DOCUMENT CONTROL DATA - R&D

(Security classification of title, body of abstract and indexing annotation must be entered when the overall report is classified)

1. ORIGINATING ACTIVITY *(Corporate author)* Air Force Cambridge Research Laboratories (LW) L.G. Hanscom Field Bedford, Massachusetts 01730	2a. REPORT SECURITY CLASSIFICATION Unclassified 2b. GROUP

3. REPORT TITLE

AERIAL PENETROMETERS FOR SOIL TRAFFICABILITY DETERMINATION

4. DESCRIPTIVE NOTES *(Type of report and inclusive dates)*

Scientific. Interim.

5. AUTHOR(S) *(First name, middle initial, last name)*

Carlton E. Molineux

6. REPORT DATE	7a. TOTAL NO. OF PAGES	7b. NO. OF REFS
2 June 1972	20	12

8a. CONTRACT OR GRANT NO.	9a. ORIGINATOR'S REPORT NUMBER(S) AFCRL-72-0323
b. PROJECT, TASK, WORK UNIT NOS. 76390101	
c. DOD ELEMENT 62101F	9b. OTHER REPORT NO(S) *(Any other numbers that may be assigned this report)*
d. DOD SUBELEMENT 681300	

10. DISTRIBUTION STATEMENT

Approved for public release; distribution unlimited.

11. SUPPLEMENTARY NOTES	12. SPONSORING MILITARY ACTIVITY
Reprinted from the Conference on Rapid Penetration of Terrestrial Materials, held February 1-3, 1972, at Texas A&M University.	Air Force Cambridge Research Laboratories (LW) L.G. Hanscom Field Bedford, Massachusetts 01730

13. ABSTRACT

The aerial penetrometer, an air-droppable indicator of soil strength or related properties, is useful for evaluating the ability of natural soil areas to sustain the loads and traffic of aircraft or vehicles. Several configurations of this device, developed, tested, and demonstrated by the Air Force Cambridge Research Laboratories over many years, are described. They range from simple "go-no go" flare indicators of soil shear strength, through adjustable devices to indicate a range of determined strength, to sophisticated models which telemeter the depth of penetration upon impact. Penetrometer functions of drop velocity, deceleration, impact force, and depth of penetration, calibration with static and dynamic strength of various soils, and correlation of aerially-determined soil strength to aircraft and vehicle mobility criteria are discussed. Airborne tests of the various aerial penetrometer types were made from propeller-driven and jet aircraft and helicopters at altitudes above 200 meters, using mechanically-dropped or explosively-launched systems, impacting at 30 to 100 meters per second velocities. Development of aerial penetrometers launched from the surface by air-cannon or rifle-grenade mechanisms to evaluate trafficability conditions ahead of ground vehicles and their modification to permit measurement of snow strength and depth has also been achieved. Unfamiliarity with the aerial penetrometer concept and the necessary logistical requirements for its use and data interpretation have deterred its operational employment in trafficability surveys.

KEYWORDS: Soils, Bearing strengths, Trafficability, Aircraft landing strips

AFCRL-72-0323

AD 744598

This paper was presented at the Conference on Rapid Penetration of Terrestrial Materials, held February 1-3, 1972, at Texas A&M University. The conference was co-sponsored by the ASCE Soil Mechanics & Foundation Division, Sandia Laboratories/Albuquerque, and Texas Engineering Experiment Station.

AERIAL PENETROMETERS FOR SOIL TRAFFICABILITY DETERMINATION

Carlton E. Molineux*

INTRODUCTION

Air Force aircraft must take off and land on the surface of the earth in all environments and may, in combat situations, be required to do so without having paved or improved soil airstrips available. For this reason, the ability to determine from the air the trafficability or load-bearing capacity of any unimpeded natural soil surface may frequently be necessary for strategic planning or immediate conduct of tactical, logistic, or rescue operations.

Similarly, Army operations may require on-the-spot knowledge of soil strength for evaluating the capability of vehicles to traverse unfamiliar terrain. Maps and estimates of soil trafficability may or may not be available to a field commander, but immediate information is the most reliable and preferred.

Measurements of soil strength conditions by contact means is a slow and tedious procedure when the area to be surveyed, such as a potential airstrip, is very large. Conduct of field measurements could also be denied by inaccessible terrain, enemy action, or political restraints. In addition, such overt survey actions might indicate military interest in a particular area which would be undesirable to disclose.

Soil strength is generally dependent on complex relationships of soil structure and soil moisture. The latter obviously varies with local meteorological conditions, seasonal variations, and vertical or

*Air Force Cambridge Research Laboratories
L.G. Hanscom Field, Bedford, Massachusetts

horizontal anomalies in distribution. Much research effort has been expended in deriving the.e relationships to enable forecasting of soil strength or trafficability (Thornthwaite, 1958; U.S. Army Engineer Waterways Experiment Station, 1951-1968). However, local factors may make the use of a mathematical strength-forecasting technique unreliable or even invalid in a particular tactical situation. A droppable indicator of in-situ soil strength, adjustable to cover anticipated values which might be required by various aircraft or vehicles, is therefore desirable. The Terrestrial Sciences Laboratory of the Air Force Cambridge Research Laboratories (AFCRL) initiated efforts toward this objective in the early 1950's. Throughout the intervening years other requirements appeared which resulted in the development of three different devices, called aerial penetrometers, which can indicate the resistance to, or depth of, penetration of soils.

