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General Mills

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DISSEMINATION OF [illegible]
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cy 1 of 10, Series C

Ft. Detrick Control
No. 60 - FDS /338

Progress Report

[illegible] June - [illegible] September [illegible]

Contract No. [illegible]

Prepared [illegible]

U. S. Army [illegible]
Fort Detrick
Frederick, Maryland

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Report No. 2125
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Date: October [illegible]

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Foreword

Several individuals have participated in directing and conducting the investigations and preparing the discussions presented in this report. Those from General Mills Inc. include Messrs. S. P. Jones, Jr., G. Whitnah, J. Upton, C. Hagberg, P. Stroom, G. Morfitt, I. Hall, J. Pilney and G. Ungs. Those from North American Aviation include Messrs. R. Lyford, M. Roe, T. Gilbert and W. Macpherson.

Abstract

This report covers the major areas of activity during the first three months of a program of research on dissemination of solid and liquid BW agents. The objective toward which the research is directed is the development of weapon systems for the dissemination of these agents as a line source from high speed low-flying aircraft.

The problems of feeding and handling of finely divided solid agents ~~are discussed~~ along with applications of feeding devices such as screw feeders, piston feeders and pneumatic feeders.

Progress in preparing for wind tunnel experiments on dissemination and deagglomeration ~~is described and the considerations~~ in the design of a special test section for these experiments, ~~are discussed. A description of~~ an isokinetic sampling probe ~~for use in the deagglomeration experiments. is included.~~

Progress on a study of the characteristics of finely divided materials is presented. This work includes literature search, theoretical analyses and experiments.

A design study ~~which has been~~ initiated on an external aircraft store for liquid agent dissemination, ~~is discussed,~~ preliminary findings of an operational analysis to determine optimum design flow rates for several agents are presented and a summary given of studies relating to specific aircraft store design problems.

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TABLE OF CONTENTS

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LIST OF ILLUSTRATIONS

LIST OF ILLUSTRATIONS (Continued)

I. INTRODUCTION

This First Quarterly Report presents progress on Contract No. DA-18-064-CML-2745 which covers a seven-month initial phase of a program of research on the dissemination of solid and liquid BW agents. General Mills Inc. is the prime contractor for the program and North American Aviation Inc. is participating as a subcontractor, in the field of liquid agent dissemination.

The ultimate objective toward which this research is directed is to provide weapon systems for dissemination of both solid and liquid BW agents as a line source from high speed low-flying manned and unmanned aircraft. These weapon systems will employ external disseminating stores, designed to be compatible with a variety of aircraft types, having speed capabilities above 0.70 Mach Number at low altitude.

Prior to the current program, the field of solid agent dissemination had received less technical effort than that of liquid agent dissemination and was therefore in a considerably less advanced state. For this reason, the types of investigations which are currently being conducted in the two fields are somewhat different.

Relative to solid agent dissemination, the major problem areas currently being studied are feeding and handling of the agent, characterization of finely divided solid materials, and deagglomeration into the required particle size range. The structural and aerodynamic problems associated with the application of external stores are also involved in all areas of the study.

In the field of liquid agent dissemination, a design study has been initiated to provide criteria for design of a research prototype disseminator store. This study includes an operational analysis to develop flow rate requirements, as well as work on more detailed problems of external store design.

Discussions of the studies performed during this first quarter are presented in the following sections of the report.

II. FEEDING AND HANDLING OF FINELY DIVIDED DRY MATERIALS

The function of the feeding system in the aircraft external store under consideration is to deliver the dry agent material from the storage section of the unit to the deagglomerating section at a uniform and adequate flow rate. The flow rates currently under consideration range up to 30 pounds per minute. It must perform this function safely, reliably and without excessive power consumption. The feeding system must deliver the agent in a condition which is compatible with the characteristics of the deagglomerating section. In the handling of the agent in the feeding system, losses in viability must be minimized.

It is also desirable that the feeding system be as nearly universal as possible with regard to the range of agent properties which are acceptable in its operation. This is brought about by the fact that several factors will influence the final selection of an agent for a given mission.

A. Geometrical Considerations

Because of the several limitations on the configuration of external stores of this type brought about by aerodynamic considerations as well as the aircraft dimensions, the shape of the storage volume from which the feeding system will draw the agent is quite well established. This storage volume can be assumed to be a horizontal, elongated volume, which could be a circular cylinder or an axially symmetric body of revolution with variable radius. The two general possibilities are sketched in Figures 1 and 2. These shapes each offer certain advantages and disadvantages, so that a clear cut choice is not indicated without consideration of all aspects of

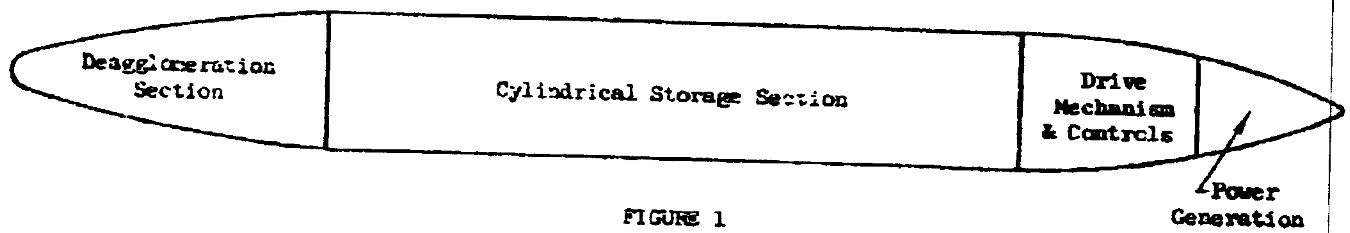


FIGURE 1

SKETCH ILLUSTRATING CYLINDRICAL STORAGE VOLUME

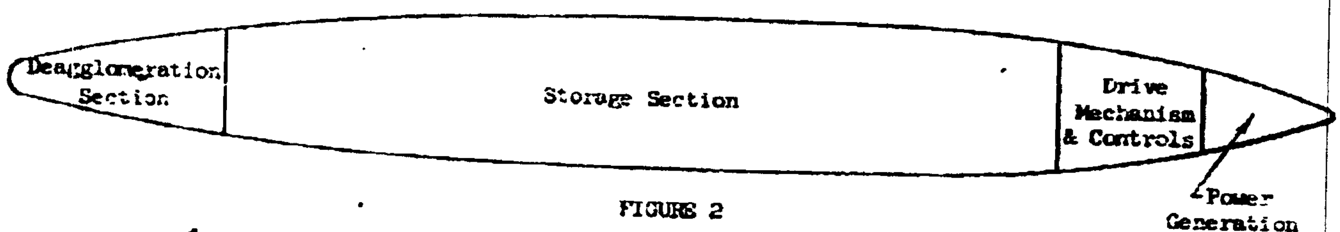


FIGURE 2

SKETCH ILLUSTRATING STORAGE SECTION WHICH IS AN AXIALLY SYMMETRICAL BODY OF REVOLUTION WITH VARIABLE RADIUS.

the storage and feeding problems. The cylindrical shape offers the advantages of simplified manufacture and compatibility with feeding systems which require constant diameter, such as pistons or rotating helical configurations. The storage volume shape of Figure 2 could provide somewhat greater storage volume for equal drag (or reduced drag for equal volume) but has the disadvantages of more complicated manufacturing and more restrictions on the characteristics of the feeding system.

The storage sections of a possible family of dry agent disseminating stores which is currently envisioned will be capable of containing large payloads. Although the effect of the aspect ratio, ℓ/d, and agent bulk density on the required dimensions are obvious, Figure 3 is presented to conveniently summarize the range of dimensions which is anticipated. It will be seen that many of the cases of interest require storage section diameters between 1.5 and 2.0 feet.

The geometrical considerations discussed above focus attention on the fact that the successful feeding system will be required to translate large masses of material over horizontal distances of several feet. In several of the potential solutions considered, the feeding mechanisms will have dimensions comparable to those shown in Figure 3. Careful consideration must therefore be given to such problems as structural weight, potential fabrication problems, rigidity, dimensional control and reliability.

B. Power and Energy Considerations

The results of preliminary studies of the power and energy requirements for several feeding concepts, including pneumatic, mechanical screw feeding systems and piston arrangements, indicate that many of the potential solutions will have reasonable power requirements when considered in light of the power available from ram-air turbine generators.

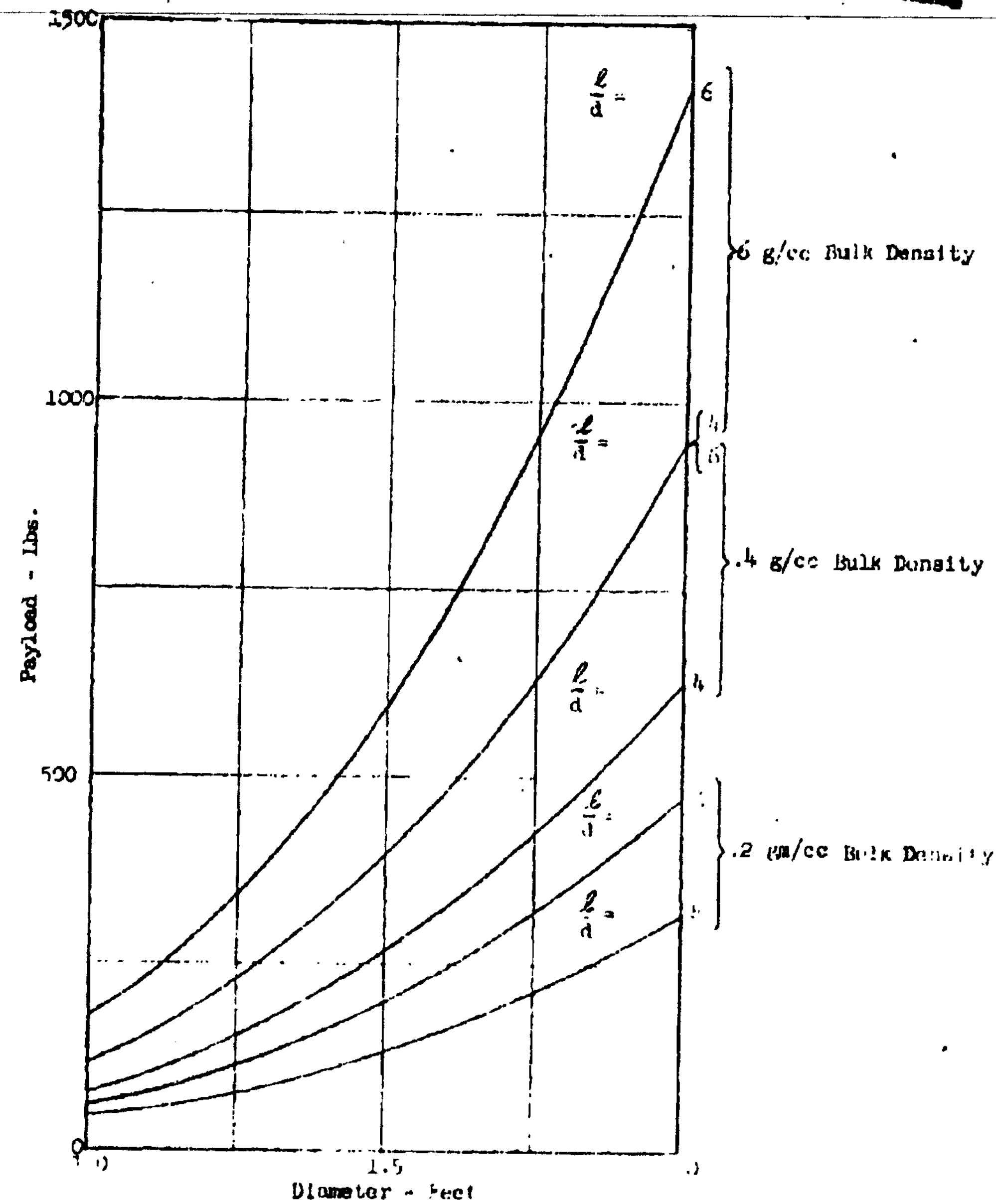


FIGURE 3

EFFECT OF AGENT PAYLOAD, BULK DENSITY AND ASPECT RATIO (ℓ/d) ON STORAGE SECTION DIAMETER

As an example, consider the case of a piston which translates a compacted slug of material horizontally. The basic power requirement is simply:

$$\text{Power} = P \times A \times U \qquad (1)$$

Where P is the pressure required to translate the piston,

A is the piston area and

U is the velocity of translation

Using a typical dimension from Figure 3, with a piston diameter of 1.5 feet and a velocity of 0.7 feet per minute, Equation (1) indicates the expenditure of 1.0 KW of power would (neglecting losses) produce a pressure of approximately 250 psi. This pressure is believed to be much higher than would be applicable in a system of this type, indicating that the power consumption of this type of feeding system will be below one kilowatt. Calculations relative to screw feeders and pneumatic systems yield even lower power levels.

Ram air turbines are capable of providing several kilowatts of power, and are therefore considered to be an adequate source of power. Typical performance characteristics are given in Figure 4. It should be pointed out that significant losses in the energy conversion systems are anticipated, but these are not expected to create any excessive requirement for power.

A much more important consideration is the structural mass associated with the mechanisms for energy conversion and final delivery to the feeding system. Several of the feeding concepts (including screw feeders, pistons, stirring devices) involve mechanisms having relatively low translational or rotational velocities. If these mechanisms are to deliver power at significant levels, high forces and/or high torques will be involved. These components will have considerable mass and must be considered in detail in evaluation of any potential feeding system.

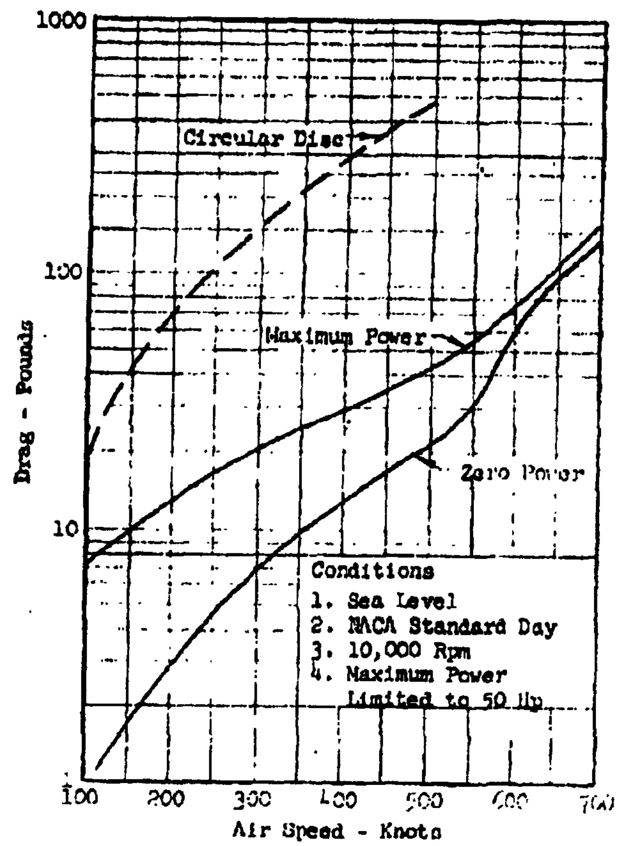


FIGURE 4. TWO-BLADED NINE-INCH RAM AIR TURBINE ESTIMATED DRAG CHARACTERISTICS (BLADES AND HUB ONLY)

Source:

AiResearch Manufacturing Division, The Garrett Corporation
Los Angeles 45, California

C. Feeding System Concepts

Since the beginning of this study, several potential feeding systems have been examined in light of the requirements and geometrical limitations discussed above. Several of these are discussed briefly below:

1. Screw Feeding Systems

Screw feeding systems of several configurations are under study. Preliminary calculations show that these devices are compatible with the mass flow rates required. A desirable feature of these systems is the variable feed rate which can be achieved by variation of the rotational speed.

Potentially significant problems exist which are broadly, (1) obtaining proper flow of a material to the screw from the storage section and (2) providing proper design to eliminate rotation of the material in the screw as a solid slug, with unsatisfactory delivery resulting.

One configuration which is of considerable interest is sketched in Figure 5, which shows a large screw feeding system which occupies the entire agent storage container. Preliminary calculations of the structural requirements indicate that a mechanism of this type is feasible. In the case of a cylindrical agent storage volume the screw could be of constant diameter. If this principle was used in a storage volume of the type illustrated in Figure 2, a variable diameter, variable pitch assembly would be required.

The attractive characteristic of the large screw feeder is that all of the agent is initially stored in the screw, eliminating the problem of obtaining flow to the screw. The structural problems are significant, due to the large dimensions, and the problem of flexibility of the outer and inner structures must be carefully considered.

Screw feeders are generally operated with the solid material occupying only part of the cross-sectional area. In industrial practice, light free-flowing materials conventionally may occupy up to 45%[1] of the cross-sectional area. This restriction, if imposed on the external store would be quite serious. However, the rotational speed is a significant variable in this consideration. The low rotational speeds which would apply to the design in question are believed to be favorable to operation with larger quantities of material.

