NOTICE: When government or other drawings, specifications or other data are used for any purpose other than in connection with a definitely related government procurement operation, the U. S. Government thereby incurs no responsibility, nor any obligation whatsoever; and the fact that the Government may have formulated, furnished, or in any way supplied the said drawings, specifications, or other data is not to be regarded by implication or otherwise as in any manner licensing the holder or any other person or corporation, or conveying any rights or permission to manufacture, use or sell any patented invention that may in any way be related thereto.
HELICOPTER DOWNWASH BLAST EFFECTS STUDY

by

G. W. Leese

October 1964

Sponsored by

U. S. Army Transportation Research Command

Conducted by

U. S. Army Engineer Waterways Experiment Station
CORPS OF ENGINEERS
Vicksburg, Mississippi
HELICOPTER DOWNWASH BLAST EFFECTS STUDY

by

G. W. Loose

October 1964

Sponsored by

U. S. Army Transportation Research Command

Conducted by

U. S. Army Engineer Waterways Experiment Station
CORPS OF ENGINEERS
Vicksburg, Mississippi
Qualified requesters may obtain copies of this report from DDC.

Destroy this report when it is no longer needed. Do not return it to the originator.

The findings of this report are not to be construed as an official Department of the Army position, unless so designated by other authorized documents.
FOREWORD

The study reported herein was conducted by the U. S. Army Engineer Waterways Experiment Station (WES) for the U. S. Army Transportation Research Command. Specific authorization for the study was given by the latter organization in first indorsement dated 7 November 1960 to WES letter dated 27 September 1960, subject, "Proposal for Downwash Blast Effects Study."

Field tests to obtain prototype data on velocities of the downwash blast of various types of operational helicopters were conducted at Fort Rucker, Ala., during March and June 1961 and at the WES in April 1962. Tests with small-scale model rotor blades were conducted in the Surface Effects Blast Facility of the WES during fiscal years 1961 and 1962. No funds were available for testing during fiscal year 1963. These tests were conducted by personnel of the WES Soils Division under the supervision of Messrs. W. J. Turnbull, W. O. Shockley, A. A. Maxwell, W. L. McInnis, C. R. Leese, and P. J. Vedros, Jr. This report was prepared by Mr. Leese.

Directors of the WES during this study and the preparation and publication of this report were Col. Edmund H. Lang, CE, and Col. Alex O. Sutton, Jr., CE. Technical Director was Mr. J. B. Tiffany.
# Contents

<table>
<thead>
<tr>
<th>Section</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>Foreword</td>
<td>3</td>
</tr>
<tr>
<td>Summary</td>
<td>7</td>
</tr>
<tr>
<td>Part I: Introduction</td>
<td>9</td>
</tr>
<tr>
<td>Background</td>
<td>9</td>
</tr>
<tr>
<td>Purpose and Scope</td>
<td>9</td>
</tr>
<tr>
<td>Definition of Terms and Symbols</td>
<td>10</td>
</tr>
<tr>
<td>Part II: Test Equipment and Instrumentation</td>
<td>12</td>
</tr>
<tr>
<td>Equipment Used in Model Tests</td>
<td>12</td>
</tr>
<tr>
<td>Instrumentation</td>
<td>16</td>
</tr>
<tr>
<td>Part III: Prototype Tests and Results</td>
<td>19</td>
</tr>
<tr>
<td>Tests</td>
<td>19</td>
</tr>
<tr>
<td>Test Results</td>
<td>21</td>
</tr>
<tr>
<td>Part IV: Model Tests</td>
<td>23</td>
</tr>
<tr>
<td>Correlation Studies</td>
<td>23</td>
</tr>
<tr>
<td>Soil Movement and Stabilization Studies</td>
<td>26</td>
</tr>
<tr>
<td>Part V: Summary of Results, Conclusions, and Recommendations</td>
<td>31</td>
</tr>
<tr>
<td>Summary of Results</td>
<td>31</td>
</tr>
<tr>
<td>Conclusions</td>
<td>32</td>
</tr>
<tr>
<td>Recommendations</td>
<td>33</td>
</tr>
<tr>
<td>Plates 1-9</td>
<td></td>
</tr>
</tbody>
</table>
Experience with helicopters has shown that during landing or takeoff over dust- or snow-covered areas, the downwash blast from the helicopter rotors produces dust or snow clouds that obscure visibility sufficiently to cause unsafe operating conditions. Recirculation of the dust-laden air through the engine can damage the engine and shorten its life; foreign objects picked up by the downwash can damage the aircraft and even cause its failure as the objects are ingested in the engine or blown against the aircraft's rotor.

Field tests were conducted with operational helicopters at Fort Rucker, Ala., and at the Waterways Experiment Station to determine downwash velocity profiles. In addition, tests utilizing scale-model rotor blades were made at the WES over wet and dry sands and a dry lean clay, and over a chemically stabilized soil, plastic-imregnated soils, and lightweight ground covers (membranes) to determine model-scale velocity profiles and air velocities at the ground surface required to dislodge and move particles of various types of soil, the size of soil area requiring protection for various VTOL aircraft, and the effectiveness of membranes and soil stabilization in preventing dust-cloud formation.

Based on results obtained in this investigation, the following conclusions are believed warranted:

a. The downwash velocities along the ground surface cause soil-particle pickup, and dust hazard conditions will develop if these velocities exceed 1200 fpm over fine dry sand and 1800 fpm over dust-size particles of lean clay.

b. Lightweight ground covers can alleviate dust in the landing and takeoff area of helicopters. A vertical lip around the edge of the membrane will reduce the size of membrane section needed.

c. Certain soil stabilizers will alleviate dust formation under rotary-wing aircraft.
d. Tests to correlate model and prototype data produced limited results. They indicated the need for more accurate measurement of prototype data for each aircraft in order to analyze completely the various parameters involved in scaling and to establish those of paramount importance, so that small-scale tests can be used to predict downwash blast effects of full-scale aircraft.

It is recommended that additional tests be conducted with larger diameter model propellers and with prototype aircraft under rigidly controlled conditions of position and weight in order to establish model-to-prototype prediction curves or equations, or both. Studies should also be continued to determine the factors involved in initial soil-particle pickup and the velocities that cause pickup of various soils in order to predict the area protection required for various helicopters.
1. The operation of helicopters and VTOL*-type aircraft from unprotected soil surfaces presents certain safety and concealment problems which are unique to these types of aircraft. Experience with helicopters has shown that during landing or takeoff over dust- or snow-covered areas, the downwash blast from the helicopter rotors produces dust or snow clouds that obscure visibility sufficiently to cause unsafe operating conditions. Recirculation of the dust-laden air through the engine can damage the engine and shorten engine life; foreign objects picked up by the downwash can damage the aircraft and even cause its failure as the objects are ingested in the engine or blown against the aircraft's rotor. Since helicopters and VTOL aircraft are to be used tactically in support of forward ground operations, dust control is also desirable for camouflage and concealment purposes.

