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General Mills

THE GENERAL MILLS ELECTRONICS GROUP

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THE GENERAL MILLS ELECTRONICS GROUP
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General Mills, Inc

FIFTH QUARTERLY PROGRESS REPORT
ON
DISSEMINATION OF SOLID AND LIQUID BW AGENTS
(Unclassified Title)

For Period 4 June - 4 September, 1961
Contract No. DA-18-064-CML-2745

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FORWARD

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ABSTRACT

This Fifth Quarterly Progress Report presents the results of continued work on the dissemination of solid and liquid BW agents. This project is directed toward advancement of the knowledge in the dissemination field and development of weapon systems for line source dissemination from high speed, low-flying aircraft.

Theoretical studies of the mechanics of particulate materials have resulted in equations for predicting the force required to move a compressed plug of powder in a cylinder; theoretical limits on a resistance parameter are given.

Experimental results on the shear strength of powders as affected by compaction and humidity are reported.

Wind tunnel studies of deagglomeration of finely divided compacted solids are covered. Particle size data and values for the frequency of occurrence of agglomerates, determined microscopically, are given.

A design concept for the first dry-agent disseminating store to be designed and fabricated on this program is presented and discussed.

Studies of the jet-plume problem as it relates to loss of viability of biological aerosols are described. Experimental data on viability loss and a theoretical analysis of the fluid mixing problem are reported.

Experimental results from a study of the rheological behavior of Sm slurries made with a fluorocarbon liquid are reported and a conclusion on the feasibility of this approach for disseminating solids is given.

Progress on the detailed design and fabrication of a liquid agent disseminating store is reported and the approach being used to fabricate this unit is outlined.

The results of computations made on the systems analysis part of the program are given. A variable decay-rate mathematical model is discussed.

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1. INTRODUCTION

This is the Fifth Quarterly Progress Report on the program of research on dissemination of solid and liquid BW agents being conducted by General Mills, Inc. under Contract No. DA-18-064-CML-2745. The overall objectives of this program are (1) to advance the state of knowledge in the BW dissemination field and (2) to provide experimental external stores for line-source dissemination of both liquid and solid agents from high-speed low-flying aircraft.

The work conducted during this reporting period is a part of Phase II of the program, which includes a continuation of research on solid agent characterization, delivery, metering, dissemination and deagglomeration and also the design and fabrication of an experimental liquid agent disseminating store. It is planned that Phases III and IV will follow the current work and will include design, fabrication, functional testing and flight testing of experimental solid-agent disseminating stores and also a continuous and intensive research program on the important aspects of dissemination of solid BW agents.

The progress during this reporting period is covered in the discussions which follow. Highlights of the progress include new theoretical analyses and experimental results on the characteristics of dry powders, establishment of a design concept for a dry-agent disseminating store and selection of the configuration and design features of the liquid-agent store.

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2. THEORETICAL STUDY OF THE MECHANICS OF PARTICULATE MATERIALS

Theoretical studies have been continued toward development of a comprehensive theory of powder mechanics. Two specific problems were examined in some detail: (1) determination of the force required to displace a plug of powder contained in a cylindrical tube and (2) preliminary study of the relationship between the energy of compaction and the bulk density of particulate materials. The results of these investigations are reported below.

2.1 Resistance of Powder Plug Contained Within a Cylindrical Tube

One proposed means for feeding particulate materials is to use a piston to force the material from the storage chamber at a controlled rate. The force required to displace the powder plug under these conditions have been determined approximately by means of the following analysis. Referring to Figure 2.1.1, suppose that the powder is contained within a cylindrical tube of diameter D with a piston at each end. We wish to determine the ratio of applied to resistive load F_A/F_R when the powder plug is at the point of moving. Denoting the axial and radial stress components by σ_z and σ_r, respectively, and the shear stress at the wall by τ_w, we have:

$$\frac{d\ \bar{\sigma}_z}{dz} = \frac{4\ \tau_w}{D} \qquad (2.1)$$

where $\bar{\sigma}_z$ is the mean axial stress.

Movement of the powder plug may be due either to shearing of the powder at the wall or to slipping of the powder plug. In the latter case the shear angle ϕ of the powder must exceed the friction angle $\theta = \tan^{-1} \mu_f$ as

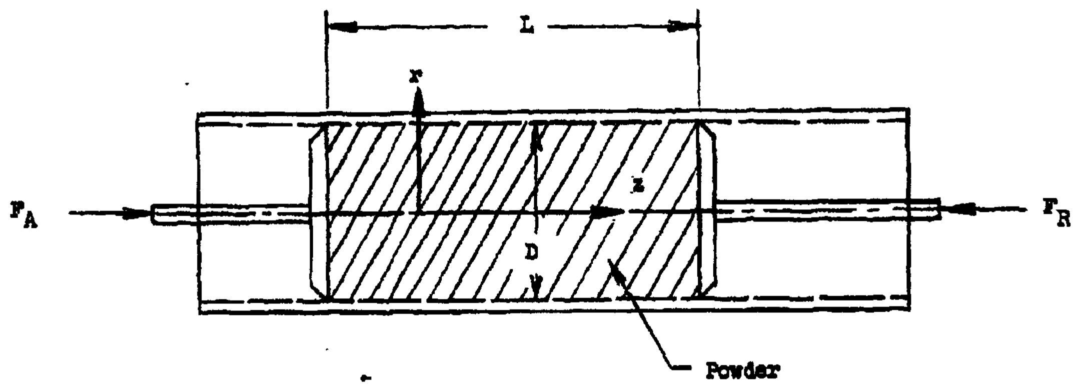

FIGURE 2.1.1 Piston-Cylinder Test Configuration

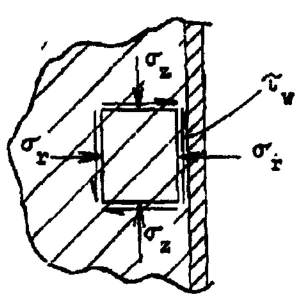

FIGURE 2.1.2-a Wall Stress Conditions - Physical Plane

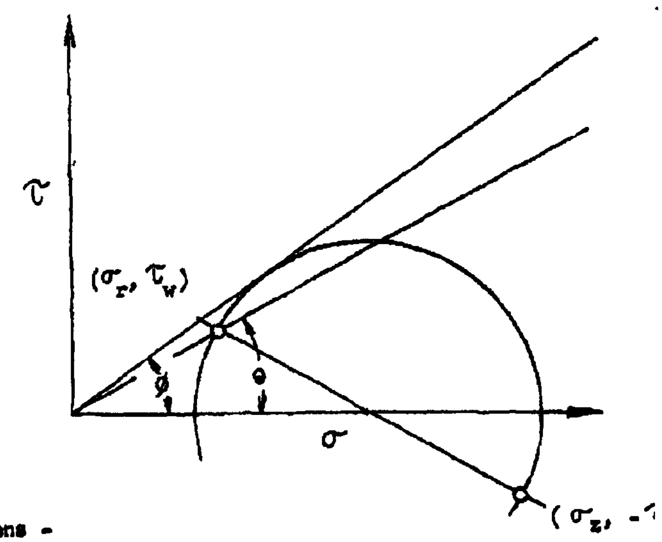

FIGURE 2.1.2-b Wall Stress Conditions Stress Plane

illustrated by Figure 2.1.2-b[2.1.1]. Letting $\sigma_r = C\,\bar{\sigma}_z$ and writing $\tau_w = \mu_f\ \sigma_r$, Equation 2.1 takes the form:

$$\frac{d\,\bar{\sigma}_z}{d\,z} = \frac{4\,\bar{\sigma}_z\,C\mu_f}{D} \qquad (2.2)$$

If it is assumed that C is a constant, Equation 2.2 may be integrated, yielding:

$$\frac{\bar{\sigma}_z\ (L)}{\bar{\sigma}_z\ (o)} = \frac{F_A}{F_R} = e^{\frac{4\,C\ \mu_f L}{D}} \qquad (\phi \geq \theta) \qquad (2.3)$$

The constant C in this equation can be easily evaluated in terms of the shear angle ϕ and the friction angle θ. The stress conditions existing at the wall in the physical plane are shown in Figure 2.1.2-a. Figure 2.1.2-b illustrates the corresponding conditions in the stress plane, if it is assumed that the material near the wall is at the point of shearing.

From the geometry of Figure 2.1.2-b, it is possible to compute the constant C; the result is:

$$C = \frac{\cos^2\ \phi}{1 + \sin^2\ \phi}\ \left[1 + \sqrt{1 - \frac{\cos^2\ \phi}{(1 + \sin^2\ \phi)^2}\ (\cos^2\phi + 4\ \tan^2\theta)}\right]^{-1} \quad (2.$$

If the friction angle $\theta = \tan^{-1}\mu_f$ is equal to the shear angle ϕ, Equation 2.4 reduces to:

2.1.1 General Mills, Inc. Report No. 2200, Third Quarterly Progress Report on Dissemination of Solid and Liquid BW Agents (Unclassified Title), May 15, 1961 (Confidential).

$$C_o = \frac{\cos^2 \phi}{1 + \sin^2 \phi} \quad (\theta = \phi) \tag{2.5}$$

Returning to Equation 2.1, if we have $\theta > \phi$, $\tau_w = \sigma_r \tan \phi$ and Equation 2.2 must be modified as follows:

$$\frac{d\,\sigma_z}{d\,z} = \frac{4 \tan \phi \;\sigma_z \;C_o}{D} \tag{2.6}$$

On integration, we obtain:

$$\frac{F_A}{F_R} = e^{\frac{4\,C_o \tan \phi\, L}{D}} \quad (\phi \leq \theta) \tag{2.7}$$

Equations 2.3 and 2.4 define the force ratio F_A/F_R for $\phi \geq \theta$ while Equations 2.5 and 2.7 apply for $\phi \leq \theta$. These results can be combined by expressing the force ratio in the following form:

$$\frac{F_A}{F_R} = e^{\frac{4\,K\,L}{D}} \tag{2.8}$$

where K is a function of ϕ and θ. For $\phi \leq \theta$, $K = C_o \tan \phi$ while for $\phi \geq \theta$, $K = C \tan \theta$. The wall resistance parameter K is plotted in Figure 2.1.3 as a function of ϕ and θ. The theory indicates that a maximum wall resistance exists, for which $K = 0.356$. Also, the wall resistance falls off rapidly with increasing ϕ for $\phi > \theta$.

The general form of Equation 2.8 has been confirmed experimentally[2.1.1];

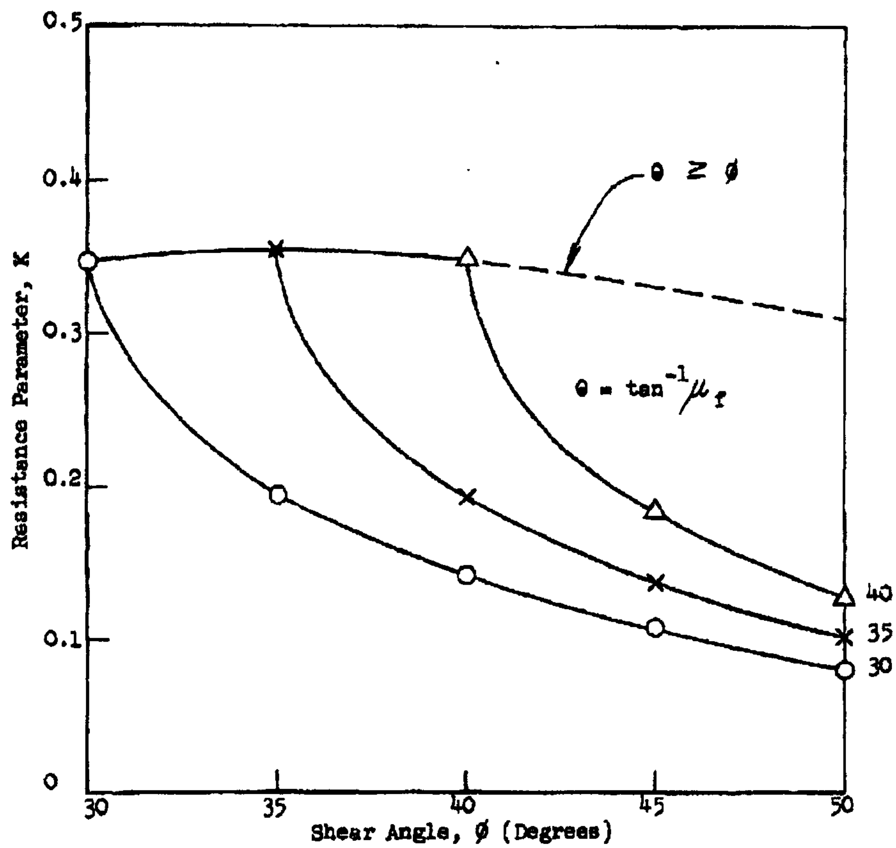

FIGURE 2.1.3 Wall Resistance Parameter as a Function of Shear Angle ø and Friction Angle θ, Piston-Cylinder Test

however, insufficient data are available on the shear strength of powders at high stresses to enable a detailed comparison of the theory with experiment at this time. The required shear strength properties of powders will be determined in the future under controlled environmental conditions. For the present, an approximate comparison between theory and experiment is possible for talc powder. Using the apparatus described in a previous report[2.1.2], the shear strength of talc was measured in a series of experiments for compressive stresses up to about 6000 dynes/cm^2. From these tests, the shear angle for talc was found to be $\phi = 35°$. Also, values of Θ and K are available from piston-cylinder tests reported in Reference 2.1.2. These values for talc on aluminum are: $\Theta = 33.6$ degrees and $K = 0.319$. From theory, we obtain $K_{th} = 0.266$. On the other hand, using data for talc on Teflon from Reference 2.1.2, we find $\Theta = 36$ degrees and $K_{exp} = 0.358$. The theoretical value in this case is $K_{th} = 0.356$. Thus, the agreement between theory and experiment is quite good for the limited data available at the time of writing.