SOIL PENETRATION DYNAMICS

The soil penetration resistance or load-bearing strength as measured in a static mode by manual cone penetrometers is usually expressed in terms of a dimensionless number called "cone index". This value is the ratio of the penetrating force of a 30° cone to the base area of the cone. The cone index unit has been correlated with the standard soils engineering strength unit known as California Bearing Ratio generally used for studies of foundations, roadways, and airfields. In an extension of the cone penetrometer by the Army Engineer Waterways Experiment Station (WES) into an "airfield penetrometer", the unit of airfield index was established. This latter unit is numerically equal to the CBR value and also directly correlated with the cone index unit.

The aerial penetrometer strikes the ground with a definite kinetic energy which may be as much as 4 times as great as that of static penetration. This results in displacement of the soil through deformation and partial destruction of the natural ground strength. This, in turn, causes partial remolding of cohesive soils and liquifaction of water-bearing sands. In weak soils, a relatively large volume is displaced and deep penetration occurs. Harder soils absorb the kinetic energy within a short distance, with shallow penetration resulting. Similar action takes place under the wheels of aircraft or ground vehicles; hence the indication of the aerial penetrometer is directly related to the soil capacity to support traffic.

Correlation of cone index or its variants with aircraft and vehicle load-bearing requirements have been made by many organizations and need not be discussed here. Tabulations of the soil strength requirements for all aircraft or vehicles in the military inventory are available. Aerial penetrometer readings are in terms of cone index.

PROTOTYPE AERIAL PENETROMETER

The first AFCRL aerial penetrometer was essentially an extension of the manual cone penetrometer, originally developed and applied by the Army Engineer Waterways Experiment Station, to remote indication of measurement. It verified the feasibility of a droppable device which could sustain the landing impact and yet be sufficiently sensitive to indicate differing values of soil resistance to dynamic penetration. It was designed and fabricated under a research contract with New York University and comprises an aluminum cone-tipped cylinder approximately 75 cm long and 5 cm in diameter, weighing less than a kilogram. Figure 1 shows an exploded view of the penetrometer assembly, while Figure 2 is a photograph of the device and its components.

The penetrometer is equipped with pop-out vanes to govern its terminal velocity and insure a stabilized vertical velocity. The weight and configuration of the device permits accurate impact at 30 meters per second on the ground when dropped from a minimum altitude of 200 meters. The original model was designed to be dropped by hand or from a simple launching chute from propeller-driven aircraft over unexplored terrain and indicate by means of a single flare signal the hardness of the ground at the depth to which it penetrates. The flare indicator is ejected by a shotgun type cartridge if the soil strength, as indicated by its penetration resistance, is greater than a pre-set level. The flare is released as an easily visible "go-no go" signal. In penetrometers of low ratings (cone index 5-100), a spring is used to fix the impact force required to activate the signal, while different sized shear pins are used in penetrometers of higher ratings (cone index 100-1000). The only parameter governing the release of the flare indicator is the strength of the ground; the signal not being activated when the device impacts on ground softer than its pre-set rating.

Initial calibration of the penetrometers was established by ejecting them over a range of velocities into prepared containers of soil having known and controlled strength and density properties. A simple air cannon launcher, shown in Figure 3, was also fabricated to project the penetrometer into the air to a sufficient height to test its drop characteristics. Additional wind-tunnel aerodynamic tests and drops from a light aircraft proved the operational merit of both the aerial penetrometer concept and the prototype instrument. Ensuing correlations with the measured cone index values of soil strength were made at the impact spots of the aerial drops. A graph of depth-of-penetration relationships with measured strength for a variety of soils is shown in Figure 4.

For evaluation of an unknown area by the aerial penetrometer method, the soil strength requirements of the particular type aircraft can be determined from available tabulations. The release mechanism of the aerial penetrometer indicator is set for that determined value and a sufficient number of penetrometers are dropped. If they consistently