The possibility that the feed rate would not be uniform as the quantity of contained material decreases could probably be handled by programming the speed of rotation during the dissemination period.

The discussion to this point has assumed a solid screw configuration. A possible alternate solution is found in the "ribbon" feeder, in which the feeding screen is open at the center. It appears that this device would also be compatible with the concept illustrated in Figure 5. Possible advantages are reduced structural weight and complexity and reduction of the problem of residual material adhering to the surfaces of the screw. The ribbon design is less positive in its action and the material could easily move horizontally through the storage section during operation. It is believed that a system of this type should be arranged for variation of the rotational speed to provide the desired feed rate.

The application of smaller screw feeding systems is also being considered. A sketch of one such concept is shown in Figure 6. In this particular

1. Hudson, W.G., Conveyors and related equipment, Third Edition, John Wiley and Son, New York, 1954 (a) p. 14, (b) p. 190.

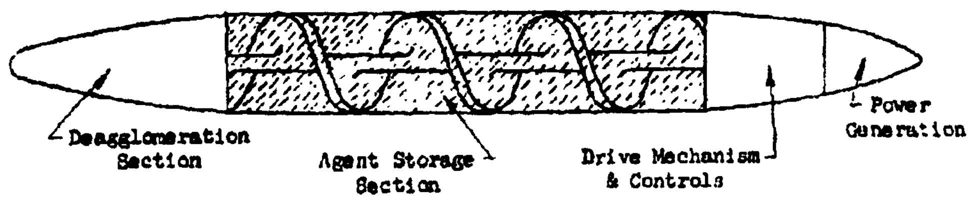


FIGURE 5

SKETCH ILLUSTRATING APPLICATION OF LARGE SCREW FEEDER

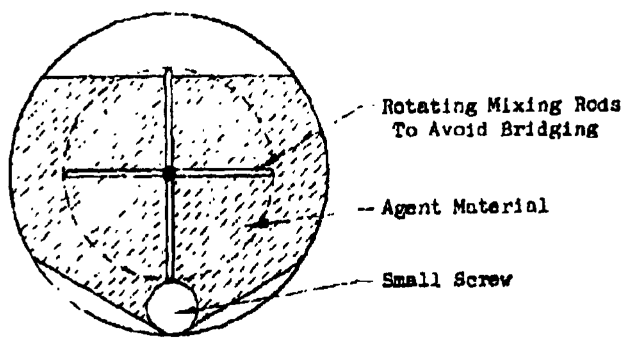


FIGURE 6

CROSS SECTIONAL VIEW OF APPLICATION OF SMALL SCREW FEEDER approach the material is delivered to the deagglomerating section by a small screw which receives material from the storage section by gravity flow. A system of rotating rods is utilized to preclude bridging of the material. Inclined planes are provided near the screw to reduce the residual material. The minimum angle with the horizontal is a function of the agent characteristics, but provision for an adequately steep angle does not appear difficult. If flow of the material along this slide presents a significant problem, the "Airslide" concept (Reference 1b) might be applied. In this system the slides are porous and air or gas flows through the surface from below. This permits the use of lower angles of inclination. The total power requirements for operating an airslide, the stirring rods and the screw feeder are expected to be well below one kilowatt. These and other concepts for application of screw feeding systems will receive continued study in the future.

2. <u>Piston Feeding Systems</u>

Piston feeding systems have been successfully used by Fort Detrick Personnel in the dry fill, HVAR Rocket Fixture. In this device, the piston exerts a pressure directly on the fill material which is also in contact with the cylinder walls, and translates it to a high speed rotary deagglomeration device.

A possible problem in utilizing this principle in very large aircraft stores containing 500 to 1500 pounds of agent is that the pressures against the piston and cylinder may exceed desirable levels due to high forces developing against the walls. Here again, the structural aspects are believed to be a much more significant consideration than the power requirement as such. It was pointed out earlier that expenditure of 1 kilowatt of power, with a piston of 1.5 ft diameter, moving at 0.7 feet per minute could produce a pressure of 250 psi.

Zenz and Othmer[2] refer to the existence of a maximum length-to-diameter ratio for a slug of material in a piston. This ratio is related to the internal angle of friction, α, as follows:

$$\tan \alpha = \ell / d$$

Some experimental evidence is reported[2] *which indicates that, at higher* values of ℓ/d the slug of material will lock, so that the plug cannot be moved, even with very high pressures on the piston.

Sufficient information on the angle of internal friction of potential agent materials is not available to permit determination of the effect of this locking tendency on feeding system design. It is also likely that the friction coefficient of the wall is an important variable. The use of low friction materials on the cylinder wall could bring about an important improvement.

Considerations of the type outlined above suggest that a piston feeding system might be enhanced by encasing the agent material in a thin shell which, when supported by the cylinder could improve the structural integrity of the slug and greatly reduce the piston pressure required. A Teflon coating on the surfaces would provide a low friction coefficient. Bowden[3] reports a friction coefficient of 0.04 for Teflon sliding on Teflon and a value of 0.10 for steel sliding on Teflon. The required piston forces would be extremely small under these conditions.

2. Zenz, F.A. and D. F. Othmer, Fluidization and fluid-particle systems, Reinhold, New York, 1960, p. 77.

3. Bowden, F.P. and D. Tabor, The friction and lubrication of solids, Oxford, 1954, p. 165.

There are, of course, many problems associated with this concept; one of the most difficult appears to be the "stripping off" of this outer shell as the slug of material is advanced toward the deagglomerator.

We are currently studying various possibilities for accomplishing this removal of the casing, with particular regard to the potential reliability.

The piston-type feeder is very well suited to handling compacted material. In fact, in its simplest form, without an external casing, a certain degree of compaction may be required so that the entire slug is advanced as the piston moves. A material of low bulk density will be compressed during the initial travel, so that the feed rate would be far from linear.

The benefits in reduction of the dimensions of the store due to compaction are illustrated by Figure 3.

3. Pneumatic Feeding Systems

Several applications of pneumatic systems are discussed by Weller[4]. A rather complete coverage is also given by Zenz and Othmer[5]. Reference 5 also presents an extensive bibliography on pneumatic conveying systems.

It is important to make a clear distinction between the problem of utilizing pneumatic energy to feed solid materials out of a bulk storage area into a conveying duct and the separate problem of transporting the two-phase mixture through the duct. A large part of the literature deals with the second problem which is considered to be minor in our application compared with the first problem of obtaining a controllable flow out of a bulk storage volume. In many of the conventional conveying systems the actual feeding is

4. Weller, L.G., Automation, Vol. 5, No. 7, Jan. 1958, p. 69.

5. Zenz, F.A. and D. F. Othmer, Fluidization and fluid particle systems, Reinhold, New York, 1960, pp. 313-350.

done by non-pneumatic methods, such as screw feeders or gravity feeders. We wish to consider here the use of pneumatic means in feeding.

a. Feeding Concepts. - The two general classes of systems that are apparent are (1) those in which the solids are thoroughly mixed with air stream so that any mass of air leaving the system will carry with it a given mass of solids and (2) those in which the airstream is so confined as to create sufficiently high surface velocities across a free powder surface (otherwise unmixed with air) to entrain a significant concentration of solids. These two classes are illustrated in Figure 7 and Figure 8.

The general principle illustrated in Figure 7 was applied by General Mills, Inc. in particle disseminating external stores.[6] In this case the source of pressurized air was ram air at a pressure differential of approximately one-half atmosphere above the ambient static pressure. In applying this principle to the currently considered dissemination problem, the significant problems appear to be (1) the device would be limited to handling non-compacted materials and (2) the use of ram air as a working fluid might be undesirable under high atmospheric humidity conditions. Further consideration of the selection of a motive gas will be presented in a following section.

The general principle illustrated in Figure 8 does not involve prolonged contact of the agent with the air and therefore is considered to be somewhat less likely to bring about deleterious effects due to the temperature or humidity, if ram air is used. This concept has a potentially strong

6. General Mills Report No. 1720 (Secret) 15 June, 1957.

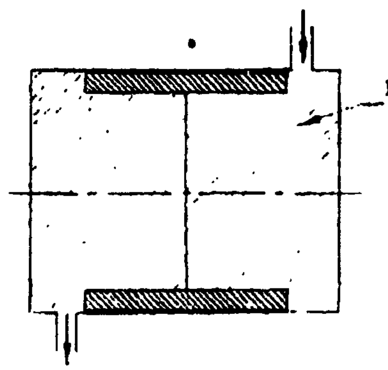


FIGURE 7. PNEUMATIC FEEDING SYSTEM IN WHICH THE SOLIDS ARE UNIFORMLY MIXED WITH GAS.

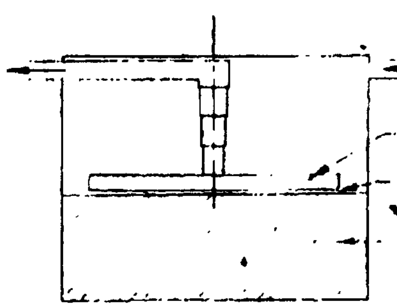


FIGURE 8. PNEUMATIC FEEDING SYSTEM IN WHICH THE SOLIDS ARE ENTRAINED FROM A FREE SURFACE BY A HIGH VELOCITY GAS STREAM.

disadvantage in that proper placement of the moveable entrainment device may be difficult as the level of agent decreases. Conceivably, multiple entrainment heads could be used to improve this situation.

b. Selection of the Motive Gas. - As previously stated ram air has been used as a motive gas in particle disseminating stores. Its availability and low drag penalty associated with its use are very attractive features. However, in systems where the ram air is thoroughly mixed with the viable agents, it may produce some deleterious effects. The moisture contained in the inlet air under high humidity conditions, may in time increase the moisture content in the agent material. The fact that the air is heated by the stagnation process, produces elevated temperatures which may cause loss of viability. Figure 9 shows the stagnation temperature versus atmospheric temperature and flight Mach Number. It can be seen that air temperatures in the region of 70°C may be encountered under normal conditions. It should be pointed out, however, that the mass flow rate of air is very low, about 1% of the solid mass flow rate, and that the total energy represented in the heated airstream is not great.

Consideration has been given to the drying of the incoming ram air stream by solid adsorbents. Although this measure could potentially remove the problem of incoming moisture, there is an additional temperature rise incurred. This is due to the latent heat of vaporization of the water vapor and the heat of wetting of the adsorbent. Depending on the atmospheric humidity and flight speed, this effect will account for an additional temperature rise of approximately 10 to 30°C, which would aggravate the heating problem previously mentioned.

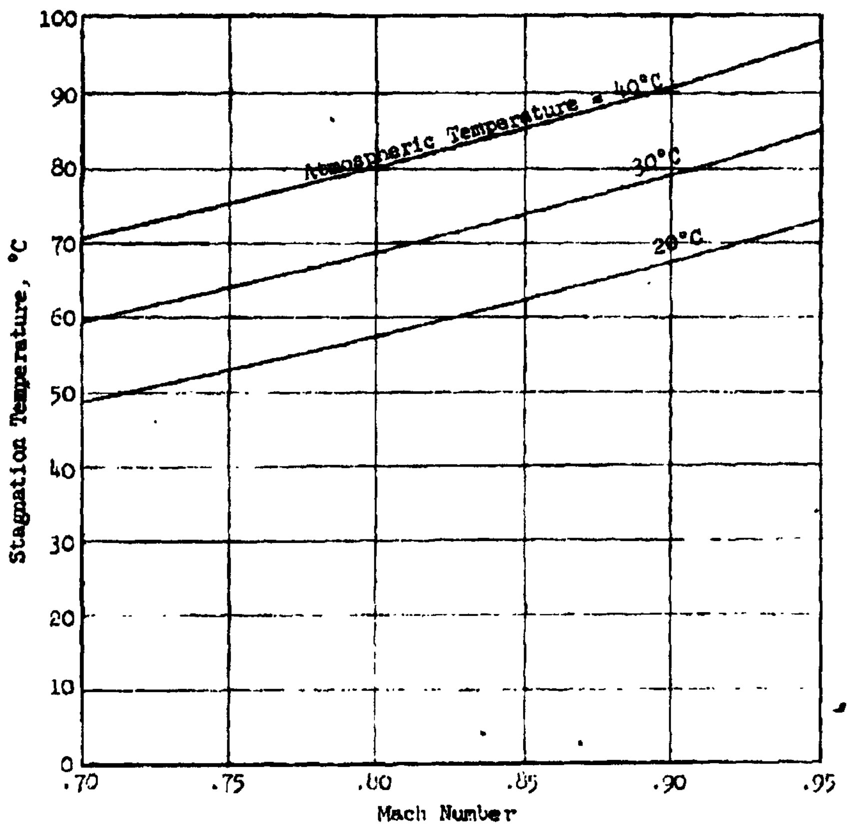


FIGURE 9

STAGNATION TEMPERATURE VS FLIGHT MACH NUMBER

The above considerations pertaining to ram air suggest that it may be better to use a stored gas for a motive fluid. It has been demonstrated that a gaseous mass flow rate of approximately 1% of the solids flow rate is adequate in some cases.

The storage of this quantity of gas in the compressed form would require a pressure vessel which would weigh from 6 to 10 percent of the agent payload. Storage of the gas in a liquified form would result in a considerably lower mass penalty. For example a carbon dioxide cylinder for liquid phase storage would weigh approximately 3% of the agent payload. These penalties do not appear to be severe enough to eliminate this approach from consideration.

Work is being continued on evaluation of the potential of pneumatic feeding systems.

III. PREPARATION FOR DISSEMINATION AND DEAGGLOMERATION EXPERIMENTS

Experiments on dissemination and deagglomeration of finely divided materials will be conducted as part of the current project. During this period, detailed consideration has been given to the special requirements for performing this type of experiment in a wind tunnel at Mach numbers of 0.60 to 0.95, the approach for the initial experiments has been selected and several items of special apparatus have been designed and fabricated.

A. Discussion of Problem and Description of Approach

The successful operation of a BW dissemination system of the type under consideration requires that the finely divided agent materials be delivered into the atmosphere at the correct rate, deagglomerated with reasonable efficiency to an effective particle size range, transported in the atmosphere to the target area and arrive with a satisfactory concentration of viable organisms in particles in the correct size range, generally considered to be below 5 microns in diameter.

In the series of events which take place before and after the material leaves the disseminator, there are several potential hazards which may reduce the final effectiveness and therefore are important considerations. A few examples are (1) possible loss of viability during deagglomeration, (2) loss of viability during the atmospheric transport phase, due to ultraviolet radiation or humidity conditions and (3) re-agglomeration during the atmospheric transport phase. Final demonstration of the performance of such a system will therefore require full-scale field operations, under a variety of meteorological conditions.

However, it is also important that regardless of the magnitude of effects of this type, the original deagglomeration of the particles must produce an aerosol with an acceptable particle size distribution. For this reason, it is considered vital to separate the variables by conducting experiments involving determination of physical particle size distributions in addition to the biological evaluation techniques.

The initial experiments to evaluate dissemination and deagglomeration concepts will involve physical particle size determination. This will be done by utilizing a high velocity isokinetic sampling probe in the test section of the aerosol wind tunnel. This probe, which is discussed in detail in a later section of the report, receives the aerosol at the test section velocity and gradually decelerates a small portion of the flow to a low velocity which is acceptable for membrane filter techniques or impactor collection techniques. Although the physical method will be used in the initial evaluation experiments, the approach is also adaptable to biological techniques by substitution of a suitable particle sampler in the low velocity section of the diffuser.

The blow-down wind tunnel and the high velocity sampling system to be used in these experiments are briefly discussed in the two sections which follow.

B. Blow-Down Wind Tunnel

The wind tunnel system to be used in these experiments is sketched in Figure 10. Air flows from the storage receivers to the test section through a storage type heat exchanger, high efficiency filter, manual control valve

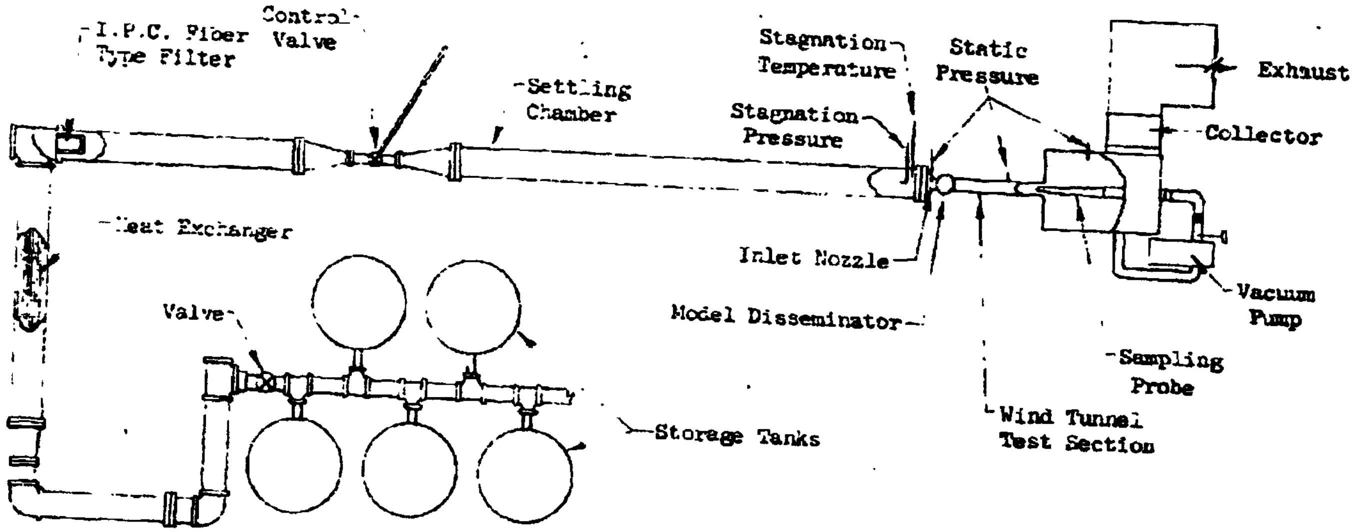


FIGURE 10

BLOW-DOWN WIND TUNNEL SYSTEM

and stilling chamber. Air is supplied to the storage receivers by two-stage non-lubricated reciprocating compressors. The heat exchanger permits control of the stagnation temperature and static temperature in the test section. Due to its high effectiveness, the temperature is held to within 3% of its initial value over the duration of the blow-down run. The internal temperature of the heat exchanger is controllable so that experiments at various test section static temperatures may be made.