2.2 Compaction Energy of Particulate Media

During this reporting period we have studied the relationship between the degrees of compaction (expressed by the bulk density, ρ) of a powder and the energy required to produce this compaction. Experiments were conducted in addition to theoretical analyses.

2.1.2 General Mills, Inc. Report No. 2216, Fourth Quarterly Progress Report on Dissemination of Solid and Liquid BW Agents, (Unclassified Title) August 10, 1961 (Confidential).

In setting up an experiment to determine this relationship one encounters the problem of accurately determining the energy adsorbed by the powder. Normally when a powder bed is compacted a certain portion of the energy input is expended in overcoming the friction between the powder and the walls of the container enclosing the bed. However, by making the bed depth sufficiently small, this energy may be neglected.

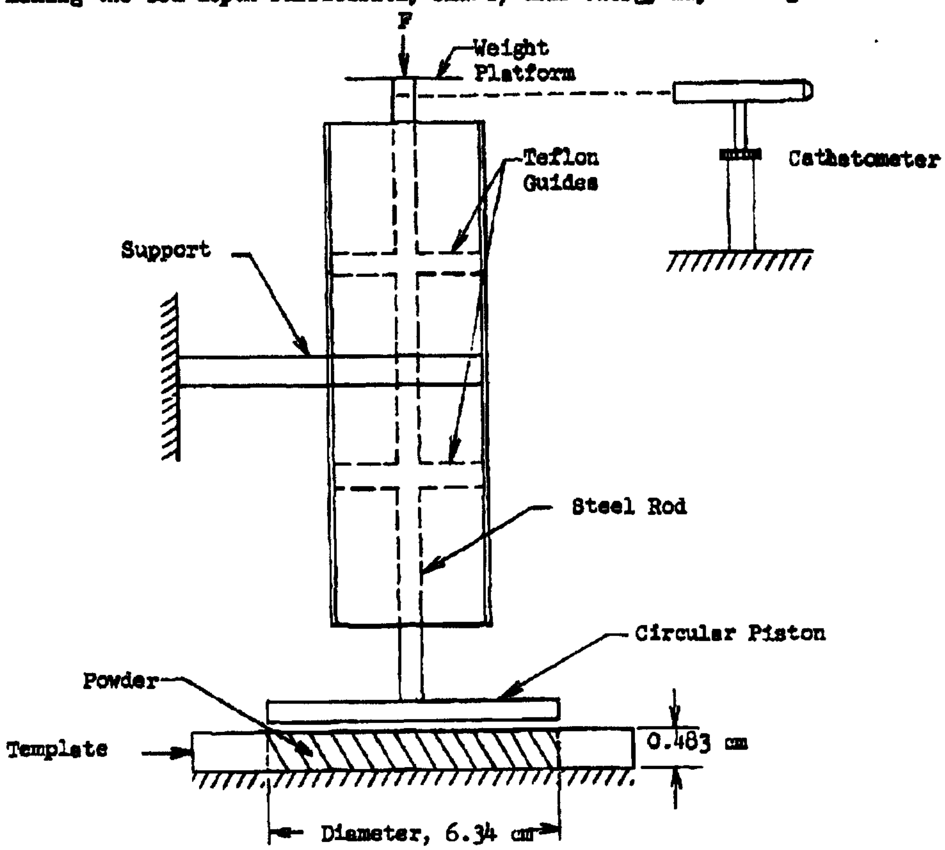

FIGURE 2.2.1 Measurement of Compaction Energy

The experimental arrangement employed in this preliminary study is sketched in Figure 2.2.1. The powder is contained within a cylindrical cavity formed by placing an aluminum template 0.483 cm thick, in which a hole 6.34 cm in diameter had been cut, on a flat surface as shown in the sketch. A piston having a diameter approximately 0.005 cm smaller than the diameter of the hole in the template was used for applying the load to the powder. Movement of the piston was measured by means of a cathetometer which could be read to within 0.005 cm.

The tests were carried out by filling the powder cavity with the powder to be tested (in this case, talc) and observing the displacement of the piston resulting from the application of known compressive stresses to the powder. The powder used in each loading sequence was weighed on an analytical balance at the completion of the experiment. The results of these tests are summarized in Table 2.2.1.

These data are presented in Figure 2.2.2 with the stress plotted as a function of the inverse density, $1/\rho$. The experimental results may be expressed with satisfactory accuracy by an empirical equation of the form:

$$\sigma = 5.558 \times 10^6 \rho^{5.46} \quad (2.9)$$

The energy E absorbed by the powder bed is given by:

$$E(x) = \int_{x}^{x_0} F \, dx \quad (2.10)$$

where F is the force acting on the piston and x is the depth of the powder bed.

TABLE 2.2.1

COMPACTION ENERGY DATA

Mass of Powder Used, grams ➡	2.43	2.58	2.52	2.46	2.43	2.52	
Stress, dynes/cm^2	Bulk Density, grams/cm^3						Δx (Average)
0	0.16	0.17	0.17	0.16	0.16	0.17	0
0.512×10^4	0.27	0.28	0.28	0.28	0.29	0.28	0
1.14	0.31	0.32	0.32	0.30	0.33	0.32	0
2.07	0.34	0.37	0.35	0.35	0.35	0.36	0
3.62	0.39	0.39	0.40	0.38	0.39	0.39	0.005
5.19	0.41	0.42	0.42	0.40	0.41	0.42	0.005
9.14	0.44	0.47	0.48	0.44	0.46	0.46	0.010
17.75	0.52	0.53	0.54	0.51	0.54	0.56	0.015

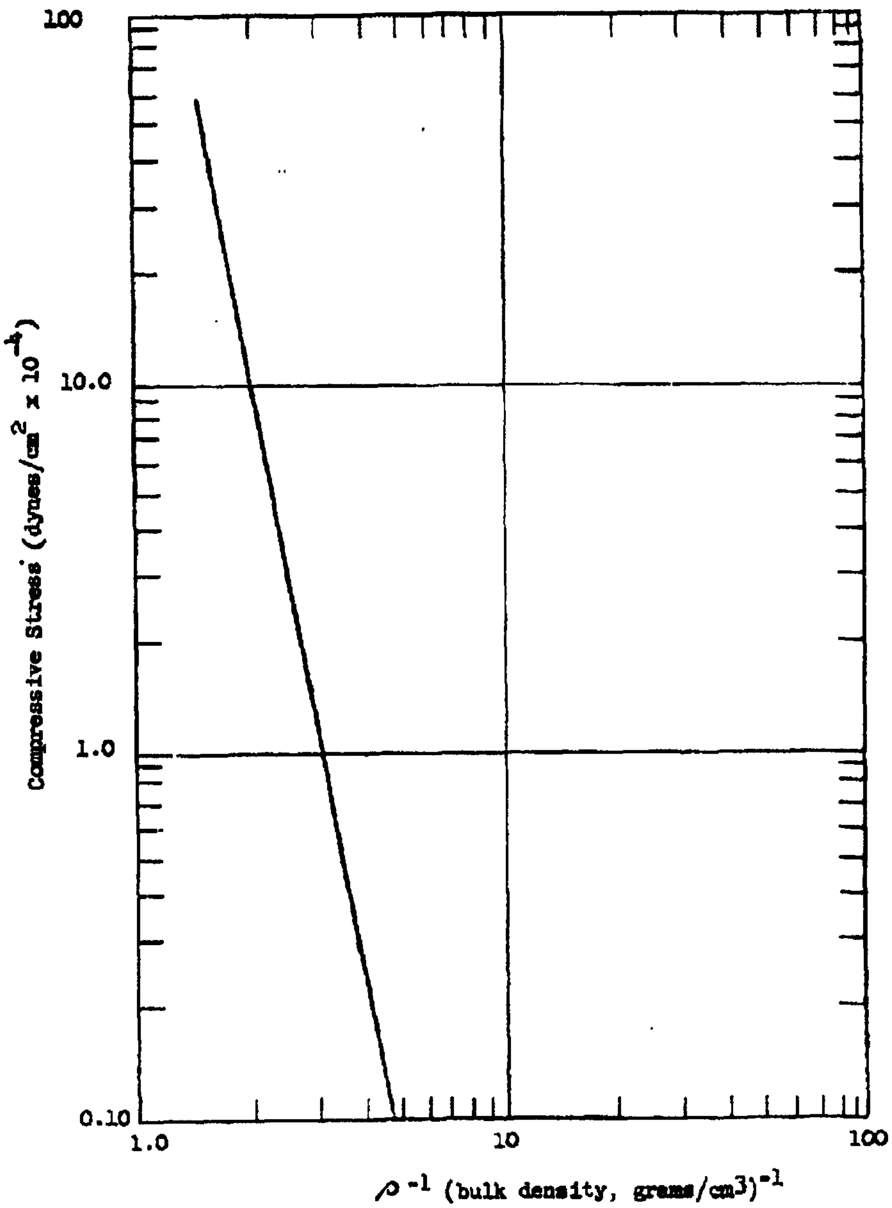

FIGURE 2.2.2 Compressive Stress versus the Reciprocal of Bulk Density for Talc

Since the area, A, of the bed remains constant we have $x_o \rho_o = x \rho$ where ρ_o is the initial bulk density and x_o is the initial depth of the powder bed. Writing $dx = x_o \, d\left(\frac{\rho_o}{\rho}\right)$ and $F = \sigma A$, Equation 2.10 gives:

$$E\left(\frac{1}{\rho}\right) = \int_{1/\rho}^{1/\rho_o} A \, x_o \, \rho_o \sigma d\left(\frac{1}{\rho}\right) = W_o \int_{1/\rho}^{1/\rho_o} \sigma(\rho) \, d\,(1/\rho) \tag{2.11}$$

where W_o is the mass of the powder in the bed and σ is the applied compressive stress.

It was noted during the course of the experiments that the powder exhibited a marked elastic behavior particularly at high stresses. Thus, with a certain load applied an associated amount of energy is stored in the material in a recoverable form. If it is assumed that the material has a linear elastic characteristic, this energy can be expressed as:

$$E_e = \int F \, dy = C \int_0^y y' \, d\,y' = C \frac{y^2}{2} = \frac{Fy}{2} = A \sigma y/2 \tag{2.12}$$

where y is the distance that the piston springs back after the removal of the force F. This distance was measured in each run for the different forces applied and is given in Table 2.2.1 under the Δx column.