2. The downwash blast of such aircraft varies widely in velocity, mass flow, and temperature. The blast originates at various heights above the ground and is directed toward the ground surface at various angles; it is generated by multiple- as well as single-rotor aircraft. Generally, the downwash characteristics of any aircraft are known or can be estimated with reasonable accuracy. Hence, this study was undertaken to provide basic data on the effects of the flow of downwash blasts on various surfaces under a range of conditions.

Purpose and Scope

Purpose

3. The original purpose of this study was to develop means of predicting the effect of downwash blast from helicopters and other VTOL aircraft on surface soils, ground-protection materials, vegetation, structures, or free objects over which the aircraft might be required to operate. However, it was requested early in the study that the scope be limited specifically to: (a) determination of the feasibility of using lightweight ground covering under VTOL aircraft to prevent soil erosion, dust cloud

* Vertical takeoff and landing.
formation, etc.; (b) determination of the areal extent of ground protection needed and possible means of reducing the areal extent of such protection; (c) limited investigations of soil-stabilization measures for controlling dust during aircraft operations; and (d) correlation of data from prototype and model studies.

Scope

4. Field tests were conducted with operational helicopters at Fort Rucker, Ala., and at the Waterways Experiment Station (WES) to determine downwash velocity profiles. Tests utilizing scale-model rotor blades were then made at the WES over sand and clay soils, a chemically stabilized soil, plastic-impregnated soils, and lightweight ground covers to determine model-scale velocity profiles and air velocities at the ground surface required to dislodge and move particles of the various types of soils tested, as well as the effectiveness of the stabilized soils and membrane.

Definition of Terms and Symbols

5. For clarity, the meanings of certain terms and symbols used in this report are defined below.

<table>
<thead>
<tr>
<th>Term</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>Disc loading</td>
<td>The total thrust on the rotor shaft divided by the projected rotor disc area</td>
</tr>
<tr>
<td>Propeller</td>
<td>A device having two or more blades which, when mounted on a power-driven shaft, produces a thrust by its action on the air</td>
</tr>
<tr>
<td>Static pressure</td>
<td>The force per unit area excited by a fluid on a surface at rest relative to the fluid</td>
</tr>
<tr>
<td>Total pressure (also called stagnation pressure)</td>
<td>The static pressure that would be obtained if the flow could be brought to a state of rest isentropically</td>
</tr>
<tr>
<td>D</td>
<td>Rotor diameter, ft</td>
</tr>
<tr>
<td>h</td>
<td>Vertical height of sensing element above ground surface, ft</td>
</tr>
<tr>
<td>k</td>
<td>Classic symbol for constant</td>
</tr>
</tbody>
</table>
$P_s$ Static pressure, lb per sq ft
$q$ Dynamic pressure, lb per sq ft
$q_m$ Jet mean dynamic pressure ($q_m = W/2$ for ducted-fan propeller and $q_m = W$ for open propeller), lb per sq ft
$R$ $D/2$, ft
$T$ Total thrust, lb
$V$ Velocity, fps
$W$ Disc loading ($T$/propeller disc area), lb per sq ft
$X$ Horizontal distance measured on the ground plane from a point directly beneath the center of the propeller hub, ft
$Z$ Vertical distance from the ground surface to center of propeller hub, ft
Equipment Used in Model Tests

Truck-mounted test rig

6. The basic test rig used in the scale-model tests was made available to the WES for these studies by the U. S. Army Transportation Research Command. It consisted of a truck-mounted, 14-1/2-ft-long parallelogram \( \text{m} \) at the outer end of which was a 128-hp engine, a 5-speed gearbox, and a propeller hub assembly for attachment of ducted fans and open, multibladed propellers. The rig was mounted on the bed of a U. S. Army Model M54, 5-ton, 6x6 cargo truck with a front-mounted winch (see fig. 1). The gearbox provided input-to-output ratios of 1:1, 1.48:1, 2.40:1, 4.38:1, and 7.58:1. The output shaft from the gearbox was attached to a right-angle drive with an input-to-output ratio of 1:2.69. The height of the propeller hub above the ground was controlled by raising or lowering the parallelogram boom assembly with the winch cable of the truck. This height could be varied from 6 in. to 14-1/2 ft. An electric starter, an electric throttle actuator, and a remote control for the engine clutch were located in an operator's remote-control panel.

Fig. 1. Truck-mounted test rig

Ducted-fan assembly

7. The ducted-fan assembly consisted of a 3-ft-long duct, a 2-ft-diam propeller with adjustable propeller hub, and a set of straightening vanes designed to remove the swirl from the exiting airstream (see fig. 2).
The duct consisted of a laminated cylinder of sugar pine with a laminated inlet; the propeller and the straightening vanes were located near the exit. The single-rotation propeller consisted of six 3-in.-chord, NACA-6, airfoil section blades machined from aluminum-alloy forgings. The blades were mounted in a split hub that allowed the pitch of the blades to be manually adjusted. The five straightening vanes were mounted just below the propeller. The duct assembly was mounted on a main support shaft by means of a welded, tubular-steel support. The inlet of the duct assembly was covered with a 1/8-in.-mesh screen to prevent solid objects from falling into the duct. At a speed of 8000 rpm, a thrust of 405 lb could be developed with the propeller-blade tips set at an angle of 17.7 deg.

**Propellers**

8. Five-ft-diam propellers with two, three, four, and five blades were used in the study. The blades were constructed of wrapped aluminum-alloy sheet to form an NACA 0012, constant-chord (5.75 in.), airfoil section. The two- and three-bladed propellers (fig. 3) were mounted in rigid hubs with the blade angles of each selected to produce the same thrust.
versus revolutions per minute curve. The hubs of the four- and five-bladed propellers were split to permit varying the pitch angles.

9. A 20-in.-diam, three-bladed propeller, also used in the tests, was mounted on the shaft of a 3000-rpm electric motor (see fig. 4) and on the shaft of a variable-speed electric motor. The propeller was made of cast aluminum; the pitch of the blades varied inversely with the radius. The measured thrust of the propeller on the shaft of the 3000-rpm motor was 15 lb, or a disc loading of 0.68 lb per sq ft; the disc loading with the variable-speed motor varied between 0.15 and 0.5 lb per sq ft.

10. The 20-in.-diam, six-bladed propeller used in the ducted-fan assembly described in paragraph 7 was removed from the test rig and adapted to a variable-speed, electric-motor drive (fig. 5). The blades were set at a 17-deg pitch; the disc loadings varied from 0.38 to 14.4 lb per sq ft.

