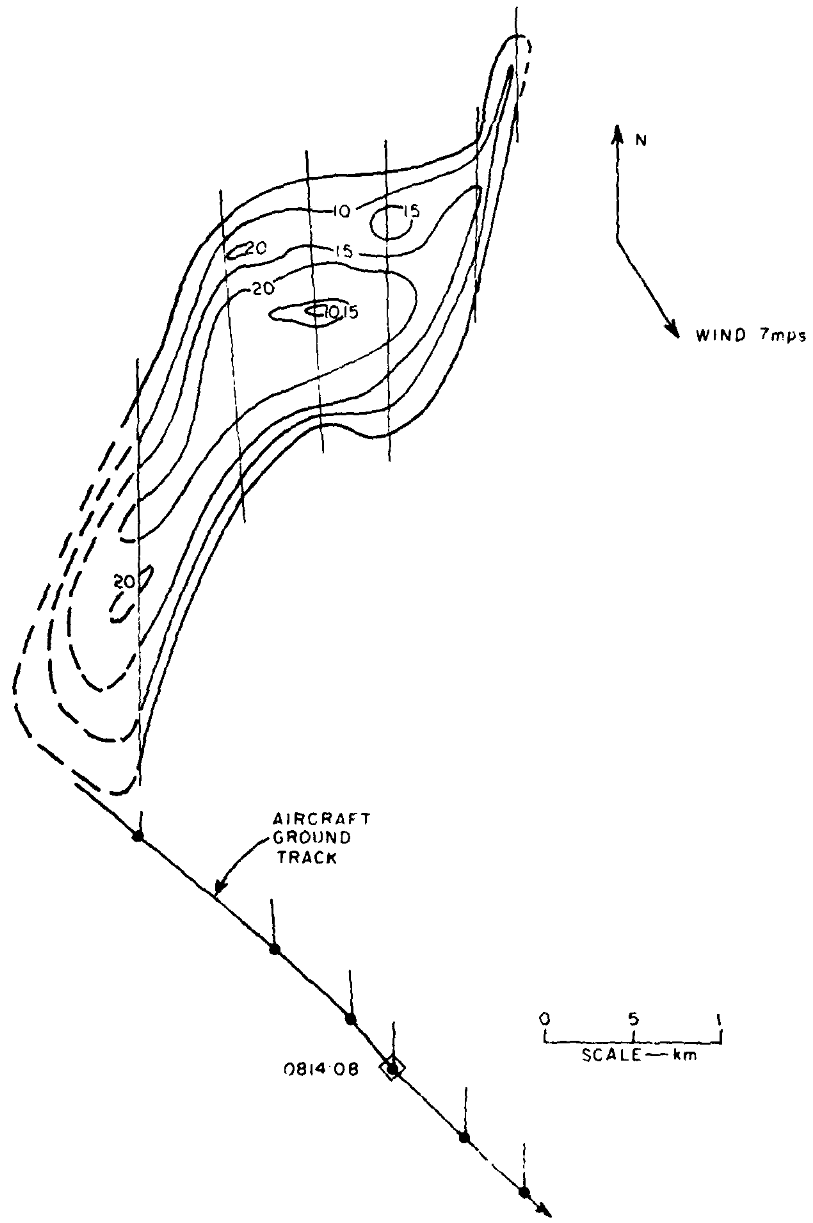

FIG. 8 RELATIVE [illegible] VARIATIONS [illegible]
CLOUD RUN [illegible] FROM GZ IN DB ABOVE [illegible]