The energy of compaction is thus given by:

$$E_c = W_o \int_{1/\rho}^{1/\rho_o} \sigma(\rho) \, d\,(1/\rho) - \frac{A\sigma\Delta x}{2} \tag{2.13}$$

Putting Equation 2.9 into Equation 2.13, dividing by W_o and integrating, we get for the energy of compaction per gram:

$$\frac{E_c}{W_o} = 1.25 \times 10^6 \left[\left(\frac{1}{\rho}\right)^{-4.46} + \left(\frac{1}{\rho_o}\right)^{-4.46} \right] - \frac{A \sigma \Delta x}{W_o \, 2} \qquad (2.14)$$

or

$$E_c/W_o = E_1/W_o - E_2/W_o$$

Using $\left(\frac{1}{\rho_o}\right) = \left(\frac{1}{\rho_o}\right)_{average} = 6.07$ and $W_o = (W_o)_{average} = 2.6$ grams, we get the following table from Equation 2.14.

Table 2.2.2

COMPACTION ENERGY AS A FUNCTION OF BULK DENSITY

$1/\rho$	$E_1/W_o \times 10^{-4}$ ergs/gram	$E_2/W_o \times 10^{-4}$ ergs/gram	$E_c/W_o \times 10^{-4}$ ergs/gram
3.55	0.41	0	0.41
3.1	0.77	0	0.77
2.8	1.21	0	1.21
2.55	1.91	0.11	1.80
2.35	2.72	0.16	2.56
2.12	4.38	0.58	3.80
1.87	7.58	1.68	5.90

If E/W_o is plotted versus $1/\rho$ as log-log graph paper, a straight line with a slope of minus 4.37 is obtained as shown in Figure 2.2.3. Thus, the energy of compaction, as determined from these experiments, is given by the empirical formula:

$$\frac{E}{W_o} = 9.75 \times 10^5 \left(\frac{1}{\rho}\right)^{-4.37} \text{ ergs/gram } \left(1.87 < \frac{1}{\rho} < 3.55\right) \qquad (2.15)$$

J. S. Derr, Jr.,[2.2.1] has derived an expression for the compaction energy as a function of the density which is of the form:

$$\frac{E}{W_o} = C_1 \left[\left(\frac{\rho}{\rho_o}\right)^{5.344} - 1 \right] \qquad (2.16)$$

Where ρ_o is the initial bulk density of the powder and C_1 depends on the initial bulk density of the powder, the absolute density of the basic particle, the diameter of the basic particle, and an undetermined constant E_c which is the energy per contact between two particles.

This relationship is compared with the experimental results in Figure 2.2.3 using the experimentally determined value of $\rho_o = 0.165$ grams/cm^3 and assuming $C_1 = 1.92 \times 10^2$. It is interesting to note that both the experimental data for talc and the theory give a power law relationship between the energy and the bulk density, although the exponents are somewhat different.

It appears likely that considerable insight into the behavior of powders may be obtained from a study of the compaction process. The experimental investigation of compaction energy will therefore be continued, using improved experimental apparatus which will enable more precise measurement of displacements and forces. Some of the effects which will be investigated are:

2.2.1 Derr, J. S., Mathematical Model for Energy of Compaction of a Bed of Powder, B. L. Tech. Memo. 9-22, Physical Science Div. Ft. Detrick, Frederick, Maryland.

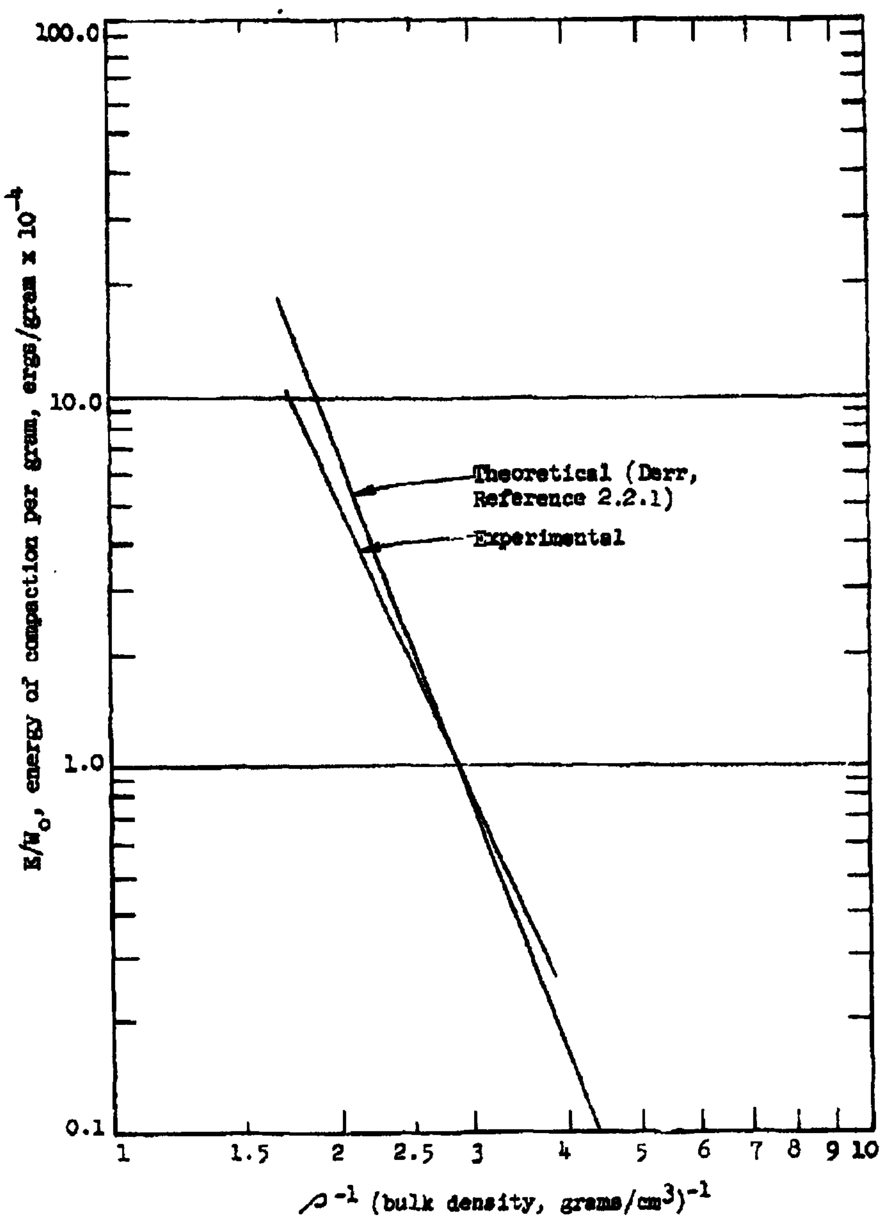

FIGURE 2.2.3 Energy of Compaction per Gram versus the Reciprocal of Bulk Density for Talc

1) Comparison of various powders with respect to compaction energy under controlled conditions and correlation, if any, between compaction energies and bulk physical properties.

2) Effect of moisture content on compaction energy for various materials.

3) Nature of elastic behavior of powders and associated hysteresis effects, if any.

4) Influence of loading history on net compaction energy change between two density states.

3. EXPERIMENTS ON THE CHARACTERISTICS OF POWDERS

In connection with both the theoretical analyses of force transmission in powders and the experimental studies of deagglomeration of finely divided solids with slipstream energy, there has developed a great interest in the property of shear strength. For this reason effort has been concentrated on obtaining experimental measurements of this property during this reporting period.

3.1 Shear Strength of Powders

Figure 3.1.1 is a sketch of the apparatus used in making the shear strength measurements. The disc and surface are roughened by cementing pieces of #100 sandpaper to the surfaces. The roughened surface is necessary to insure shearing of the powder, rather than sliding of the powder on the metal surface. The force necessary to shear the powder is determined by measuring the output of the full bridge formed by four SR-4 strain gages which are cemented to the aluminum cantilever beam.

The procedure for making the shear strength measurements is as follows: A mask, consisting of a piece of 0.1 cm thick aluminum with a 6.34 cm diameter hole in it, is placed on the roughened surface. The powder is sifted onto the mask, leveled with a spatula, and the mask then removed. The roughened disc, which is 4.57 cm in diameter, is carefully placed on the powder. Additional weights are then placed on top of the disc to give the desired compressive load. Care must be taken to properly align the disc so that it will not be subjected to a torque when the shear strength is measured. Force is then applied

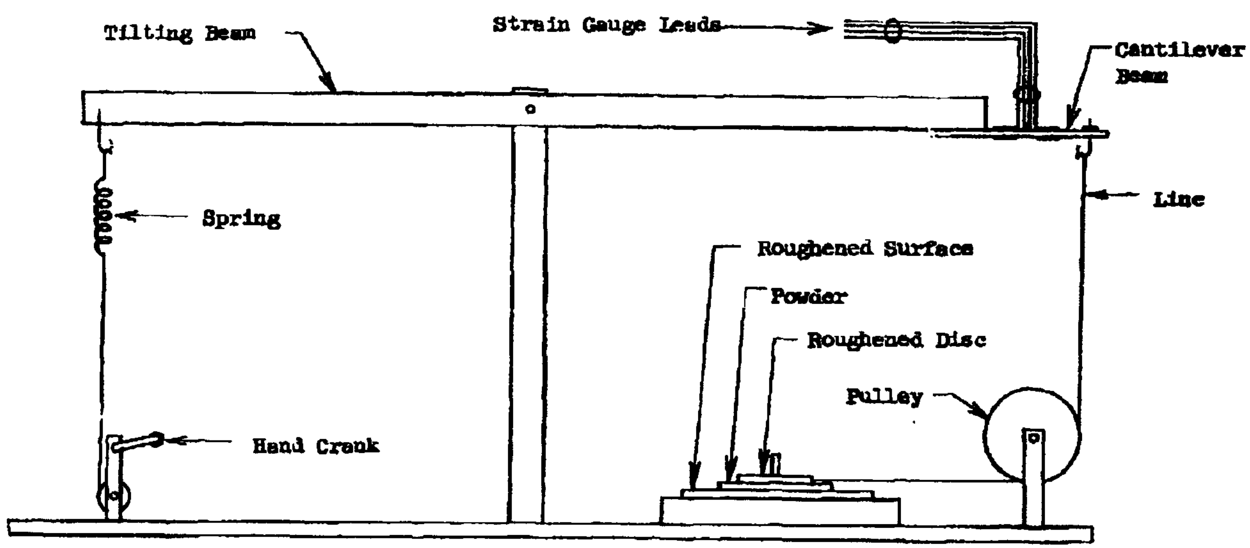

FIGURE 3-1.1 Shear Strength Apparatus

to the disc by means of the cantilever beam until the disc moves, thus shearing the powder.

The shear strength of Sm, talc, and polyvinyl alcohol powders was determined during the current report period, and the results are presented in Figure 3.1.2. These tests were made at room conditions, i.e., 75°F and about 50% relative humidity. Each point plotted in Figure 3.1.2 is the average of four measurements.

3.2 Effect of Humidity on Shear Strength

Since it is expected that the mechanical properties of most powders will be affected by humidity, the shear strength of powders is being studied under controlled humidity conditions. A controlled atmosphere cabinet has been obtained and a system has been built to control the humidity in the cabinet in the range from 1% to 75% relative humidity. Figure 3.2.1 is a sketch of the apparatus. Saturated and dry air are mixed in the proper ratio to obtain the desired humidity. Drying Unit #1 contains about four liters of "Drierite" dessicant. The final drying Unit #2 contains Linde Moleculer Sieve, Type 13X. The atmosphere in the cabinet is monitored by an infrared hygrometer which records the humidity with an accuracy of ±5% of the absolute humidity.