11. Soil-particle traps were used to catch the air-blown soil during tests of soil-particle movement in order to determine the amount of soil movement caused by the downwash blast from the propeller. The soil trap consisted of eight, 1-in.-high by 4-in.-wide, 6-in.-deep compartments, one
Fig. 4. Propeller, 20 in. in diameter, mounted on 3500-rpm motor
above the other. Each compartment could be emptied individually to determine weight and particle size of the soil collected at various heights above the soil surface.

**Instrumentation**

12. The instrumentation utilized in this study was in general that installed in the Surface Effects Blast Facility of the WES. Basic electrical recording equipment consisted of commercially available amplifiers, power supplies, magnetic tapes, and an oscillograph; since these are commonly used data-recording devices, they are not described here. Transducers to permit continuous electrical recording of test phenomena were developed as needed. Other devices used to obtain data or operate test equipment under known parameters are described below.
Tachometers used in model tests

13. An electronically tachometer was used to determine accurately the revolutions per minute of the small-scale propeller. A photoelectric cell was mounted on the propeller shaft housing adjacent to a directed light source. This photoelectric cell sensed intermittent reflected light from the propeller drive shaft, which was painted black and white. This arrangement made possible the correlation of revolutions per minute with thrust.

14. A tachometer was also used on the variable-speed drive of the electric motor to determine revolutions per minute of the drive shaft. This instrument consisted of a 60-tooth spur gear and a magnetic proximity-pickup transducer. A pulse was picked up each time a gear tooth passed the proximity-pickup transducer; these pulses were counted by an electronic counter to determine the revolutions per minute of the drive shaft. Thus, calibration of the propellers was obtained as revolutions per minute versus thrust.

Instruments used in both model and prototype tests

15. Pressure sensors. Pressure sensors used in the study to measure downwash velocities consisted of commercially available, aircraft-type pitot tubes, fabricated pitot tubes constructed of concentric metal tubing, and single brass tubes. The pitot tubes measured both total pressures and static pressures; the single tubes measured either total pressure or static pressure, depending on their fabrication. The tubes were connected to either electrical indicating devices or manometers for recording measured static and total pressures. One arrangement of the pressure sensors is shown in fig. 4, page 15.

16. Manometer panel. The manometer panel consisted of 3/4 inclined glass tubes with a suitable scale attached. Colored vegetable dye was used in the manometer fluid to allow photographs to be taken showing the fluid level. A 4 x 5 camera mounted above the panelboard made it possible to photograph all the manometer tubes at once; thus, all readings were recorded at the same instant. By using Polaroid film, the records could be read within a short time after they were taken.

17. Pitot tube electrical bellows unit. It was desired early in the study to obtain continuous recordings of surface air velocities with a time base. To do this a system was designed whereby a mechanical motion was translated to an electrical potential (representing the air velocity) and the change in potential was recorded by an oscillograph. The mechanical motion device consisted of a small bellows unit from an aircraft airspeed indicator mounted inside a sealed container with a
differential transformer. One end of the bellows unit was fixed to the container, with the opposite end free to move. A small iron core was attached to the free end of the bellows unit and suspended inside the differential transformer that was also secured to the container. The total pressure was admitted through tubing to the inside of the bellows unit, and the static pressure from the pitot tube was admitted to the sealed container (outside the bellows unit). As the air velocities increased, the pressure inside the bellows unit increased and caused the bellows unit to lengthen; this moved the iron core within the differential transformer, causing an electrical potential change within the transformer which was recorded by the oscillograph. Through pretest calibrations, the pressure change could be determined from the oscillograph record. This arrangement made possible continuous recording of the downwash blast velocities at several points over a period of time. Since the unit measured the dynamic pressure, which is the difference between the stagnation and the static pressures, the velocity of the airstream could be computed.

18. Hot-wire anemometers. The hot-wire anemometers used to measure air velocity consisted of a short length of platinum wire that was heated by an electric current. The resistance to flow of electricity through the wire was a function of its temperature. Thus, as air flowed around the wire, cooling it, its resistance changed, and this change was recorded on an electric meter. For continuous recordings, calibration was accomplished by placing the hot wire in an airstream of known velocity and recording the output signal on an oscillograph.
PART III: PROTOTYPE TESTS AND RESULTS

19. Prototype tests were conducted at Fort Rucker, Ala., in March and June 1961 and at the WES in April 1962. The purpose of the full-scale tests was to determine downwash blast velocities beneath the helicopters and along the ground surface during normal takeoff and landing operations for correlation with velocities to be determined in model-scale rotary-wing tests. The H-13, H-11A, H-21, H-34, and H-37 helicopters were utilized in these tests.

Tests

Fort Rucker

20. In the tests conducted at Fort Rucker, downwash blast velocities were measured both above and along the ground surface. The tests were conducted on a helicopter landing pad (fig. 6) constructed on a bare area over which a membrane ground cover had been placed. The membrane, which gave a relatively smooth surface for the tests, was No. 8 cotton-duck material coated on both sides with vinyl.

21. In the tests conducted in March 1961, the downwash velocities along the ground surface were determined by placing the pitot tube bellows units along a line starting near the point of touchdown of the aircraft. The unit placed nearest the touchdown point measured vertical velocities 1 ft above the landing-pad surface. Similar units placed 10 and 20 ft from the first unit measured both vertical and horizontal downblast velocities. At 10-ft intervals on a staggered line beyond this, hot-wire anemometers were placed to determine the decay of surface velocity with distance. Plate 1 shows the test area layout for these tests. Each of the five

Fig. 6. Test area at Fort Rucker with velocity transducers in place
helicopters was landed in such manner that the center of its rotor was at a known distance from the first probe. Downblast velocities were recorded continuously during the landing-and-takeoff cycle. Two landing-and-takeoff cycles were made with each type of helicopter, one cycle with the fuselage axis parallel to the line of anemometers and one with the axis normal to it. The dual-rotor H-21 was landed several times so that the effects of a single rotor and the combination of both rotors could be observed (see fig. 7).

22. In the June 1961 tests, the downwash velocities above the ground were determined by the electrical bellows velocity pickups supported on a frame which positioned them at given points above the ground surface. The three helicopters used in these tests (the H-21, H-34, and H-37) were landed at various distances from the pickups so that a vertical velocity profile could be obtained at given distances from the rotor blades.