The minimum test section dimensions are 2.800 x 2.800 inches. The tunnel is designed to operate in the Mach number range of 0.60 to 0.95 at a pressure of 1.15 atmospheres. Under the maximum flow conditions the system is capable of a 20-second flow duration. The model disseminators will discharge into the air stream at a location 6 inches from the inlet to the test section. The inlet of the aerosol sampling probe will be placed near the downstream end of the test section which is 31 inches long.

1. Test Section Design and Flow Conditions

During the injection of large agglomerated powder particles into the wind tunnel, a drag force causes their acceleration and break-up into small particles. Since drag is a strong function of the stream velocity, it is apparent that this parameter will be one of the more important ones in the studies. A special emphasis has been placed on its control.

Preliminary calculations of the Mach number variation in the tunnel indicated that it is necessary to make the walls diverge slightly to provide Mach numbers above 0.70 at the injection location. The resulting design allows for a constant Mach number along the full length of tunnel.

The amount of divergence was determined by calculating the boundary layer displacement thickness and showed that a total divergence of 0.2° was necessary. Thus the inlet and exit dimensions are respectively, 2.800 in. x 2.800 in. and 2.908 in. x 2.908 in.

A manually operated, eccentric plug-type control valve is used to maintain a constant stagnation pressure in the stilling chamber. Experience has shown that the pressure can be held to within one percent of the required stagnation value of approximately 30 psi, even though the storage tank pressure varies continuously during the run from 200 psi to 60 psi. To further improve the control, an adjustable sonic nozzle was designed into the exit section, which acts as a flow regulator. The Mach number remains constant in this application. An adjustment of the sonic nozzle permits operation at different velocities.

At the tunnel inlet section, smooth uniform flow is desirable. To assure that it is obtained, the NACA standard requirements for nozzle flow metering were applied by using the 12 ft. long settling chamber and the standard nozzle profile shown in Figure 11. An inlet nozzle having this profile has been fabricated from polyester resin with glass fiber reinforcement. By applying this material over a polished mold, a very smooth surface was obtained. This technique was used because of previous favorable experience in a similar application. It is considerably less expensive than machining the nozzle, since the process eliminates the need for machining internal surfaces.

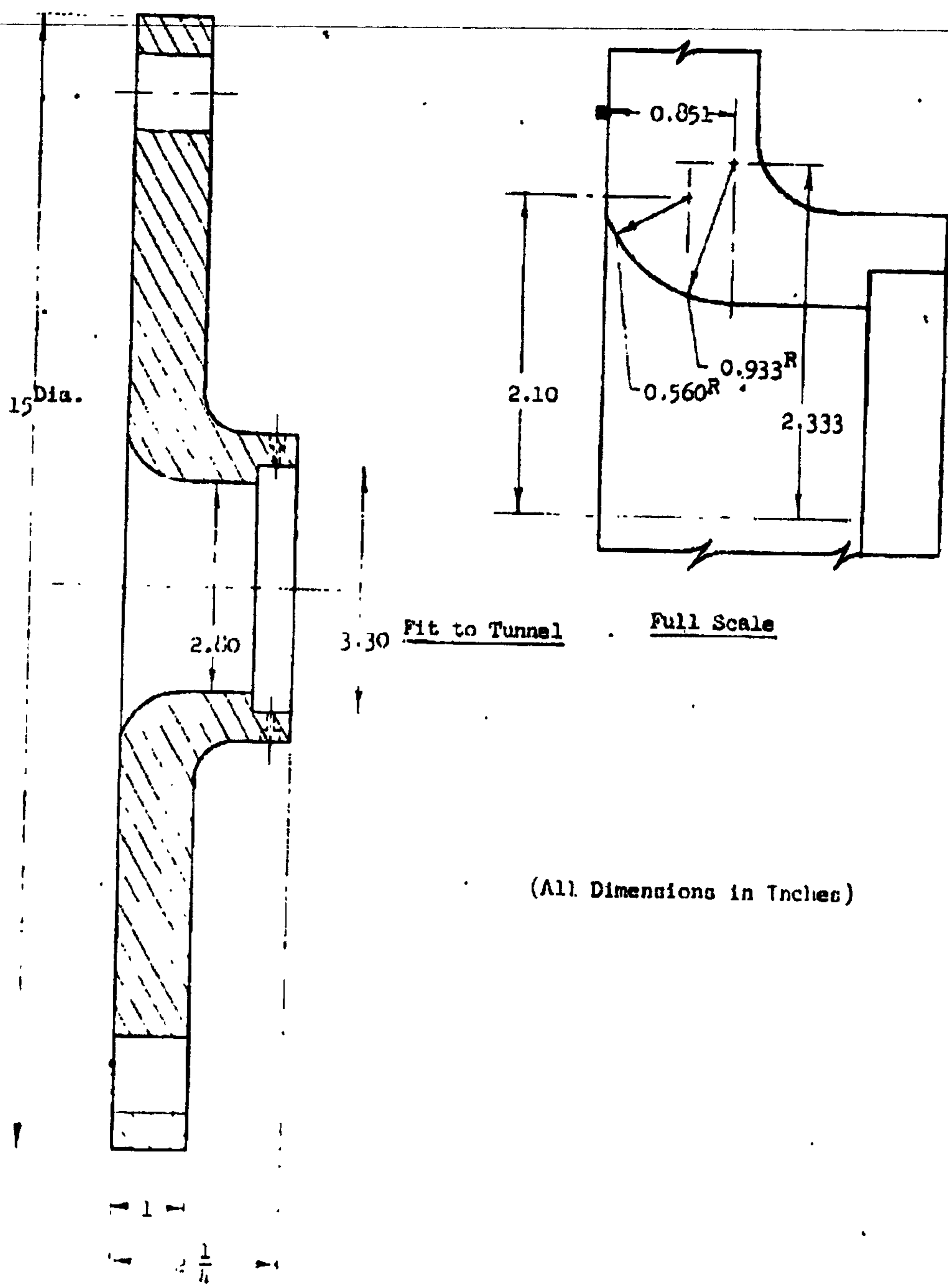


FIGURE 11. INLET NOZZLE PROFILE

2. Instrumentation

It will be necessary to obtain such flow information as tunnel Mach number, velocity, mass flow rate, and Reynolds number. This will be done by measuring the stagnation pressure and temperature in the stilling chamber, just upstream of the tunnel inlet, and the static pressure at the inlet. The following isentropic flow relations will be used to calculate the tunnel temperature and determine such air properties as density and viscosity:

$$\frac{p_o}{p} = \left(1 + \frac{\gamma - 1}{2} M^2\right)^{\frac{\gamma}{\gamma - 1}}$$

$$\frac{T_o}{T} = 1 + \frac{\gamma - 1}{2} M^2$$

The velocity, mass flow rate, and Reynolds number will then be calculated from the following equations:

$$V = M \sqrt{\gamma R T}$$

$$\dot{m} = \rho V A$$

$$R_{ed} = \rho \frac{Vd}{\mu}$$

where
- p_o - stagnation pressure
- p - static pressure
- M - Mach number
- T_o - stagnation temperature
- T - static temperature
- γ - ratio of specific heats
- V - velocity
- R - gas constant

m - mass flow rates

A - cross-sectional area

ρ - density

R_{ed} - Reynolds number

d - hydraulic diameter of tunnel

μ - viscosity

C. High Velocity Sampling System

In connection with the wind tunnel study of dissemination concepts, it will be vital to determine the particle size distribution in the aerosol which is generated. Since suitable techniques for sampling at high subsonic Mach numbers have not been previously developed, a new sampling probe has been designed.*

In order to make this high velocity sampling system compatible with the use of membrane filters as well as impactors and impingers, a diffuser sampling probe has been designed which handles only a small part of the total mass flow rate in the tunnel. The velocity is reduced to approximately one percent of the inlet velocity before leaving the diffuser. In designing the probe, three factors were considered to be very important: (1) provision for isokinetic inlet conditions, (2) avoidance of flow separation and (3) limitation of the particle deceleration rates.

Figure 12 is a sectional view of the probe. The internal surface is parallel to the tunnel axis at the inlet. The maximum angle of divergence is 10 degrees, which is considered as the upper limit for efficient diffusion. During isokinetic sampling, the mass flow rate through the probe will be 0.79 percent of that in the tunnel.

* The experience gained by General Mills in developing an isokinetic aircraft sampling system under Contract No. AF 19(604)-7226 has been applied to this design.

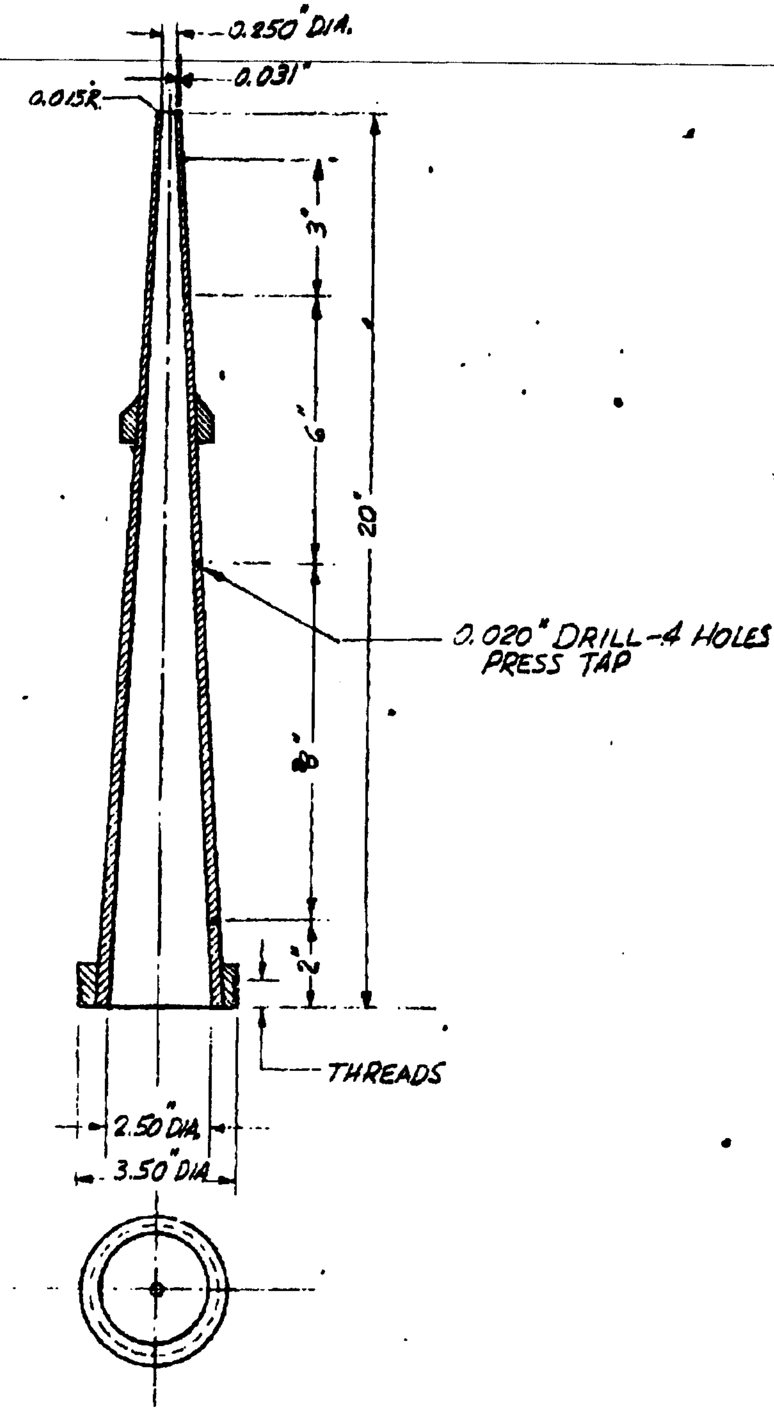


FIGURE 12. SECTIONAL VIEW OF SAMPLING PROBE

Because of the small inlet diameter and continuously curving internal surface through most of the diffuser, a fabrication technique was selected which involved molding the probe from polyester resin, reinforced with fiberglass. This method, which has been used successfully at General Mills in a similar application, employs a metal mold which has been machined to the correct contour and polished to give the desired smooth inner surface finish on the probe. Figure 13 shows the probe made by this technique. This probe may be silver plated by the chemical deposition method, if future experiments show that a conductive surface is required to preclude particle collection due to electrostatic charges on the plastic surface.

To obtain close control over the inlet conditions, a vane-type vacuum pump will be used downstream for the diffuser. The flow and pressure characteristics of this pump will be determined before it is used in these experiments. A pre-determined mass flow can be obtained by controlling the inlet pressure with a throttling valve just upstream from the pump. It is believed that the isokinetic inlet requirement can be fulfilled by this method.

It is felt that flow separation from the diffuser wall should be avoided, since it might cause a non-uniform particle distribution at the actual sampling location. The most critical region is believed to be in the section of the diffuser where the Mach number is above 0.50. Therefore, to avoid separation, the angle of divergence in this area was made small; approximately 2 degrees. Since the performance of the probe with regard to flow separation is considered important, a thorough study of the flow conditions throughout the probe will be made in a 22 x 22 inch high subsonic

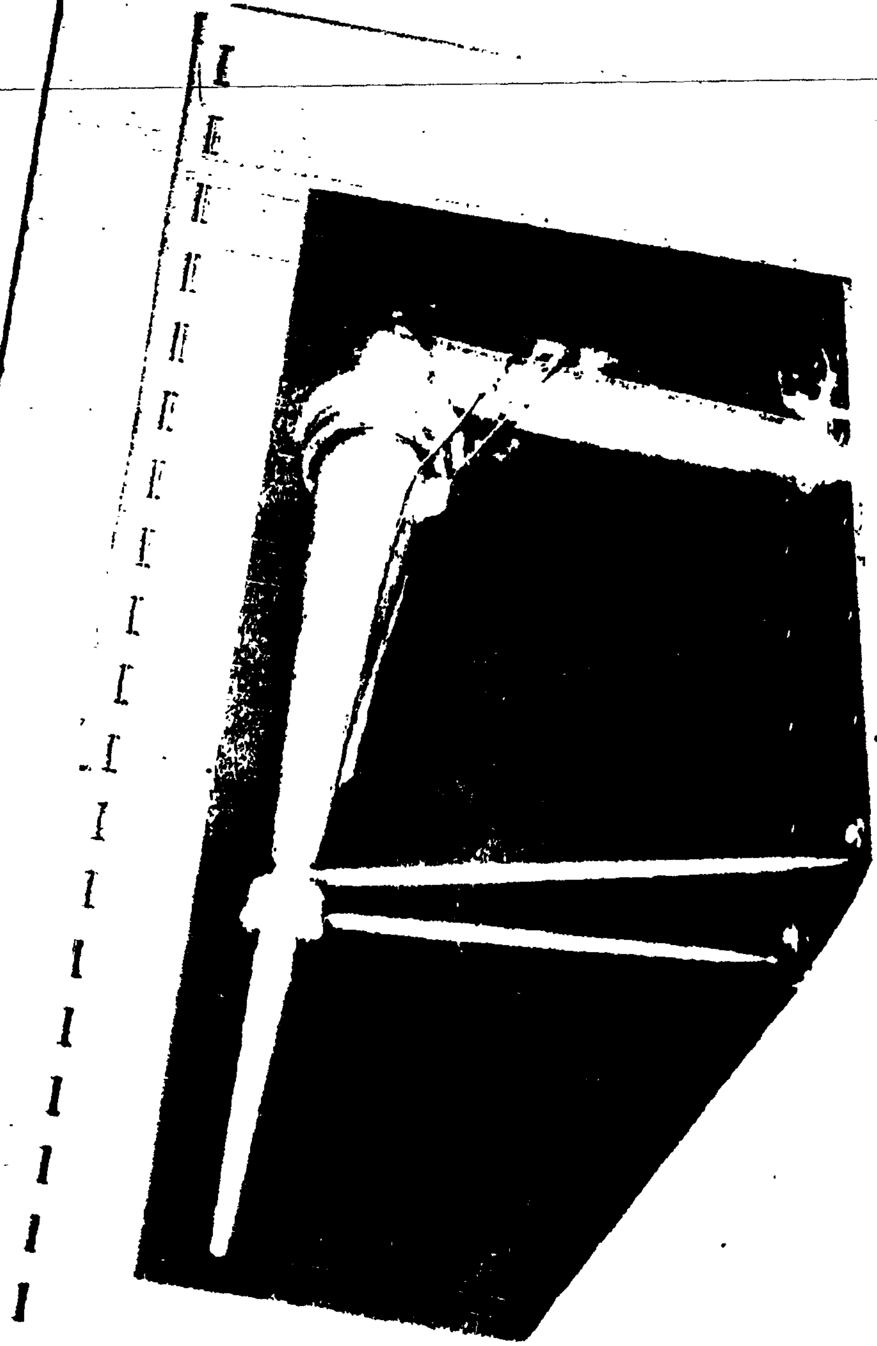


FIGURE 13. SAMPLING PROBE

wind tunnel, provided to General Mills by Fluidyne Engineering Corporation. In preparation for this wind tunnel work, four pressure taps have been installed in the diffuser wall, as shown in Figure 13. By determining the pressure recovery for various inlet velocities and mass flow rates, flow separation can be detected.