During conditioning of the powder, the cabinet is maintained at a very slight positive pressure (0.2 - 1.0 in. of water). It is maintained at the desired humidity for at least 48 hours prior to measurements in order to let the powder attain equilibrium with the environment inside the cabinet. During the actual shear strength measurements,the cabinet

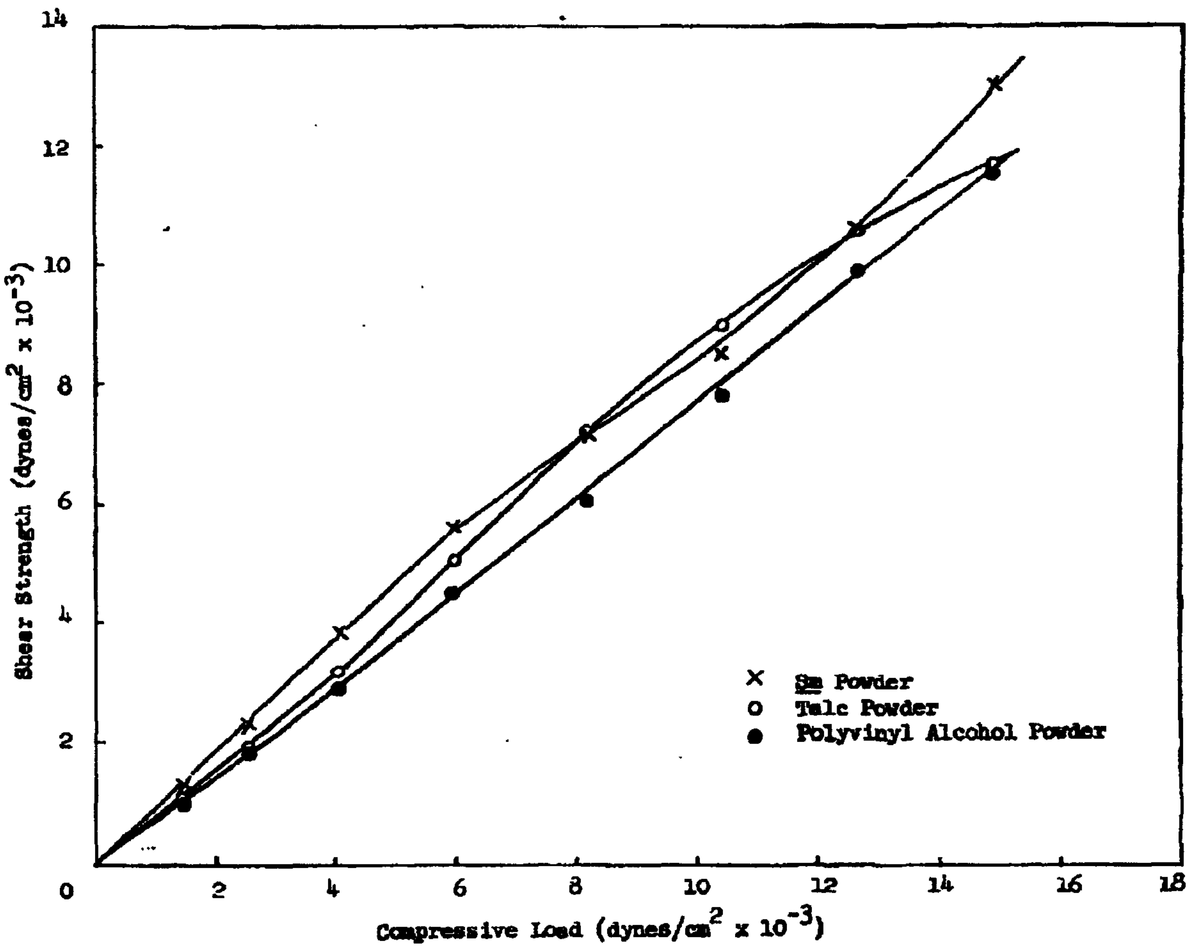

FIGURE 3.1.2 Shear Strength of Various Powders versus Compressive Load

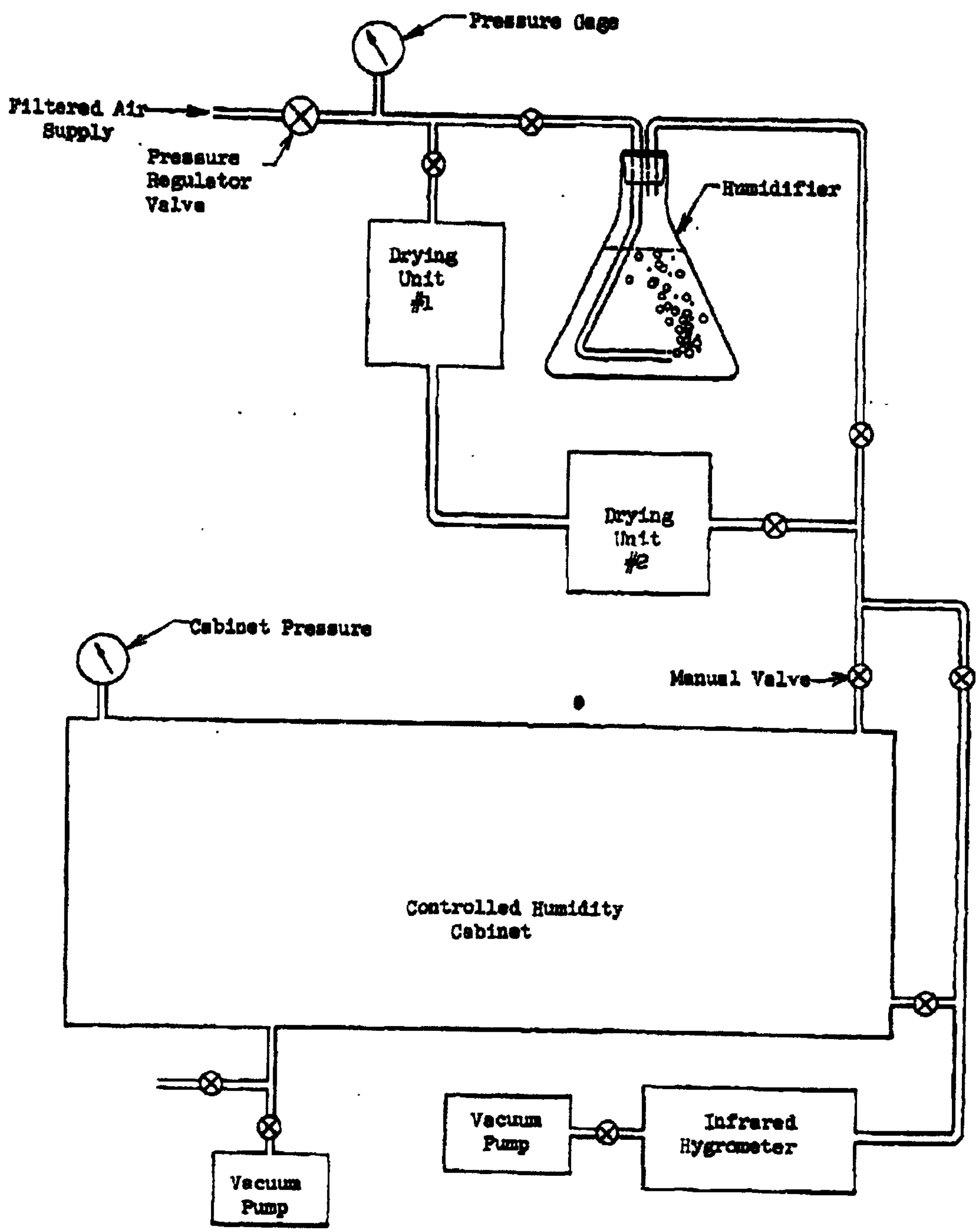

FIGURE 3.2.1 Controlled Humidity Apperatus

is maintained at a very slight negative pressure to facilitate working with the rubber gloves.

By using this system, the shear strength of Sm powder vs. compressive load has been determined at various relative humidities. Figure 3.2.2 is a plot of the results obtained (each point representing the average of four determinations). It will be noticed that the shear strength increases with increasing humidity up to 30% relative humidity. However, at 45% and greater relative humidity, the shear strength decreases to a value lower than that recorded for any of the other conditions. Other investigations[3.2.1] have obtained similar results with finely ground Carbowax 6000. A possible explanation for this apparent drop in the shear strength can be offered in terms of the condition of the powder. At the lower humidities the powder is in the form of individual particles. At the higher humidities the powder becomes caked and contains many relatively large aggregates. These can be broken up by sifting the material through a screen, but the sifted material still contains many aggregates which are the size of the screen openings. When the shear strength measurements are made, it is possible that these aggregates roll with the movement of the disc. Therefore, it is likely that some combination of shear strength and rolling friction is being measured rather than pure shear strength.

3.2.1 General Mills, Inc., Report No. 2229, Fundamental Studies of the Dispersibility of Powdered Materials, Fifth Quarterly Progress Report, Contract No. DA-18-108-405-CML-824 (30 September 1961).

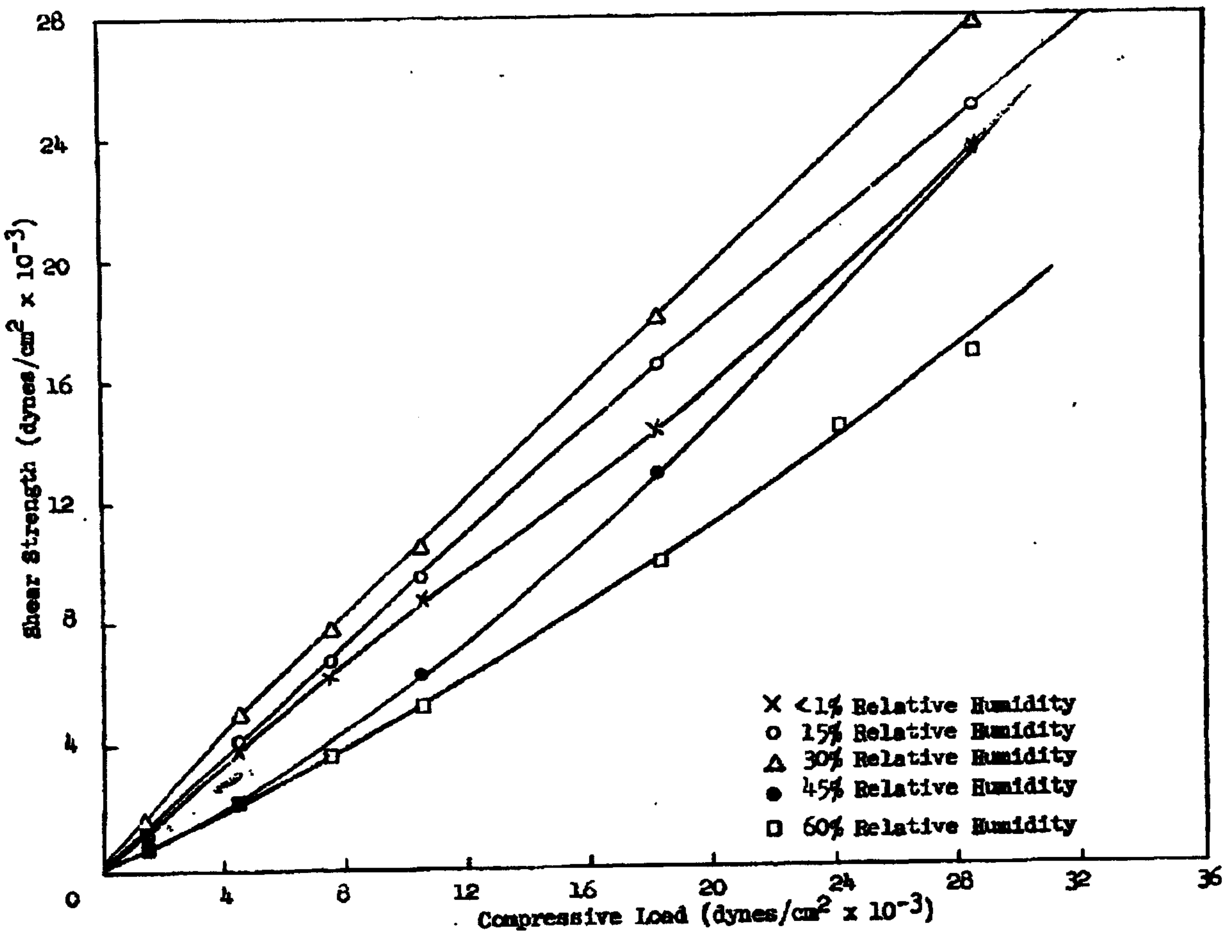

FIGURE 3.2.2 Shear Strength of Sm Powder as a Function of Compressive Load

During the next quarterly period, the shear strength of *Bacillus globigii* versus compressive load will be determined as a function of relative humidity. To supplement these experiments, the moisture content of both *Sm* and *Bg* will be measured after exposure to constant temperature environments of different relative humidity.