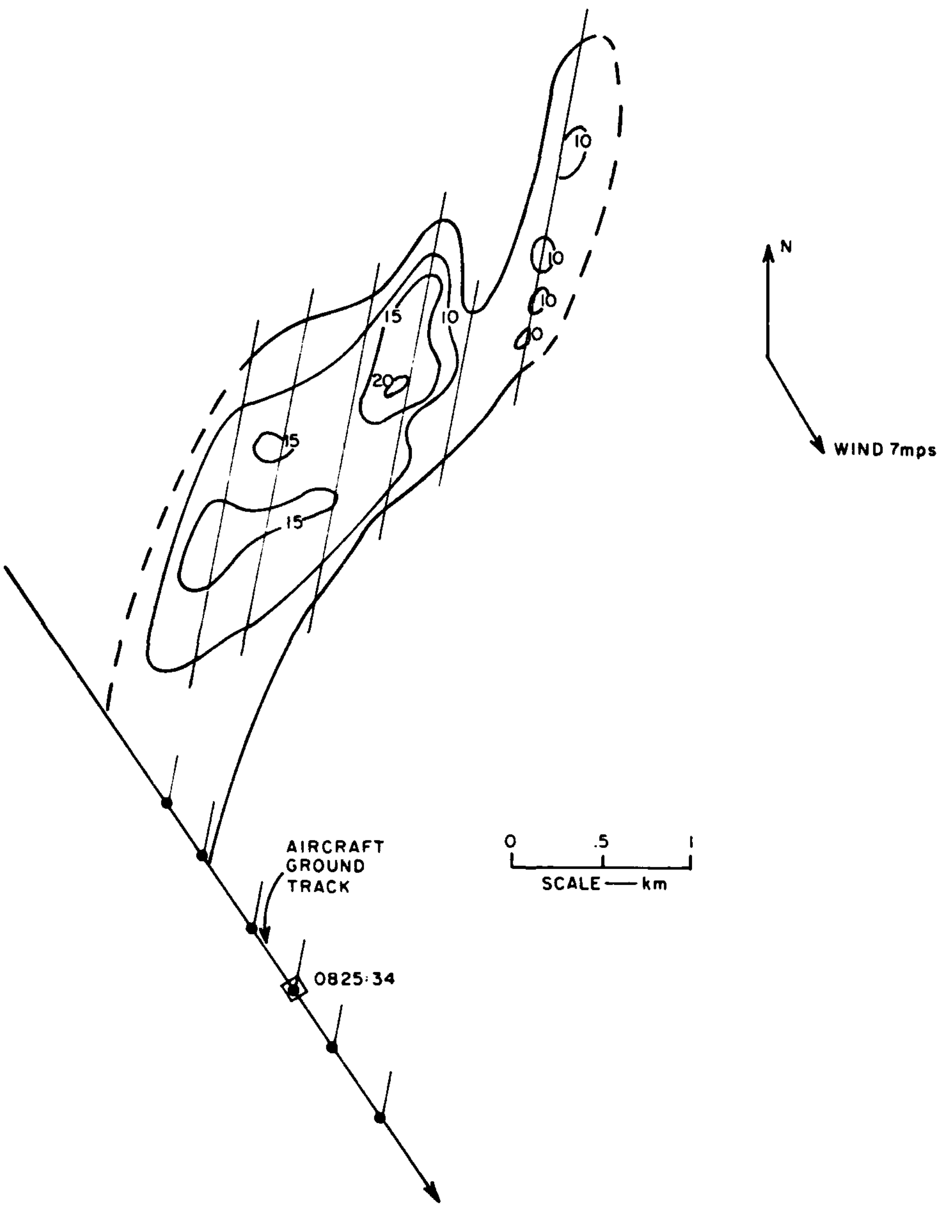

FIG 9 RELATIVE DENSITY VARIATIONS OF THE SUB-VISIBLE CLOUD RUN 4 11.5 km FROM GZ IN DB ABOVE BACKGROUND

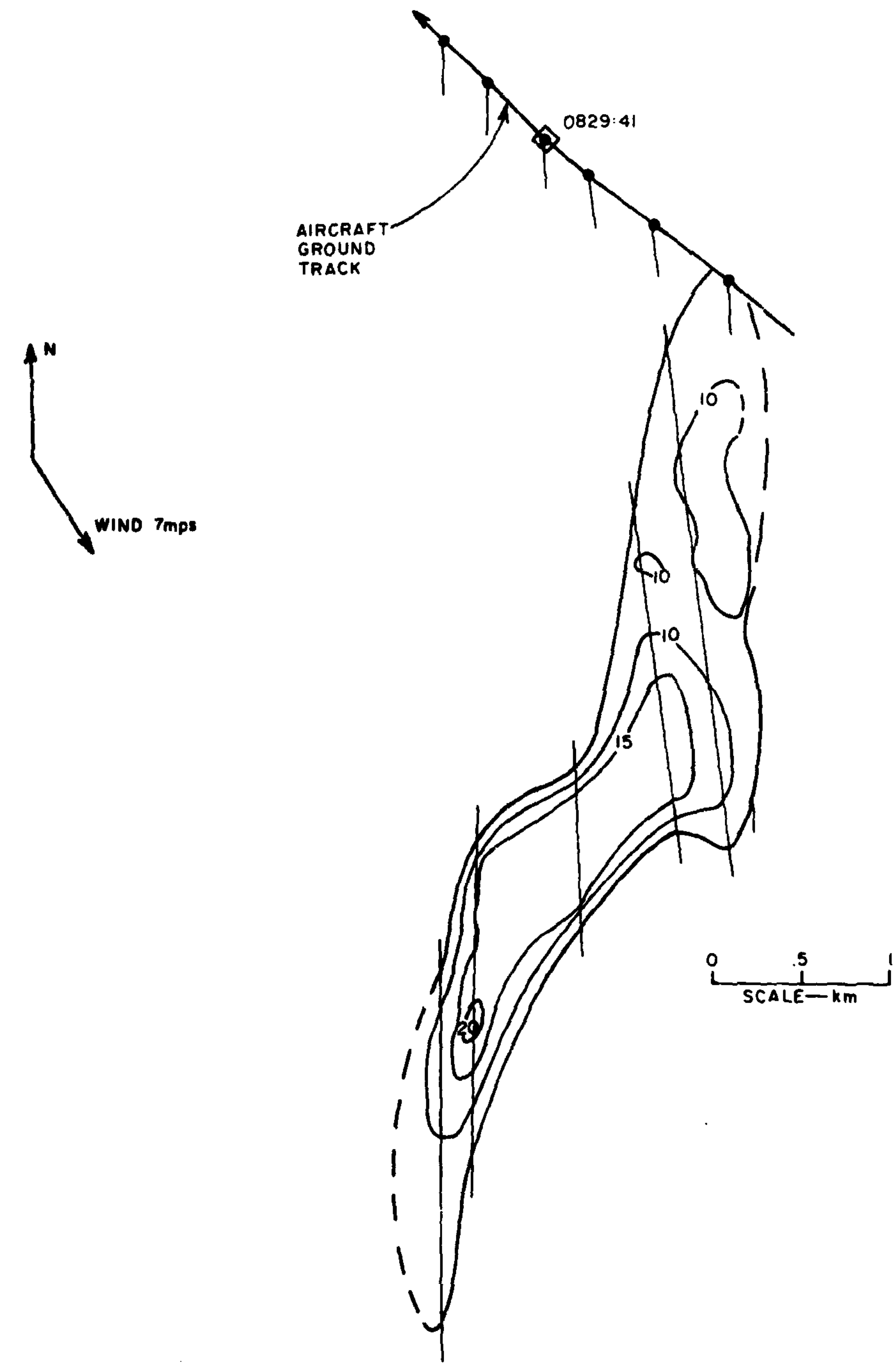

FIG. 10 RELATIVE DENSITY VARIATION OF THE SUB-VISIBLE CLOUD RUN 5 12.8km FROM GZ IN DB ABOVE BACKGROUND

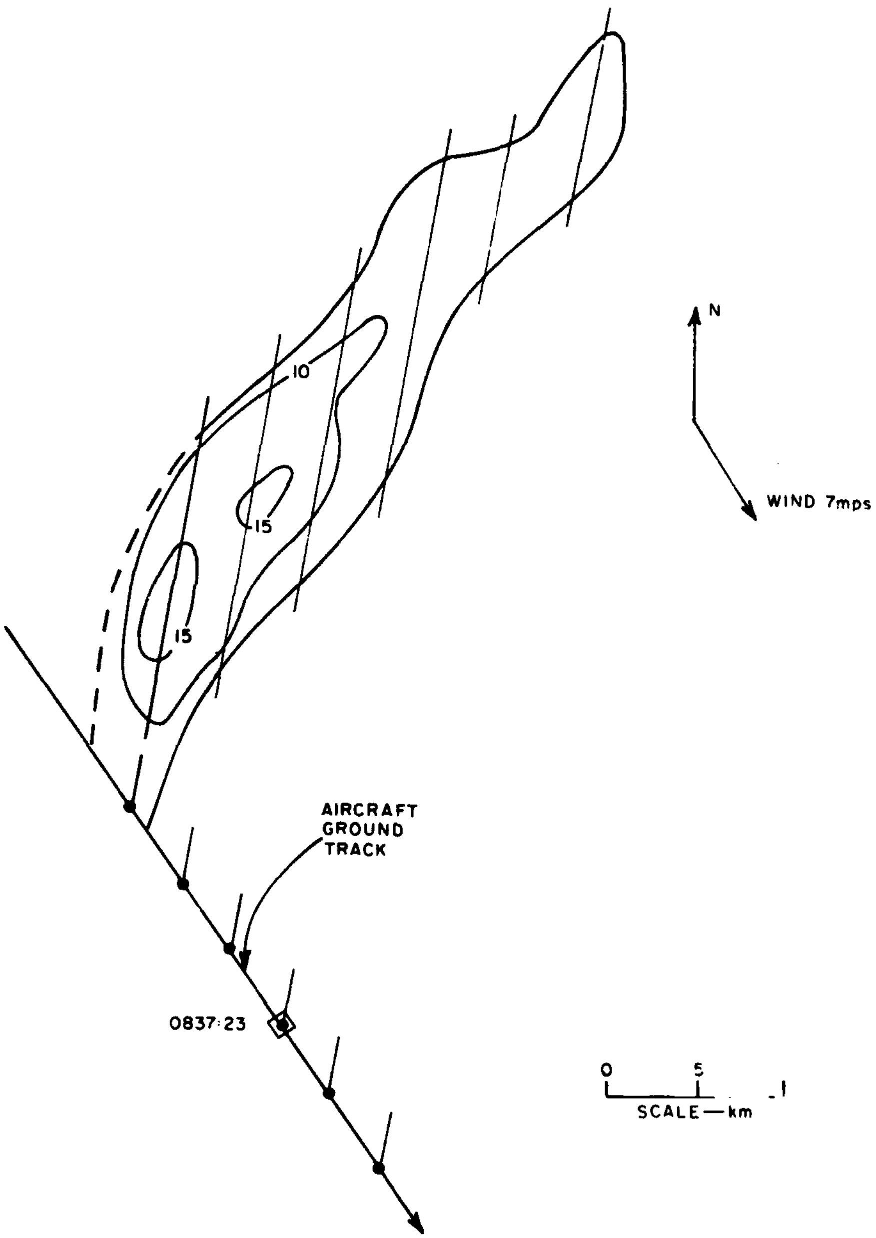

FIG 11 RELATIVE DENSITY VARIATION OF THE SUB-VISIBLE CLOUD RUN 6 15.6km FROM GZ IN DB ABOVE BACKGROUND

E. Cloud Volume

It was not possible to derive any meaningful values of cloud volume from the available data, since the dimensions were measured in only one plane. (All of the observations of Run 1 through 6 were taken in a single horizontal plane, approximately 225 meters above the terrain. Had a suitable opportunity arisen, it was planned to make several runs past the cloud at different altitudes in order to obtain data upon which a volume estimate could be based).

V CONCLUSIONS

It is concluded that the experiment has very successfully demonstrated the potential of airborne lidar for tracking clouds of debris even when the clouds are invisible.

Because of the diversion of the aircraft for a higher priority flight immediately before this experiment, the preparations for the actual observational program were hurried and limited. Nevertheless, the earlier technical preparation and the reliability of the lidar system used were such that the installation and operation of the lidar presented no difficulties and no malfunctions were experienced.

The observational program carried out ran less smoothly than it could have, due mainly to problems in maintaining an effective running plot of the operation and positioning the aircraft correctly. These problems were due to the fact that it had not been possible to carry out the necessary training and development flights that had been planned.

Nevertheless, a very effective series of observations was made of the cloud, which in any case was not as large or dense as we had anticipated. It was found possible to track the cloud long after it had become invisible to the eye, and to determine its internal structure at each successive location (at the flight level--viz., 225 meters above the surface).