To assure that a representative particle sample is obtained which indicates the condition of the particles in the tunnel stream, the deceleration in the diffuser was made small in comparison with the acceleration on the particles during injection into the tunnel. An estimate of the drag force on the particles showed that during deceleration it is less than 5% of that during acceleration. This is considered small enough to meet the objective.

The first collection device to be used will be the Millipore filter. This method will provide such useful information as particle distribution over the cross-sectional area of the probe. Since the counting process involved in this method is tedious, it is expected that a cascade impactor technique, which will give the necessary results faster, will be utilized in later experiments.

IV. INVESTIGATIONS OF THE CHARACTERISTICS OF FINELY DIVIDED MATERIALS

As a part of this program of dissemination research, the characteristics of finely divided materials are being investigated. The future design and successful application of line source disseminators for dry agent materials will require a more complete understanding of the properties of these materials.

Our work in this area has included a search of the literature, preliminary independent theoretical analysis and laboratory experiments. Each of these phases is discussed below.

A. Literature Search

The problem of developing a general theory covering the behavior of particulate material is an extremely complex one which has been approached by many investigators. An extensive literature search was conducted by Orr and Dallavalle[7] covering the factors influencing the agglomeration and deagglomeration of solid particles. This search has served as very useful background for the present work.

Two major subjects which are widely discussed in the literature are (1) forces between particles and (2) flow characteristics of powders. A brief review of each of these subjects follows.

1. Forces Between Particles.

The forces between molecules contribute strongly to the characteristics of powders. These forces operate over longer ranges than chemical attractions which link atoms into compounds, and are capable of drawing

7. Orr, C. and J. M. Dallavalle, Studies and investigations of agglomeration and deagglomeration of solid particles, Semifinal Report, Project No. A-233, Georgia Institute of Technology, June 30, 1956.

particles into an agglomeration. Intermolecular forces are responsible for surface tension, adsorption, capillary action and other surface phenomena which contribute to the characteristics of powders.

Newton's law of universal gravitation contains the terms G/R^2; where G is the constant of proportionality and R the particle separation distance. However, Pierre Simon de Laplace and Alexis Claude Clairaut, mathematicians of the 18th century, found that intermolecular forces fell off more sharply than the square of the distance and that the constant of proportionality could be different for different molecules. Estimates of intermolecular forces have now taken the form C/R^n, where both C and n are constant.

Many investigators of the forces between particles found Van der Waals' forces and electrostatic forces to be the most important. Van der Waals' forces are always present between particles brought together; electrostatic forces exist only when charged particles are close together.

Van der Waals' forces even exist between neutral particles and are not due to coulomb forces or permanent electrical dipoles. Lennard-Jones derived from wave mechanics the relationship:[8]

$$F = \lambda R^{-7}$$

where F = Van der Waals' force

λ = Van der Waals' constant for attraction

R = intermolecular distance.

Many believe that molecular forces are not influenced by interactions with neighbors, and therefore the total force exerted on a molecule is

8. Lennard-Jones, J. E., Cohesion, Proceedings of the Phys. Soc. 43: 461-62 (1931)

obtained by addition of the forces exerted by each neighboring molecule. Hamaker[9] and Bradely[10] approximated the energy necessary to pull two particles apart as

$$F = \frac{dE}{dx} = \frac{\lambda \pi^2 q^2}{12x^2} \cdot \frac{D_1 D_2}{D_1 + D_2} \quad (2)$$

where E = interparticle energy

D = the particle diameter

x = the interparticle distance

q = number of molecules contained in a unit volume.

It may appear that the force becomes infinite when the particles are together, but the force is limited by a minimum value of x.

Many investigators determined results which were consistant with the theoretical London-Van der Waals' interparticle force. Investigators de Boer[11] and Hamaker[9] calculated the order of magnitude of these forces, and Hamaker gave equations for the interaction of particles as a function of the particle distance, x, for different shapes of particles. Hamaker found the force for two flat surfaces separated by a distance, x, to be inversely proportional to the cube of the separation. Van der Waals' forces become significantly more important as the particle size becomes smaller. Irregular shaped particles made the problem considerably more difficult, since Van der Waals' force is dependent on particle shape.

9. Hamaker, H. C., A general theory of Lyophobic Colloids, I, Rec. Traz. Chim., 55: 1015-26 (1936); A system of Colloid Phenomena, Rec. Traz. Chim., 56: 727-47 (1937); and London-Van der Waals' attraction between spherical particles, Physica, 4: 1058-72 (1937).

10. Bradely, R. S., The cohesion between smoke particles, Trans. of the Faraday Soc., 32; 1088-90 (1936).

11. de Boer, J. H., The influence of Van der Waals' forces and primary bonds on binding energy, strength and orientation, with special reference to some artificial resins, Trans. Faraday Soc., 32: 10-38 (1936).

It is common belief that Van der Waals' forces between particles are due to the molecules at or near the surface. Thus, the radius of curvature of the opposing surfaces of close particles will determine the interparticle force.

B. G. Casimir and D. Polder, who worked out an electromagnetic theory of molecular forces in 1948 did not use the classical picture of radiation but rather the ideas of quantum mechanics. The Casimir-Polder theory showed a force dependent on K/R^8 where K is different from Van der Waals' constant for attraction. Some investigators today feel that both Casimir-Polder and London-Van der Waals' formulas apply only over an appropriate range of R and that each contain unmeasurable constants.[12] Further, these relationships do not give the force between two bodies containing many molecules, since the molecular interaction forces are not believed to be additive.

When particles carry electrostatic charges, coulomb forces may be the controlling forces in bringing about agglomeration. A few individuals believe that in general the charges are not large enough to give rise to forces of attraction comparable with the intermolecular force between small particles in contact. Particles are known to carry electrical charges even though the total charge of the powder may be neutral. Electrification can be caused by the interaction with gas ions from the atmosphere, by friction or contact between particles or by separation. Particles may be discharged by contact with a surface of higher capacity or neutralized

12. Derjaguin, Boris V., Scientific American, 203: No. 1 (1960).

by agglomeration. Electrostatic forces of attraction cannot be calculated for a powder since the distribution of the charge on the particles is unknown.

An extensive study of static electrification of dust particles from 0.5 to 30.0 microns in diameter, on generation of a cloud was made by Kunkel.[13] He used the method developed by Hopper and Laby[14] where particles were allowed to fall in a horizontal electric field and their tracts were photographed under intermittent illumination. He concluded that in general the average charge increased more slowly than with the square of the diameter.

The above comments serve to illustrate the great scope of the problem of determining forces between particles, even under rather simplified conditions.

2. Flow Properties of Powders

The flow properties of finely divided materials have been of great interest in a wide variety of industrial applications. Perhaps the most frequently studied case is that of gravity flow of the material.

A test performed by R. R. Trani[15] and others consisted of measuring the behavior of powders in a funnel of specific dimensions. One funnel was placed directly above another on a ring stand. Samples of 50 to 100 gms of material were introduced to the top funnel and allowed to fill the stoppered funnel below. Three minutes or more were allowed for the trapped air to escape before removing the plug. If the sample completely flowed out when the plug was removed, the material was classified as free-flowing.

13. Kunkel, W. B., J. Appl. Phys., 21: 820 (1950).
14. Hopper, V. D. and T. H. Laby, Proc. Roy. Soc. A, 178: 243 (1941).
15. Trani, R. R. et al., Ind. & Eng. Chem. 51: 1285-8 (Oct. 1959).

Powders were classified according to the time required for a sample to flow out. If the sample did not completely flow out, 100μ diameter glass beads were added until it did so. Glass beads were added until the minimum weight fraction needed for free flowing was obtained. The quantity of glass beads added was an indication of the flow properties of the powders tested. From these measurements, five arbitrary flow classifications were set up for the funnel specified.

The flow properties of finely divided materials are radically affected if they are mixed with a gas in two-phase flow. Some investigators have suggested that a powder could possibly be characterized in terms of a property similar to the viscosity of liquids and that the pseudo-viscosity might be a fundamental correlant of slugging, fluidity or other bed characteristics. Matheson, Herbst and Holt[16] presented the results of such a study in which they measured the relative pseudo-viscosity of various fluidized beds in terms of the torque weight required to rotate a paddle of fixed size at 200 rpm in a 3 inch deep by one inch ID bed of solid fluidized by air. They found the torque necessary to rotate the paddle was extremely high for unaerated beds, but decreased rapidly when aerated and soon reached a point where further aeration had no effect on the required torque. The relative viscosity of the bed was found to increase with particle size and particle density. Matheson also measured the torque necessary for various beds made up of two components: fines blended with larger particles. The rate of change of the viscosity with composition showed a decided break at the point of minimum fines added to prevent interlocking.

16. Matheson, G. L., Herbst, W. A. and Holt, P. H., Ind. Eng. Chem., 41: 1099 (1949).

An extensive discussion of the rheological properties of powders is given by Zenz and Othmer.[17] Measurements of five angles pertaining to the powder bed are suggested as a means of characterizing finely divided materials. These are:

(1) The angle of internal friction

(2) The angle of repose

(3) The angle of wall friction

(4) The angle of rupture

(5) The angle of slide.

One or more procedures for conducting each measurement are outlined in the cited reference and will not be repeated here.

The previous work outlined above has served as a point of departure for our own experimental work in this area.

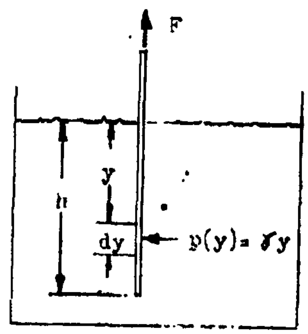
B. Preliminary Theoretical Investigation

In initiating a theoretical study of this type, one immediately encounters the problem of setting up a model. As a first approach to the problem, a two dimensional model was set up in which the piling of a powder was considered as being analogous to the piling of cylinders. The essence of this investigation is given in Appendix A.

Several phenomenon such as angle of repose, angle of internal friction, compressibility, angle of rupture and others can be associated with the rheological properties of powders. Knowledge of these may contribute to evaluating the forces acting in the system.

17. Zenz, F. A. and Othmer, D. F., Fluidization and fluid-particle systems, Reinhold, New York, 1960.

A force acting on an incremental volume of bulk powder seems to distribute itself in a certain fashion. Tests such as the rod-tension test and the piston test as described by Zenz and Othmer[17] give credence to this idea. The way in which such a force distributes itself would seem to depend on the shear modulus and tensile strength of the powder. In an effort to gain some information on the shear modulus, the following model was constructed.



A plate p is submerged in a powder material to a depth h. Due to the weight of the material, the pressure on the plate p will be directly proportional to the magnitude of y.

Now
$$p(y) = \gamma y \tag{1}$$

where γ is the density of the material.

We now make the following assumption: that the maximum shear, τ, between the plate and the particles is proportional to the pressure or

$$\tau_{max} = Cp$$

and that all points on the plate are on the verge of slipping simultaneously.

The total force, F, to move the plate can be expressed by the integral

$$F = 2 \int_0^h \tau_{max}\, dy = 2C\gamma \int_0^h y\, dy$$

or
$$F = C \gamma h^2 \tag{2}$$

This F gives the maximum shear force to be expected.

Experiments have been carried out to check this relation, as discussed in the following section.

C. Experiments

As a part of this program of dissemination research, experiments are being conducted to evaluate physical tests which have been suggested by the theoretical studies or the search of the literature. The emphasis in this work is to find and apply physical tests which will be useful in predicting the behavior of a finely divided material in a disseminating system.

1. Experiments on Force to Extract a Vertical Plate from a Bed of Powdered Material.

Experiments were conducted to check Equation (2), presented in the previous section. The force required to extract a thin vertical aluminum plate from a bed of fine lead shot (500-1000 μ) was measured on a Jolly spring balance. The results are plotted in Figure 14. A straight line with a slope of approximately 2.0 fits the data points reasonably well, indicating that the relation given in Equation (2) is adequate for this case. The coefficient C in this equation can be considered to be related to the coefficient of friction between the particles and the plate. Further experimentation along this line is planned.

2. Experiments on Stress Versus Bulk Density.

Measurements of the effect of compressive stress on bulk density appear to be of interest in several areas of the dissemination problem. First, the information gained may contribute to the basic knowledge of

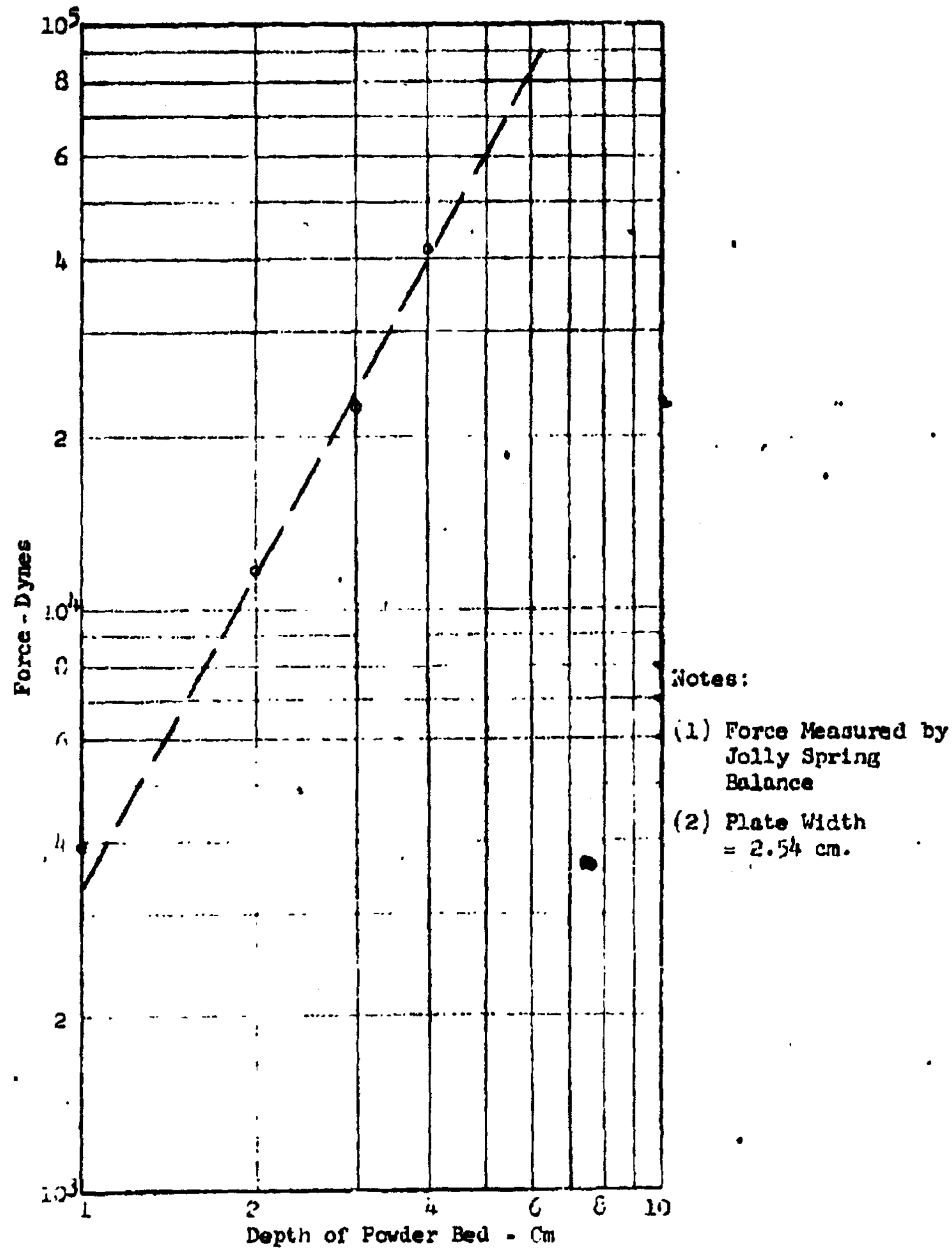


FIGURE 14. FORCE REQUIRED TO MOVE A VERTICAL FLAT PLATE SUBMERGED IN A BED OF FINE LEAD SHOT (500-1000 μ)

fine powders. Secondly, the data obtained is directly related to certain application problems including (1) determination of the volumetric behavior of the bulk material under high accelerations, (2) determination of the requirements for filling systems designed for compacted material and (3) prediction of the performance in piston type feeding systems.

