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SAND AND DUST CONSIDERATIONS IN THE DESIGN OF MILITARY EQUIPMENT

by

Paul A. Blackford and Harry S. McPhilimy

July 1972

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U.S. ARMY ENGINEER TOPOGRAPHIC LABORATORIES
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13. ABSTRACT

Sand and dust definitions found in military references show little uniformity and, in some cases, little logic. Based on a review of pertinent literature, it is reasonable to define dust as particulate matter smaller than 74 μm and to define sand as particles in the size range between 74 and 1,000 μm. Of the two sizes of particles, dust has by far the greater potential for damaging most materiel. Because of the wide range of possible effects of dust, it is concluded that three different concentration categories can be considered in materiel design. Military items likely to be used in remote areas and not in association with common military activities may be designed for concentrations of only 5 mg/ft^3; items in common military usage should be designed to meet concentrations up to 30 mg/ft^3; and items likely to be used near aircraft, particularly helicopters, should be designed for concentrations of about 60 mg/ft^3. In the latter case, particles are not limited to dust-size, since rotor downwash is strong enough to raise sand grains to considerable heights.

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The Commanding Officer
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SUMMARY

Sand and dust definitions found in military references show little uniformity and, in some cases, little logic. Based on a review of pertinent literature, it is reasonable to define dust as particulate matter smaller than 74 μm and to define sand as particles in the size range between 74 and 1,000 μm. Of the two sizes of particles, dust has by far the greater potential for damaging most materiel.

Because of the wide range of possible effects of dust, it is concluded that three different concentration categories can be considered in materiel design. Military items likely to be used in remote areas and not in association with common military activities may be designed for concentrations of only 5 mg/ft^3; items in common military usage should be designed to meet concentrations up to 30 mg/ft^3; and items likely to be used near aircraft, particularly helicopters, should be designed for concentrations of about 60 mg/ft^3. In the latter case, particles are not limited to dust-size, since rotor downwash is strong enough to raise sand grains to considerable heights.

FOREWORD

This report was prepared as part of the Army's contribution to the revision of MIL-STD 210A, *Climatic Extremes for Military Equipment*, which outlines environmental requirements for the design of materiel. Although the Air Force is the preparing activity for this Standard, an ad hoc committee has been formed to make final judgments on the limits to be recommended for inclusion in the current revision. The Army and Navy members of the committee are contributing background studies on environmental elements of particular importance to their materiel. The present study for this purpose was funded by the Environmental Sciences Division, Office, Chief of Research and Development, under Project 2M025001A724.

CONTENTS

SAND AND DUST CONSIDERATIONS IN THE DESIGN OF MILITARY EQUIPMENT

I. INTRODUCTION

Practically all materiel can be damaged in some way through association with sand and dust. The damage may be caused by abrasion, clogging or blocking, or corrosion.

Abrasion damage is particularly important in internal combustion engines where dust particles caught between any moving parts exert a cutting action. Examples of this kind of damage are numerous and dramatic. In fact, the failure of the German campaign against Russia during World War II has been attributed in large part to dust problems.[1] Abrasive action by dust caused such a reduced efficiency and a high rate of complete engine failure that the German tanks were almost useless by the time of the autumn muddy season and the following severe winter. Also, during World War II, noticeable engine wear and high oil consumption in aircraft engines were caused by dust at airfields in Britain after as little as 10 hours of use.[2] The effects of dust have been the subject of considerable investigation by the automotive industry; in general, it has been shown that abrasive action can be and has been reduced considerably by the use of efficient air filters and by increased attention to preventive maintenance. Abrasive action is not limited to internal moving parts but is also damaging to exposed components such as propeller blades and various kinds of linkages which, when lubricated, rapidly collect a heavy layer of dust that may act as a grinding compound on the mating surfaces.

The effects of dust in the category of clogging and blocking include a wide variety of specific problems brought about by the mere presence of dust. These include many kinds of electrical failures where dust prevents positive contact; many cases where small openings are blocked and made inoperative by dust accumulations; and even cases where the weight of accumulated dust in dead-air spaces in aircraft may seriously affect performance by changing aerodynamic characteristics.

The effects of dust in promoting corrosion and microbiological growth are less well documented and may be less important than the other effects; certainly, they are less dramatic. In any case, it has been suggested that dust acts as a catalyst for the corrosion of exposed metal, and dust particles may be a means of transport for micro-organisms.

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[1] U. S. Department of the Army, *Effects of Climate on Combat in European Russia*, Pamphlet No. 20-291 (Washington, D. C., U. S. Government Printing Office, February 1952).

[2] C. G. Vokes, "Air Filtration," *Flight*, 45 (1835), 207 (Feb. 1944).

It should also be noted that sand and dust have adverse effects on personnel, and they are important to military operations both for concealing and exposing various types of movement; but these considerations are beyond the scope of this report.