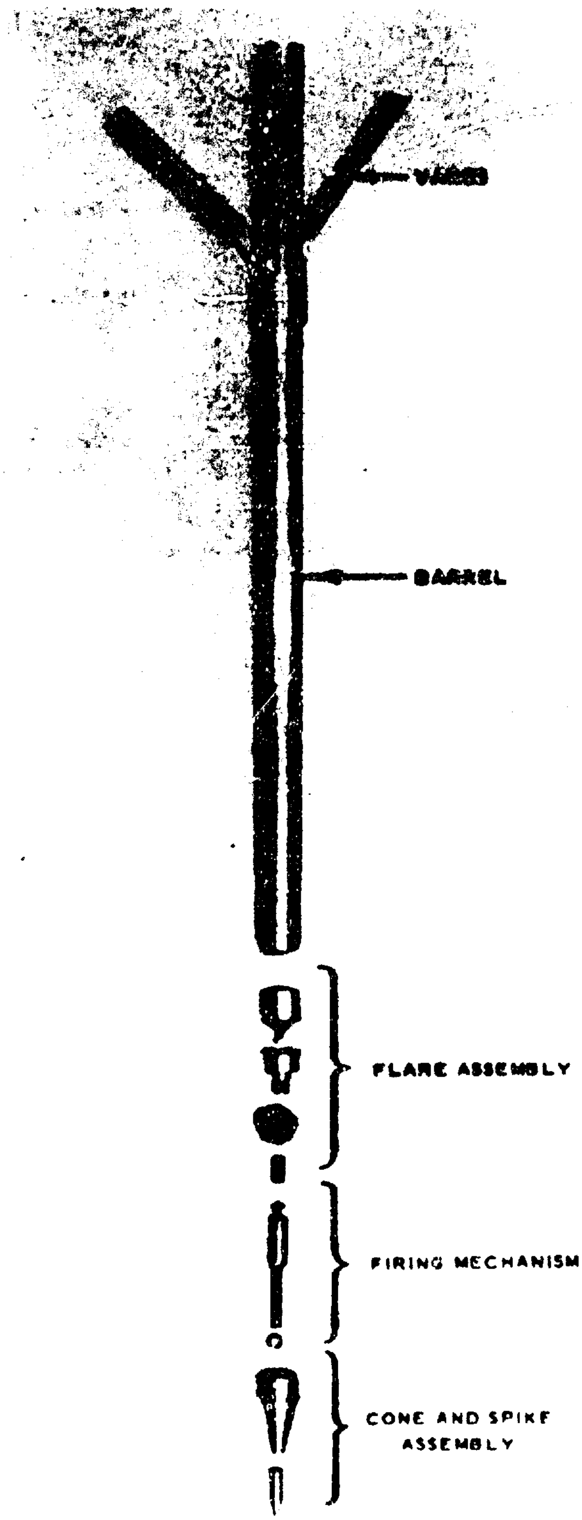

Fig. 1. Disassembled spring-type aerial penetrometer

5

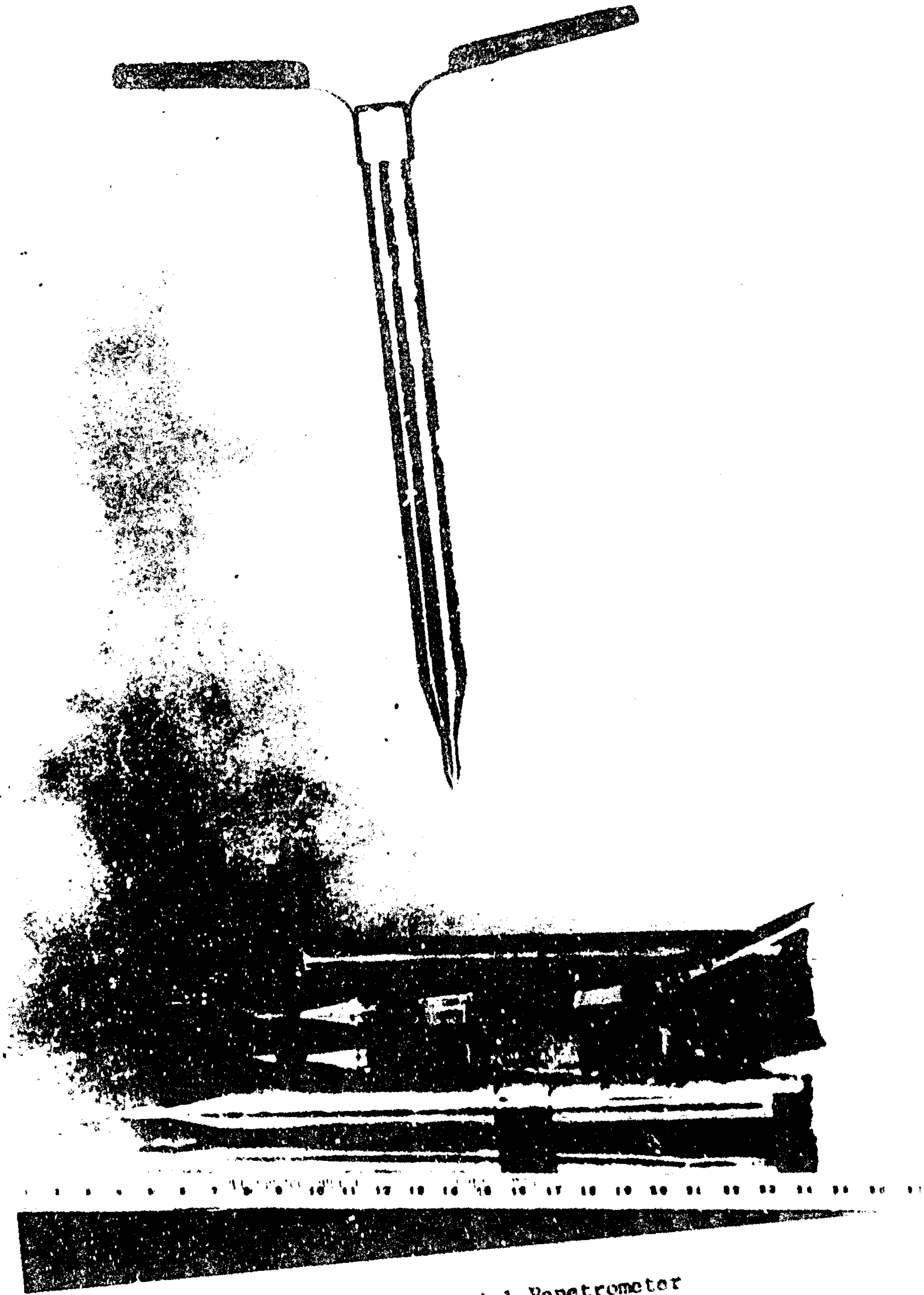

Fig. 2. Prototype Aerial Penetrometer

Fig. 3. Air Cannon Launcher

7

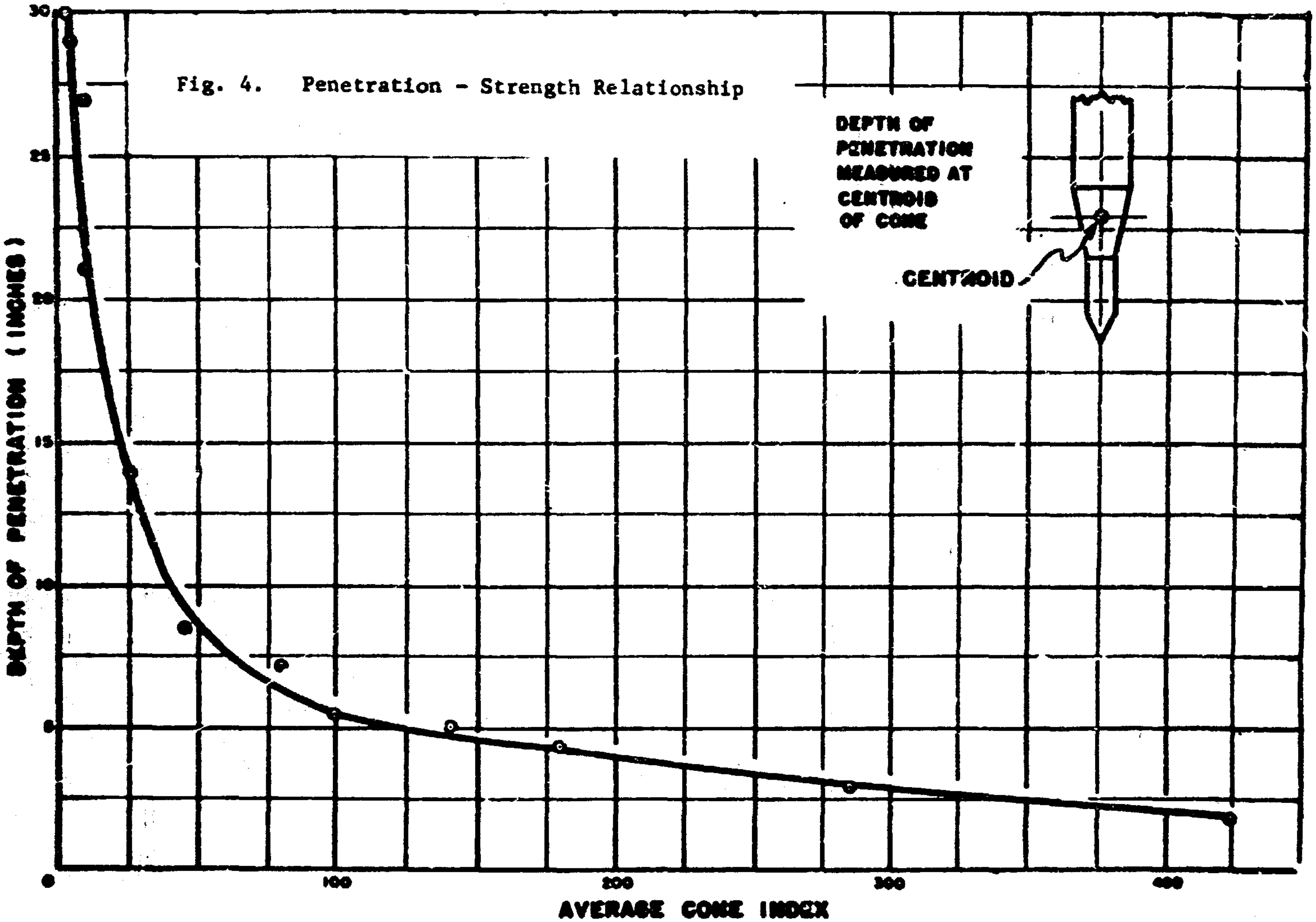

Fig. 4. Penetration - Strength Relationship

AFCRL PHOTO 81-420

give a positive signal, then landings can safely be attempted. If no signals are seen or if they are erratic, the estimation would be of intermittent soft spots and the proposed area would generally be suitable.

An initial demonstration of the aerial penetrometer concept and use was given for representatives of many Department of Defense operating commands, in which a number of prototype devices were dropped from light aircraft and also shot to 200 meters altitude from the air cannon launcher. The indicated soil strength values were verified by measurements with hand cone penetrometers at the impact spots.

This was followed by a formal operational suitability test of the aerial penetrometer conducted by the Air Proving Ground Command at Eglin AFB, Florida. Soil strengths were determined by drops from a C-47 aircraft for a variety of areas, including both undisturbed and plowed natural fields, tidal flats, and a sod airstrip. Favorable evaluation of the aerial penetrometer and recommendation as a usable device for airborne determination of trafficability was documented (APGC, 1953).