Experiments have been conducted utilizing the apparatus shown in Figure 15, which consists of a thin Teflon piston, closely fit to a transparent plastic cylinder, which is vented to preclude entrapment of air. The piston is guided by a rectangular structure with Teflon edges which make only line contact with the cylinder in order to minimize friction. The height of the piston above a fixed reference plane is measured by a cathetometer. The bulk density for any piston position is derived from the system dimensions and the mass of the powder charge.

Figure 16 (2 pages) present the results of a series of measurements on samples of talc (Mistron - 18) which have a particle size range of 0 to 6 microns and a MMD of 0.83 microns. The three lines shown on the graph are for initial mass quantities of 30, 40 and 50 grams. It can be seen that, at the lower range of stress, the bulk density is somewhat dependent on the size of the material sample. The spread in the values of bulk density increases at the lower values of bulk density. The maximum spread is approximately 7 percent. At the higher stress levels, the curves come together within the limits of experimental error. This effect may be due to additional wall friction in the case of the larger samples.

It is interesting to note that the stress versus bulk density curves approach straight lines on the same log plot, in the region of high bulk

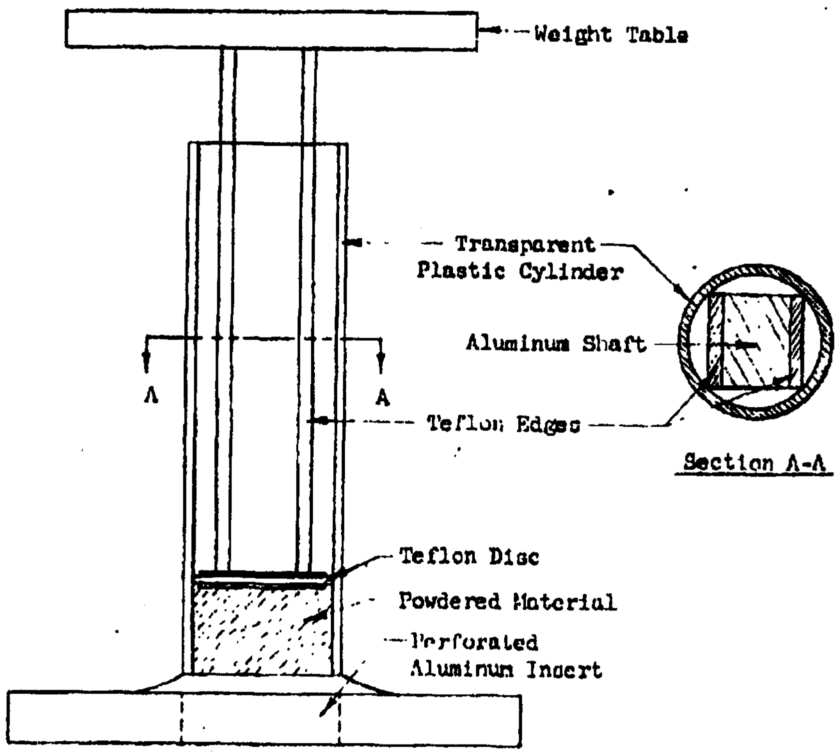


FIGURE 15. PISTON-CYLINDER APPARATUS FOR COMPRESSIVE STRESS EXPERIMENTS

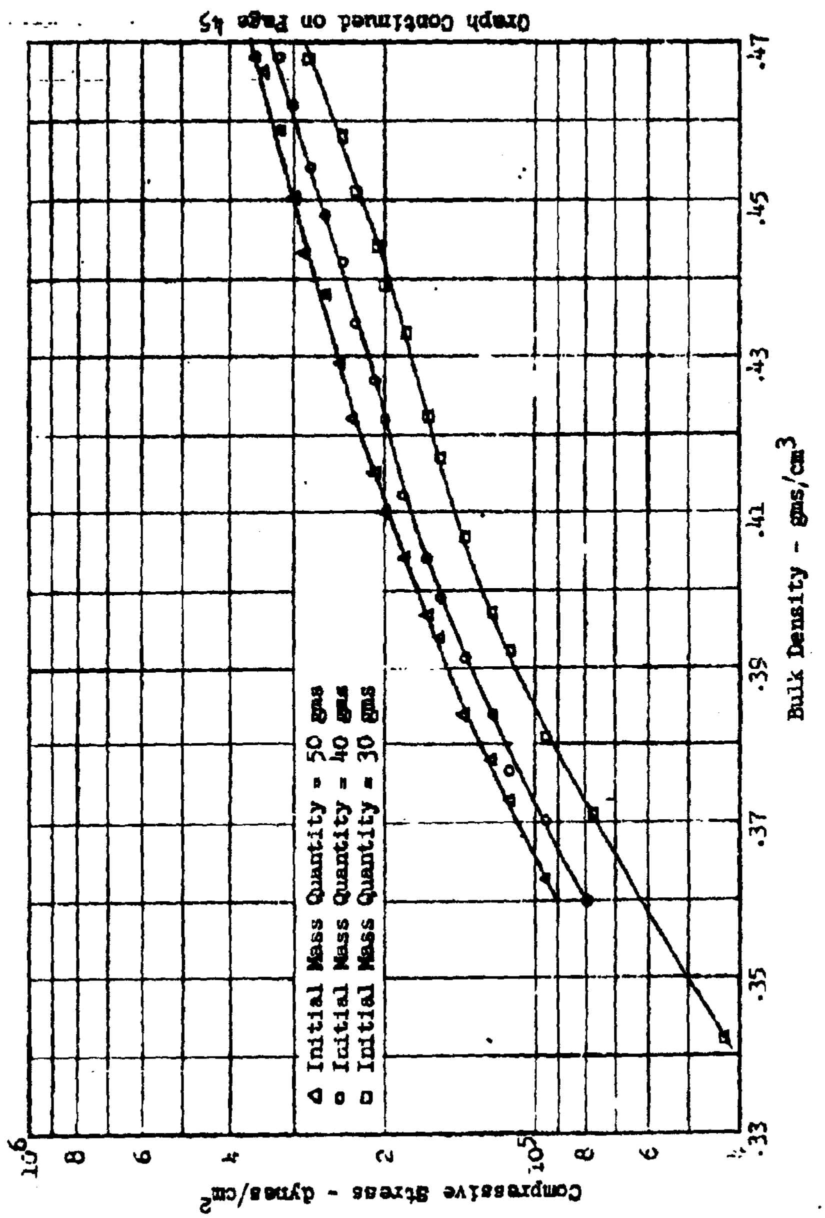


FIGURE 16. COMPRESSIVE STRESS VERSUS BULK DENSITY FOR TALC (MISTRON-18)

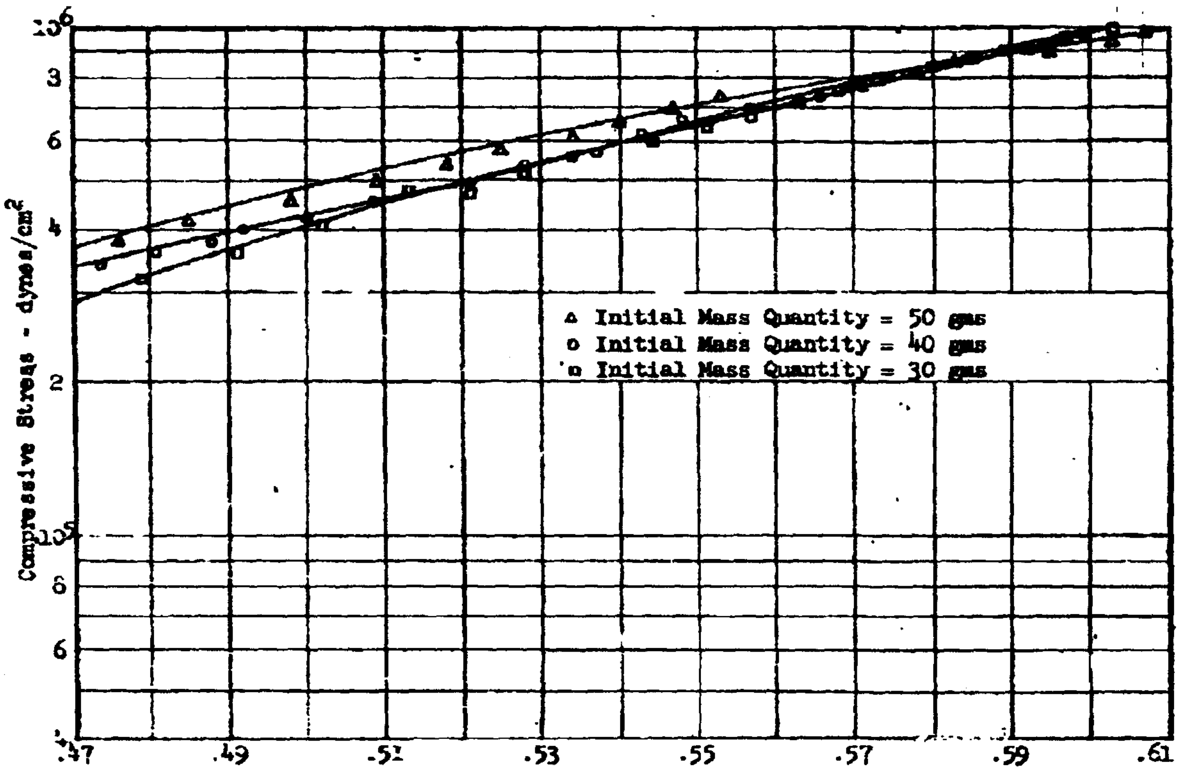


FIGURE 16. (Continued)

densities. The slope and intercept of this type of curve may be very useful in evaluating finely divided powders. Similar experiments with aspirin powder, produced nearly straight line relationships on a comparable graph. However, the values of slope and intercept were widely different. A change in the applied compressive stress of an order of magnitude (from 10^5 to 10^6 dynes/cm^2) produced a change in bulk density of approximately 10 percent as contrasted to the change shown in Figure 15 of approximately 60 percent.

The data obtained from these experiments are being examined more thoroughly to determine whether more complete correlations with material properties are possible.

3. Measurements of Force Required to Extract A Circular Disc from A Powder Bed.

An experiment is outlined by Zenz[17] in which a vertical rod is extracted from a powder bed. The magnitude of the force is influenced by the internal friction of the material. Preliminary experiments with this technique, utilizing a Jolly spring balance indicated that the sensitivity was quite low. It became obvious that substitution of a horizontal circular disc for the rod would result in a considerable improvement. Three circular discs with diameters of 1, 2 and 2.54 cm were made. This permitted investigation of the influence of disc diameter, as well as the bed depth.

Two devices have been used for measurement of the force in these experiments. These are shown in Figures 17 and 18. The Jolly balance is a standard item of laboratory apparatus, which employs a calibrated spring

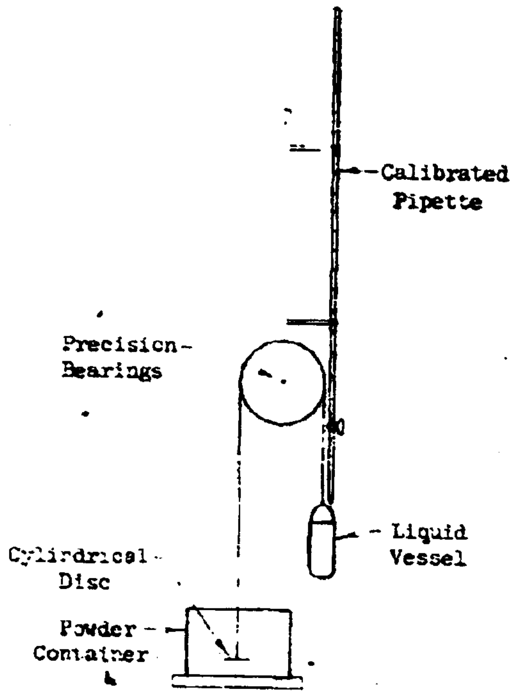


FIGURE 17

GRAVITATIONAL METHOD OF FORCE MEASUREMENT

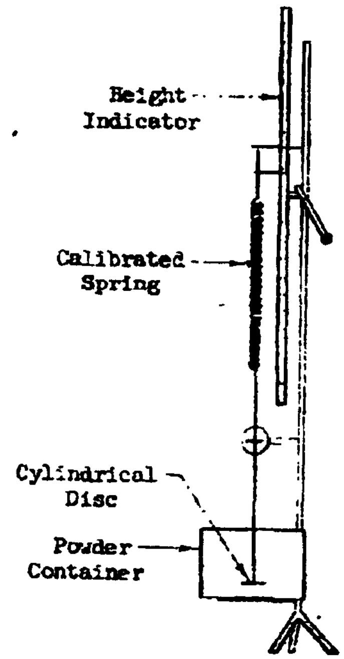


FIGURE 18

JOLLY BALANCE TECHNIQUE FOR FORCE MEASUREMENT for force measurement. The gravitational system of force measurement was developed specially for this application. With the latter device, force is applied to the circular disc by slowly adding a metered quantity of liquid to the vessel which is shown in the sketch. The force is transmitted by a line, operating on a pully, fitted with a precision bearing. This system has an advantage, in that the initial displacement of the disc, which takes place before the surface of the bed is interrupted, does not influence the applied force. In the case of the spring balance, this initial creep effect was found to slightly affect the measurement of applied force.

The results of experiments of this type are summarized in Figure 19, which is a plot of F/d versus F/d·h on log log paper. The force of F dynes is applied to a disc of diameter d centimeters, which is submerged in a bed to a distance of h centimeters below the free surface. Results for three powders are shown. These are talc, saccharin and aspirin. Figure 19 is believed to be a very useful correlation. The data for each sample indicate a straight-line relationship between the two coordinates, and the slope for each case is nearly identical. For the materials studied, the force has been found to be proportional to h^n where the exponent n is approximately 1.5. The intercepts and the slopes of these curves are identifying characteristics of the individual samples. Further experimentation along this line is planned to determine the reproducibility of these data for additional materials, and to evaluate the effects of moisture content.

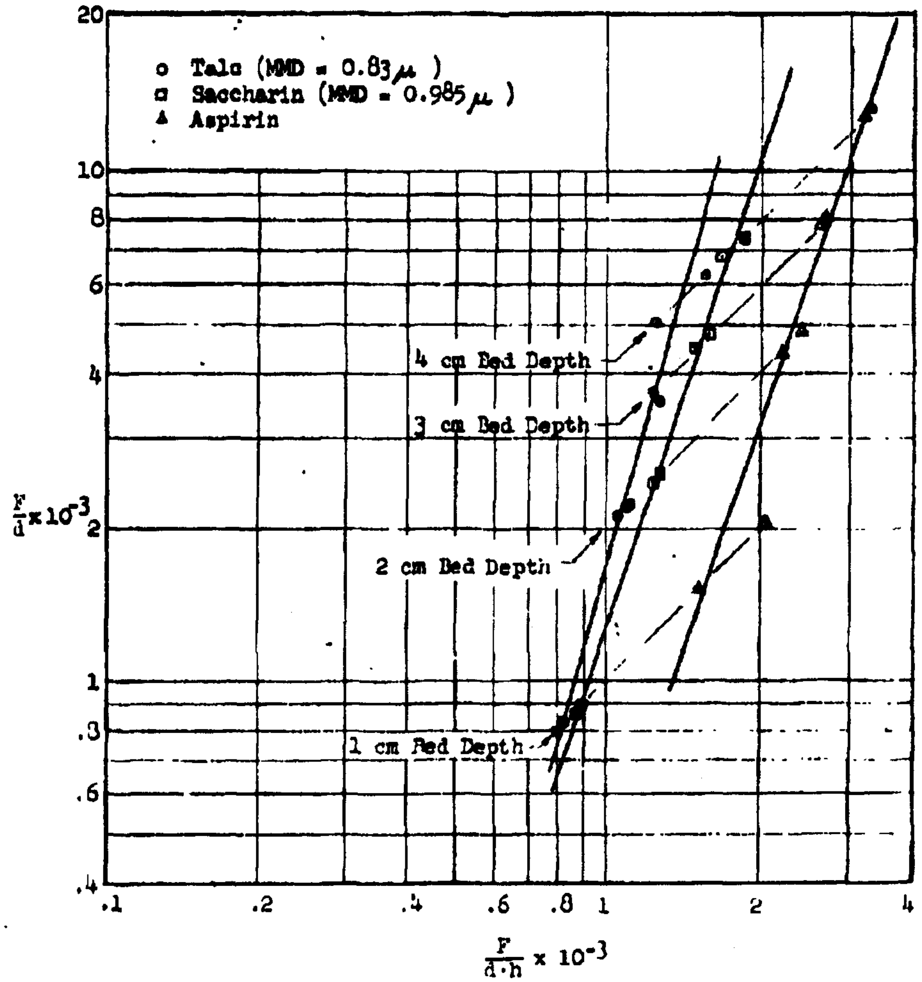


FIGURE 19. CORRELATION OF DATA FROM MEASUREMENT OF FORCE TO EXTRACT A DISC FROM A POWDER BED.