WES

23. The purpose of the tests at the WES was to obtain additional velocity data in the boundary layer (the layer of air adjacent to the ground surface) of downblast from a full-scale helicopter. A temporary landing pad was constructed of steel blast panels placed over a leveled area, with a cloth membrane placed over the panels to provide a smooth surface. Several pitot tubes were placed at selected locations on the surface of the temporary landing pad. The heights of the pitot tubes varied between 1/16 and 30 in. The helicopter utilized was an H-13. Measurements were taken with the helicopter rotor at several heights, ranging from 12 to 50 ft, above the surface and at distances of 75, 52-1/2, 35, and 17-1/2 ft from the pitot tubes. Test data were recorded by photographing the inclined manometer panel and reducing the pressure readings to velocity data.
Fort Rucker Tests

24. The March 1961 tests at Fort Rucker produced data which appear to be erratic, indicating that the downwash flow along the ground surface either was turbulent or moved in an oscillating or wavy motion and not in a horizontal plane. Maximum surface horizontal velocities recorded during the March 1961 tests as the various helicopters were landing and taking off were as follows:

<table>
<thead>
<tr>
<th>Helicopter</th>
<th>Maximum Velocity, Fpm</th>
</tr>
</thead>
<tbody>
<tr>
<td>H-U1A</td>
<td>3000</td>
</tr>
<tr>
<td>H-13</td>
<td>1700</td>
</tr>
<tr>
<td>H-21</td>
<td>3500</td>
</tr>
<tr>
<td>H-34</td>
<td>3800</td>
</tr>
<tr>
<td>H-37</td>
<td>5200</td>
</tr>
</tbody>
</table>

It was noted that these maximum surface horizontal velocities occurred at distances of 1 to 1-1/2 rotor diameters from the rotor shaft center line.

25. Data obtained during the June 1961 tests to develop downwash velocity profiles under the H-37, H-34, and H-21 were as follows:

<table>
<thead>
<tr>
<th>Distance from Rotor Center Line, ft</th>
<th>Rotor Height, ft</th>
<th>Horizontal Velocities, Fpm, at Indicated Heights Above Ground</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>18 in.</td>
<td>25 in.</td>
</tr>
<tr>
<td>H-37 Helicopter, 72-ft-diam Rotor</td>
<td></td>
<td></td>
</tr>
<tr>
<td>40</td>
<td>14.1</td>
<td>3000</td>
</tr>
<tr>
<td>50</td>
<td></td>
<td>3800</td>
</tr>
<tr>
<td>60</td>
<td></td>
<td>4000</td>
</tr>
<tr>
<td>70</td>
<td></td>
<td>3800</td>
</tr>
<tr>
<td>80</td>
<td></td>
<td>3700</td>
</tr>
</tbody>
</table>

H-34 Helicopter, 56-ft-diam Rotor

<table>
<thead>
<tr>
<th>Distance from Rotor Center Line, ft</th>
<th>Rotor Height, ft</th>
<th>Horizontal Velocities, Fpm, at Indicated Heights Above Ground</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>18 in.</td>
<td>25 in.</td>
</tr>
<tr>
<td>40</td>
<td>9.2</td>
<td>3400</td>
</tr>
<tr>
<td>50</td>
<td></td>
<td>3100</td>
</tr>
<tr>
<td>60</td>
<td></td>
<td>3200</td>
</tr>
<tr>
<td>70</td>
<td></td>
<td>3400</td>
</tr>
<tr>
<td>80</td>
<td></td>
<td>3100</td>
</tr>
</tbody>
</table>

(Continued)
Distance from Rotor Center Line, ft

<table>
<thead>
<tr>
<th>Height, ft</th>
<th>Horizontal Velocities, fpm, at Indicated Heights Above Ground</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>15 in.</td>
</tr>
<tr>
<td>h0</td>
<td>2700</td>
</tr>
<tr>
<td>50</td>
<td>2200</td>
</tr>
<tr>
<td>60</td>
<td>-</td>
</tr>
</tbody>
</table>

Note: Velocities shown for the dual-rotor H-21 were measured below the front rotor.

The portion of the above-tabulated data representing a distance of about one rotor diameter from center of rotor is plotted in plate 2. The shape of the lower part of the curves is estimated. The exact shape of the velocity profile for prototype data through the boundary layer is not well defined since sufficient prototype data were not available in this area.

WES tests

26. Data obtained in the WES tests with the H-13 helicopter are plotted in plates 3, 4, and 5, which show that maximum downblast velocities, 2100 to 2500 fpm, occurred about one rotor diameter horizontally from the rotor center line. Also, data obtained very close to the ground surface (within 1 in.) indicated velocities sufficient to create large dust clouds, with the upper-air (1 to 8 in. above ground surface) velocities being strong enough to distribute the disturbed soil particles over a large area.

27. It should be remembered that the Fort Rucker and WES prototype tests were conducted with free-flying aircraft, and all distances and heights were approximated by sight; thus inaccuracies are contained in the data. Also, instrumentation error was caused by natural winds blowing at irregular velocities across the test area.
PART IV: MODEL TESTS

Correlation Studies

28. The correlation phase of the study consisted of correlating downwash velocity profile data of the 20- and 60-in.-diam propellers, and developing a prediction curve for model-to-prototype correlation. Velocity profile data of the various propellers were obtained by placing the pitot tubes at various heights above the ground surface and at various values of X/D. As the propellers developed various disc loadings at various values of Z/D, the dynamic pressures and static pressures were recorded by photographing the manometer board and the downwash velocities were computed. These data were used to determine the boundary-layer conditions as well as the velocity profiles. Fig. 4 (page 15) shows one test setup using the 20-in.-diam propeller and pitot tubes placed at various heights.

Velocity profiles

29. A series of tests was conducted in which various X/D and Z/D values were used with the 20-in.-diam propeller. Then with similar X/D and Z/D values, the disc loading was varied with the 60-in.-diam propeller until the maximum deflection on the manometer panel equaled the corresponding maximum deflection on the manometer panel for the 20-in.-diam propeller. Data obtained at Z/D = 0.675 and X/D = 1.0 are plotted in plate 6. Data obtained at other Z/D and X/D values correlated fairly well. The disc loading for the 60-in.-diam propeller was 9.05 lb per sq ft, while that for the 20-in.-diam propeller was 6.88 lb per sq ft. It is interesting to note in this case that the ratio of the square roots of the propeller diameters and the ratio of the squares of the disc loadings are the same. If this relation holds true, model-to-prototype scaling becomes a function of disc loadings and rotor diameters as indicated by the following relation:

\[
\frac{V_d^2}{W_m^2} = \frac{D_p}{D_m}
\]

Solving for \( W_m \),

\[
W_m = W_p \sqrt{\frac{D_m}{D_p}}
\]
where

\[ W_p = \text{prototype disc loading} \]
\[ W_m = \text{model disc loading} \]
\[ D_p = \text{prototype rotor diameter} \]
\[ D_m = \text{model rotor diameter} \]

Additional data are needed for further study of model-to-prototype correlation.

**Boundary-layer velocity**

30. Ground-surface dust is disturbed by the layer of moving air immediately adjacent to the ground. It was seen from the velocity profiles that the velocity of the boundary layer of air adjacent to the ground surface was slightly less than that of the layer just above it; thus, it is easily seen that once the dust particles are lifted off the ground, they will be quickly blown into the surrounding area. Therefore, maximum downwash velocity is not too important in initiating dust; it is the boundary layer of air adjacent to the ground which initiates it and the upper layers of higher velocity air which distribute it over a wide area.