II. DEFINITIONS OF SAND AND DUST

Sand and dust are terms for small particles of matter usually of mineral origin. They are usually differentiated from one another by means of differences in size, but the terms are often used loosely and sometimes interchangeably. Drawing a distinction between the two may seem rather academic because the particle sizes involved grade into one another, and any boundary size used for distinguishing between them will be somewhat arbitrary at best. Nevertheless, there are differences in the physical characteristics and in the military effects of sand and dust that make worthwhile the attempt to continue a distinction. For example, Bagnold,[3] who has done a considerable amount of experimental work on the behavior of blowing sand, suggests that there are four important differences, all of which are a function of particle size alone, in the behavior of grains of the same material and the same shape. These are: (1) the fact that there is a critical diameter for which the threshold wind is a minimum (as the particle diameters increase or decrease from this size, stronger wind pressures are required to move the grains); (2) smaller particles may be maintained aloft indefinitely by eddy currents of normal winds; (3) smaller particles tend to collect moisture and become bound together; and (4) smaller particles, even though angular, feel smooth when rubbed between the fingers. Bagnold suggests that these behavioral differences are noticeable in the narrow range of sizes between 70 and 150 micrometers (μm) and that all groups of materials that behave like sand have predominent diameters larger than 80 μm.

Table I shows that, although boundary sizes have been used in the past in various military and other documents, there has been no consistency and, sometimes, no apparent logic in their selection. For convenience and because there is a need for some standardization in the definition, it is suggested here that the distinction between sand and dust be based on particle size and that the boundary value approximate the point at which the behavioral changes noted by Bagnold occur. An actual limit of 74 μm, which corresponds to a No. 200 National Bureau of Standards sieve, would meet this criterion and is, therefore, recommended. This size limit also has the advantage that it is nearly equal to 0.003 in. which is a frequently specified tolerance limit for vital machinery parts.

Thus, it is recommended that dust be defined as all particulate matter up to 74 μm in size—all material that will pass a No. 200 standard sieve. Sand may be defined as solid, noncohesive, particulate matter in the size range of 74 to 1,000 μm.

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[3] R. A. Bagnold, *The Physics of Blown Sand and Desert Dunes* (Methuen, London, 1954).

Table I. Particle Sizes Used by Various Sources to Distinguish Between Dust and Sand (Size ranges given in micrometers (μm))

Source	Dust	Sand	Remarks
Bagnold, R. A., *The Physics of Blown Sand and Desert Dunes.*[a]	1 to 80	80 to 1,000	Oversimplified—Bagnold states that predominant diameters of sand are never less than 80.
Glossary of Geology.[b]	–	62 to 2,000	Dust size not given; presumably less than 62.
Pauly, James, *The Dust Environment and its Effect on Dust Penetration*, WADC Report No. 56-556.[c]	1 to 150	100 to 300	Particles between 100 and 150 are in both classes.
MIL-STD 210, *Climatic Extremes for Military Equipment* (1 June 1953).	1 to 10	180 to 300	Particles between 10 and 180 are unclassified. Size for sand is that given by OQMG, EPB Report No. 146[d] as the predominant diameters for windborne sand.
MIL-STD 210A, *Climatic Extremes for Military Equipment* (2 Aug 1957).	0.1 to 10	10 to 1,000	Source unknown: Specifies predominant diameters for sand as 150 to 300 which corresponds to Bagnold's statements taken, in turn, from Udden.[e]
MIL-STD-810B, *Environmental Test Methods*, 15 June 1967.	Up to 150	Not defined	Dust is defined as fine sand.
MIL-STD-1165, *Glossary of Environmental Terms (Terrestrial)* (25 Mar 1968).	< 75	75 to 4,760 (50% in this range)	Dust size recommended by ECOM; sand also defined as 500 to 2,000.
AR 70-38, *Research, Development, Test and Evaluation of Materiel for Extreme Climatic Conditions* (5 May 1969).	0.1 to 10	10 to 1,000	Same as MIL-STD-210A.
Naval Weapons Center, China Lake, Calif.	2 to 50	50 to 2,000	Proposed in unpublished report which also includes a range for dust particles from 2 down to colloidal size.
AF Systems Command Design Handbook 1-5, *Environmental Engineering.*	0.1 to 50 (Ave. size: 0.5 to 1.5)	Larger than 50 (Ave. size: 150 to 300)	
NASA Technical Memorandum, Report No. 53872.[f]	0.1 to 80 (90% between 0.1 and 2)	80 to 1,000 (90% between 80 and 300)	
UK, Particle sizes recommended in a draft environmental handbook.	1 to 150	100 to 1,000	Specifies rounded quartz grains for sand; otherwise, same as Pauly.

[a] R. A. Bagnold, *The Physics of Blown Sand and Desert Dunes* (Methuen, London, 1954).

[b] American Geological Institute, *Glossary of Geology and Related Sciences*, 2nd ed. (Am. Geol. Inst., Washington, D. C. 1966).