The experience gained has been most valuable and has clearly indicated how navigational and directional procedures could be improved.

It is considered that even the present laboratory type lidar equipment could give useful operational information on the location and structure of a large cloud over extended distances. The extent of this information, however, would depend significantly upon the data-handling arrangements used in this trial. Various possibilities for improving this aspect of the application are apparent, however, and their adoption should be considered in terms of the operational requirement and the economics involved.

For early application of the currently available lidar, no major changes appear needed in the installation arrangements, although improvements could readily be made in the area of providing power, particularly for the operation of the Q-switch.

Ways in which the subsequent development of improved lidar systems for this purpose should be approached emerge fairly clearly from the experience gained, and future programs in this area will benefit accordingly.

VI RECOMMENDATIONS

A. Operational Techniques

Recommendations regarding improvements in operational techniques are intimately related to the recommendations made regarding equipment developments and data processing discussed in detail below. Again, the very important question of positioning the aircraft for making the observations is discussed in detail separately.

It appears, however, that the basic concept explored in this experiment is correct for the type of lidar that has too low a data rate to make two- or three-dimensional scanning feasible. With lidars with limited data rates it seems that the optimum probing techniques, and one that accords well with safety practices, is to install the lidar in a fixed position pointing horizontally, either at right angles or inclined to the aircraft's axis. Scanning at a selected level can then be accomplished by flying past the anticipated position of