V. WORK ON LINE-SOURCE LIQUID AGENT DISSEMINATOR

A design study on an aircraft external store for liquid agent dissemination has been initiated by North American Aviation, Inc. under subcontract to General Mills, Inc. The scope of this work in the current phase includes (1) determination of flow rates for various agent-target requirements, (2) review of operational military aircraft for compatability of a universal BW store, (3) determination of means of agitation, (4) determination of means of heating to prevent freezing of the agent during transit to the target and during dissemination, (5) study of performance penalty due to system installation and (6) study of effects of local flow fields on the disseminating process.

Work was initiated in these areas following a coordination meeting which was held at General Mills, Inc. on 13 July 1960. Attending this meeting were representatives of the Biological Warfare Laboratories, General Mills, Inc. and North American Aviation, Inc.

Progress during July and August in each of the above areas is summarized below:

A. Flow Rate Optimization

A parametric trades study is in progress which will define near-optimum flow rates for a liquid biological agent dissemination system. Six biological agents are being considered in the analysis. These are the causative agents of Q-fever, Brucellosis, Tularemia, Anthrax, Plague, and Venezuelan Equine Encephalomyelitis. The biological and physical properties of these agents are contained in North American Aviation Report NA59-632, which also contains a description of Calder's mathematical effectiveness model used to compute their effectiveness. In addition to considering the specific on-target effects of these agents, the study considers several delivery vehicle parameters (speed, range, and agent capacity) and major weather and terrain characteristics.

The analysis optimizes flow rates in terms of the probable area of coverage for a typical mission in a European tactical situation (Circa 1963). The analysis methodology is illustrated in Figures 20 through 23 (4 figures). For a fixed delivery speed and agent capacity, the release line length can be shown as a function of the flow rate used for dissemination. An example of such a curve is shown in Figure 20 for delivering 400 gallons of agent at 600 knots. Cloud travel can also be shown as a function of flow rate for a specified agent, level of incapacitation, and weather condition. This effect is shown in Figure 21 for the causative agent of Q-fever and 50% incapacitation level ($P_I = 0.5$). An average weather condition (stable temperature gradient) and a 5-mph wind speed over open terrain were considered for this case. The product of release line length (Figure 20) and cloud travel (Figure 21) will yield an area of cover for any flow rate selected.

To more realistically appraise the effect of flow rate on the area of coverage achieved, other factors such as air vehicle survival and the ability to predict meteorological conditions existing in the target area have been considered.

As the delivery line length is increased, the length of time within enemy territory is proportionately increased and air vehicle survival probabilities will be decreased. This is illustrated in Figure 22 showing the

[redacted]

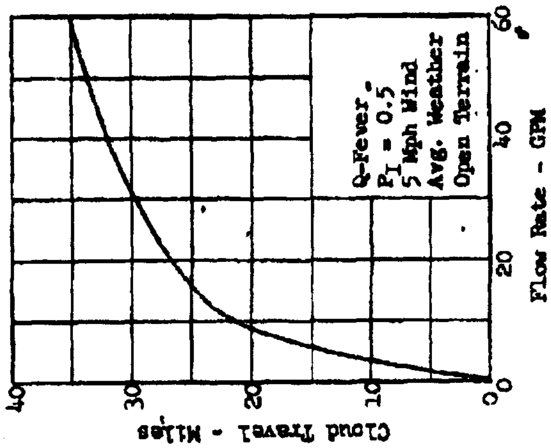


FIGURE 21

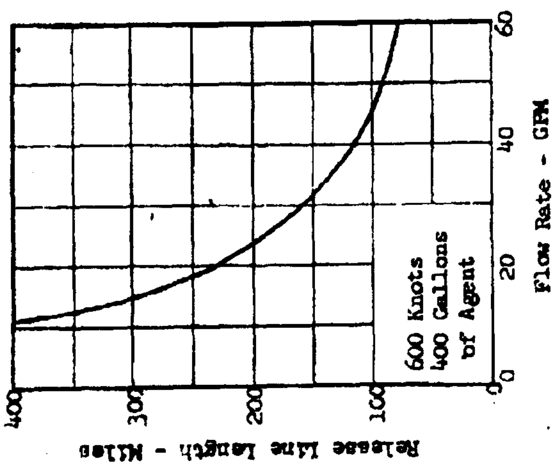


FIGURE 20

[redacted]

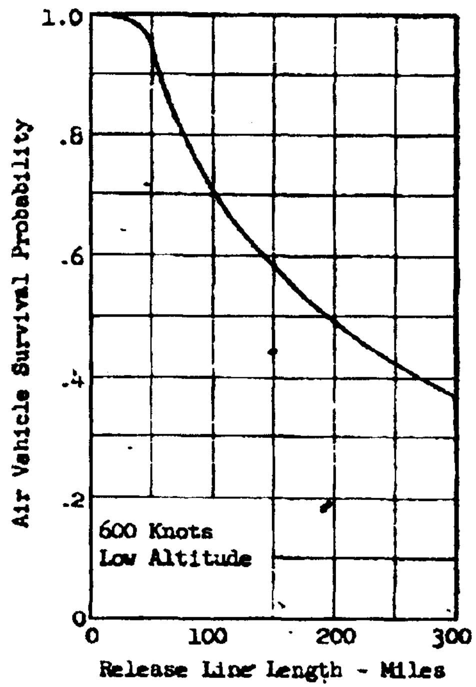


FIGURE 22

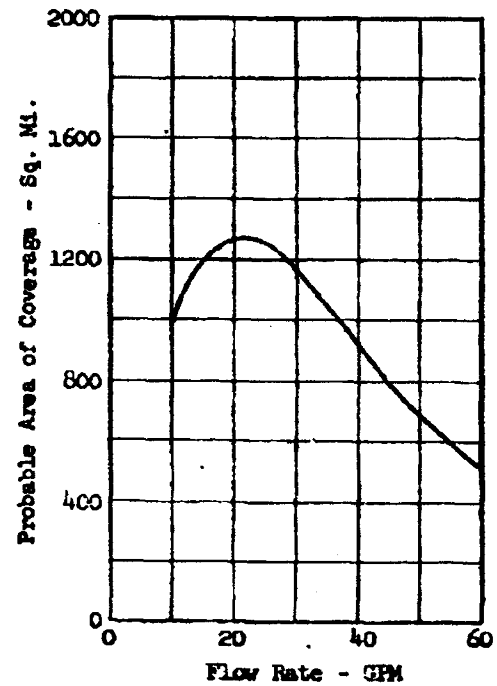


FIGURE 23

[redacted]

effect of release line length on survival probability for a European tactical situation in the 1963 period. By including the effects of survival probability, the probability of accurate meteorological predictions (assumed to be 75%) and the effectiveness against possible countermeasures (assumed to be 75%), the probable area of coverage can be obtained as a function of flow rate (see Figure 23).

It has been determined in this analysis that variations in wind speed, terrain conditions, temperature gradient (inversion, stable, or lapse) and level of incapacitation do not significantly affect the selection of a design flow rate. The probable area of coverage is increased or decreased as variations in these parameters are introduced, but the peaks in the curves show no sensitivity to these variations (see Figure 24). This is true of other wind speeds and incapacitation levels also. Consequently, an "average" meteorological condition (stable), an open terrain condition, a 5 mph wind, and an incapacitation level of 50% are assumed for analysis purposes. These values are felt to be both conservative and realistic and are used throughout the study to investigate the effects of speed, agent type, and agent capacity on design flow rate selection.

The type of agent, capacity of agent, and delivery speed were found to be the most sensitive parameters and have been the object of concentrated analysis effort. The effect of agent capacity on flow rate is shown in Figure 25. From the curves of Figure 25, it can be seen that the optimum flow rate increases from 6 gpm to 24 gpm as agent capacity is increased from 100 to 400 gallons. The effect of speed on flow rate is similar to that of

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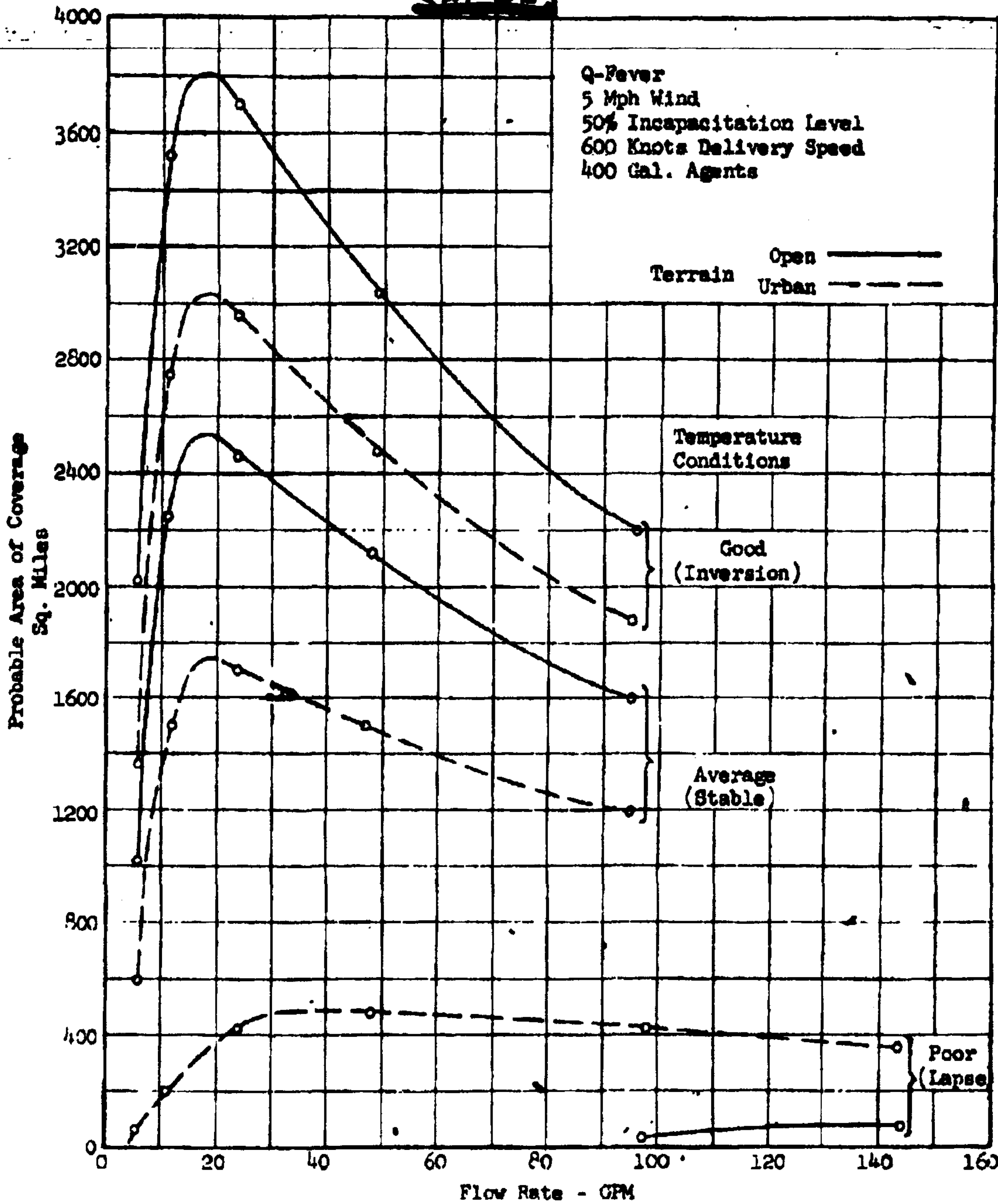

FIGURE 24

EFFECT OF WEATHER & TERRAIN

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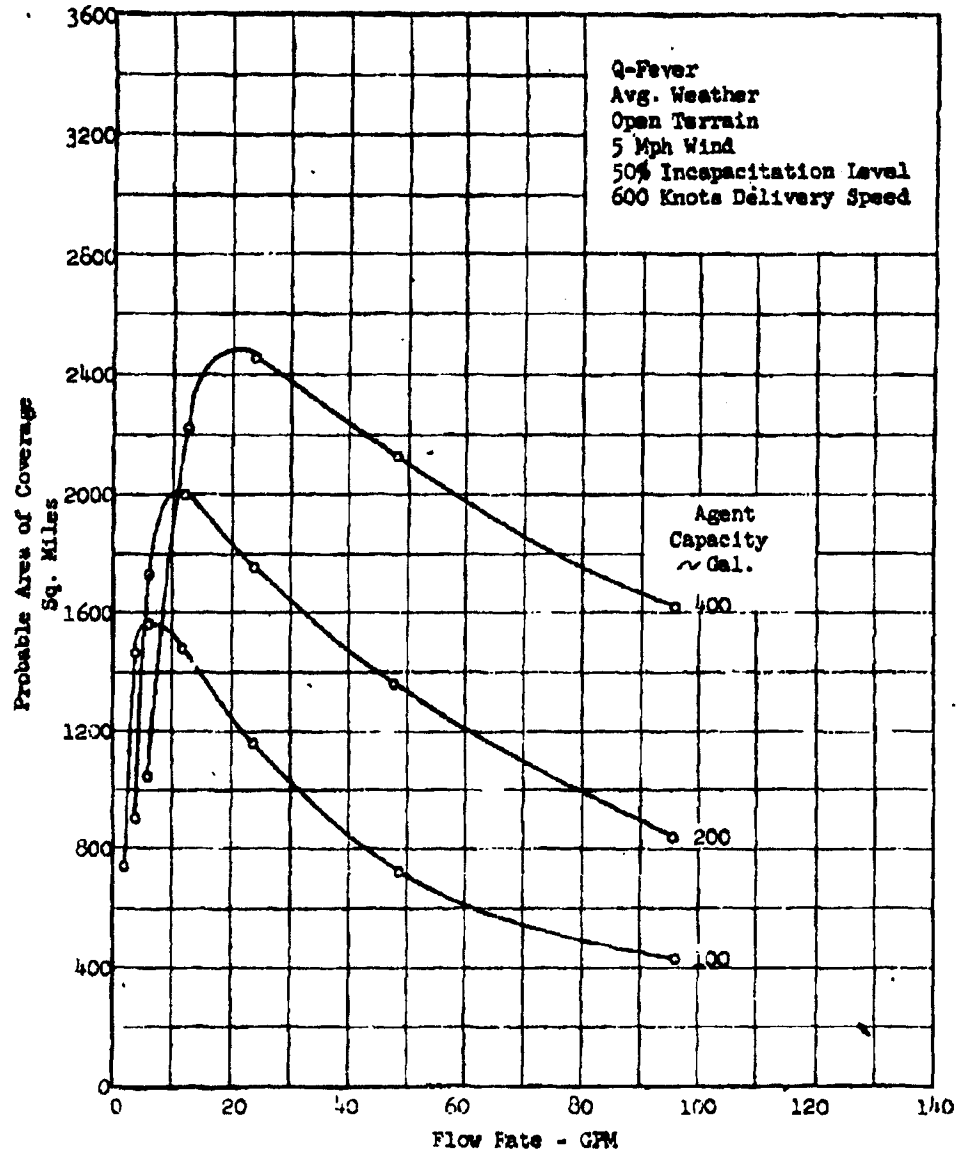

FIGURE 25

EFFECT OF AGENT CAPACITY

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agent capacity. This effect can be seen in Figure 26 where the optimum flow rate is approximately 15 gpm for a 300 knot delivery speed and 24 gpm for a 600 knot delivery speed.

The effect of agent characteristics on design flow rate can be seen by the histogram of Figure 27 where optimum flow rates vary from 16 gpm for the causative agent of Q-fever to 48 gpm for the causative agent of anthrax. The characteristics of these six agents show large variations which should include most potential agent developments. For example: ID_{50}'s vary by a factor of 800, agent concentrations vary by a factor of 20, decay rates range from 1%/min to 5%/min, and spray efficiencies range from 10% to 45%. Because of these ranges, these six agents are felt to be representative of a great many agents which will be developed and represent a large statistical sample space.

The goal of this study is to optimize flow rate of the dissemination system so as to be adaptable for a variety of delivery vehicles. This might result in extreme differences in delivery speed and agent capacity. If a weapon system optimization were being conducted, the relationship between agent capacity and range could be established and a desirable value of speed, range, agent capacity, and flow rate could be defined. But, since the system characteristics determined by the study must be amenable to a variety of delivery conditions, an average of extremes will be used to select a design value. Unusual situations which are not characteristic of the remainder of the sample will be eliminated. A statistical review of the results is in progress.