[c] James Pauly, *The Dust Environment and its Effect on Dust Penetration*, WADC Technical Report 56-556, ASTIA (DDC) Doc. No. AD 110472 (Wright Air Development Center, Ohio, Sep. 1956).

[d] N. Sissenwine and A. Court. *Climatic Extremes for Military Equipment*, EPB Res. Rept. No. 146 (OQMG, Washington, D. C. Nov. 1951).

[e] J. A. Udden, "Dust and Sand Stress in the West," *Popular Science Monthly*, 49: 655-664 (1896).

[f] G. E. Daniels, ed., *Terrestrial Environment (Climatic) Criteria for use in Space Vehicle Development, 1969 Revision*, NASA Technical Memorandum, Report No. 53872 (Marshall Space Flight Center, Ala., 1970).

III. CHARACTERISTICS AND BEHAVIOR OF SAND

For most military considerations, angularity and hardness are the most important characteristics of sand grains. Hardness, in turn, is a function of the mineral composition of the particles. Significantly, on a world-wide basis, most sands are composed of quartz (SiO_2) which is one of the very common rock-forming minerals. Although quartz is a polymorph, many of its common forms have a hardness of 7 (on the Mohs scale) which is hard enough to cause abrasive damage to most forms of steel. In particular localities, materials other than quartz may be locally important as constituents of sand. These include the white gypsum sands of southwestern United States (hardness, 2); the black, seashore sands containing magnetite (hardness, 6) found in various parts of the world; some stream sands containing corundum (hardness, 9); and sands made up of calcite (hardness, 3) in marine or former marine locations.

Whether most sand grains likely to be encountered are rounded or angular may be a matter for some conjecture, but there can be little doubt that a substantial proportion of sand grains have an angular shape. Even though they may have been rounded at one time by abrasion, quartz particles in desert areas, through impact action and because of their tendency to fracture conchoidally, may well have become angular again.

Because sand in its large accumulations tends to exist in relatively pure form, i.e., particles in the general size range of 100 to 1,000 μm, its behavior under wind pressure is fairly well-defined and predictable. At some threshold wind speed, which depends on the roughness of the ground surface and the size of the grains, sand grains begin to move in the direction of the wind. As the particles move, they impact on other grains and bounce off or they move the impacted grains, or both, so that there is soon a mass of moving sand particles which appears to the observer to be suspended indefinitely in the air. Actually, however, each sand grain moves in a rather flat and relatively short trajectory after which it bounces again into the air or moves other grains into similar paths. This bounding movement of sand grains is referred to as saltation.

In general, the sand movement is confined to the air layer within the first meter above the ground. Even within this layer, about half the sand grains (by weight) move within the first 10 mm above the surface; and most of the other half are within the first 10 cm.[4] As a consequence of the low elevation at which most sand grains move, most abrasive damage caused by the sand is at or near ground level. Nevertheless, the smaller number of grains at the relatively high levels can be effective in removing paint from various surfaces as well as in causing severe erosion to exposed materials—particularly, glass and plastics. Clements *et al.*[5] suggest that most direct abrasive damage done

[4] R. A. Bagnold, *The Physics of Blown Sand and Desert Dunes* (Methuen, London, 1954).

[5] T. Clements, *et al.*, *A Study of Windborne Sand and Dust in Desert Areas*, Technical Report ES-8, Earth Sciences Div., U. S. Army Natick Labs., Natick, Mass., Aug. 1963).

by sand to automotive surfaces and windshields, however, might be avoided by the simple expedient of ceasing movement during a sandstorm.

The relationship between sand movement and meteorological wind speeds is not well established in a quantitative sense, although it has been shown experimentally that winds of about 11 mph (measured near the ground surface) can move small, dry sand particles in areas of loose sand dunes. In other areas where surface particles are somewhat agglomerated, winds up to 30 mph may be required to cause appreciable movement. Because of this kind of variation in threshold wind speeds, it is difficult to generalize about sand movement even where wind speeds are well documented. Clements *et al.*[6] observed the movement of a particular dune over a period of 9 months and found that the bulk of the dune moved approximately 40 feet in one direction during the first 7 months and then moved about 30 feet back toward its original position in the other 2 months. Most of the backward movement apparently took place during a particular windstorm when wind speeds of up to 32 mph were measured a few miles away. This example merely demonstrates that substantial amounts of sand are commonly moved about by wind pressure.

The distribution of sand over the earth's surface is widespread. There are vast sandy areas in the Sahara and in Saudi Arabia as well as significant areas in most of the world's deserts. All of the continents have sandy beaches of varying width, and there are large sand deposits at or near the surface in many inland areas formerly covered by water. Because of the widespread occurrence of sand, it can be assumed that most types of military equipment will be exposed in sandy areas during any extensive operations. However, the effect of such exposure depends on the nature of the equipment, the ground moisture, and the wind speeds. At present, there are no standard testing procedures designed primarily for evaluating the effects of blowing sand, although some of the dust procedures specify small quantities of particles up to 150 μm in diameter.