the cloud, and making a series of lidar shots, starting well ahead of the cloud and continuing until no further echoes are detected. This technique requires that at least a minimal indication of the lidar return be available to the operator immediately after firing the lidar, and also that an adequate running plot of the operation be maintained during the course of the observations. The latter is of course necessary in any case if any immediate operational use is to be made of the lidar observations.

To acquire data throughout the vertical extent of the cloud it is necessary in this method to make a series of passes at different levels. The type of data acquired by this scanning procedure, if conveniently and rapidly presented, appears to be very suitable for many operational purposes. With larger clouds, the limitations of data rate and resolution noticed in probing the Pre-GONDOLA II cloud would be less restrictive. In fact, the type of scanning proposed is most effective in the case of very extended or diffuse clouds.

B. Lidar Equipment

The design of an operational airborne lidar should not necessarily be based upon the current Mark V equipment. The first step in planning for an optimum operational lidar should include a systems analysis study to accomplish the following:

(1) Define the operational requirements that the prospective equipment must satisfy.

(2) Define an optimum arrangement of equipment that will satisfy the operational requirements, within various practical constraints (such as available time and funding, the performance limits of present and future equipment, and laser safety).

A study of this nature would yield a number of advantages:

(1) It would provide high performance equipment well suited to the operational requirements at a minimum cost.

(2) It would provide a unified plan for gradually upgrading the equipment as the future operational requirements become more severe.

(3) It will result in a smaller, more compact system which could be installed in a smaller, more maneuverable

aircraft, thus significantly reducing direct operating costs.