The then-current status of aerial penetrometer development and potential was described for the military community (Molineux, 1955). Scientific and operational interests were stimulated in various directions, in addition to aircraft trafficability.

RELATED APPLICATIONS

An independent evaluation of the concept and use of an aerial penetrometer was conducted by Stevens Institute of Technology for the Army Ordnance Corps. This study (Morrison, 1953) verified the operational practicality of airborne soil strength determinations and gave particular consideration to the number of drops required to obtain statistically-significant determinations over a large area planned for airborne survey. The Army Tank-Automotive Command then established a contract with New York University for development of an aerial device which could be launched from the ground to impact into areas of unknown soil strength ahead of vehicle, tank, or troop movement. Such a device was fabricated to be fired from a rifle grenade launcher (Tramposch and Murray, 1955), and was successfully proof-tested at the U.S. Military Academy, West Point, N.Y.

Army efforts toward establishing criteria for vehicle mobility in snow brought about interests in an aerial penetrometer which could measure depth and/or strength of a snow field which vehicles could possibly traverse. Reconfiguration of the prototype penetrometer to slow its velocity upon impact was undertaken, and drop tests were made by AFCRL from a helicopter in Arctic snows in Labrador and from the air cannon launcher in continental snow fields at Camp Hale, Colorado. The feasibility of such snow property determinations using a refined aerial

9

penetrometer was reported (Warlam, 1956), but further redesign and application for snow measurements were not supported by military organizations.

The Army Engineer Waterways Experiment Station has maintained a strong interest in the AFCRL aerial penetrometer program since its inception. Their personnel have conducted extensive theoretical and experimental studies of the original penetrometer principles and models in a joint cooperative effort, and havedeveloped and tested other versions of the devices including telemetry components and air-pressure launchers. A series of reports (U.S. Army Engineer Waterways Experiment Station, 1957-1970), (Knight, 1967) describing these activities have been published.

The Army Aviation Board, with headquarters at Fort Rucker, Alabama, expressed interest in the aerial penetrometer concept, resulting in a formal demonstration of the prototype penetrometer conducted jointly by USAEWES and AFCRL in late 1958. Drop tests were made from a helicopter onto selected areas of differing soil strengths, again with the aerial indications being verified by on-the-spot ground measurements. Valid results and favorable evaluation of the device were reported (USAEWES, 1959).

RECONNAISSANCE PENETROMETER

A formal operational support requirement was levied on AFCRL from the USAF Tactical Air Command, specifying a system for aerial penetrometer deployment by high-speed reconnaissance aircraft, provision of an inconspicuous soil strength indicating means, and increased accuracy of emplacement. A responsive study (Bennett and Appoldt, 1956) was made by New York University under AFCRL contract, and a second generation penetrometer was developed.

This penetrometer can be ejected in quantities up to 10 in a controlled sequence from tip-tank launchers on jet aircraft flying at speeds of approximately 450 knots and altitudes exceeding 300 meters above the terrain. Ejection is by an electrically detonated charge contained within the launching system and the penetrometers themselves are inert. Figure 5 is a photograph of the penetrometer and its ejection cartridge. It is aerodynamically stable with pop-out vanes governing its trajectory. The strength-indicating mechanism is more versatile than in the prototype aerial penetrometer, being adjustable to allow determination through a large continuous range of values typically required by various aircraft landing loads. Adjustment is by a screw mechanism which governs the amount of internal travel of a calibrated mass required to make electrical contact activating the indicator.