IV. CHARACTERISTICS AND BEHAVIOR OF DUST

In contrast to the distributional patterns that could be associated with sand, dust particles, because of their low terminal velocity, can remain suspended in air indefinitely and can settle to the surface anywhere. Consequently, dust and its associated problems are ubiquitous; although there are differences in degree from place to place.

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[6]T. Clements, *et al.*, *A Study of Windborne Sand and Dust in Desert Areas*, Technical Report ES-8 (Earth Sciences Div., U. S. Army Natick Labs., Natick, Mass., Aug. 1963).

Some effort has been made to evaluate the potential dustiness of places by examining the proportion of dust-size particles (smaller than 74 μm) in the surface soil.[7] It was concluded by Engelhardt and Knebel that any area that has soil containing more than 9 percent by weight of such particles may become at least moderately dusty at times. Soils with 14 percent or more of dust-size particles are potentially very dusty. However, it was also concluded that soils with more than 9 percent of dust particles are very common on a world basis; so, one must look for other factors on which to base estimates of the likelihood of dust problems.

These other pertinent factors, however, are so closely related that it is impossible to separate their individual effects except under carefully controlled long-term study. For example, the state of agglomeration of the surface particles, caused either by chemical association or the binding action of moisture, is an extremely important consideration in the prediction of dust problems. Even bare soils, such as the undisturbed crusts of playas, may not give rise to dust problems until the soil is disturbed or agitated by mechanical means. Such agitation, a common feature of military activities, facilitates the drying process and breaks the surface down into its tiny constituent particles. It also happens in many cases that surface dust particles become re-cemented soon after the disturbing forces cease. Because of this characteristic, the Vehicle Dust Course at Yuma Proving Ground is disked prior to use for testing.

Another important factor in assessing the dust potential of a given area is the presence (or absence) of protective cover, either natural or artificial. Dense vegetation of any kind, for example, provides excellent mechanical protection from wind movement; and plant roots tend to bind the soil particles. Artificial protection is provided by paving over areas subject to hard usage or by employing various soil-stabilization techniques. Even sprinkling with water will provide temporary relief from dust problems.

Climatic factors, particularly precipitation, are of considerable importance in determining the state of agglomeration of particles. Since dust-size particles may be found in abundance nearly everywhere and low soil moisture is a primary deagglomerating factor, any climatic conditions that favor evaporation tend to increase the dust potential. Excluding Antarctica, over 40 percent of the world's land surface is classified as moisture deficient. Another 40 percent of the earth is seasonally dry, which means that dust problems may be expected over most of the earth's surface for substantial parts of the year. Less obvious, perhaps, is the fact that even in regions and seasons of heavy rainfall dust continues to create problems where protective cover has been removed. Many moist areas are so well drained that mud becomes dust in a remarkably short time after

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[7] R. E. Engelhardt and G. W. Knebel, *Characteristics of the Dust Environment in the Vicinity of Military Activities*, U. S. Army Mobility Equip. R&D Center (MERDC) Report No. AR 642 (Ft Belvoir, Va., Jan 1968).

a heavy rain. A good example is Vietnam, where many Americans have been surprised, particularly during wet seasons, at the extent of sand and dust problems.

Climatic factors other than precipitation also have an effect on dust potential. Since dust is hygroscopic, relative humidity plays some part. Many dust tests, for example, specify a relative humidity of less than 30 percent in order to achieve maximum particle separation. There is also some evidence that dust problems are more severe at higher temperatures.[8] Finally, both because of its drying action and its ability to circulate dust, wind has a considerable effect on dust potential.

All the factors listed above are important in determining natural dust potential even though the effects are known only qualitatively. Nevertheless, the most important deagglomerating factor, except when the surface is completely wet, is man himself, especially when he is equipped with machinery to increase his speed and mobility. Tanks, trucks, bulldozers, artillery, aircraft, and even marching troops are very effective in the destruction of protective cover and the separation of small particles so much so that dust problems must be expected anywhere these activities take place. Possible exceptions are those places under permanent snow, ice, or water cover, and those rare places that have precipitation so often that the surface never dries out.

A considerable part of the military literature on dust deals with particle sizes and concentrations. Dust concentration measurements are often made by trapping the dust from a given volume of air and expressing the concentration in terms of weight per unit volume. For some reason, it has become common in the United States to use the rather strange expression of grams or milligrams per cubic foot. Because it is already so common, this convention is continued here; but milligrams per cubic meter will also be given. The measurement of particle sizes is covered in some detail in the literature.[9] For particles down to 74 μm, which are those that will be retained by a No. 200 U. S. standard sieve, it is customary to use a series of sieves to differentiate between size groups. Below 74 μm, the further use of sieves, although they are available, is considered impractical by many investigators because of the large variations in the sieves and consequent large proportion of errors. Therefore, particles smaller than 74 μm are often referred to as sub-sieve size. There are various ways to measure sub-sieve particles, but test runs have shown that measurements made by different methods seldom are in close agreement.[10] Therefore, data comparisons for small sizes are not likely to be representative unless it is known that the same measurement methods were used. This

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[8]James Pauly, *The Dust Environment and Its Effect on Dust Penetration*, WADC Report No. 56-556.