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Authority: EO 13526
Chief, Records & Declass Div, WHS
Date: MAY 17 2018

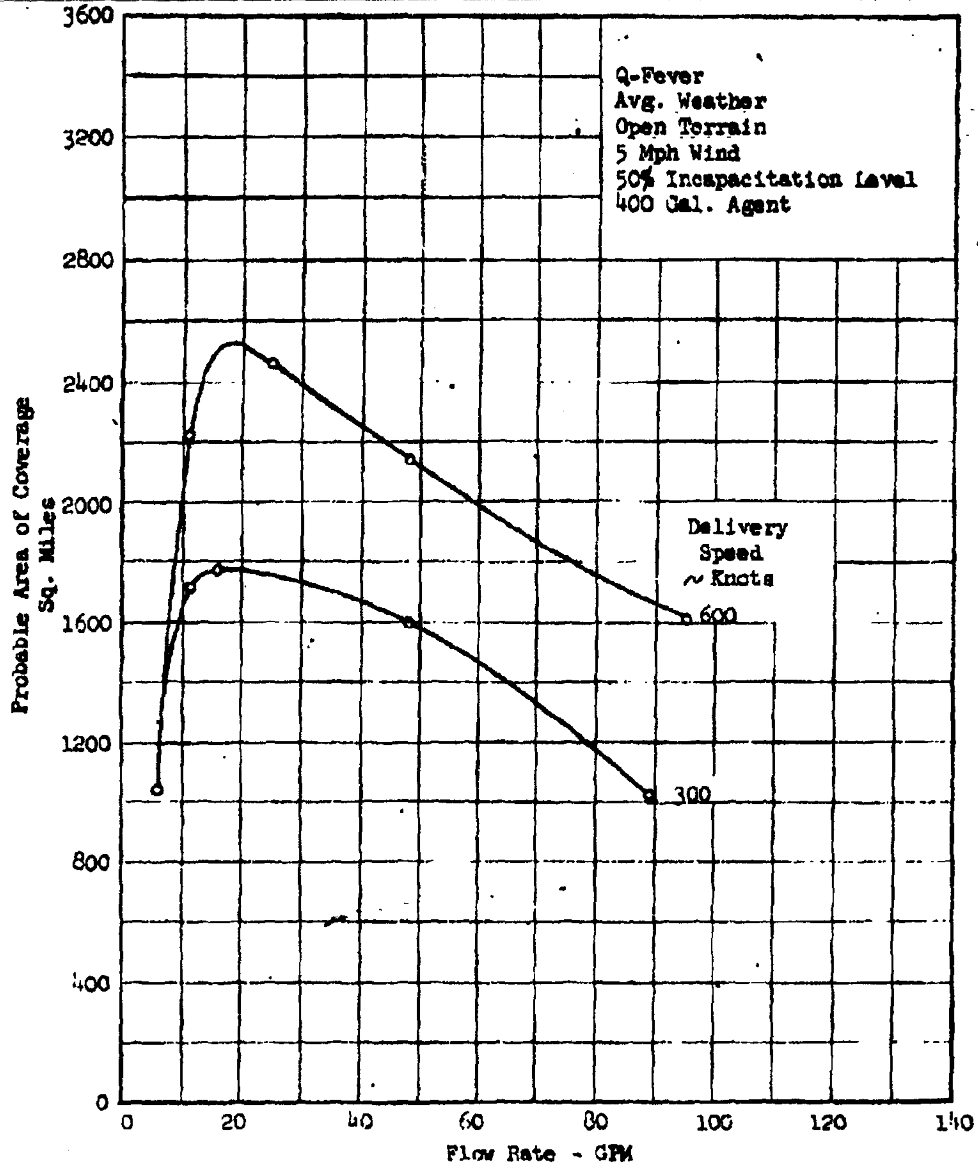

FIGURE 26

EFFECT OF DELIVERY SPEED

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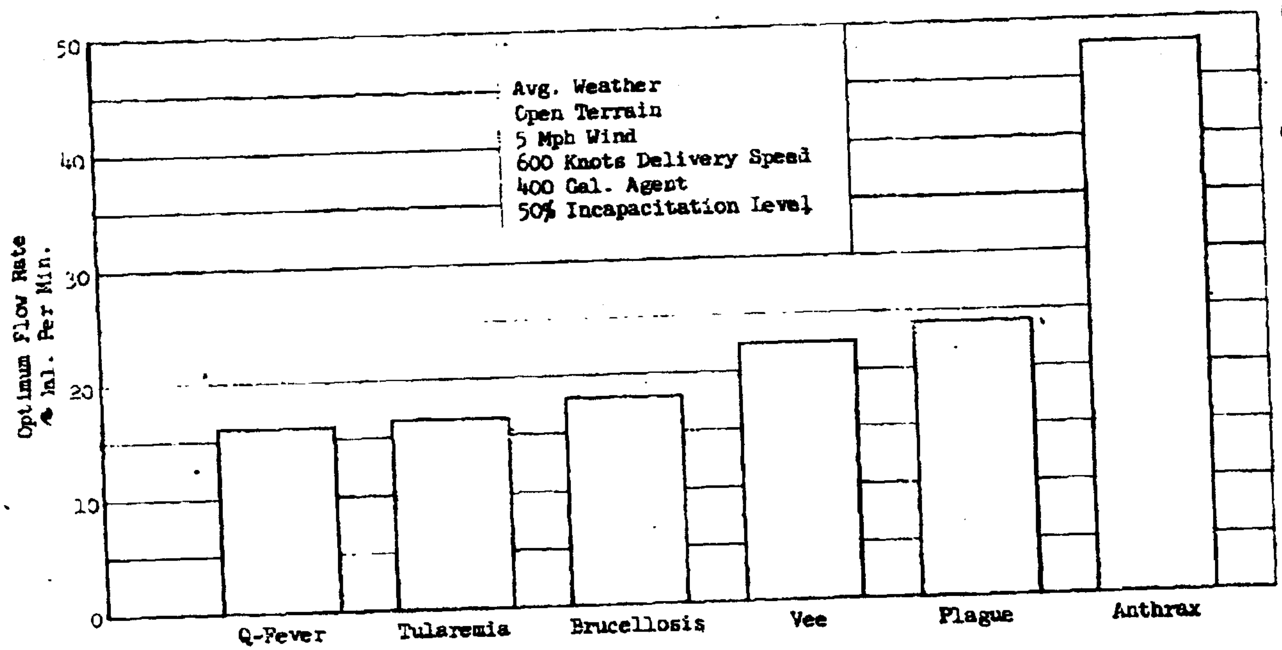

FIGURE 27

EFFECT OF AGENT CHARACTERISTICS

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B. Review of Operational Aircraft

Notification was received from BWL that the Need-to-Know request had been mailed to all manufacturers of currently operational aircraft. A questionnaire, listing desired information relative to external store capabilities was prepared for distribution to these manufacturers. These requests have been sent to the following ten companies:

1. Douglas Aircraft
2. Convair Division of General Dynamics
3. Norair Division, Northrup Corporation
4. Boeing Airplane Company
5. Chance Vought Aircraft
6. Republic Aviation Corporation
7. Grumman Aircraft Engineering Corporation
8. Lockheed Aircraft Corporation
9. McDonnel Aircraft Corporation
10. Martin Company

Response to this request has been received from three companies, giving information on 11 aircraft.

Flight handbooks for 33 of the pertinent aircraft are available in the NAA library. Data have been compiled from these publications concerning airplane performance and stores capability. This material can be used to calculate mission radius, delivery speed, and to indicate in a general sense the compatibility of various types of stores with these airplanes. For more specific information on store clearance envelopes, control circuits to the stores, pylon capabilities, and lug spacing, the requested information from the manufacturer will be required.

C. Agitation of Liquid Agents

A definite requirement for agitation of the liquid agent during the approach phase of the mission has not, as yet, been established by the BWL. If such a requirement were to be established, it would no doubt vary considerably for various types of agents. It is, therefore, concluded that a reasonable solution is to provide for circulation of the agent within the BW store by means of the dispensing pump and a by-pass valve. It is visualized that a stand-by position would be provided on the pump switch which would open the by-pass valve and energize the pump. Actuation of the switch to the standby position at some time prior to the disseminating run would be part of the operational procedure for use of the BW store.

D. Heating and Cooling

An analysis has been made to determine the requirements for maintaining the temperature of the agent within the prescribed temperature limits during the critical conditions of cruise on an "Air Force Winter Day". For this calculation a cruise time of 3 hours at 38,000 to 43,000 feet at a Mach number of 0.86 was used.

The results of this analysis indicate that with the agent tank insulated with 1/2" of fibreglass insulation, the temperature of the agent will remain above 35°F, with the initial agent temperature of 40°F. With no insulation the agent temperature would be below freezing. For these calculations, the physical properties used in the calculations include thermal conductivity, specific heat, density, absolute viscosity, and coefficient of thermal expansion.

In addition to insulation of the tank to prevent freezing, it will be necessary to heat the nozzle to prevent the agent from freezing as it is being discharged and consequently plugging the nozzle orifices.

The heat required to maintain the outside surface temperature of the nozzle assembly at 50°F while the assembly is retracted is approximately 4 watts per square inch of surface area.

The heating of the supply tubing and nozzle can be accomplished by means of an electrofilm coating, with operation of the heaters controlled by means of a simple thermal switch sensing outside surface temperature.

An analysis has also been made to determine the effects of ram-air heating on agent temperature in the tank during the critical condition of low altitude cruise on an "Air Force Summer Day". For this calculation a time of 1 1/2 hours and a Mach number of 0.5 was assumed.

Results of this analysis indicate that the 1/2" fibreglass insulation is sufficient to maintain the agent temperature within acceptable limits. The temperature rise of the agent is approximately 2°F with the insulation as compared with approximately 50°F with no insulation.

E. Performance Penalty

No effort has been expended on this subject during the reporting period.

F. Effects of Local Flow

1. Engine Exhaust

A method of estimation of engine exhaust temperature profiles has been devised. It has been found that although extensive effort has been placed on the study of jet streams exhausting into quiescent air, relatively little has been done in the study of jet exhausting into moving air. The procedure developed gives results which compare favorably with the limited test data available.

For purposes of analysis the engine exhaust is divided into two regions: (1) the supersonic core immediately downstream of the nozzle in which the exhaust pressure is expanding to free stream pressure; and (2) the region of turbulent diffusion downstream of the supersonic core. Characteristics of the flow in these regions are then defined in terms of the exhaust Mach number, exhaust static pressure ratio, nozzle angle, free stream Mach number, and distance downstream. Analysis of the supersonic core region is based on work presented in the following references:

U. S. Navy Development Center Report NADC-ED-5401, Characteristics of Free Supersonic Jets Exhausting Into Quiescent Air, by A. R. Anderson and F. R. Johns.

NACA Report RML54L31, Some studies of Axisymmetric Free Jets Exhausting from Sonic and Supersonic Nozzles Into Still Air and Into Supersonic Streams, by E. Love and C. E. Grigsby

The region of turbulent diffusion is defined by the procedures given by W. Szablewski in the NACA reports:

TM 1288, The Diffusion of a Hot Air Jet in Motion

TM 1311, Contributions to the Theory of the Spreading of a Free Jet Issuing from a Nozzle.

Application of this procedure is illustrated in Figure 28 for the case of a J-57 jet engine installed in a vehicle travelling at 0.7 Mach number. Isotherms are shown for temperatures down to 100°F. The rate of spreading

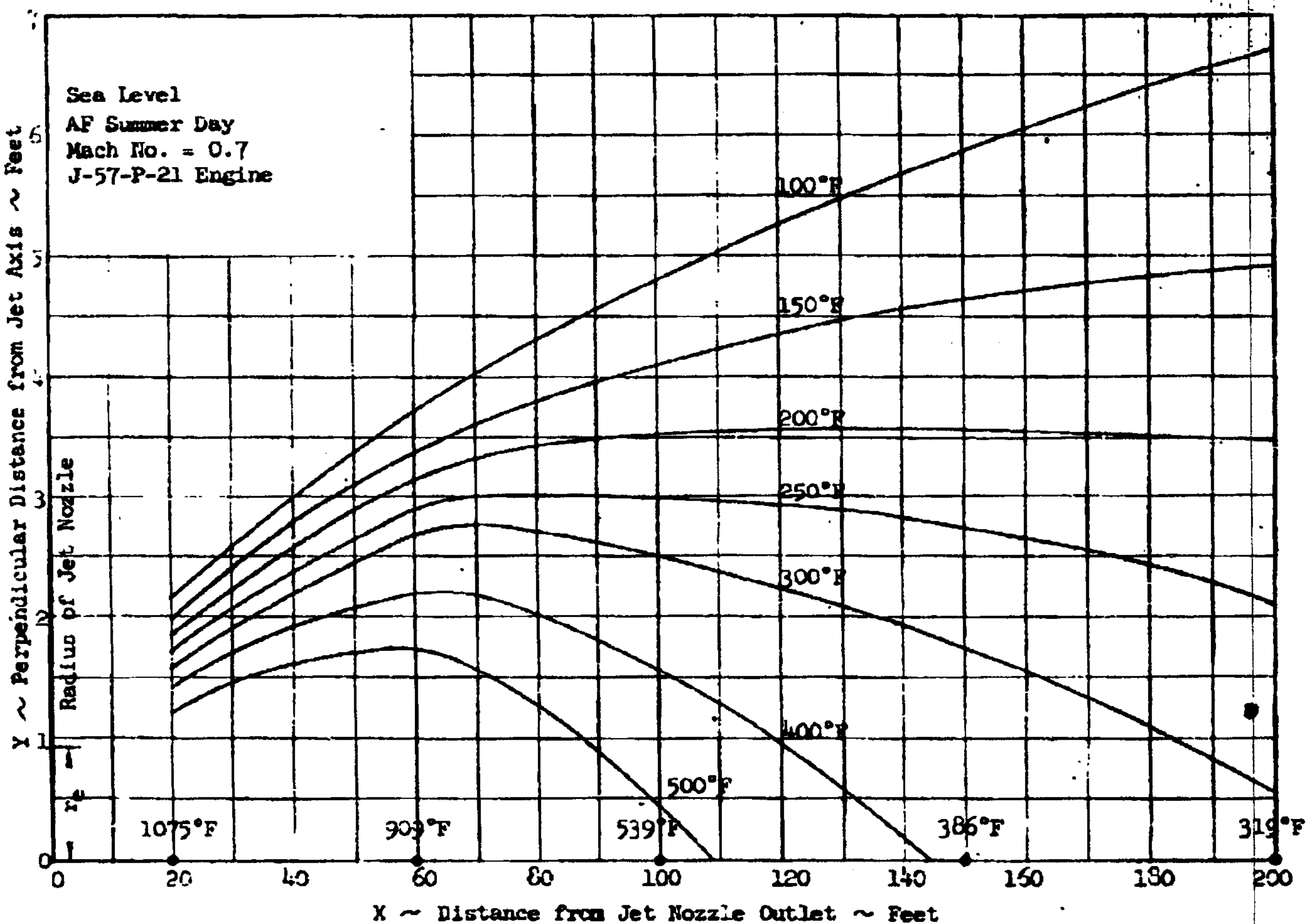


FIGURE 28

JET LONGITUDINAL TEMPERATURE PROFILE

of the exhaust indicates that in any practical installation of a BW disseminating store that some mixing of the agent with exhaust gases in the temperature range of 100°F will occur. This does not imply a serious loss of effectiveness since the exposure is of very short time duration and cooling by evaporation will lower the environmental temperature.

2. Aerosol Stream

Because of the very small momentum of the aerosolized agent particles, they are accelerated into the airstream direction almost immediately upon ejection from the nozzle. In consideration of location of BW disseminating nozzles on an aircraft, it may be assumed, then, that in the vicinity of the aircraft the aerosol follows the stream lines flowing past the nozzles.

The primary flow characteristics to be considered are due to the vortex system of the wing. This vortex system produces a downward velocity component downstream of the wing which is a maximum in the inboard region of the wing and diminishes toward the wing tip. A trailing vortex emanates from the wing tip with the core of the vortex located approximately at the 0.8 semi-span of the wing.

Dissemination of the agent in the downwash field will give the aerosol a downward velocity of the order of 1% of the airspeed of the aircraft. This effect may be very important in transport of the aerosol to the ground but will be of lesser importance in separation of the aerosol from the aircraft structure and from the engine exhaust because of the very short time period involved.

If the agent is disseminated in the region of the trailing vortex, the aerosol stream will be more rapidly diffused, but will experience no net downward velocity.

Characteristics of the vortex system are being prepared in graphical form for wing plan forms representative of current military aircraft.