31. Data from tests utilizing the 24-in.-diam ducted fan were obtained at various values of X/R and under several disc loads and Z/D values, the objective of the tests being to gather sufficient data with which to develop curves and equations that would assist in determining the boundary-layer air velocity when related to given Z/D and X/R ratios. These data are plotted in Plate 7 as disc loading in pounds per square foot versus velocity in feet per second. Assuming that the three lines in Plate 7 have the same slope, the equation of each curve becomes:

\[ W_1 = 0.00193 v^2 \quad (Z/D = 0.5) \]
\[ W_2 = 0.00252 v^2 \quad (Z/D = 1.0) \]
\[ W_3 = 0.00295 v^2 \quad (Z/D = 2.0) \]

Taking the three above-stated equations of the form \( W = K v^2 \) and expressing \( K \) as a function of \( Z/D \), the general equation form will be

\[ K = a + (Z/D)b + (Z/D)^c \]

Substituting and solving, it is found that:
0.00193 = a + 0.5b + 0.25c
0.00252 = a + b + c
0.00395 = a + 2b + 4c

\[
\begin{align*}
\text{a} &= 0.00109 \\
\text{b} &= 0.00193 \\
\text{c} &= -0.0005
\end{align*}
\]

so that \( K = 0.00109 + (Z/D) \times 0.00193 - (Z/D)^2 \times 0.0005 \)

and \( W = (10.9 + 19.3 (Z/D) - 5 (Z/D)^2) \times 10^{-4} \times \nu^2 \) \( (2) \)

By similar computation and expressing \( K \) as a function of \( X/R \),
\[ W = [3.667 \times 10^{-4} (X/R)^2 + 46.33 \times 10^{-5} (X/R) - (27.4 \times 10^{-5})] \times \nu^2 \] \( (3) \)

32. Though these equations were based on results of tests with the 24-in.-diam ducted fan, results of tests with the 24-in.-diam open-bladed propeller compare favorably, as can be seen in plate 8. This plate shows curves computed by means of equation 2, with actual open-propeller data plotted for \( X/R = 2 \) and \( Z/D = 0.5 \) and 1.0.

**Prediction of velocities initiating soil-particle movement**

33. Various materials are available to preclude the dust clouds that are detrimental to helicopter operations, among which are membranes, landing mats, chemicals, and plastics. However, because of the difficulty of transporting large quantities of any of these materials to forward landing areas, the area to be covered should be as small as possible for each type aircraft.

34. To determine the minimum area of protection required for various VTOL aircraft, a prediction curve was developed from data obtained for the 60-in.-diam propellers. This curve, shown in plate 9, represents measured dynamic pressure, \( q \), divided by the jet mean dynamic pressure, \( q_m \), plotted against the radial distance, \( X \), divided by the propeller radius, \( R \). As an example of use of the curve, the test data indicate that the minimum velocity that will produce appreciable movement of fine sand is about 1750 fpm. The dynamic pressure, \( q \), for this velocity is 1.01 lb per sq ft, and the maximum rated disc loading \( (W = q_m) \) for open propellers for an overload mission for the H-13 helicopter is 2.59 lb per sq ft, giving a \( q/q_m \) ratio of 0.39. From the curve, a \( q/q_m \) ratio of 0.39
indicates an X/R ratio of about 3.2. Since the H-13 has a propeller radius of 17.55 ft, the indicated extent of ground cover required to prevent movement of sand by this aircraft would be a circle about 112 ft in diameter. It is emphasized that the curve in plate 9 is based on model test data and has not been checked against full-scale test data.

Soil Movement and Stabilization Studies

Soil movement velocities

35. To determine the downwash velocities that cause dust-cloud formation, studies were made using the 60-in.-diam propellers to determine the minimum air velocity at the soil surface that causes soil movement sufficient to reduce visibility. For these tests, a 10- by 10-ft test section was constructed, and various soils were placed in the section as testing progressed. To assure airflow parallel with the soil surface, a curved deflector was constructed and placed on the edge of the test section to make the downblast air flow horizontally. A hot-wire anemometer was placed in the airstream at the trailing edge of the deflecting surface to accurately record the velocity of the air passing over the soil surface (see fig. 8). The soils used in the test sections were dry concrete sand and a dry lean clay.

36. The fine particles of dry sand ranging from fine through about No. 50 sieve size were observed to begin moving along the surface at about 1200 fpm air velocity; these particles became airborne at a velocity of about 1500 fpm. The largest particles of dry sand, ranging between about Nos. 4 and 50 sieve sizes, began moving along the surface at an air velocity of approximately 2300 fpm. Tests made on a wet sand showed initial movement of fine particles at approximately 3800 fpm. Tests made on the lean clay indicated initial movement of dust particles at approximately 1800 fpm. It is these dust-size particles which become detrimental to pilot visibility and aircraft operation.

Size of protected area

37. In this series of tests, methods of surface protection were studied which would decrease the dust-cloud formation sufficiently to eliminate occurrence of detrimental conditions during landing and takeoff operations. The test area was otherwise prepared by placing fine sand in the 10- by 10-ft test section. The two- and three-bladed 60-in.-diam propellers were set at various distances from the test section at heights up to 10 ft above the ground surface which was covered with membrane material. The disc loading was maintained at 5.1 lb per sq ft.
38. Results of these tests indicated that an area 30 to 40 ft in
diameter (6 to 8 times propeller diameter) would have to be covered to
provide full protection from downwash. Such an area would be excessive
for the larger helicopters. In order to study the possibility of de-
creasing the area requiring protection during the landing and takeoff of
helicopters, tests were made using deflectors on the outer edge of the
protected area. The deflectors, placed on the front edge (toward the pro-
peller) of the test section, were 6 in. high and sloped 30, 60, and 90 deg
from the horizontal (see Fig. 9). The 60-in.-diam propeller was placed
adjacent to the test section at a distance of 1/2 rotor radius from the
deflector and operated at disc loadings of 5.1 and 7.65 lb per sq ft to
determine the effectiveness of the deflectors in reducing the areal ex-
tent of ground cover required to provide protection against soil erosion
and dust-cloud formation. Results indicated that the ground area re-
quiring protection beneath the 60-in.-diam propellers can be reduced
about 50 percent (i.e. from about 30 to 40 ft to about 15 to 20 ft in
diameter) by the use of a 6-in. vertical (90 deg) deflector.
Fig. 9. Deflectors with sloped faces used on outer edge of test section.
Soil stabilization