[9]R. E. Engelhardt and G. W. Knebel, *Characteristics of the Dust Environment in the Vicinity of Military Activities*, U. S. Army MERDC Report No. 642 (Ft Belvoir, Va., Jan 1968).

[10]*ibid.*

caution may be largely academic since relatively few particle-size determinations have been made for dust in the several investigations where samples were taken from dust plumes raised by various kinds of vehicles in dusty areas; it is also pertinent that particles larger than 74 μm are rare in these plumes.

As shown in Table I, NASA gives an indication that the predominant sizes of dust particles will be between 0.1 and 2 μm, but there is no indication as to whether the percentages are by weight or by count. Other samples, taken from dust plumes around operating tanks at Yuma Proving Ground, indicate a maximum size in this situation somewhat smaller than 74 μm; but more than 80 percent of the particles, by weight, were larger than 5 μm.[11] From these two studies, it is apparent that one cannot generalize too freely about dust sizes. It is fair to state, however, that the higher the sample (above the ground), the smaller the particles; larger sizes tend to settle out first.

Likewise, there is a wide variability in concentrations of dust suspended in the air. This variability within a seemingly uniform micro-environment is illustrated by a series of nine dust samples collected next to a bulldozer backfilling a trench with dry earth. All samples were collected within a time span of 1 hour, and care was taken to get as nearly identical conditions as possible; yet, the concentrations varied from 0.26 to 5.19 mg/ft^3 (9 to 183 mg/m^3). Most of the pertinent data available regarding measured dust concentrations are incorporated in Table II which shows some of the variety of dust concentrations in different circumstances. Table II also demonstrates that dust concentrations from ordinary windstorms tend to be much lower than those associated with military activities.

In addition to actual measurements of dust concentrations, some attempts have been made to correlate concentration with visibility. In fact, the most common method of reporting dust occurrence is based on restriction to visibility. Apart from the inherent differences among observers in their perception of what constitutes poor visibility, consistent correlation between visibility and dust concentration is difficult to achieve because properties other than concentration are important in determining light transmission. For example, at a given concentration (weight per volume of air), dust clouds composed of smaller particles pass much less light than those composed of larger particles. Particle shape and composition may also have significant effects on the transmission of light. As an example of the kinds of variation that may result from these differences, concentrations as low as 0.3 mg/ft^3 (10.6 mg/m^3) have restricted visibility to less than 50 feet; yet, under other circumstances, as high as 8 mg/ft^3 (282 mg/m^3) have resulted in visibilities of 500 feet or more.[12]

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[11] James Pauly, *The Dust Environment and Its Effect on Dust Penetration*, WADC Report No. 56-556.

[12] R. E. Engelhardt and G. W. Knebel, *Characteristics of the Dust Environment in the Vicinity of Military Activities*, U.S. Army MERDC Report No. AR 642 (Ft Belvoir, Va., Jan. 1968).

Table II. Dust Concentrations Under Various Field Conditions

Activity or Event	Type of Surface	Concentration	
		mg/ft³	mg/m³
Dust Storm in Australia			
500 feet above ground	Dry surface: little protective	0.06	2
1,000 feet above ground	cover.	0.5	18
2,000 feet above ground	Wind: 24 to 30 mph	0.2	7
3,000 feet above ground	Ground visibility: 1,000 ft.	0.05	2
4,000 feet above ground		0.02	1
Wind: 12 to 14 mph	Scrub covered field: no activity	0.4	14
Fresh breeze: 19 to 24 mph	Unpaved sandy area: no disturbing activity	1.7	60
Severe storm: not defined	Dry surface: no cover	5.0	176
Troops drilling	Dry parade ground	0.9	32
Troops marching	Dry unpaved road	2.0	71
One staff car	Unpaved maneuver road	2.9	102
Convoy of trucks and towed guns	Unpaved maneuver road	5.1	180
Column of tanks	Bare, dry, sand and dust surface: measured beside column	7.3	258
Muzzle blast from gun on M-60 Tank	Bare, dry surface: measured approx. 65 feet away	1.3	46
MQM61-A Drones: one JATO Bottle	Hard packed sand and gravel: two separate measurements	0.9 2.4	32 85
Half-track in operation	Loose sand: measured 30 feet away	29.2	1031
One Tank - 10 mph	Heavy dust surface	27.2	960
Column of 6 Light Tanks	Moving into wind over heavy dust surface	53.5	1889
Engine compartment in Tank		170.0	6001
Aircraft taking off	Clean, paved runway	0.8	28
H-21 Helicopter	Over freshly plowed fields		
During take-off		40.0	1412
Hovering at 1 foot		15.5	547
Hovering at 10 feet		18.1	639
Hovering at 75 feet		7.3	258
Hovering with second Helicopter maneuvering nearby		64.0	2259

Note: The examples in this table were taken from several of the references listed herein.