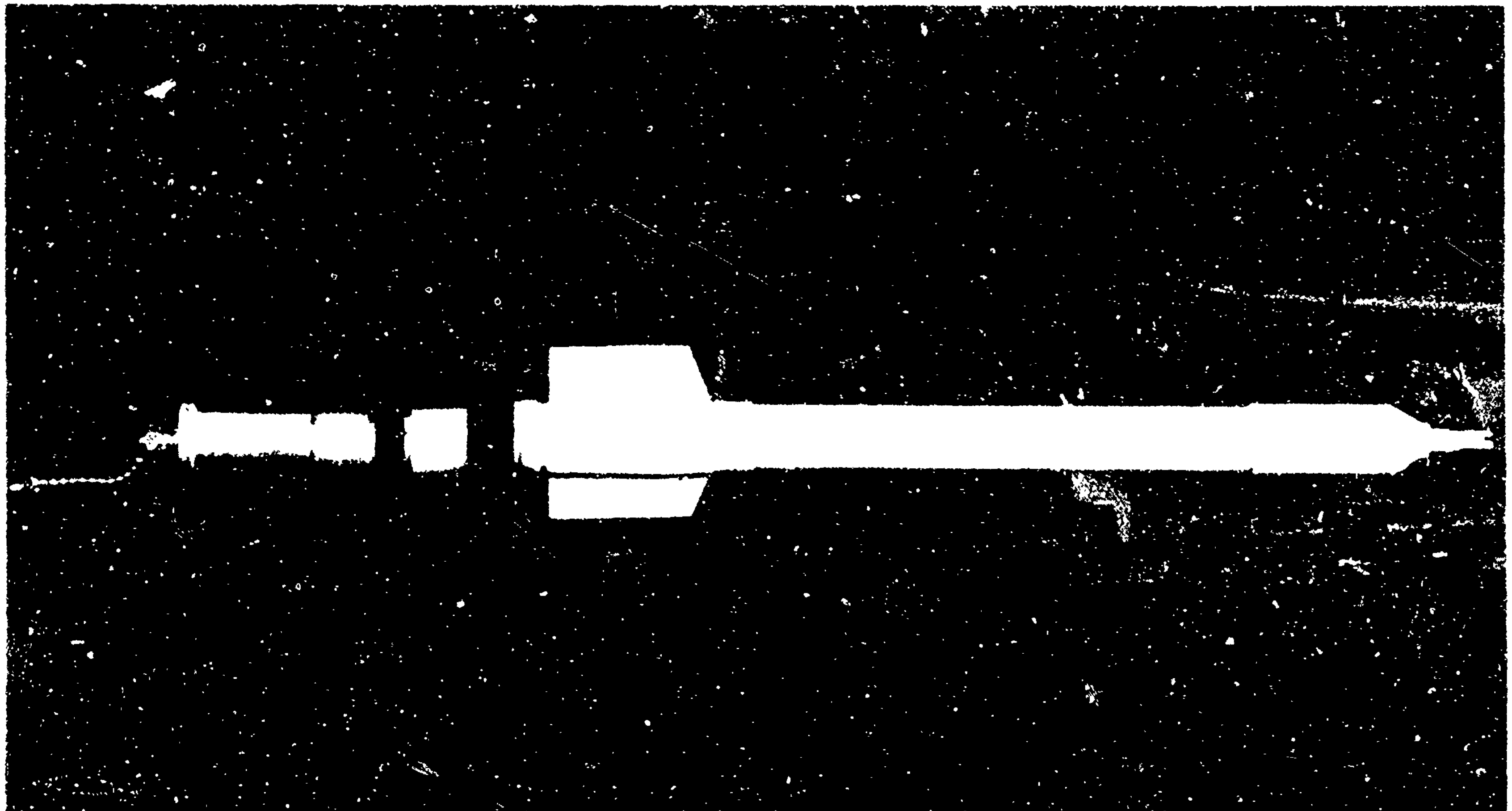

Fig. 5. Reconnaissance Penetrometer

The launching system, essentially a series of large rifle barrels installed in a tip tank, is shown in Figure 6. It shoots the penetrometers downward and backward at a component velocity sufficient to counteract the forward speed of the aircraft, so that the penetrometer hits the ground vertically at approximately 100 meters per second directly under the spot where airborne ejection takes place. For multiple deployment the firing sequence is 0.5 seconds apart, with the penetrometers thus landing about 100 meters apart along the flight path. About 1.5 seconds are required from ejection to impact at typical jet aircraft speeds. The penetrometers are nearly buried in their own holes upon impact, depending on the soil strength encountered, and are expended. Soil hardness exceeding the pre-set value is indicated by the appearance of a self-contained infrared-coated light bulb visible through the vertically-impacted cylinder. Development tests proved that such spots of infrared light energy are detectable at aircraft altitude by suitable reconnaissance instrumentation.

Flight proof tests of the reconnaissance penetrometer were conducted by AFCRL from T-33 aircraft at sand beach sites on Cape Cod, Mass. and on natural soil fields near L.G. Hanscom Field, Bedford, Mass. In these tests the ejection system worked perfectly and the ability to deploy a quantity of penetrometers at spaced intervals along a flight path is indicated in Figure 7. The white flags visible on the photograph mark the impact spots of all penetrometers ejected into an area the size of the simulated airstrip being surveyed. Figure 8 shows the appearance of a typical penetrometer imbedded in the soil after impact. Visual inspection on the ground verified the actuation of the indicator lights to differentiate soil hardnesses.

A change in reconnaissance requirement concepts resulted in cancellation of further use of this system. However, formal military nomenclature and specifications were established for this version of the aerial penetrometer, placing it in the DoD inventory as MIL-P-9768 (USAF), "Penetrometer, Soil, Aerial Drop MXU-8( )/B". The original quantity of these devices has been expended in various proof tests and demonstrations, but existing engineering drawings would permit their refabrication if desired.

PROFILING PENETROMETER

The aerial penetrometer program remained dormant for a considerable period, until AFCRL received responsibility to develop techniques for periodic monitoring of the trafficability of unimproved landing areas as a cooperative portion of an Air Force Weapons Laboratory (AFWL) project. Objective of this phase of the project was to permit in-situ determination of the strength capability of pre-selected sites to sustain aircraft traffic after rainfall. Development of a third type aerial penetrometer, operating on a differential depth-of-penetration principle, was completed for AFCRL by a contractor, Atlantic Research Corporation. This principle, was judged more suited to determination of

12

Fig. 6. Penetrometer Launching System

Fig. 7. Pattern of Penetrometer Impact Spots

Fig. 8. Penetrometer Appearance after Impact

relative strength differences in preknown strength areas.