39. Dust alleviation by means of soil stabilization was investigated. An 8- by 10-ft test area was divided into four sections, each 4 by 5 ft. Two sections were filled 4 in. deep with sand of medium grain size, one section with a fine dune sand, and one with pulverized lean clay. Approximately 1/2 lb of polyester resin per square foot of area was poured onto one of the medium sand sections; it penetrated the sand to a depth of about 1/8 in. Like amounts of a mixture of polyester resin and chopped fiber glass were sprayed on the other medium sand section and the lean clay section, and penetrated to depths of about 1/8 and 1/16 in., respectively. The dune sand was pulvimixed with approximately 0.12 lb per sq ft of aniline-furfural to a depth of about 1/2 in. Fig. 10 shows the stabilized sections as they appeared before the downwash blast tests. The crack in the surface of section 4 in fig. 10 was caused by the shrinkage of the polyester resin upon curing. The fiber glass prevented such cracking in sections 1 and 3. The stabilized sections were subjected to downwash blast of the 60-in.-diam propeller at a disc loading of 10 lb per

Fig. 10. Soil stabilization sections before test. Section 1 is the treated lean clay; section 2 is the dune sand; sections 3 and 4 are medium sand with polyester resin and fiber glass, and polyester resin, respectively.
sq ft with no detrimental effects to any of the four sections. The test sections were then subjected to disc loadings up to 145 lb per sq ft from the 24-in.-diam ducted fan. No damage occurred to the polyester sections; however, an area of the aniline-furfural section (section 2) failed at a disc loading of about 110 lb per sq ft. Failure was caused by the shrinkage cracks (see fig. 10), which allowed the downwash blast to get underneath the stabilized surface. Fig. 11 shows the test area after testing.

Fig. 11. Soil stabilization sections after test
Summary of Results

Prototype tests

40. Data obtained during the Fort Rucker and WES prototype tests appeared to be erratic in that the velocity readings varied constantly as the helicopter hovered or landed, and the data also varied during the several repeat tests. A large part of this variation of data is attributed to the instrumentation used. The prototype data were obtained early in the study when velocity and pressure pickups were rather crude; refinements of these instruments were used in the later, small-scale tests and not only decreased this variation but indicated the same results for repeated, similar tests. It is believed that the prototype data obtained define fairly accurately the maximum velocities produced by the various helicopters and velocity profile variations both with height above the ground surface and distance from the rotor center line. However, sufficient data were not obtained in the boundary layer (below 6 in.) to definitely define the velocity profile in this critical area. It was noted during the study that maximum surface velocities were greatest at a distance of about one rotor diameter from the rotor center (horizontally) in both model- and full-scale studies. Since this is the area where dust-cloud formation will be initiated as an aircraft approaches for landing or increases power for takeoff, more measurements are needed in this area than in others to define the phenomena.

Model tests

41. Model studies comprised not only boundary-layer and velocity-profile studies (as did the prototype studies), but also studies of soil-particle movement, size of area requiring protection, and effectiveness of soil stabilizers. Boundary-layer and velocity-profile studies were made to attempt correlation with prototype test results; however, it was quickly seen that prototype test conditions could not be controlled as accurately as model test conditions or results measured as accurately. Thus, no satisfactory comparisons could be made. Test data were then obtained on the 20-, 24-, and 60-in.-diam propellers and an attempt made to correlate these data, and through an extension of this procedure to predict prototype results. As is seen in plate 6, this approach to the correlation study produced results which appear favorable; however, the limited data available at this time for both model and prototype do not allow definite conclusions to be drawn. Data presented in plate 7 and discussed in paragraph 31 indicate that boundary-layer velocity varies with disc loading and vertical height. Equations developed for these two small-scale conditions compare
favorably with other similar small-scale data (plate 8), but sufficient data from larger diameter or prototype propellers are not available for comparison.

42. Soil particle movement studies indicated that dust-hazard conditions would develop if boundary-layer velocities exceed 1200 fpm over dry fine sand and 1800 fpm over dust-size particles of lean clay. Thus, ground protection would be required over an area where these velocities were exceeded.

43. As mentioned earlier, the correlation of model and prototype data yielded little information, mainly because of the inability to control exact height and distance of the prototype aircraft from instruments during the tests. Also, the presence of wind during prototype testing caused the data obtained to be inaccurate. The correlation of results of tests of the small and large propellers appears to yield usable values although the available data are limited. Additional data are needed on larger model blades and more exactly positioned prototype aircraft to accurately define model-prototype relations.

Conclusions

44. Based on results obtained in this investigation, the following conclusions are believed warranted:

a. The downwash velocities along the ground surface cause soil-particle pickup, and dust-hazard conditions will develop if these velocities exceed 1200 fpm over fine dry sand and 1800 fpm over dust-size particles of lean clay.

b. Lightweight ground covers (membrane) can alleviate dust in the landing and takeoff area of helicopters.

c. A vertical lip around the edge of the membrane will reduce the size of membrane section needed.

d. Certain of the soil stabilizers tested will alleviate dust under VTOL aircraft.

e. Tests to correlate model and prototype data indicated the need for more accurate measurement of prototype data for each aircraft in order to analyze completely the various parameters involved in scaling and to establish those of paramount importance so that small-scale test results can be used to predict prototype blast effects.
Recommendations

45. In view of the findings presented in this report, it is recommended that the correlation study be continued. Additional tests should be conducted with larger diameter model propellers and with prototype aircraft under rigidly controlled conditions of position and weight in order to establish model-to-prototype prediction curves or equations, or both. Soil movement studies should be continued to determine the factors involved in initial soil-particle pickup and the velocities that cause pickup of various soils in order to predict the area protection required for various helicopters.
9 EQUAL SPACES COVERING 90 FEET

LEGEND
- PITOT PICKUP
- HOT-WIRE ANEMOMETER

FORT RUCKER TEST AREA LAYOUT
VERTICAL HEIGHT OF PROBE ABOVE GROUND IN INCHES

HORIZONTAL VELOCITY IN FPM

LEGEND

- H-37
- H-34
- H-21

NOTE: X·D = 1

PROTOTYPE DATA
VELOCITY PROFILES
FT. RUCKER TESTS

PLATE 2
LEGEND

- ○ X/D = 1/2
- ▽ X/D = 1
- ▲ X/D = 1-1/2
- ▼ X/D = 2

H-13 HELICOPTER DATA
VELOCITY PROFILES
WES TESTS, Z/D = 0.34
LEGEND

- ○ X/D = 1/2
- X/D = 1
- X/D = 2

H-13 HELICOPTER DATA
VELOCITY PROFILES
WES TESTS, Z/D = 0.71
LEGEND

\[ - \quad X/D = 1-1/2 \]

\[ \quad X/D = 2 \]

H-13 HELICOPTER DATA
VELOCITY PROFILES
WES TESTS, Z/D = 1.42
CORRELATION OF MODELS
20- AND 60-IN. PROPELLERS

Z/D = 0.876
X/D = 1.000
CORRELATION OF DATA
24-IN. DIAM DUCTED FAN

LEGEND

<table>
<thead>
<tr>
<th>Z/D</th>
<th>X/R</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.5</td>
<td>1.9</td>
</tr>
<tr>
<td>1.0</td>
<td>2.2</td>
</tr>
<tr>
<td>2.0</td>
<td>2.4</td>
</tr>
</tbody>
</table>
RATIO OF RADIAL DISTANCE FROM AXIS OF ROTATION TO PROPELLER RADIUS, $X/R$

NOTE: CURVE SHOWN FOR 2- AND 3-BLADED, 5-FT-DIAMETER PROPELLER.
PRESSURES OBTAINED AT $h/D = 0.0333$.