In short, a systems study of modest proportions could make the difference between an effective lidar cloud tracking system and one of marginal usefulness.

A study of this nature is beyond the scope of the present report; however, because of the experience gained during the airborne program, several general improvements to the lidar can be identified:

(1) Lidar Firing Rate. - Although the firing rate of the Mark V (approximately 10 shots per minute) was adequate for the present experiment, significantly higher firing rates will be necessary to realize the full potential of airborne lidar. These higher firing rates can be achieved by the addition of liquid cooling to the laser cavity.

(2) Laser Q-Switch. - The air-driven Q-switch presently used in the Mark V presents several difficulties: a source of compressed air is necessary, which usually requires the use of some form of air compressor. In addition, changes in aircraft altitude cause variations in turbine speed.

Saturable-dye passive Q-switches for Neodymium lasers are still under development, and no presently available dye is entirely satisfactory for the applications discussed here.

A good alternative solution is an electric-motor driven Q-switch. These items are currently available and could be readily adapted to present equipment.

(3) Laser Power Supply. - The transmitter power supply presently used with the Mark V lidar is designed to operate directly from the 28 volt dc electrical supply of the aircraft, thus eliminating the bulky and inefficient conversion equipment necessary to produce 110 volt power either at 60 Hz or 400 Hz.

C. Data Procession System*

1. Introduction

The primary tasks of any lidar data processing system are to record the raw data, process these data, and display the results in a convenient, meaningful form. Some form of computer processing will certainly be required to cope with the volume of data generated by airborne lidar observations. The major problem becomes one of recording and converting the raw data into proper form for input to a computer.

Many possible designs (of varying degrees of sophistication) could be formulated; however, the decision regarding the best approach for a given time period should be based on the relative importance attached to various performance criteria such as (1) the amount of data to be reduced; (2) the accuracy desired; (3) how quickly the results are required; and (4) the overall costs of acquiring and operating the data reduction system.

Several examples of data processing systems are described below

*By J. W. Oblanas. Note: Since this section was prepared, alternative proposals have been submitted to Lawrence Radiation Laboratory for possible use in the BUGGY experiment.

to illustrate the variety of methods that are feasible using present-day technology.

2. Analog Data Storage

A minimum useful system would use a magnetic disc recorder as a buffer storage element. That is, each lidar shot would be recorded on the disc, and a number of recordings (approximately 10) could be played back repetitively (at 30 times a second) into a conventional oscilloscope (or into a storage oscilloscope). One possible form of display could take the form of a contouragraph,[5] which has range, signal amplitude, and observation time as coordinates. This display, along with navigational data, could provide the airborne controller with enough real-time to enable the aircraft to properly track the sub-visible cloud. At the end of each run, the data recorded on the disc could be converted to digital form and re-corded on magnetic tape for later analysis by computer. The computer could apply various analysis techniques and present data regarding cloud size, volume, density variations, etc.

The video disc recorder presents some mechanical disadvantages (limited lifetime of the disc and recording head) when operated for extended periods of time. This approach is unlikely to be the most reliable, particularly in view of the mechanical problems inherent in subjecting a device rotating at high speed to the accelerations encounterd even in smooth flight.

3. Digital Storage of Data

Rapid developments in the field of digital integrated circuits may soon make possible the construction of high speed digitizers suitable for lidar use at a cost lower than that of the video disc slow-speed digitizer discussed above. The high-speed digitizer will be able to process a larger number of data points with greater accuracy than is possible with the video disc arrangement. For example, a currently available integrated circuit digitizer can divide an analog waveform into 1024 samples each one microsecond long, digitize each of these samples to 5-bit accuracy, and store the resulting values in a magnetic core memory.

One possible use of a suitable high speed digitizer would be to replace the video disc described earlier. Each lidar shot would be digitized immediately and stored on magnetic tape. The stored data could be displayed on a storage oscilloscope to provide real-time tracking data. The tape would later be fed into a computer to provide a detailed analysis of the cloud structure, etc.

4. A Second-Generation Data Processing System

For both of the systems described previously, the real-time display is limited only to the raw lidar data. These data must be combined with manually plotted navigational data to yield the information necessary for effective cloud tracking. The reduction of the lidar data must be subsequently performed by a ground-based computer. The experience gained during routine airborne lidar cloud tracking (or the demands of future applications) may show the desirability of combining the reduced lidar data with navigational data on one real-time display.

It is interesting to speculate about further improvements to the lidar data processing system in the event that real-time processing and display of a large amount of data become necessary. The main reason for the following discussion is to describe the increased observational capability of the lidar system that could be provided by the use of computer-controlled displays.