This penetrometer is designed to be dropped by hand through a simple hollow tube from slow-flying aircraft above 200 meters altitude. It comprises two parts which on impact move in proportion to their weight and transmit their relative displacement by radio telemetry. The 2.5 kg device is roughly cylindrical in shape with side drag fins which serve as the transmitting antenna as well as to provide aerodynamic stability. Dimensions are 10 cm in diameter and 70 cm in length. It was designed so that upon vertical impact of approximately 30 meters per second with the ground, the forward portion of the body will crush somewhat but will remain on the surface. The heavier probe section drives into the soil to a distance governed by the soil hardness and its displacement relative to the outer shell surface is telemetered. Correlations of depth of penetration to soil strength were established for a variety of soils during the development program.

Figure 9 is a photograph showing the penetrometer body lifted off the probe rod after impact. The body consists of an energy-absorbing front end, a radio telemetry section, and the central guide tube for the probe. The entire outer shell of the body is made of varying thicknesses of Kraft paper tube. The front end is made of several polyurethane foam disks placed behind a tempered masonite impact plate, thus relieving stress concentration and reducing soil penetration.

The steel probe which penetrates the soil consists of a 45° conical end with an abrupt decrease in diameter at the base of the cone. This configuration allows most of the mass of the penetrometer to be located at the front for satisfactory flight stability. Attached to the cone is a 1.25 cm diameter steel rod to which a non-metallic cutter is mounted on the far end.

The radio telemetry section of the body is also made of Kraft paper, with the telemetry components and the battery suspended in flexible silicone foam filling the section. This reduces the impact shock on the electronics to a tolerable level of 500 "G". An outer Kraft paper tube attached to the telemetry section extends for the remaining length of the penetrometer and the aerodynamic hardware is attached to this. The cavity between this outer tube and the central guide tube is filled with polyurethane foam for structural support.

The central guide tube is placed within the body shell along its axis for the full length of the body. It is made of a polycarbonate resin, with an inner split tube providing the keyway in which the cutter rides and across which are placed the successive wire conductors of the transmitter circuit. Each cutting causes an increase in resistance of the circuit modulating the transmitter output, so the frequency of the received signal increases as each is cut. By the number of step increases in the signal frequency the depth of penetration is indicated. Also the uniformity of deceleration is indicated by the step spacing.

Fig. 9. Profiling Penetrometer

The signal from each individual penetrometer can be distinguished by an identifying code from a pre-set grouping of pickups. Figure 10 is a photograph of the penetrometer components disassembled after a laboratory calibration test.

An operational suitability test of this penetrometer was conducted jointly by AFWL and AFCRL in October 1969 at a dry lakebed in California typical of a feasible unimproved landing area. Drops were made from a helicopter supplied by the Air Force Flight Test Center, Edwards AFB. Aerodynamic stability was erratic, due in part to helicopter downwash, and local radio interference prevented optimum reception of the telemetered signals and subsequent analysis of the tape-recorded data. However, the penetrometers which impacted satisfactorily gave good correlation of differences in soil strength as measured among soft and medium-hard areas of the clay surfaces. Figure 11 is a representative plot of the telemetered data, indicating the time spacing of signals related to the depth of penetration and also the measured soil strength profile.

Test evaluation was documented (Atlantic Research Corporation, 1970), and the penetrometers were furnished AFWL for recommended redesign. This is described in the paper by Mssrs. Marien and Wilkes at this Conference. The active development of aerial penetrometers by AFCRL terminated with these tests of 1969.

CONCLUSIONS

The technique of airborne determination of trafficability and its related parameters by use of aerial penetrometers has been theoretically and experimentally validated, proof-tested, and demonstrated. Relationships have been established among soil strength, depth of penetration, and parameters of impact velocity and deceleration.

Development of three types of aerial penetrometers has been made by AFCRL and variants of these by WES and AFWL. Other organizations have participated in feasibility and development efforts for specialized objectives.

Routine use of aerial penetrometers for trafficability studies has not been established as an operating procedure by pertinent military commands. This no doubt stems both from relative unfamiliarity with the concept and from the necessary logistical requirements for quantity airborne deployment of the device and means for recording and interpretation of the resulting data.