Zero visibility during dust storms has often been reported, but such reports are usually grossly exaggerated; most experienced observers agree that actual visibilities of less than 10 feet are very rare occurrences in nature. Oliver,[13] writing of the Egyptian and Libyan deserts, states that visibility during storms was generally between 50 and 200 meters, and only in the most severe storms did it fall below 50 meters. However, during the most violent storm in the period between 1939 and 1945, the visibility at Burg, Egypt, was almost nil for a period of 3 hours.

Having indicated some of the limitations to determining dust concentration from visibility, we can now portray in Table III the general relationships that have been estimated to exist.[14]

Table III. General Relationships Between Visibility and Dust Concentrations

Visibility		Dust Concentrations	
(feet)	(meters)	(mg/ft^3)	(mg/m^3)
>500	>152	<0.4	<14
100 to 500	30 to 152	0.4 to 1.3	14 to 46
50 to 100	15 to 30	1.3 to 5.0	46 to 176
<50	<15	5.0 to 40.0	176 to 1412

V. SPECIAL DUST AND SAND CONSIDERATIONS

In previous sections of this report, a distinction between sand and dust has been based on the fact that there are significant differences in the behavior of the two kinds of particles. In reviewing the report of a series of tests with helicopters, however, it would appear that under some circumstances there is little reason for differentiating between sand and dust.[15] The following capsule summary is given to demonstrate that helicopter-induced conditions may be more extreme, as well as somewhat different, than any others.

Concentration measurements and some particle-size determinations were made in dust clouds generated by a tandem-rotor H-21 helicopter at Yuma Proving Ground and at Fort Benning. These measurements are partially summarized in Table IV.

[13] F. W. Oliver, "Dust Storms in Egypt and Their Relation to the War Period as Noted in Maryut 1939-45," *Geographical Journal*, 106 (1, 2): 26-49. Supplement same, 108: 221-226 (1945).

[14] R. E. Engelhardt and G. W. Knebel, *Characteristics of the Dust Environment in the Vicinity of Military Activities*, U. S. Army MERDC Report No. AR 642 (Ft Belvoir, Va., Jan. 1968).

[15] S. J. Rodgers, *Evaluation of the Dust Cloud Generated by Helicopter Rotor Downwash*, USAAVLABS Technical Report 67-81, U. S. Army Aviation Materiel Laboratories, Ft Eustis, Va., Mar. 1968.

Table IV. Sand and Dust Concentrations Near Hovering Helicopter[a]

Location	Hover Height[b]											
	1 Foot				10 Feet				75 Feet			
	<74 μm	74 to 250 μm	250 to 500 μm	Max. (All Sizes)	<74 μm	74 to 250 μm	250 to 500 μm	Max. (All Sizes)	<74 μm	74 to 250 μm	250 to 500 μm	Max. (All Sizes)
Phillips Drop Zone, YPG, Arizona	2.1 (74)	9.7 (341)	0.6 (22)	27.9 (985)	4.6 (163)	12.9 (457)	0.9 (33)	27.6 (974)	3.4 (120)	1.9 (65)	0.1 (2)	7.8 (275)
Vehicle Dust Course, YPG, Arizona	8.1 (285)	7.4 (263)	0	28.6 (1010)	9.6 (339)	8.5 (300)	0	33.6 (1186)	–	–	–	–
Lee Drop Zone, Fort Benning, Ga.	3.3 (117)	13.8 (487)	1.3 (45)	28.5 (1006)	2.3 (81)	14.1 (497)	1.2 (43)	40.6 (1433)	1.7 (59)	0.9 (33)	0.1 (3)	3.5 (124)

[a]Concentrations are given in mg/ft^3; numbers in parentheses are conversions to mg/m^3.

[b]Hover height refers to wheel clearance.

To obtain the data, 25 samplers were mounted on a framework attached to the helicopter fuselage and on a boom underneath the rotor. For uniformity, all three of the test sites (two separate sites at Yuma) were plowed to a depth of 6 inches and then disked prior to the test runs. This process was repeated after each six tests. One of the significant things shown by the data in Table IV is that, at all three sites and at all three test elevations, substantial proportions of the particles were in the sand-size range (74 to 250 μm) although there was a greater proportion of dust over the Vehicle Dust Course at Yuma Proving Ground. It was also found that operations under such conditions may be expected to take their toll in equipment. Within a 3-month period at Yuma, the helicopter was used 50 times for 4-minute tests. During the period, the rotor blades were replaced three times and the engine was replaced once. In the first few test runs, after a total hovering time of about 20 minutes in the dust, three layers of wood on the leading edges of the rotor blades were worn away. For subsequent tests at Yuma, the leading edges were taped for protection—a procedure that was effective as long as the tape was replaced after 12 to 16 minutes of hovering. Before the tests at Fort Benning, metal rotor blades were installed; and their leading edges were covered with a special polyurethane film for protection. The film provided excellent protection for the leading edges; but, after 25 tests, the unprotected rotor-tip caps were completely eroded through.