One possible solution of the problem of processing high data rate signals is to replace the oscilloscope display of raw data with a small computer and cathode-ray tube display that would become a permanent component of the lidar data processing system. The full-time use of a computer for such an application is not as unreasonable as it might first appear. Small, relatively inexpensive computers have already found numerous applications in similar full-time tasks, such as controlling the production line testing of electronic components, calculating steering signals for large radar antennas, and as a general-purpose data-reduction computer aboard research aircraft. Because of the rapid advances in integrated-circuit technology, the cost of these small computers has been steadily decreasing. One advantage of an on-line computer is to allow the acceptance and storage of the digital data at the rate they are generated. A much more significant advantage would be that an on-line computer will allow the use of a radar-type cathode ray tube display. The computer could be programmed to accept, store, and reduce the lidar and navigational data, store the results, and sequentially display the results on the CRT in a number of different ways. The use of a computer as a data storage element will allow the lidar display to perform in a manner analogous to the various displays currently employed with meteorological radars, with the significant difference that a considerable amount of digital processing will be performed on the lidar data prior to display. Other forms of data (such as radiation levels and particle count data) pertinent to a given experiment could be fed into the computer and superimposed on the display along with the lidar data. The computer could also accumulate navigational and meteorological data, and display the predicted location of the cloud to aid in effective tracking. The information could be retained on the display as long as desired.

For example, assume the lidar is used to make a number of observations during a run past the cloud. The computed values of spatial backscatter function computed from the raw data could be shown on the CRT similar to the well known range-azimuth angle display, with signal strength indicated by intensity variations. Since the dynamic range of intensity variations is relatively small (even for the more sophisticated CRT), the computer could be programmed with a variable threshold such that only the stored signals above a certain amplitude would be displayed. This signal threshold could be varied over a number of discrete steps and a photograph taken of each display. In this way, the large amount of processed data obtained from an extended series of observations could be summarized in a compact form convenient for immediate study and analysis. Digital magnetic recordings of the basic data or photographs taken of the display at selected times would provide a permanent record of the observations

Figure 2 illustrates one form [illegible] general [illegible] data processing system [illegible] take. The [illegible] the lidar receiver is fed into a fast digitizer [illegible] divide [illegible] signal into 10 [illegible] intervals of 100 ns each and [illegible] digitizer output is fed to a signal averager. If the repetition rate of a sophisticated lidar is fast compared to the time scale of the cloud conditions under observation, a signal averager could be used to advantage to increase the accuracy and sensitivity to the system, and to reduce the amount of