Tests also will be made on the shear strength of *Sm* containing varying amounts of Cab-O-Sil, a deagglomeration agent, to determine the optimum concentration for minimum shear strength.

4. DISSEMINATION AND DEAGGLOMERATION STUDIES

4.1 Introduction

Studies on the dissemination of Sm simulant were conducted in the high-subsonic wind tunnel during this reporting period. These experiments were concerned with determination of the degree of deagglomeration produced by the air stream when compacted and uncompacted Sm were disseminated by the piston-type disseminator, described in our earlier report.[4.1.1]

All of the evaluation of deagglomeration was performed by microscopic examination of particles collected on Millipore filters, placed in the isokinetic particle sampling probe. This procedure, although it is much more difficult than the Whitby centrifuge method (which is also in use on the project) was considered necessary for this phase of the work. The microscopic analysis technique minimizes the probability of breaking agglomerates collected from the airstream and permits examination of the nature of individual agglomerates.

Two types of studies were made. In the first, the particle size distribution of the collected particles was determined by direct counting. In the second, specific attention was given to the presence of agglomerates, and the number of agglomerates compared to the total particles was determined. Compacted Sm samples up to 0.65 grams/cm^3 were studied The results of these studies are given below:

4.1.1 General Mills, Inc. Report No. 2161, Second Quarterly Progress Report, Dissemination of Solid and Liquid BW Agents (Unclassified title) Feb. 13, 1961, p. 36 (Confidential).

4.2 Sm Dissemination - Particle Size Distribution

The deagglomeration of Sm in a high velocity air stream was determined by comparing the particle size distribution of the material before and after dissemination in the wind tunnel. In these tests Sm "B"* was injected at an approximate velocity of 4 meters/sec into an air stream maintained at Mach number 0.50. The resulting aerosol was sampled at the tunnel exit on Millipore filters used with the high velocity sampling probe.

A microscopic method was employed in analyzing the samplers. The specific techniques used in preparing slides from the wind tunnel sampler and the method of measuring the particles are discussed in the previous progress report[4.2.1]. For analysis of the control material before dissemination, Sm was dispersed in benzene with a Waring blender. One drop of the suspension was placed on a Millipore filter from which a slide was prepared using the technique discussed in the reference.

The Sm simulant was disseminated in both its loose and compacted forms, at bulk densities of 0.33 and 0.50 gm/cc respectively. In the latter case the material was compacted with a low-friction, piston device in cylindrical segments with a length to diameter ratio of 0.15.

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*Run S1-Sm-342

4.2.1 General Mills Report No. 2216, Fourth Quarterly Progress Report, Dissemination of Solid and Liquid BW Agents, (Unclassified title) August 10, 1961, pp. 99-100 (Confidential).

Since the moisture content of Sm has been found to be extremely important in deagglomeration, this factor was controlled by storing and working with the material in a dry box at dew point temperatures below -23°C (Relative Humidity, 3 percent). In these tests the Sm moisture content was thereby maintained at 1.7 percent.

A slight modification of the piston-type disseminator discussed in an earlier progress report[4.2.1] was made for these tests so as to provide a close control over the injection of small quantities of material. At the bottom end of the piston, a special screw was installed at the axis. It has a disc shaped head which is of the same diameter as the piston. A space of 0.63 cm is provided between the end of the piston and the disc, into which the Sm is loaded. During ejection the disc travels 0.7 cm into the tunnel air stream and small quantities of material, such as 0.01 gm, are released during periods less than 1.5 m sec.

In these tests the average mass flow rate of Sm during dissemination was about 450 gm/min (1 lb/min). As in previous tests, the resulting aerosol was concentrated near the upper tunnel wall. Therefore, the samples were taken at a position 0.63 cm below this surface.

Figure 4.2.1 shows the particle size distribution of Sm "B" before and after dissemination, plotted on log probability paper on a number basis. For each test 5 microscopic slides were prepared and a total of 1000 particles were measured. Each treatment represents an average of

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4.2.1 General Mills Report No. 2161, Second Quarterly Progress Report, Dissemination of Solid and Liquid BW Agent (Unclassified title) Feb. 13, 1961, pp. 35-36 (Confidential).

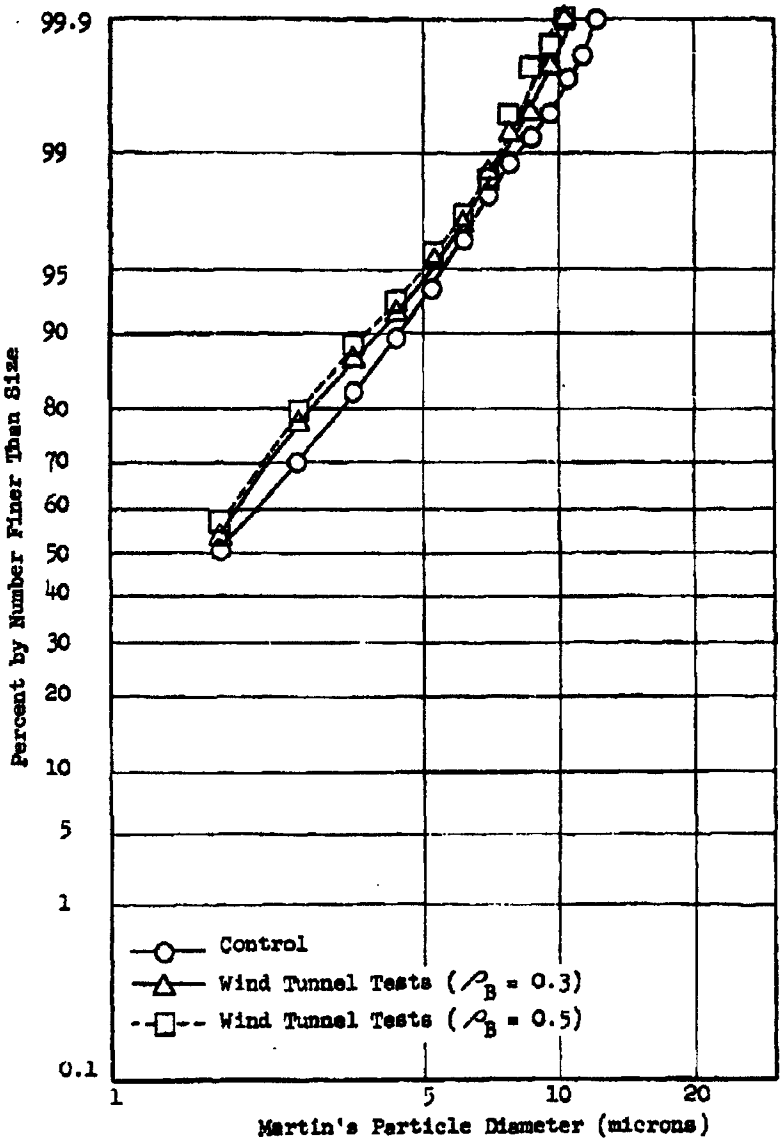

FIGURE 4.2.1 Particle Size Distribution for Sm "B" Before Dissemination and After Sampling in Wind Tunnel at Mach Number 0.5

two tests. The results show that approximately 94 percent of the particles were smaller than 5μ, in all cases.

For further insight into these data, an analysis of variance was performed. The components of variance that exist are between treatments (bulk densities and control), between samples (replicate runs of a given treatment) and the residual (between different microscope slides prepared from the same sample). To facilitate this analysis, the distribution resulting from each microscope slide was reduced to a basis of 100 particles and discretized into three fractions: 0.88 - 1.75μ, 1.75 - 3.50μ and 3.50 - 11.4μ. For the analysis each fraction was treated separately.

At the 10% confidence level no significant difference exists between samples of the same treatment. Thus, the variances may be pooled to provide a better estimate. The percent of particles in each fraction under the effect of each treatment is given in Table 4.2.1 together with the overall means, pooled standard deviations and coefficients of variation.

TABLE 4.2.1

TABULATION OF DISPERSED DATA

Treatment	Fraction 0.88 - 1.75μ	1.75 - 3.50μ	3.50 - 11.4μ
Control	50.7	31.9	17.5
Wind Tunnel (ρ_B = 0.5)	56.8	31.8	11.5
Wind Tunnel (ρ_B = 0.3)	53.6	33.4	13.0
Overall Mean	53.7	32.4	14.0
Pooled Std. Deviation	5.2	3.7	3.0
Coeff. of Variation	0.10	0.11	0.21

The results of the analysis of variance plus inspection of Figure 4.2.1 and Table 4.2.1 may be summarized by:

1. Each treatment is reproducible. There exist no statistically significant differences between samples of each treatment.

2. The difference between dispersion in all the wind tunnel tests is negligible.

3. The control sample distribution is coarser than those obtained in the wind tunnel. This implies a better dispersion was obtained in the wind tunnel than in preparation of control samples. It is felt this difference arises from difficulties in preparing a microscopic control sample. The difference is considered to be within acceptable limits from the practical standpoint of deagglomeration.

4.3 Sm Dissemination - Agglomerate Study

The degree of deagglomeration was also studied over the range of Sm bulk densities, 0.30 - 0.65 gm/cc, by determining the relative number of agglomerates and basic particles present on Millipore filter samples. The sampling probe was again located 0.63 cm below the top wall. At this location the observed agglomerates were all below 20 microns in size, with the majority in the range 1-5 microns. Also, they primarily consisted of doublets and triplets. The possibility of doublets forming as a result of two basic particles falling at the same point on the filter means that the data obtained should be on the conservative side.

Figure 4.3.1 shows the percentage of particulate material sampled that consisted of agglomerates. For each data point 1000 particles were counted under the microscope. There appears to be very good deagglomeration at bulk densities up to 0.6 gm/cc. However, at higher densities a sharp increase in the presence of agglomerates was found. Also, it was

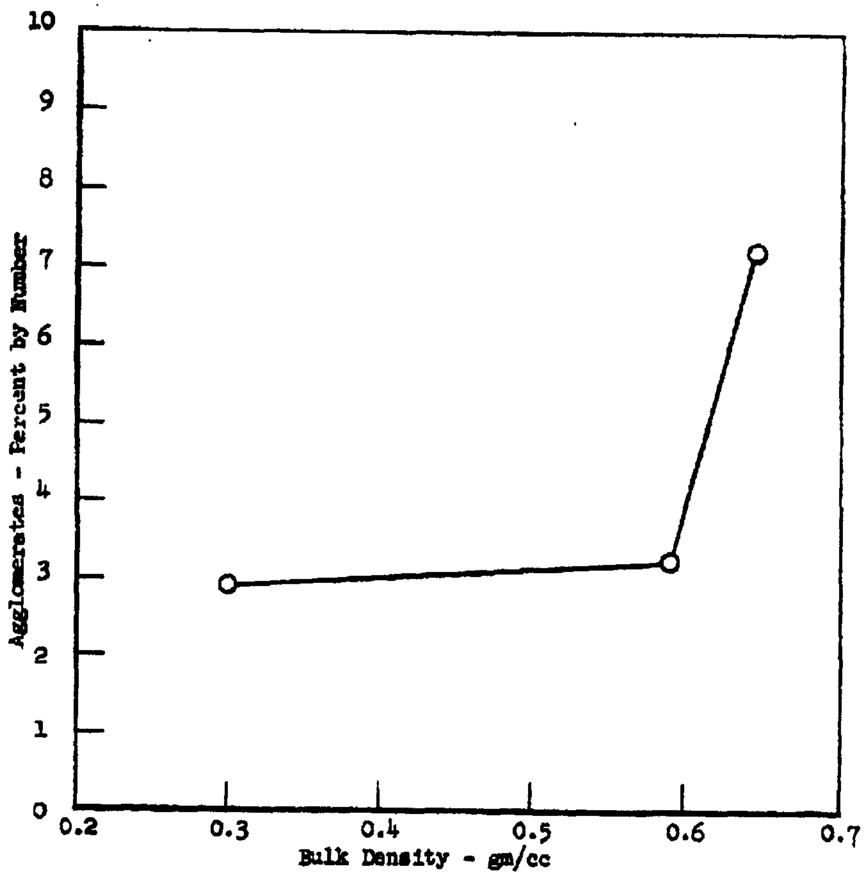

FIGURE 4.3.1 Amount of Sm Agglomerates Present in Wind Tunnel Aerosol as Compared to Basic Particles

observed that a very small number of agglomerates, on the order of 200 microns were sampled at the higher densities. In future experiments, these will be studied further to establish the amount of mass they represent.