VI. SUMMARY AND CONCLUSIONS

Study of the feeding and handling problems for dry agent disseminators indicates that promising concepts exist in the application of screw feeders, piston feeders and pneumatic feeding systems. → to p. 68

When considering the use of screw feeders, the two concepts which currently appear most promising are (1) the use of a very large screw, probably of the ribbon type which is so designed that all of the agent is originally contained in the screw and (2) the use of a smaller screw feeder, with an auxiliary mechanical agitation mechanism to preclude bridging. There appears to be no incentive to rely exclusively on gravity flow in any part of the systems, because the power requirements are small compared to that readily available from a ram-air turbine generator. The piston feeding systems appear to be most feasible for handling highly compacted agent materials. The power requirements for a system of this type would again be well within the limits available. The major problem is expected to be the potentially high wall friction in a large store, which could impose excessive structural loads on the system. To encase the compacted slug in a material of low friction is apparently required to eliminate this problem. Adequate means for stripping off this casing during dissemination are required.

In the pneumatic feeding systems, two concepts have been considered: (1) systems in which the entire stored agent quantity is continually mixed with the flowing motive gas, and (2) systems where a surface entrainment principle is utilized. Of these, the first is believed to be the most promising due to the extremely small gas flow rate required. The use of motive gases other than ram air have been considered and appear to be desirable. For example the use of carbon dioxide, stored in the liquid phase would provide a controllable, inert atmosphere, and is expected to involve a weight penalty of only a few percent of the agent payload.

Preparations have been made for deagglomeration experiments on a blowdown wind tunnel. A special test section has been designed to provide close control of Mach number in the high subsonic range above 0.70. This test section has slightly tapered walls to permit uniform Mach number. An adjustable sonic nozzle at the discharge has been included to minimize fluctuations in flow. A molded plastic inlet nozzle is also utilized to provide for minimum turbulence. A special high velocity aerosol sampling probe has been designed and fabricated for use in the deagglomeration experiments. This probe is designed for isokinetic sampling of the stream. It incorporates a diffusing section to reduce the velocity to a level which is compatible with membrane filters and impaction sampling devices.

A literature search has been made in the field of the characteristics of finely divided materials. The classic treatments of intermolecular and interparticle forces have been reviewed. In general, these do not appear to offer solutions to the real problems at hand because many effects, such as contamination with adsorbed vapors, cannot be adequately handled. The various experimental techniques for evaluation of the physical characteristics of finely divided materials have also been reviewed, including those for measurement of such values as the angle of internal friction, the angle of slide and the angle of repose. Additional experiments were devised which yield information which should be useful in considering the suitability of a given powdered material for use in dissemination systems. One of these involves determination of the effect of compressive stress on the bulk density of a finely divided material, the results of which bear on the questions of volumetric behavior under high acceleration and the problem of filling disseminators with compacted material. A second experiment involves determination of the force required to remove a horizontal circular disc from a bed of the material. This measurement shows that, for the cases investigated, the required force varies approximately as the 3/2 power of the bed depth. The force characteristic for each powder tested can be used to identify the sample. A third experiment involved the measurement of force to extract a vertical plate from a powder bed. This experiment was suggested by a preliminary theoretical analysis. The data obtained for a bed of lead shot agreed substantially with the theoretical treatment.

Progress has been made in several areas of work on the liquid dissemination problem. The operational analysis work associated with liquid agent dissemination has been advanced and the effects of several parameters have been explored. The most significant parameters affecting the optimum flow rate are delivery speed, agent capacity and agent characteristics.

Causative agents were considered. The optimum flow rates indicated by this study vary from a minimum of 16 gpm for a Q-Fever to a maximum of 48 gpm for anthrax. A review of operational aircraft for compatibility with external stores has been initiated. Questionnaires have been sent to pertinent aircraft manufacturers. Additional information is available from flight handbooks for 33 aircraft. The requirement for heating to prevent agent freezing has been studied. Satisfactory solutions for the nozzle heating requirement and the storage tank insulation problem have been found. Studies of the effect of local flow have been advanced, and a method for analyzing the temperature gradients produced by engine exhaust has been developed.

Several studies are in progress which will be covered in the final report. These include (1) an investigation of the characteristics of non-Newtonian fluids, (2) experiments on unconventional disseminating concepts, including liquid and solid phase, carbon dioxide systems and ram-air erosion systems and (3) a study of air flow around external stores as it affects solid agent store design.

The work planned for the near future is discussed in the technical portion of the narratives which are submitted monthly to the Chemical Corps.

APPENDIX A

PRELIMINARY THEORETICAL STUDY OF FORCE DISTRIBUTION IN POWDERS

I. TWO-DIMENSIONAL ANALYSIS (Particle Analysis)

The initial two-dimensional analysis will assume particles in the shape of uniform circular cylinders. The axes of the particles will be assumed normal to the two-dimensional plane. The angle of repose, β, is defined in Figure 1.

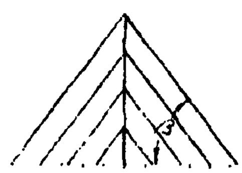


FIGURE 1

If the size of the pile is reduced such that the angle of inclination is kept constant, then, ideally, the pile size can be reduced until only three particles remain. This is shown in Figure 2.

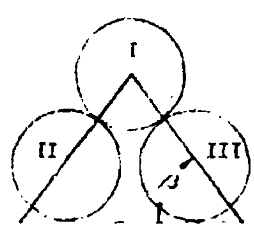


FIGURE 2

For circular cylinders, the angle of repose should be the relationship

$$\beta \simeq 60°$$

For Figure 2, $\beta \sim 60°$. It seems reasonable to assume that $\beta \sim 60°$ for non-circular shapes.

A. Three Particle Analysis

Central forces such as electrostatic forces, Van der Waals' forces, etc. may exist between two particles and between a particle and the surface. Central forces will be assumed negligible if two particles or a particle and the surface are kept from contact by a third particle. In Figure 3 the surface pushes up with normal force N_2 and attracts particles II and III with central force C_2:

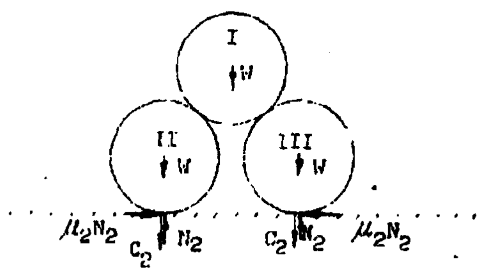


FIGURE 3

Summing forces in the vertical direction:

$$\sum Y: \quad 2\,N_2 - 2\,C_2 - 3\,W = 0 \tag{2}$$

or

$$N_2 - C_2 = \frac{3W}{2}$$

or

$$N_2 = C_2 + \frac{3W}{2} \tag{3}$$

Next, an analysis of Cylinder I of Figure 3 is carried out: Its free-body diagram is shown in Figure 4.

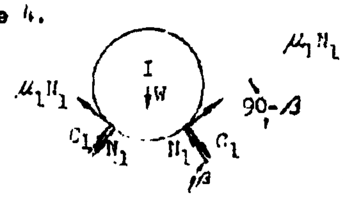


FIGURE 4

μ_1 is the coefficient of friction between two cylindrical surfaces and is assumed constant. C_1 is the central force between two particles in contact. Particle size, electrostatic charges, moisture content are some of the phenomena that may affect the central force between two particles. How the variation in central forces will affect the coefficient of friction, μ, is not known. The vertical force summation is the only one of any consequence:

$$\sum Y: \quad 2\mu_1 N_1 \cos\beta - W + 2(N_1 - C_1)\sin\beta = 0 \qquad (4)$$

A free-body diagram of Cylinder II is shown in Figure 5:

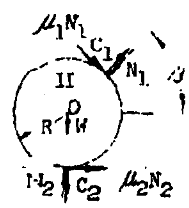


FIGURE 5

Since particles tend to spread out when poured in a pile, the normal force between two adjacent particles in the same horizontal plane will be assumed zero. There may be, however, a central force C_3 where

$$C_3 \neq C_1 \qquad (5)$$

$$\sum X: \quad C_3 - (N_1 + C_1)\cos\beta + \mu_2 N_2 + \mu_1 N_1 \sin\beta = 0 \qquad (6)$$

$$\sum Y: \quad -(N_1 - C_1)\sin\beta - \mu_1 N_1 \cos\beta - W + N_2 - C_2 = 0 \qquad (7)$$

$$\sum M_o: \quad \mu_1 N_1 R - \mu_2 N_2 R = 0 \qquad (8)$$

Equations (2), (4), (6), (7), (8) permit the solving of 5 unknowns. Since there are 9 variables, μ_1, N_1, W_1, C, β, μ_2, N_2, C_2, and C_3, some of these variables must be considered known. The angle β is readily measured and it will be assumed that the weight W can be determined or estimated. If the coefficient of friction, μ_2, between the particle and the surface, can be correlated with the angle of slide, then it too may be considered determinable. It can also be assumed that

$$C_1 = C_2 = C_3.$$

Making these assumptions, we can obtain expressions for N_1, N_2, μ_1 and C_1 in terms of the other variables:

$$N_1 = \frac{W}{2} \frac{1 - 2\mu_2 (1 + \sin\beta) + (1 - 3\mu_2) \cos\beta}{\mu_2 + (\mu_2 + 1) \sin\beta} \qquad (10)$$

$$N_2 = \frac{W}{2} \frac{\mu_2 - \sin\beta \cos\beta + 3\mu_2 \sin\beta \cos\beta - \mu_2 \sin^2\beta - 3 \sin^2\beta}{[\mu_2 \cos\beta - \sin\beta \;\; \mu_2 (1 + \sin\beta) + \sin\beta]} \qquad (11)$$

$$\mu_1 = \mu_2 \frac{\mu_2 + \sin\beta \cos\beta (3\mu_2 - 1) - \sin^2\beta (\mu_2 + 3)}{(\mu_2 \cos\beta - \sin\beta) [1 - 2\mu_2 (1 + \sin\beta) + (1 - 3\mu_2) \cos\beta]} \qquad (12)$$

$$C_1 = \frac{W}{2} \frac{\mu_2 - 3\mu_2^2 \cos\beta - 3\mu_2^2 \sin\beta \cos\beta + 3\mu_2 \sin\beta + 2\mu_2 \sin^2\beta - \sin\beta\cos\beta}{[\mu_2 \cos\beta - \sin\beta] [\mu_2 (1 + \sin\beta) + \sin\beta]} \qquad (13)$$

B. <u>Six Particle Analysis</u>

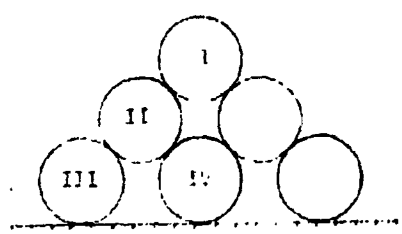


FIGURE 6

Analysis of Cylinder I:

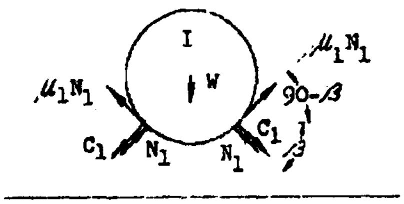


FIGURE 7

$$\sum Y: \quad 2\mu_1 N_1 \cos\beta + 2(N_1 - C_1)\sin\beta - W = 0 \tag{14}$$

Analysis of Cylinder II:

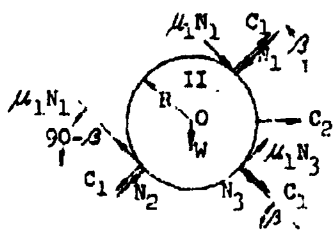


FIGURE 8

$$\sum Y: \quad -(N_1 - C_1)\sin\beta - \mu_1 N_1 \cos\beta - W + (N_2 - C_1)\sin\beta + \mu_1 N_2 \cos\beta + (N_3 - C_1)\sin\beta + \mu_1 N_3 \cos\beta = 0 \tag{15}$$

$$\sum X: \quad -\mu_1 N_2 \sin\beta + (N_2 - C_1)\cos\beta - (N_1 - C_1)\cos\beta + \mu_1 N_1 \sin\beta + C_2 + \mu_1 N_3 \sin\beta - (N_3 - C_1)\cos\beta = 0 \tag{16}$$

$$\sum M_o: \quad \mu_1 N_1 R - \mu_1 N_3 R + \mu_1 N_2 R = C$$

or $N_1 - N_3 + N_2 = 0$ (17)

Analysis of Cylinder III:

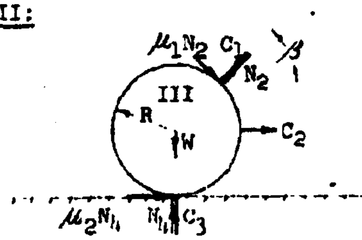


FIGURE 9

$$\sum X: \; -(N_2 - C_1)\cos\beta + \mu_1 N_2 \sin\beta + C_2 + \mu_2 N_4 = 0 \qquad (18)$$

$$\sum Y: \; -(N_2 - C_1)\sin\beta - \mu_1 N_2 \cos\beta - W + N_4 - C_3 = 0 \qquad (19)$$

$$\sum M_o: \; \mu_1 N_2 R - \mu_2 N_4 R = 0$$

or $\mu_1 N_2 - \mu_2 N_4 = 0$ (20)

Analysis of Cylinder IV:

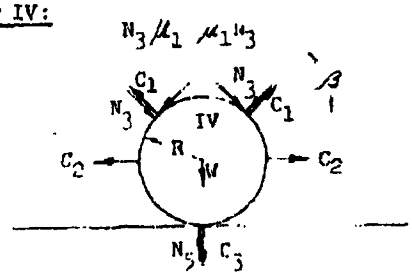
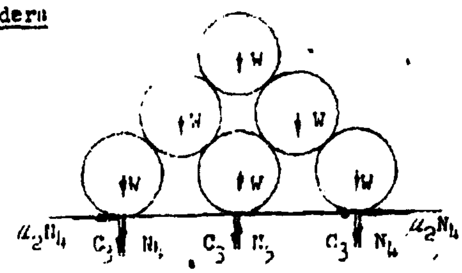


FIGURE 10

$$\sum Y: \; -2(N_3 - C_1)\sin\beta - 2\mu_1 N_3 \cos\beta - W + N_5 - C_3 = 0 \qquad (21)$$

Analysis of all Six Cylinders

FIGURE 11



$$-6W - 3C_3 + 2N_4 + N_5 = 0 \qquad (22)$$

There are 9 equations and 12 variables, which include μ_1, N_1, W, β, C_1, C_2, N_2, N_3, C_3, N_4, N_5, μ_2.

The known quantities will be assumed to be β, W, μ_2. Because of the difficulty of solving nine simultaneous non-linear algebraic equations, further simplifying assumptions will probably be necessary. The equations may be summarized thus:

$$N_1 = \frac{\frac{W}{2} + C_1 \sin\beta}{\mu_1 \cos\beta + \sin\beta} \tag{23}$$

$$-N_1 + N_2 + N_3 = \frac{W + C_1 \sin\beta}{\mu_1 \cos\beta + \sin\beta} \tag{24}$$

$$N_1 - N_2 + N_3 = \frac{C_1 \cos\beta + C_2}{\cos\beta - \mu_1 \sin\beta} \tag{25}$$

$$N_1 + N_2 - N_3 = 0 \tag{26}$$

$$N_2 = \frac{C_1 \cos\beta + C_2}{\cos\beta - \mu_1 \sin\beta - \mu_1} \tag{27}$$

$$N_2 = \frac{C_1 \sin\beta - W - C_3}{\mu_1 \cos\beta + \sin\beta - \frac{\mu_1}{\mu_2}} \tag{28}$$

These are six independent equations. The unknowns are N_1, N_2, N_3, C_1, C_2, C_3, μ_1, which totals 7. It will then be assumed that

$$C_1 = C_2 \tag{29}$$

Omitting the details, one finds the following relations which are of interest.

$$N_2 = \frac{W + C_1 \sin\beta}{2\,(\mu_1 \cos\beta + \sin\beta)} + \frac{C_1 \cos\beta + C_1}{2\,(\cos\beta - \mu_1 \sin\beta)} \tag{30}$$

$$C_1 \left[\frac{\cos\beta + 1}{\cos\beta - \mu_1 \sin\beta \cdot \mu_1} - \frac{\cos\beta + 1}{2(\cos\beta - \mu_1 \sin\beta)} - \frac{\sin\beta}{2(\mu_1 \cos\beta - \sin\beta)}\right] =$$

$$\frac{W}{2(\mu_1 \cos\beta + \sin\beta)} \qquad (30)$$

$$\cos\beta(\cos\beta + 1)(5\sin\beta + 3)\mu_1^2 - \left[5\cos\beta + 5(\cos^2\beta - \sin^2\beta)\right.$$

$$\left. + \sin\beta(2\cos\beta - 3)\right]\mu_1 - 5\sin\beta\cos\beta = 0 \qquad (32)$$

This is a quadratic in μ_1 where the coefficients are functions of the assumed known angle of repose, β.

That is:

$$a(\beta)\mu_1^2 + b(\beta)\mu_1 + c(\beta) = 0 \qquad (33)$$

From this analysis the angle of repose, β, is a direct measure of the coefficient of friction, μ_1, between cylinders. From Equation (31) it is seen that the central force, C_1, between cylinders is a function of β and W. N_1, N_2, and N_3 are also functions of β and W.