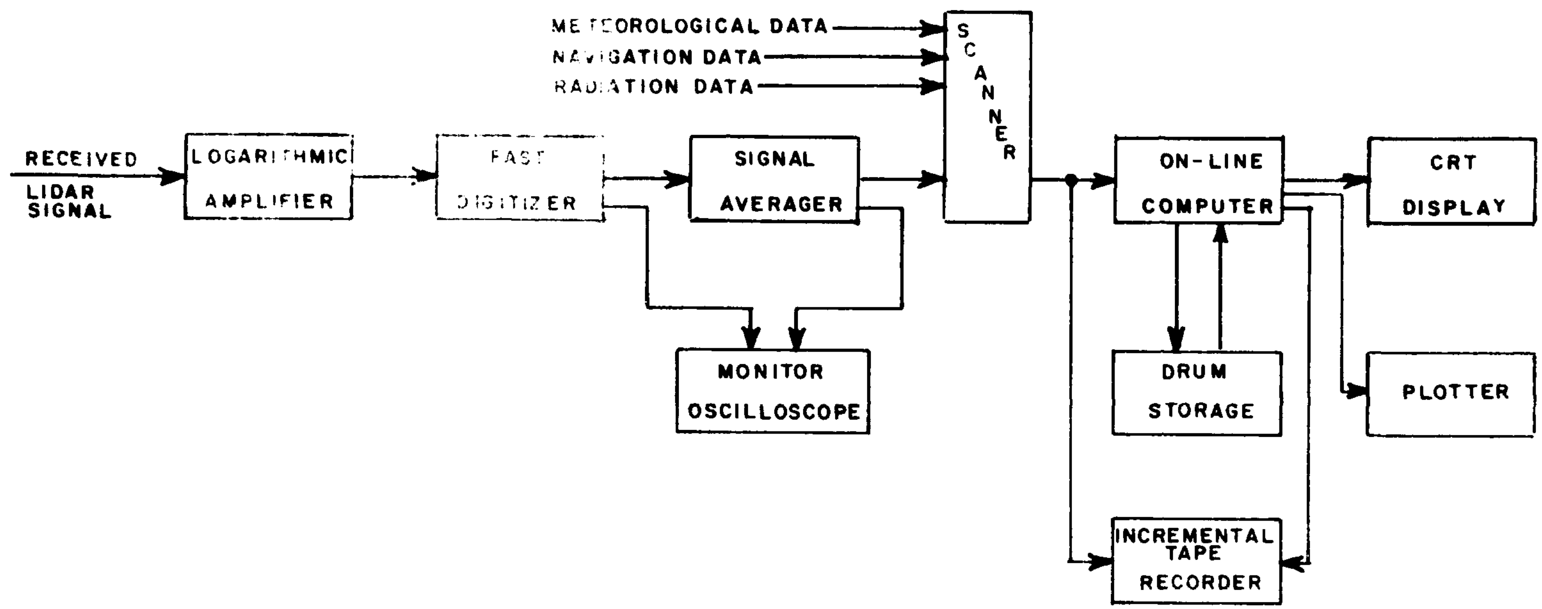

FIG 12 PROPOSED SECOND—GENERATION DATA PROCESSING SYSTEM

data generated. The output of the averager, consisting of the sum of a number of return signals, is fed to the digital computer through a scanner. The scanner also collects auxiliary data pertaining to each shot (such as time, navigation data, computed winds, etc.). The raw data and/or the averaged data can be viewed by means of an auxiliary monitor oscilloscope. The on-line computer (such as the PDP-8 made by Digital Equipment Corporation) accepts the raw data, performs the required calculations, and stores the results in the memory. The computer also controls the CRT display. On command, the computer will present the reduced data on the CRT in any one of several selectable forms. For example, a number of displays used in radar work may be useful (such as range-elevation angle and range-azimuth angle). In addition, a contouragraph display[5] that has range, signal amplitude, and observation time as coordinates may be useful. A camera mounted on the display will photograph the CRT data. In addition, an auxiliary x-y plotter could produce a selected group of observations in graphic form. If permanent retention of the data is desirable, the reduced data in the drum memory could be periodically transferred to magnetic tape. The magentically stored digital data can be fed back into computer memory when additional analyses are required.

The precise form that future lidar systems will take is difficult to predict. For one thing, the exact operational requirements imposed on a particular lidar will have considerable influence on the final form of the data system. Slight variations in the operational requirements assumed could easily invalidate many of the discussions and conclusions reached here. However, the rapid advances that are being made in the allied fields of integrated circuit components and in computer technology strongly suggest that digital data processing will play an increasingly greater role in operational lidar equipment.

D. Navigation

The problems of positioning the aircraft with respect to an invisible (or at best, semi-visible) cloud which is moving with the wind, and to carry out an effective lidar observational program, are considerable. There were difficulties experienced in the Pre-GONDOLA II experiment. However, these were not fundamental, and the experience gained on this one occasion clearly points the way to improvements. In fact, there is little doubt that most of the navigational problems could have been overcome in one additional practice flight.

The Doppler navigation system of the type used would appear to be wholly suitable for this operation. In this system, positional data is displayed to the pilot in terms of (1) distance ALONG and (2) distance LEFT or RIGHT, of a pre-set track. (The use of an improved compass, such as was subsequently fitted in the aircraft, minimizes the errors to which Doppler systems are prone.) The advantage of this system lies not only in providing the positional data essential for keeping track of the positions of the aircraft and the cloud (and the points from which the lidar observations are made), but in assisting the pilot in flying his aircraft accurately to provide an optimum observational platform.

Specifically, it is recommended that the Doppler plot be oriented so that its track passes through ground zero (GZ) and parallel with the direction which it is expected that the cloud will follow (i.e., the wind direction). The origin of the Doppler plot could be at GZ or, if desired, could be a recognizable landmark sufficiently far upwind of ground zero to ensure that all operations can be carried out without change of sign of ALONG track distances in any run.

In this arrangement, we are thus provided with a rectangular coordinate system in which position is experssed as distance ALONG track and distance LEFT or RIGHT of track. (The resolution readily available depends upon the scale setting--e.g., 100 mile along track, plus and minus 10 miles across track).

Lines on the ground can most readily be identified on this coordinate system if they lie parallel or at right angles to the Doppler track.

Provided we are able and willing to conform to this coordinate system in flying the observational passes, we thus have (1) a simple mechanism for monitoring all positions and keeping a running plot of the cloud and aircraft positions and (2) an effective method of directing the pilot in a way with which he can most readily comply.

For example, given any assumed position of the cloud, it is desired to position the aircraft at a specific point flying in a given direction. The pilot is simply instructed to fly at n miles RIGHT of track from a position m miles ALONG track. The pilot positions the airplane accordingly and holds course to ensure that his track as indicated by the Doppler is consistently n miles RIGHT of track and his distance ALONG track is increasing steadily. Lidar firing operations can be begun at any desired increment of distance ALONG track. If a pass is to be made at right angles to the wind direction, the pilot is instructed to fly from a position x miles RIGHT of track to y miles LEFT of track while keeping his distance ALONG track constant at z miles. This system remains effective even when the direction is towards the origin of the Doppler plot; ALONG track distances can either be expressed as negative numbers ALONG track or as positive numbers BACKTRACK. The Doppler display has provisions for coping with reciprocal tracks that should be exploited appropriately in this context.