5. DESIGN CONCEPT FOR DRY-AGENT DISSEMINATOR

5.1 Introduction

In the field of dry agent dissemination, one of the principal objectives on this project is to provide a solid-agent external disseminating store which will be as nearly as possible universal with respect to the carrier aircraft, the characteristics of the agent being disseminated and the type of mission being performed. Research conducted under this program has provided data in several areas related to disseminator design which now make it possible to establish a design concept for the first full-size airborne dry agent disseminating store to be fabricated under a later phase of this project. These findings are briefly summarized below:

(1) Deagglomeration studies in the high-subsonic wind tunnel have shown (Section 4) that dry Sm simulant (with mositure content of 1.7 percent) is satisfactorily deagglomerated by an airstream at Mach number 0.5, when compacted to a bulk density of 0.5 gm/cm^3.

(2) Experimental studies of the effect of compaction on the viability of Sm reported previously[5.1.1] have shown that approximately 80 percent of the original viability is retained after compaction with pressures as high as 16 atmospheres. Independent work at Fort Detrick indicates that bulk densities of approximately 0.5 are feasible (from the viability standpoint) with dry UL agent.

(3) In connection with the above studies it has been observed that compacted plugs of Sm (with low moisture content) can be readily broken into agglomerates which are generally in

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5.1.1 General Mills, Inc. Report No. 2216, Fourth Quarterly Progress Report on Dissemination of Solid and Liquid BW Agents (Unclassified title) August 10, 1961 (Confidential) p. 113.

> the millimeter size range. High speed photographs have shown that compacted plugs several millimeters in diameter are readily deagglomerated in the wind tunnel if the moisture content is maintained below approximately 2 percent.

The above work indicates that provision should be made in the design of the airborne disseminating store for handling compacted solid agents. For maximum flexibility it is also desirable that the store be capable of disseminating unimpacted agents. It is anticipated that the design concept described below will be suitable for both applications.

5.2 Design Concept

Figure 5.2.1 shows the principal features of the dry agent disseminating store currently under study. A cylindrical agent container is located inside the aerodynamically shaped outer skin. The space outside the agent container is filled with low-density foam insulation to minimize heat transfer into the agent before arrival at the target.

The agent container is fitted with two pistons which are mounted on a lead screw which extends the full length of the cylinder. Rotation of the screw advances the pistons toward the center of the store. This is accomplished by providing a left-hand thread on one side and a right-hand thread on the other. A guide fixed to the cylinder prevents the pistons from turning relative to the cylinder.

At the center of the agent storage container, a disaggregator is mounted on the shaft which scrapes the agent from the two plugs which are advanced from each side. The loose material falls to the bottom of the central section where it is discharged through an orifice in

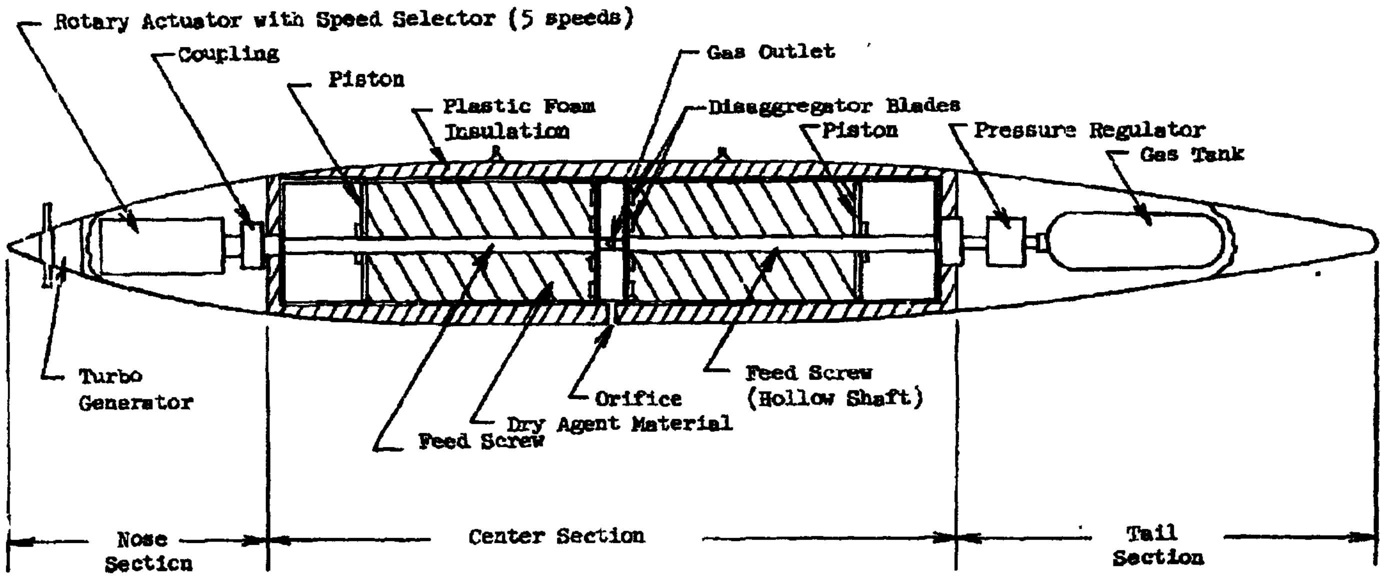

FIGURE 5.2.1 Design Concept of Airborne Dry Agent Disseminating Store

a two-phase mixture with the motivating gas (probably dry nitrogen) which is stored in a cylinder in the aft-section of the store.

The central shaft of the disseminator is driven by an electric motor through a high-torque variable speed transmission. The power for the system is generated by a ram-air turbine located in the nose of the store.

This configuration appears to have several advantages, the most important of which are listed below:

1. The length-to-diameter ratio of the plug of material being translated by the piston is approximately 3, which is compatible with moderate frictional forces. Research investigations on this contract have shown that the force required on the piston in such systems increases exponentially with the length-to-diameter ratio and becomes prohibitively high at values ($L/D \sim 6$) which would be required in a single-piston system designed for best utilization of an optimum external store shape.
2. This configuration will maintain the center of gravity within narrow limits during the entire dissemination run, in contrast with a system in which the material is transferred to the aft end of the store. This feature will minimize the required corrections to the flight controls during dissemination.
3. The arrangement of pistons is convenient for experimental use of the disseminating store with small quantities of solid agent. The residual quantities of material should be minimal and filling with a small quantity will be possible.

4. Materials with a wide range of bulk density should be compatible with this configuration giving a maximum flexibility to the disseminator.
5. The power required to drive the mechanism is low, and will be compatible with that available from a small ram-air turbine. The pistons and the slow-speed disaggregator put a very low energy into the dry agent, minimizing heating of the agent.
6. By providing a speed-selection feature, a wide range of feed rates will be available. We are currently planning to provide speeds of 100%, 75%, 50%, 37.5% and 25% of the maximum rate.

5.3 Other Design Considerations

Preliminary study has been given to several aspects of the dry-agent disseminator design, as summarized below:

5.3.1 External Shape

Six external store shapes have been considered, as listed below:

Store Designation	Fineness Ratio
NACA - 65A	6
NACA - 65A	8
NACA - 65A	10
NACA - 65A	12
Cylindrical Body	9.33
DAC Store	8.57

Ordinates for the NACA - 65A series were presented in the Second Quarterly Progress Report.[5.3.1] Ordinates for the cylindrical body and the Douglas Aircraft (DAC) store are given in Table 5.3.1.

With respect to these store shapes, two important considerations are:

1. The aerodynamic drag, and
2. The volume of the largest cylindrical agent storage container that can be placed inside the shell (see Figure 5.2.1).

The aerodynamic drag of these store shapes is summarized in Figure 5.3.1. It may be seen that at subsonic velocities below $M = 0.9$, all of these bodies have low drag coefficients (below $C_{D_\pi} = 0.1$). In supersonic flight there is a considerable increase in the drag coefficient, and the spread between the several configurations is larger. The DAC store and the NACA - 65A store with $\ell/d = 10$ have the best supersonic performance.

A study was also made to determine the volume of the largest cylindrical agent storage container that would fit in the stores. For illustrative purposes a fixed maximum outer diameter of 22 inches was used. Table 5.3.2 presents the results for the six cases studied. The highest agent volume was for the cylindrical body. In final selection of the store shape, this desirable characteristic must be weighed against the drag advantage of the DAC store in supersonic flight. The NACA - 65A store with $\ell/d = 12$ is favorable (considering agent volume) but is not a very practical design because of clearance problems associated with the greater length.

5.3.1 General Mills, Inc. Report No. 2161, Dissemination of Solid and Liquid BW Agents (Unclassified title), Feb. 13, 1961 (Confidential) p. 71.

TABLE 5.3.1

ORDINATES, IN PERCENT OF LENGTH, FOR CYLINDRICAL BODY AND DAC STORE

Cylindrical Body, Fineness Ratio 9.33		DAC Store, Fineness Ratio 8.57	
x/l, percent	r/l, percent	x/l, percent	r/l, percent
0.	0.	0.	0.
.360	.300	1.944	.946
1.210	.730	4.722	2.033
3.040	1.440	7.500	2.869
4.870	2.090	10.278	3.513
6.710	2.650	13.056	4.016
8.260	3.070	15.833	4.416
9.150	3.290	18.611	4.745
9.690	3.440	21.389	5.026
10.840	3.700	24.167	5.272
11.990	3.940	26.944	5.485
13.140	4.120	29.722	5.661
14.290	4.300	32.500	5.785
15.440	4.440	35.278	5.833
17.740	4.700	42.500	5.833
20.040	4.920	49.722	5.833
22.340	5.080	52.500	5.812
24.640	5.200	55.278	5.749

Table 5.3.1 Continued

x/l, percent	r/l, percent
26.940	5.300
29.240	5.340
31.540	5.360
61.700	5.360
68.690	5.200
74.950	4.760
81.220	3.940
87.480	2.760
90.600	2.110
93.750	1.420
96.890	.720
98.440	.360
100.000	0.

x/l, percent	r/l, percent
58.046	5.646
60.833	5.507
63.611	5.332
66.389	5.125
69.167	4.808
71.944	4.623
74.722	4.334
77.500	4.023
80.278	3.693
83.056	3.347
85.833	2.989
88.611	2.620
91.389	2.246
93.611	1.944
95.833	1.630
98.056	1.208
100.000	0.

Source: Stevens, J. E. and P. E. Purser, "Flight Measurements of the Transonic Drag of Models of Several Isolated External Stores and Nacelles", NACA Research Memorandum RM L54L07, 1955, p. 11.

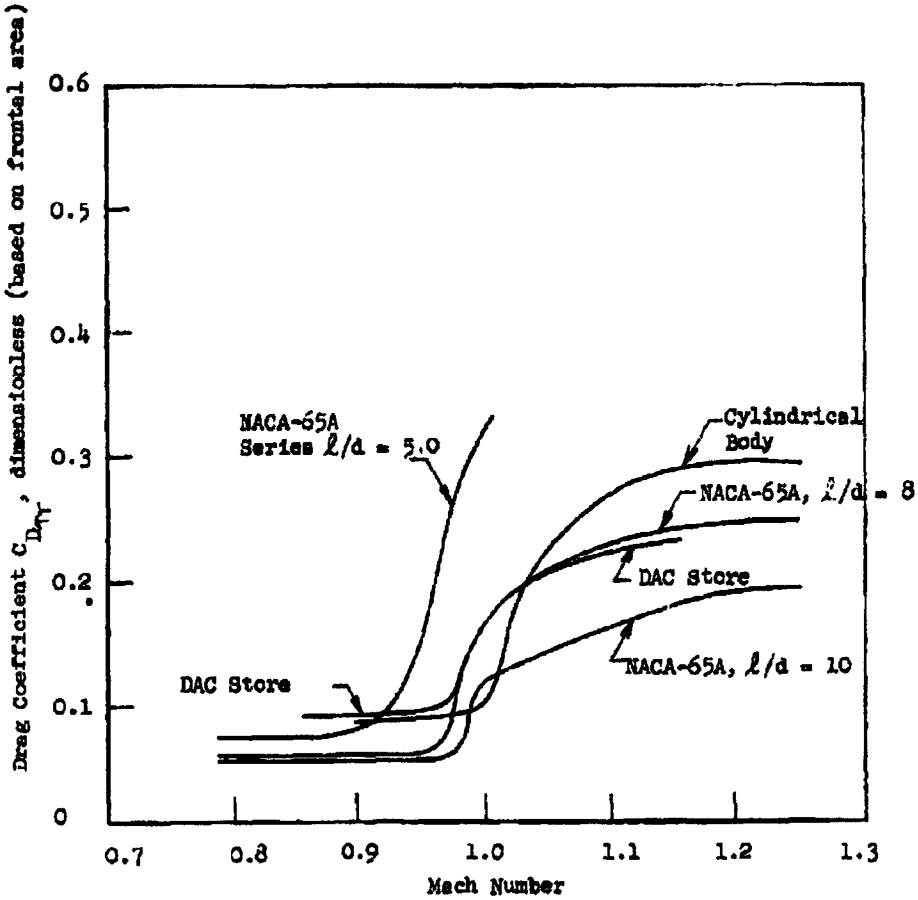

FIGURE 5.3.1. Transonic Drag Coefficients of Isolated Stores

Source: Stevens, J. E. and P. E. Purser, "Flight Measurements of Transonic Drag of Models of Several Isolated External Stores and Nacelles", NACA Research Memorandum RML54L07, 1955.