Fig. 10. Dissambled Penetrometer Components

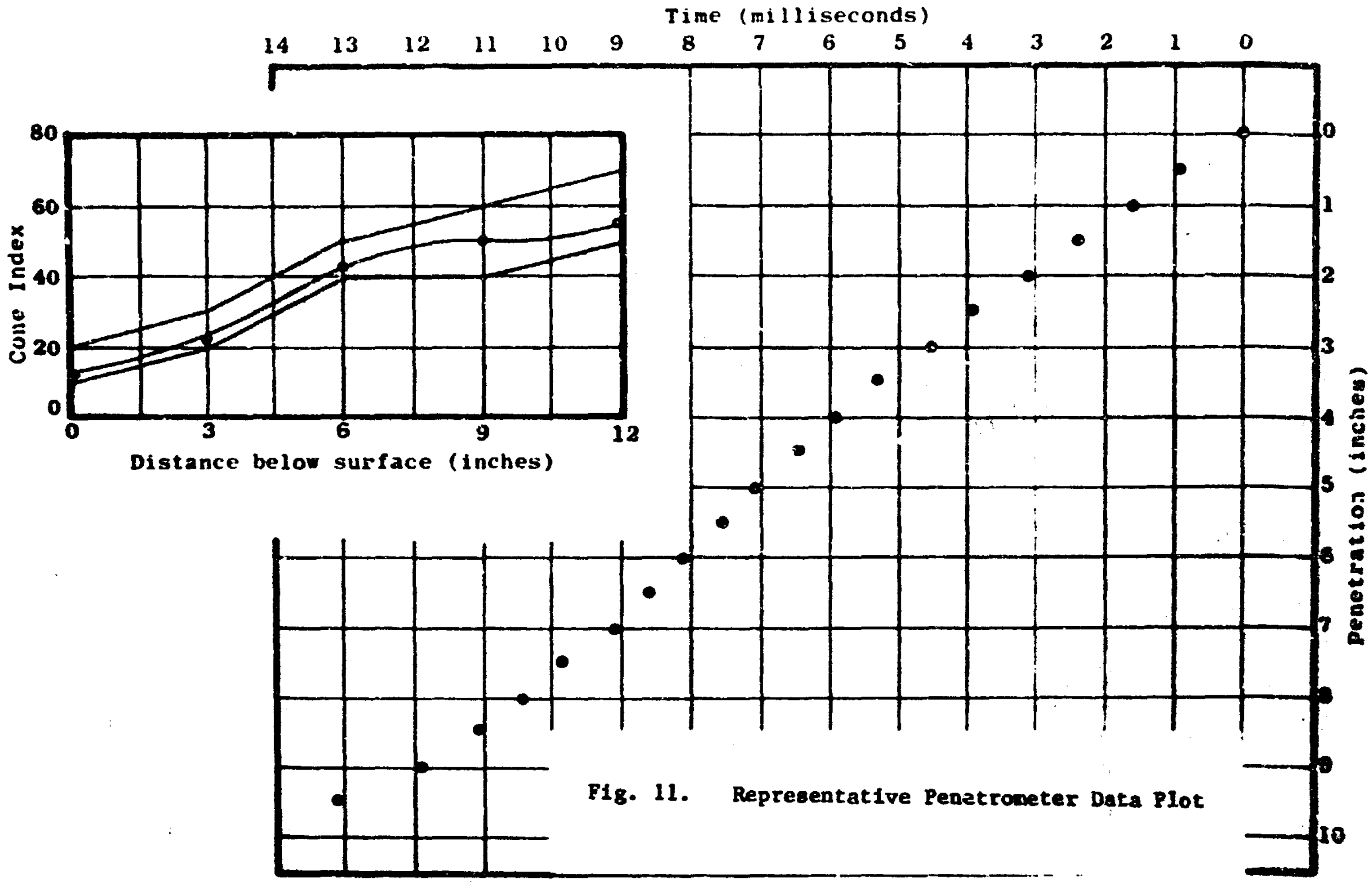

Fig. 11. Representative Penetrometer Data Plot

AFCRL PHOTO 81-419

20

REFERENCES

1. Air Proving Ground Command, "Air Support Development, Phase III," Eglin AFB, Florida, 2 October 1953, pp. 8-10, 47-51

2. Atlantic Research Corporation, "Penetrometer Tests, Harper Lake, California, September 1969," Contract F19628-67-C-0165, January 1970.

3. Bennett, L.A. and Appoldt, F.A., "Soil Trafficability Intelligence," Final Report 457.01, Contract AF19(604)-1919, New York University College of Engineering Research Division, 26 December 1956.

4. Knight, S.J., "The Aerial Cone Penetrometer," The Military Engineer, No. 390, July-August 1967, pp. 240-241.

5. Molineux, C.E., "Remote Determination of Soil Trafficability by the Aerial Penetrometer," Air Force Surveys in Geophysics No. 77, AFCRC-TN-55-223, Air Force Cambridge Research Center, October 1955.

6. Morrison, Milton, "Evaluation of an Aerial Penetrometer," Report No. 495, Stevens Institute of Technology, May 1953.

7. Thornthwaite, C.W., Mather, J.R., Carter, D.B., and Molineux, C.E., "Estimating Soil Moisture and Tractionability Conditions for Strategic Planning," Air Force Surveys in Geophysics No. 94, AFCRC-TN-58-201, Air Force Cambridge Research Center, March 1958.

8. Tranposch, H. and Murray, W.D., "Development of a Ground-Launched Penetrometer," Technical Report 325.01, Contract DA-30-069-ORD-1299, New York University College of Engineering Research Division, 9 December 1955.

9. U.S. Army Engineer Waterways Experiment Station, "Forecasting Trafficability of Soils," Technical Memorandum No. 3-331, Reports 1-10, October 1951-July 1971.

10. U.S. Army Engineer Waterways Experiment Station, "Studies of Aerial Cone Penetrometer," Technical Report No. 3-462, Reports 1-4, July 1957-June 1970.

11. U.S. Army Engineer Waterways Experiment Station, "Aerial Penetrometer Demonstration at Fort Rucker, Alabama," Miscellaneous Paper No. 4-300, January 1959.

12. Warlam, A.A., "Determination of Snow Characteristics from Aircraft: A Feasibility Study," Air Force Cambridge Research Center and U.S. Army Engineer Snow, Ice, and Permafrost Research Establishment, 1 April 1956.

21