Provided that the cloud remains fairly well centered in this Doppler coordinate system and observational passes can be made along the rectangular grid lines thereof, no changes need be made in the Doppler setting, even if it has drifted. Provided regular landmark identification is made to tie-in the Doppler coordinates, and marked into the record, errors can be eliminated and the detailed analysis adjusted subsequently in the same way as a traverse is adjusted in surveying. Unless serious drift errors occur, it would probably be quite satisfactory to work from the Doppler coordinates (even if slightly in error) in relating the cloud to the ground. Should more precise navigation be necessary -- e. g., as in controlling other aircraft with high accuracy -- the necessary adjustments would have to be calculated by the navigator, with or without resetting of the Doppler. Should the cloud move out of the initial grid coverage, it would be necessary to reset the Doppler, or again, if it became too large for the scale used, a scale change would have to be made.

The precise details of such a scheme would obviously need further study in the preparation period of any subsequent operation, but the basic approach appears very straightforward. It should be stressed, however, that if it is necessary to relate the lidar-observed cloud positions to the ground or to have aircraft vectored in and around the cloud with great precision, care must be taken in making any conversions necessary from the lidar (arbitrary Doppler) coordinate system to any other. Such procedures would present no difficulty to a professional navigator, however.

Should an aircraft be employed that is not fitted with Doppler, the problem of navigation would be onerous but not insurmountable. Everything would depend upon what other navigational aids are available, and the skill of the navigator and pilot team in coordination with the lidar crew. In principle, the task is similar to that familiar to military air crews in such operations as precision bombing or laying mine patterns. In the absence of Doppler, the assistance of a special system of ground marks or electronic beacons would be highly desirable. It would be essential in this case to provide ample time for developing appropriate techniques and practicing them in flight with all the personnel involved.

E. Communications

Problems arose on this test in communication between the lidar crew and the air crew.

In view of the difficulties caused by the noise of the aircraft, it is recommended that all intercommunication between personnel be carried out by telephone headsets (of a type designed for aircraft intercom).

Two separate transmitting circuits could be provided, each recorded on tape in a separate channel. (The simple stereo audio tape recorder used on this project is very suitable for this purpose.) One circuit would be used for lidar operations, the other for aircraft operations.

Microphones would be connected accordingly. Facilities could be provided for switching, if desired, although it would probably be better to have only the lidar director capable of speaking into both circuits simultaneously (with appropriate switch control). Similar arrangements would be made in the receiver circuits. This system would appear to offer flexibility during the operation and also in the subsequent data retrieval and analysis.

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APPENDIX

PRE-GONDOLA TECHNICAL REPORTS

Title of Report	Agency	Author and/or Technical Program Officer	Number
Pre-GONDOLA -			
Seismic Site Calibration	NCG	M. K. Kurtz B. B. Redpath	PNE-1100
Site-Selection Investigations	NCG/Omaha	H. A. Jack W. W. Dudley	PNE-1101
Pre-GONDOLA I - Technical Director's Summary Report	NCG	M. K. Kurtz et al.	PNE-1102
Geologic and Engineering Properties Investigations	NCG/Omaha	P. R. Fisher et at.	PNE-1103
Close-in Ground Motion, Earth Stress, and Pore Pressure Measurements	WES	J. D. Day et al.	PNE-1104
Intermediate Range Ground Motion	LRL	D. V. Power	PNE-1105
Structures Instrumentation	WES	R. F. Ballard	PNE-1106
Crater Studies: Crater Measurements	NCG	R. W. Harlan	PNE-1107 Part I
Surface Motion	NCG	W. G. Christopher	PNE-1107 Part II
Cloud Development Studies	NCG/LRL	W. C. Day R. F. Rohrer	PNE-1108
Close-in Displacement Studies	AWFL	C. J. Lemont	PNE-1109
Lidar Observations of Pre-GONDOLA I Clouds	SRI	J. W. Oblanas R. T. H. Collis	PNE-1110

Pre-GONDOLA I, cont'd.			
Preshot Geophysical Measurements	LRL-N	R. T. Stearns	PNE-1111
Pre-GONDOLA II - Technical Director's Summary Report	NCG	W. C. Day W. K. Kurtz	PNE-1112
Close-in Ground Motion and Earth Stress	WES	J. D. Day	PNE-1113
Engineering Properties Investigations	NCG	P. R. Fisher W. W. Dudley A. D. Frandsen	PNE-1114
Intermediate Range Ground Motion	LRL	D. Power	PNE-1115
Structures Instrumentation	WES	R. F. Ballard	PNE-1116
Crater Studies: Crater Measurements and Ejecta Studies	NCG	R. W. Harlan M. A. Novak	PNE-1117 Part I
Crater Studies: Ground Surface Motion	NCG	J. E. Lattery	PNE-1117 Part II
Cloud Development Studies	NCG	W. C. Day	PNE-1118
Airborne Lidar Observations	SRI	R. T. Collis J. Oblanas	PNE-1119
Survival of Simulated Pre-emplaced Charges	WES	J. D. Day	WES TR
Close-in Air Blast	BRL	J. Keefer	BRL TR