TABLE 5.3.2

DIMENSIONS FOR MAXIMUM VOLUME TANKS FITTING INSIDE BODIES OF REVOLUTION 22-IN. MAX. DIA. (1-In. Min. Clearance at Ends of Tank)

Body Designation	Fineness Ratio	Agent Volume (Cu. In.)	Length (In.)	Diameter (In.)	ℓ/d
NACA - 65A	6	11,440	58.0	15.8	3.67
NACA - 65A	8	15,420	81.2	15.2	5.23
NACA - 65A	10	18,900	94.0	15.8	6.07
NACA - 65A	12	23,150	116.5	15.8	7.37
Cylindrical	9.33	28,500	111.1	18.1	6.15
DAC	8.57	19,580	94.8	16.3	5.83

5.3.2 Discussion of the Rotating Mechanisms

It is currently planned that the rotational speed of the central shaft will be used as the main control of feed rate. The function of the gas flow will be to discharge the material into the slipstream at the same rate it is delivered by the pistons. It is planned that the unit will be provided with a speed selection feature to permit operation at 100%, 75%, 50%, 37.5% and 25% of the maximum speed. Considering the possibility of intentionally varying the bulk density of the agent over a range of approximately 2 to 1, these 5 speeds could provide a range of agent mass flow rates varying by a factor of eight (8).

The process of removal of material from the advancing slugs is a slow-speed low-energy process which should have a minimum effect on the viability of the agent. For illustrative purposes we may assume that the agent mass flow rate is to be 30 pounds per minute, the diameter of the agent container is 18 inches, and the agent is initially compacted to a bulk density of 0.5 gm/cm^3 (31.2 $pounds/ft^3$). Each piston must then deliver 0.482 ft^3/min, which corresponds to a rate of advance of 0.272 ft/min. A rotational speed of 16 rpm would be compatible with a rate of advance of 0.017 ft (.20 inch)/revolution. A variety of designs for the disaggregator suggest themselves. Multiple cutter-blades are perhaps the most straightforward design. An array of spikes or needles is also a possibility. Such designs will be evaluated in future laboratory investigations.

With the lead screw running through the cylinder, it will be necessary to devise a method for cleaning out the thread just ahead of the piston. If this is not feasible, the screw will have to be covered by a telescoping or collapsing shroud.

It will be necessary to seal off the ends of the cylinders to prevent escaping material adhering to the cylinder walls. This might be done by placing a bulkhead at the ends of the cylinder. An alternate solution would be to use a pleated sleeve sealed to the piston at one end and the cylinder at the other. As the piston moves toward the center, the sleeve would unfold.

As the piston moves toward the center, the space behind the piston must be filled with air (or other gas) to equalize the pressure.

One aspect of the proposed concept which needs to be investigated more fully is the force required to move the pistons when the cylinder is loaded with compacted material. Data presently available on piston forces pertain to small-diameter cylinders initially filled with loose material. Tests are needed in which material is compacted into cylinders approximately 18 inches in diameter and forces required to move the compacted load are measured. In the event that excessively large cylinder wall resistive forces are encountered, methods will be sought for reducing these forces. Some thought has been given to methods for accomplishing this.

Since these forces result from radial pressure of the compacted material against the inner cylinder wall, it should be possible to lower the force if the cylinder of material is allowed to expand slightly after the material is compacted. This could be accomplished by compacting the material in an auxiliary loading cylinder which is slightly smaller in diameter than the cylinder in the store. When the compacted plug is pushed into the store, the plug can be expanded, without creating high radial pressures.

5.3.3 Estimate of Power Required to Drive Feeding System

Because of the low rotational speed (approximately 16 rpm) of the disaggregator, the power consumed by this portion of the unit is expected to be small relative to the power required to move the material along the cylinder by means of the screw-driven pistons. An estimate of the power required to drive the pistons can be made if the experimental values of piston forces obtained with small-diameter cylinders are assumed to apply to large-diameter cylinders as well. This relationship will be studied in detail before final designs are made. However, preliminary indications from tests with talc (compressed to 0.5 gm/cm^3) are that a pressure of 20 psi will be adequate.

To exert a pressure of 20 psi, a piston 18 inches in diameter must be driven by an axial force of 5090 lbs. The screw which drives the piston has a pitch of 0.2 inches. If we assume a conservative value of 15 percent for the efficiency of the screw, it is possible to calculate the torque which must be applied to the screw from the following equation:

$$T = \frac{F\,p}{2\pi e}$$

where:

T = applied torque

F = axial force

p = pitch of screw

e = efficiency of screw

Thus:

$$T = \frac{5090\ (.2)}{2\pi(.15)} = 1080 \text{ inch lbs.}$$

Since there are two pistons on the screw, the total torque required is 2160 inch lbs.

The horsepower required to drive the screw is calculated by means of the following equation:

$$\text{Horsepower} = \frac{2\pi N T}{33{,}000}$$

where:

N = speed in rpm

T = torque in ft lbs.

Therefore,

$$\text{Horsepower} = \frac{2\pi \times 16 \times \frac{2160}{12}}{33{,}000} = .55$$

Power of this magnitude is readily attainable with the ram-air turbo-generator proposed as the power source. It is quite possible that experimental results will demonstrate that values selected for the above calculations were too conservative and that a lower power requirement can be assigned to the screw drive.

6. STUDIES OF THE JET PLUME PROBLEM

6.1 Introduction

We have been very much interested in evaluating the potential deleterious effects of hot gases from jet engine exhausts on the viability of BW aerosols. This consideration is believed to be important in cases where the disseminator is located in close proximity to an engine, such as a center-line installation on a single engine aircraft or on inboard pylon installation on small aircraft where the separation distance is short.

We have experimentally studied the effect of elevated air stream temperatures on the viability of Serratia marcescens, aerosolized from a liquid suspension, and have found substantial losses in viability, for exposure durations as low as 0.6 seconds. The most recent work is discussed in Paragraph 6.2 below. An analysis has also been made which indicates that, in cases where the aerosol is released close to the engine, mixing of the aerosol cloud and the engine exhaust is very likely to expose the biological material to temperatures which are high enough to reduce the viability of the aerosol. This work is discussed in Paragraph 6.3.

6.2 Effect of Elevated Air Stream Temperatures on the Viability of Serratia marcescens Aerosolized from Liquid Suspension

In the previous report[6.2.1] it was shown that the viability of Serratia marcescens aerosolized from a liquid suspension was significantly reduced by exposure to temperatures of 50°, 75°, 100° and 125°C

6.2.1 General Mills Report No. 2216, Fourth Quarterly Progress Report on Dissemination of Solid and Liquid BW Agents (Unclassified title), August 10, 1961, pp. 2-9 (Confidential).

for a period of 1.7 seconds. The purpose of these experiments was to obtain data which would enable prediction of the effect of mixing a viable biological aerosol with the hot exhaust gases of a jet engine. An exposure time as large as 1.7 seconds was considered necessary in order to account for turbulent mixing effects which exist at the point of interception of the aerosol streamlines with the jet plume. These experiments have been continued during the present report period to investigate the effect of shorter exposure times at various temperatures. Data reported here were obtained at exposure times of 1.1 and 0.6 seconds in the temperature range from 50° to 125°C.

6.2.1 Experimental

The experimental setup was identical to that previously described[6.2.1]. Aerosols were generated using a modified Vaponephrin nebulizer charged with 6.0 ml of the Sm suspension. The aerosols were sampled simultaneously from both the heated leg of the apparatus and the unheated control leg using All Glass impingers. Flow rate in all experiments was 12.5 liters per minute and the duration of each run was 15 minutes. Viability determinations were made in the manner discussed in the above referenced report.

6.2.2 Results and Discussion

The effect on viability of exposure of Sm aerosols to heated air streams for periods of 1.1 and 0.6 seconds is presented in Table 6.2.1. These data on the mean percent recovery as a function of temperature are plotted in Figure 6.2.1 along with the data previously obtained at an exposure time of 1.7 seconds. It is apparent from this figure that,

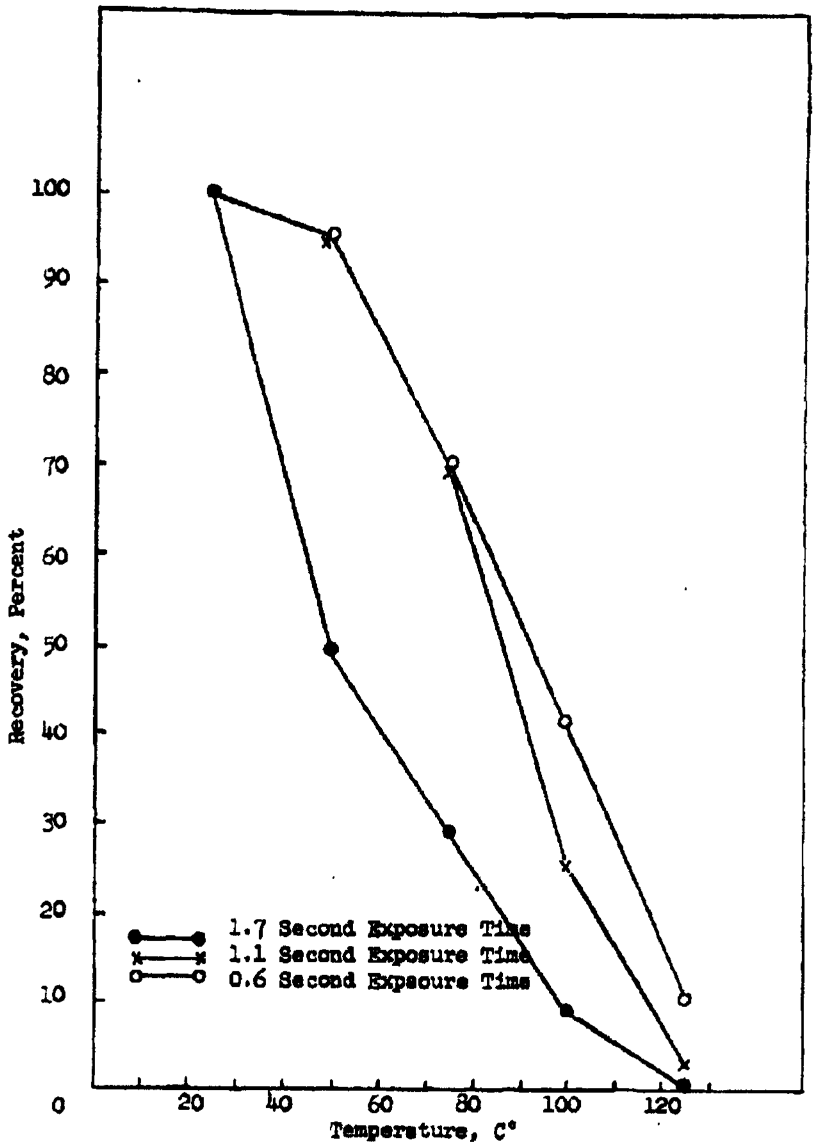

FIGURE 6.2.1 Effect of Heated Air Streams on the Viability of Aerosols of S. marcescens

regardless of the exposure time to heated air, the viability decreases rapidly with increasing temperature.