Another interesting feature of the test runs was that, on two occasions at the Vehicle Dust Course, visibility was so reduced that the pilot lost all ground reference during attempts to clear the hover area. It was also found that dust concentrations were much higher (by a factor of about 3) when the helicopter landed and took off again after the dust cloud was allowed to clear.

Even though the test runs with helicopters represent extreme conditions since the hovering areas were deliberately prepared to produce as much dust as possible, it may be desirable to insure that material likely to be so exposed be capable of withstanding considerable concentrations of dust and fine sand.

VI. DESIGN AND TEST CONSIDERATIONS

Translation of sand and dust information into reasonable design and test criteria is difficult because many widely different opinions can be supported by the available data. Tables V and VI contain specific recommendations for changing the criteria now specified in MIL-STD 210A, but some explanation of the reasons behind these recommendations and of the manner in which they should be applied may be in order. This discussion is based on the premise that dust is always present in varying amounts and is, therefore, something to be considered in all design problems. This assumption is not strictly

Table V. Current Sand Criteria in MIL-STD 210A and Recommendations for Revision

Current MIL-STD 210A	Recommended Changes	Remarks
2.8.‒.1 Definition. By one definition, sand consists of particles large enough to attain a terminal velocity greater than the eddy currents of the average surface winds, but small enough to be movable by the direct pressure of wind. Predominant diameters of sand grains generally lie between 0.15 and 0.30 millimeters; in no case are predominant diameters less than 0.08 millimeters. Sand concentrations are generally measured in terms of the weight of sand transported in a given time through a given cross-sectional width. Sand is seldom lifted more than five feet above the earth's surface, and the bulk of the movement takes place very close to the ground.	Suggest chan[illegible] ding to "Definition and Characteristics." Sa[illegible] rticulate mineral matter in the size range betw[illegible] 4 and 1,000 μm whose predominant diameters are generally between 150 and 300 μm. Loose sand is subject to movement by wind pressure, and the bulk of the movement takes place very near the ground (within the first 10 cm); sand-size grains subject to natural wind pressures are seldom found higher than about 1½ meters.	Recommendation eliminates statement about sand concentration which is improperly used in the document. If a concentration were appropriate, it would be expressed as weight or volume per unit volume. However, sand is not truly suspended, and much of the movement is in a rolling or bouncing motion at the ground surface so that any concentration statement would be a variable depending on the size of the volume unit.
2.8.2.2 Operation, ground, world-wide. Sand, 0.01 to 1.0 mm. diameter, with predominant diameters between 0.15 and 0.3 mm: wind, 40 mph at a height of five feet: temperature, 100° F (37.8° C). Concentration of sand, 10 lb per foot cross-section distributed in such a manner that only a few grains are present at a five-foot height, and two-thirds of the grains are lower than one inch.	Mineral particles 74 to 1,000 μm in diameter, with predominant diameters between 150 and 300 μm, moving in the direction of wind blowing at 26 to 35 knots (30 to 40 mph). About half the grains will remain within 1 cm of the ground surface, and most of the remainder will move within the first 10 cm. In some circumstances, e.g., in the influence of helicopter rotor downwash, significant amounts of sand-size particles (2.9 mg/cu ft or 102 mg/cu meter) may be found as high as 75 feet above the ground. In the most favorable situation for sand movement, temperatures are likely to be above 70° F and R.H. below 30%. Sand particles are likely to be composed mostly of angular quartz (Hardness, 7 on the Mohs scale), but some sands may include significant amounts of harder minerals such as corundum (Hardness, 9).	Some conditions are added. The concentration at ground level is eliminated because that given in the current version is meaningless without a time factor. Probably the intent was to have the statement indicate that 10 lb could move past the foot-wide cross-section in 1 minute, since Stallings* measured a movement of 490 lb per hour. Nevertheless, this kind of figure seems to have little practical use.

*J. H. Stallings, *Mechanics of Wind Erosion*, SCS-TP-108, U. S. Dept. of Agriculture, Soil Conservation Service, Washington, D. C. (1951).