VARIATION OF $\frac{c_i}{q_m}$ WITH $X/R$
**DISTRIBUTION LIST**

| Commanding General, U. S. Army Materiel Command | 1 |
| ATTN: AMCRD, Washington, D. C. 20315 |

| Commanding General, U. S. Army Materiel Command | 1 |
| ATTN: AMCRD-RP-A, Washington, D. C. 20315 |

| Commanding General, U. S. Army Mobility Command | 1 |
| ATTN: AMSMO-RR, Warren, Michigan 48090 |

| Commanding General, U. S. Army Mobility Command | 1 |
| ATTN: AMSMO-RD, Warren, Michigan 48090 |

| Commanding General, U. S. Army, Hawaii | 1 |
| ATTN: Transportation Officer, AFO 957, San Francisco, California |

| Office of Chief of Research and Development | 1 |
| ATTN: Combat Materiel Division, Department of the Army, Washington 25, D. C. |

| Office of Chief of Research and Development | 1 |
| ATTN: Air Mobility Division, Department of the Army, Washington 25, D. C. |

| Commanding Officer, U. S. Army Transportation Research Command | 9 |
| ATTN: Research Reference Center, Fort Eustis, Virginia 23604 |

| Commanding Officer, U. S. Army Transportation Research Command | 65 |
| ATTN: 24FOE-AMG, Fort Eustis, Virginia 23604 |

| Chief, U. S. Army Research and Development Group (Europe) | 1 |
| ATTN: USATRECOM Liaison Officer, APO 757, New York, New York 10000 |

| Commanding Officer, U. S. Army Limited War Laboratory | 1 |
| ATTN: Chief, Mobility Branch, Aberdeen Proving Ground, Maryland 21005 |

| Commanding Officer, Army Research Office-Durham | 2 |
| ATTN: Information Processing Officer, Box CM, Duke Station, Durham, North Carolina 27706 |

| Director, U. S. Army Engineer Waterways Experiment Station | 3 |
| ATTN: Research Center Library, Vicksburg, Mississippi 39181 |
DISTRIBUTION LIST (Continued)

Commanding General, U. S. Army Combat Developments Command
Aviation Agency
ATTN: Archives/Library
Fort Rucker, Alabama 36362

Commanding General, U. S. Army Combat Developments Command
Aviation Agency
ATTN: Maj. H. W. Huntzinger, TC Liaison Officer
Fort Rucker, Alabama 36362

Commanding Officer, U. S. Army Combat Developments Command
Transportation Agency
Fort Eustis, Virginia 23604

Commandant, U. S. Army War College
ATTN: Library, K-1018
Carlisle Barracks, Pennsylvania 17013

Commandant, U. S. Army Command and General Staff College
Library Division, Fort Leavenworth, Kansas 66027

Commandant, U. S. Army Aviation School
ATTN: Library, Bldg. 531J, Fort Rucker, Alabama 36362

Commanding General, U. S. Army Infantry Center
ATTN: Transportation Officer, Fort Benning, Georgia 31905

President, U. S. Army Aviation Test Board
Fort Rucker, Alabama 36362

President, U. S. Army Transportation Board
ATTN: STETT-SB, Fort Eustis, Virginia 23604

Transportation Corps Liaison Officer, U. S. Army Airborne
Electronics and Special Warfare Board
Fort Bragg, North Carolina 28307

Headquarters, U. S. Army Aviation Test Activity
ATTN: STEAV-P, Edwards Air Force Base, California 93523

Headquarters, U. S. Army Aviation Test Activity
ATTN: AFFTC (FTAT-2), Edwards Air Force Base, California 93523
<table>
<thead>
<tr>
<th>Address</th>
<th>No. of Copies</th>
</tr>
</thead>
</table>
| Commander, Aeronautical Systems Division  
Air Force Systems Command  
ATTN: ASNDE (Dr. Dausman)  
Wright-Patterson Air Force Base, Ohio 45433 | 2 |
| Commander, Aeronautical Systems Division  
Air Force Systems Command  
ATTN: ASRMC-1, Wright-Patterson Air Force Base, Ohio 45433 | 1 |
| Chief of Naval Operations (OP-343), Department of the Navy  
Washington, D. C. 20350 | 1 |
| Chief, Bureau of Naval Weapons  
ATTN: R-38, Department of the Navy  
Washington, D. C. 20360 | 1 |
| Chief, Bureau of Naval Weapons  
ATTN: Code R-55, Department of the Navy  
Washington, D. C. 20360 | 1 |
| Chief, Bureau of Naval Weapons  
ATTN: RAAD-32, Department of the Navy  
Washington, D. C. 20360 | 1 |
| Chief, Bureau of Naval Weapons  
ATTN: RR-25, Department of the Navy  
Washington, D. C. 20360 | 1 |
| Library, Technical Reports Section  
U. S. Naval Postgraduate School  
Monterey, California 93940 | 1 |
| Commander, Naval Air Test Center, U. S. Naval Air Station  
ATTN: Technical Library, Patuxent River, Maryland 20670 | 1 |
| Commanding Officer and Director, David Taylor Model Basin  
Aerodynamics Laboratory Library, Washington, D. C. 20007 | 1 |
| National Aeronautics and Space Agency, Ames Research Center  
ATTN: Library, Moffett Field, California 94035 | 2 |
| NASA-LRC, Langley Station,  
ATTN: Tech Library, B-1244, Hampton, Virginia 23665 | 2 |
<table>
<thead>
<tr>
<th>Address</th>
<th>No. of Copies</th>
</tr>
</thead>
<tbody>
<tr>
<td>National Aeronautics and Space Administration</td>
<td>1</td>
</tr>
<tr>
<td>Lewis Research Center</td>
<td></td>
</tr>
<tr>
<td>ATTN: Chief, Library, 2100 Brookpark Road</td>
<td></td>
</tr>
<tr>
<td>Cleveland, Ohio 44100</td>
<td></td>
</tr>
<tr>
<td>National Aeronautics and Space Administration</td>
<td>1</td>
</tr>
<tr>
<td>Manned Spacecraft Center</td>
<td></td>
</tr>
<tr>
<td>ATTN: Technical Library, Houston, Texas 77000</td>
<td></td>
</tr>
<tr>
<td>Scientific and Technical Information Facility</td>
<td>2</td>
</tr>
<tr>
<td>ATTN: NASA Representative (SAK/DL)</td>
<td></td>
</tr>
<tr>
<td>P. O. Box 5700, Bethesda, Maryland 20014</td>
<td></td>
</tr>
<tr>
<td>Director, Research Analysis Corporation</td>
<td>1</td>
</tr>
<tr>
<td>ATTN: Library, McLean, Virginia 22101</td>
<td></td>
</tr>
<tr>
<td>National Aviation Facilities Experimental Center</td>
<td>3</td>
</tr>
<tr>
<td>ATTN: Library Branch, Bldg. 3, Atlantic City, New Jersey 08400</td>
<td></td>
</tr>
<tr>
<td>The George Washington University, Human Resources Research Office</td>
<td>2</td>
</tr>
<tr>
<td>ATTN: Library, 300 North Washington Street</td>
<td></td>
</tr>
<tr>
<td>Alexandria, Virginia 22300</td>
<td></td>
</tr>
<tr>
<td>Defense Documentation Center, Cameron Station</td>
<td>20</td>
</tr>
<tr>
<td>Alexandria, Virginia 22314</td>
<td></td>
</tr>
<tr>
<td>U.S. Government Printing Office, Division of Public Documents</td>
<td>1</td>
</tr>
<tr>
<td>ATTN: Library, Washington, D. C. 20401</td>
<td></td>
</tr>
</tbody>
</table>
Field tests were conducted with operational helicopters at Fort Rucker, Ala., and at the Waterways Experiment Station to determine downwash velocity profiles. In addition, tests utilizing scale-model rotor blades were made at the WES over wet and dry sands and a dry lean clay, and over a chemically stabilized soil, plastic-impregnated soils, and lightweight ground covers (membranes) to determine model-scale velocity profiles and air velocities at the ground surface required to dislodge and move particles of various types of soil, the size of soil area requiring protection for various VTOL aircraft, and the effectiveness of membranes and soil stabilization in preventing dust-cloud formation. It was concluded that (a) the downwash velocities along the ground surface cause soil-particle pickup, and dust hazard conditions will develop if these velocities exceed 1800 fpm over fine dry sand and 1800 fpm over dust-size particles of lean clay; (b) lightweight ground covers can alleviate dust in the landing and takeoff area of helicopters, and a vertical lip around the edge of the membrane will reduce the size of membrane section needed; (c) certain soil stabilizers tested will alleviate dust formation under rotary-wing aircraft; and (d) there is need for more accurate measurement of prototype data for each aircraft in order to analyze completely the various parameters involved in scaling and to establish those of paramount importance so that small-scale tests can be used to predict downwash blast effects of full-scale aircraft.
Dowwash
Helicopters
Dust control
Soil-stabilization

INSTRUCTIONS

1. ORIGINATING ACTIVITY: Enter the name and address of the contractor, subcontractor, grantee, Department of Defense activity or other organization (corporate author) issuing the report.

2a. REPORT SECURITY CLASSIFICATION: Enter the overall security classification of the report. Indicate whether "Restricted Data" is included. Marking is to be in accordance with appropriate security regulations.

2b. GROUP: Automatic document is spooled into Group 5294, 10 and Armed Forces Industrial Manuals. Enter the group number. Also, when applicable, show that optional markings have been used for Group 1 and Group 1 as authorized.

3. REPORT TITLE: Enter the complete report title in all capital letters. Often in all cases should be unclassified. If a meaningful title cannot be selected without classification, show type classification in all capital in parentheses immediately following the title.

4. DESCRIPTIVE NOTES: If appropriate, enter the type of report, e.g., interim, progress, summary, annual, or final. Give the inclusive dates when a specific reporting period is covered.

5. AUTHORS: Enter the name(s) of author(s) as shown on or in the report. Enter last name, first name, middle initial. If military, show rank and branch of service. The name of the principal author is an absolute minimum requirement.

6. REPORT DATE: Enter the date of the report, not date of publication.

7a. TOTAL NUMBER OF PAGES: The total page count should follow normal pagination procedures, i.e., enter the number of pages containing information.

7b. NUMBER OF REFERENCES: Enter the total number of references cited in the report.

8a. CONTRACT OR GRANT NUMBER: If appropriate, enter the applicable number of the contract or grant under which the report was written.

8b, 8c, & 8d. PROJECT NUMBER: Enter the appropriate military department identification, such as project number, subproject number, system number, task number, etc.

8e. ORIGINATOR'S REPORT NUMBER(s): Enter the official report number by which the document will be identified and controlled by the originating activity. This number must be unique to this report.

9a. OTHER REPORT NUMBERS: If the report has been assigned any other report numbers (other than the originator or by the sponsor), also enter this number(s).

10. AVAILABILITY/LIMITATION NOTICES: Enter any limitations on further dissemination of the report, other than those imposed by security classification, using standard statements such as:

10a. "Qualified requesters may obtain copies of this report from DDC."

10b. "Distribution is authorized and dissemination of this report by DDC is not authorized."

10c. "U. S. Government agencies may obtain copies of this report directly from DDC. Other qualified DDC users shall request through..."

10d. "U. S. military agencies may obtain copies of this report directly from DDC. Other qualified users shall request through..."

10e. "All distribution of this report is controlled. Qualified DDC users shall request through..."

If the report has been furnished to the Office of Technical Services, Department of Commerce, for sale to the public, indicate this fact and enter the price, if known.

11. SUPPLEMENTARY NOTES: Use for additional explanatory notes.

12. SPONSORING MILITARY ACTIVITY: Enter the name of the sponsoring departmental project office or laboratory performing (paying for) the research and development. Include address.

13. ABSTRACT: Enter an abstract giving a brief and factual summary of the document indicative of the report. Even though it may also appear elsewhere in the body of the technical report, if additional space is required, a continuation sheet should be attached.

It is highly desirable that the abstract of classified reports be unclassified. Each paragraph of the abstract shall end with an indication of the military security classification of the information in the paragraph, represented as (TS), (C), or (U).

There is no limitation on the length of the abstract. However, the suggested length is from 150 to 225 words.

14. KEY WORDS: Key words are technically meaningful terms or short phrases that characterize a report and may be used as index entries for cataloging the report. Key words must be selected so that no security classification is required. Identifiers, such as equipment model designations, trade name, military project code name, geographic location, may be used as key words but will be followed by an indication of technical content. The assignment of help, ratings, and weight is optional.

Unclassified
Security Classification