Table VI. Current Dust Criteria in MIL-STD 210A and Recommendations for Revision

Current MIL-STD 210A	Recommended Changes	Remarks
2.8.3 Blowing Dust 2.8.3.1 Operation, ground, world-wide. Dust, 6×10^{-9} grams/cubic centimeter, 0.0001 to 0.001 mm. diameter; blowing at 40 mph (35 knots) at a height of 5 feet; temperature, 70° F (21.1° C).	Particulate matter, with diameters ranging between 0.1 and 74 μm, suspended in the air. Materiel to be used near helicopters maneuvering over unpaved areas may be subject to dust concentrations of about 60 mg/cu ft (2118 mg/cu meter) blown about by strong but unmeasured air currents, literally, from all directions. Items never used or exposed in proximity to aircraft but which may be found near operating vehicles may be subjected to dust concentrations of 30 mg/cu ft (1059 mg/cu meter) while the wind is blowing at 35 knots (40 mph) at a height of 10 feet. These two categories are likely to include most military items. Items subject only to natural dust conditions may be exposed to concentrations of about 5 mg/cu ft (176.5 mg/cu meter). Accompanying temperatures are likely to be in the range between 70 and 120° F (21.1 to 48.9° C), and relative humidity is likely to be less than 30%, although the conditions can prevail at lower temperatures and higher humidities. Dust particles may be composed of a variety of materials but usually include a high percentage of angular mineral particles of Hardness 7.	The concentrations currently specified were derived from a fairly old source,* which gave particle counts measured during dust storms. Although there is no reason to question the data, it seems more reasonable to specify the higher concentrations commonly found in the vicinity of military operations as indicated in Table II.

*E. G. Brown, *Dust Storms and Their Possible Effect on Health*, U. S. Government Printing Office, Washington, D. C. (1936).

true because there may be equipment designed for use only in dust-free environments, but this is not a general consideration.

From the information presented, one can conceive of three different levels of dust exposure that might apply to nearly all military materiel. One of these levels describes a possible situation in which certain items might be used only in places remote from normal military activities and subject mainly to dust picked up and transported by wind from dry, loose surfaces. A second situation, which may be considered normal, is one in which the mere fact of military presence creates environmental problems ranging from mud to dust depending largely on the moisture content of the surface soil. As has been shown, this is the situation that must be considered realistic for most materiel even though it is considerably more severe than natural dust storms. A third category might best be established for the special conditions associated with aircraft (particularly helicopter) operations. These conditions which generally are the most severe that have been measured, should be used to apply to those items normally used in and around helicopters.

Design specifications nearly always have testing implications, so some thought must be given to testing for dust and sand. The present dust test found in MIL-STD 810B, *Environmental Test Methods*, may be adequate for the normal dust condition. The test specifies concentrations of 300 ± 200 mg/ft^3 (10.6 ± 7.1 grams/m^3), which is somewhat higher than most concentrations measured in the field. Also, the test specifies that a small proportion of the dust particles be in the size range between 74 and 150 μm which is larger than most dust particles measured in the field, but it is not an unrealistic requirement. If such particles cannot remain airborne they will merely drop to the chamber floor and will cause no harm. One possible weakness of the test is the fact that the specified dust is at least 97% quartz; whereas, there is a possibility that significant quantities of other and harder minerals, such as corundum, may be part of the dust in the field. The whole question of dust composition on a world scale, however, is one that has yet to be solved; and little evidence remains on which to base a change that would require specific quantities of other minerals. Another potential weakness, depending on the purpose for which the tests are conducted, is that the test dust may be recirculated repeatedly through the chamber with the distinct possibility that its size distribution and shape will change drastically even after one pass.

For testing against the severe dust condition, it would appear that the techniques used previously for sampling dust in the rotor downwash of helicopters might be the most practical. That is, use a helicopter over a prepared dry surface and keep the conditions as near standard as possible even though they are not completely controlled.

To this point, the subject of design and testing specifically for sand has been ignored but with some reason. For one thing, if penetration into small openings is the problem under consideration, the seals or openings that will exclude moderate-sized dust will also exclude sand. If the question is one of resistance to abrasion, this can be tested in many cases by using small samples of the materials involved. Further, a wind tunnel capable of simulating the natural phenomenon of blowing sand as it impinges on large items would be difficult and expensive to achieve. Weighed against the limited risk that most military equipment will be exposed to a true sandstorm, even though sand surfaces are fairly common throughout the world, the advantages of a simulated sand test applied on a broad scale seem very small. For those items truly likely to be involved in a sand environment, it might be worthwhile to expose them in a testing procedure similar to that suggested for severe dust conditions but over a surface that is composed largely of loose sand.

VII. CONCLUSIONS

Military items intended for world-wide use are likely to encounter sand and dust conditions in widely varying degrees. Although existing literature is inconsistent in its definitions of sand and dust, it is generally accepted that size is the basis for distinguishing between the two kinds of particles. Particles smaller than 74 μm may be considered dust, and particles larger than 74 μm may be referred to as sand. For several reasons, dust is of much greater importance to most materiel than sand, so much so that sand can be almost ignored in the design of most items. Although research on world-wide distributions and characteristics of dust has been very limited, enough information is available to indicate that changes in the specification of dust design criteria may be desirable. Recommendations for such changes are found in Table VI, Current Dust Criteria in MIL-STD 210A and Recommendations for Revision.