TABLE 6.2.1

EFFECT OF ELEVATED AIR STREAM TEMPERATURES
ON THE VIABILITY OF S. MARCESCENS
AEROSOLIZED FROM LIQUID SUSPENSIONS*

Temperature C°	Recovery, Percent Exposure Time, Seconds 1.1 Seconds	0.6 Seconds
25	100	100
50	95	95
75	70	68
100	25	44
125	7	10

*Duration of all runs was 15 minutes

The results obtained to date indicate that a viable aerosol, formed from liquid suspension and then exposed to heated air, attains temperature equilibrium with its surroundings very rapidly (< 0.6 seconds). As a result, there is an appreciable decrease in the viability of the organisms even for short exposure times at fairly low temperatures.

The conclusions reached as a result of this study are based on the experimentally determined behavior of aerosols produced from a liquid suspension of the one simulant, Sm. Similar experiments will be performed in the future on aerosols of Serratia marcescens and Bacillus globigii produced from the dry material. This future work will provide information on the behavior of an additional simulant, and also will determine the susceptibility of these organisms when they are disseminated directly from a dry agent store into a heated air stream.

6.3 Analysis of Jet Plume Mixing

After reviewing the earlier work on this subject we found that a geometric approach was being used; that is, the degree of interaction between the aerosol cloud and the jet exhaust was being determined by estimating the geometrical shape of the aerosol cloud and superimposing the average temperature profiles of the engine on this cloud. Conclusions were then drawn as to the proportion of the aerosol cloud which would be exposed to temperatures above a selected critical level. We feel that this approach does not properly consider the turbulent nature of the exhaust plume, which (once mixing of the aerosol with the plume occurred) could bring the biological material into regions of much higher temperature than indicated by the plot of the average temperature distribution. Therefore, it appears that the boundary of the jet plume established by the velocity discontinuities are more important to this problem than that established by a selected average temperature profile.

The boundary of the jet plume can be defined as the surface on which the velocity ratio $\frac{V - V_o}{V_a - V_o} = 0.10$ where V is the local mean velocity, V_o is the flight speed and V_a is the mean velocity on the axis of the jet. According to Kuchemann,[6.3.1] this condition is obtained on a conical surface having a semi-vertical angle given by:

6.3.1 Kuchemann, D. and Weber, J., Aerodynamics of Propulsion, McGraw-Hill (1953).

$$\bar{\theta} = 9.0 \frac{1 - \lambda}{1 + \lambda} \quad \text{(degrees)}$$

where $\lambda = \frac{V_o}{V_e}$, V_e being the velocity at the exit of the engine. As an illustrative case, taking $\lambda = 0.5$, $\bar{\theta} = 3$ degrees.

At this boundary of the plume, air is entrained from the surrounding atmosphere. A study of the entrainment of air by the jet exhaust indicates that streamlines originating upstream of the plume tend to be deflected toward the axis of the jet before entering the plume. However, neglecting this tendency for the aerosol to be drawn into the plume, the point of entry into the plume may be calculated by assuming that these streamlines are straight lines parallel with the engine axis. For an example case of a small dro..s, where the disseminator mounting station is approximately three feet from the center line of the engine, this point of entry into the plume would be at a distance of $\bar{x} = 57$ ft downstream from the engine exhaust nozzle.

Using results from Reference 6.3.1, the temperature distribution along the axis of the plume can be represented by the empirical equation:

$$\frac{T(x) - T_o}{T_e - T_o} = \frac{5}{(1 - \lambda)(\frac{x}{D_e})} \qquad (\text{for } \frac{x}{D_e} \geq 5)$$

where $T(x)$ is the mean temperature on the axis at a distance x from the engine exhaust nozzle, T_o is the ambient temperature, and T_e is the engine exhaust temperature. The engine nozzle diameter is D_e. For the drone, we have $T_e = 1200°F$; thus for $\bar{x} = 57$ ft, $T_o = 80°F$, $T(\bar{x}) = 420°F$.

Experimental investigations cited in Reference 6.3.1 have shown that the temperature distribution in the plume is broader than the velocity distribution. Thus, a 10 percent temperature rise occurs on a conical surface of semi-angle $\delta_t = 4°$ while the 50 percent rise occurs at an angle of about 2 degrees. This temperature distribution is indicative of the turbulent mixing process taking place in the plume, since thermal energy is transported largely by turbulent diffusion. It follows that material entering the plume will be subject to mixing throughout the plume and may therefore be exposed to the full range of temperatures existing within the plume.

7. RHEOLOGICAL BEHAVIOR OF <u>SERRATIA</u> <u>MARCESCENS</u> SLURRIES

The investigation of the flow characteristics of slurries of Serratia marcescens in a fluorochemical liquid was concluded during the present report period. An extrusion rheometer was used to study the flow properties of slurries of high solids concentration.

7.1 Extrusion Rheometer

The capillary viscometer[7.1.1] and rotational viscometers previously employed in studying the rheological behavior of Sm slurries in the fluorochemical liquid FC-75 were not capable of handling slurries of greater solids concentration than 25 - 30 percent by weight. To extend the investigation to slurries of higher solids concentration, a simple extrusion rheometer was constructed for use with an Instron tensile tester. The rheometer consisted of a 1.625 inch (4.14 cm) diameter cylinder capped at one end and containing a small orifice in the cylinder wall, and a close-fitting piston. The cylinder was loaded with the slurry under examination, the piston was inserted, and the device was placed in the compression test cage of the Instron. The force required to extrude the slurry through the orifice at a constant flow rate was recorded automatically as a function of the piston travel.

The orifice initially used was 0.078 inches (0.198 cm) in diameter. By varying the rate of jaw travel of the Instron, the volumetric flow rate through this orifice could be changed from 0.1 to 2.8 cm^3/sec.

7.1.1 General Mills Report No. 2216, Fourth Quarterly Progress Report on Dissemination of Solid and Liquid BW Agents (Unclassified title) August 10, 1961, p. 59-61 (Confidential).

Additional tests were performed with an orifice 0.1 inches (0.25 cm) in diameter.

7.2 Experimental Results

Force versus flow rate curves were obtained on slurries of 33-1/3 and 40 percent by weight Sm. An attempt was made to prepare slurries of Sm more highly concentrated than 40 percent by weight with no success. At higher concentrations there is not sufficient liquid present to suspend the dry material.

The results obtained with the rheometer showed that the force required to extrude the slurries at a constant volumetric flow rate increased continuously with the amount of material extruded. Figure 7.2.1 presents the results of a typical experiment with a 33-1/3 percent by weight Sm slurry. The pressure required to initiate flow through the orifice was about 10 psi (0.68 atm). The pressure required to maintain flow rose continuously to a value of 1000 psi (68 atm), the limit of the load cell, after 23 cm^3 of slurry had been extruded. Similar behavior was observed at other flow rates and with the 40 percent by weight Sm slurry. At higher flow rates and solids concentration, the rise in force occurred more rapidly.

It was thought that the phenomenon described above might be due to a preferential displacement of the fluorochemical liquid which would deplete the Sm slurry remaining in the rheometer of liquid FC-75. This hypothesis was tested by taking samples of the extruded Sm slurry in weighing bottles periodically throughout one of the runs. The slurry tested was initially 33-1/3 percent by weight Sm. The samples which were

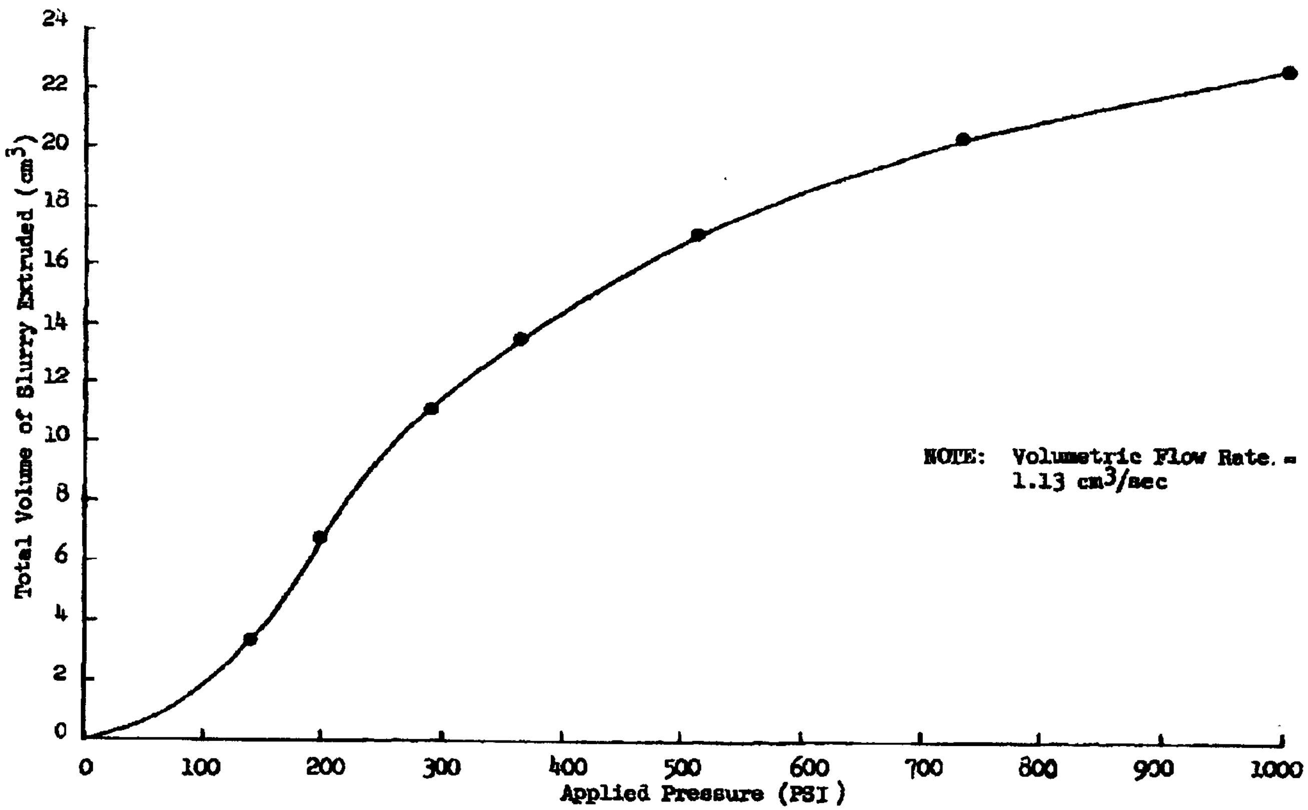

FIGURE 7.2.1. Pressure Required to Extrude 33-1/3 Percent by Weight Sm Slurry

analyzed were richer in FC-75 than the original mixture. The sample taken from the first material extruded was only 29.2 percent by weight Sm. The Sm content increased gradually as more slurry was extruded reaching a value of 32.3 percent at the 1000 psig limit of the Instron. At this point considerable unextruded slurry remained in the cylinder which had an Sm content in excess of 33-1/3 percent by weight.

Extrusion tests made with the 0.1 inch (0.25 cm) diameter orifice yielded similar results to those described above.

7.3 Conclusions

These rather simple tests described above were made to determine the feasibility of feeding highly concentrated Sm slurries through restrictions such as an orifice. From the information obtained it is concluded that it would not be feasible to handle slurries more highly concentrated than 25 - 30 percent by weight of Sm. At higher concentrations extremely large pressures would be required to move the slurry through an orifice, and the extruded slurry would vary in Sm concentration throughout the extrusion process. Finally, a slurry of higher Sm content than 40 percent by weight cannot be prepared because there is not sufficient liquid present to suspend the material.

In view of these findings, it appears that the maximum concentration of Sm which can be conveyed and metered by the slurry technique lies in the range of 25-30 percent by weight. A slurry containing 25 percent by weight Sm has a density of 1.58 gm/cm^3.[7.3.1] Since 25 percent of the slurry is Sm, it follows that there would be 0.40 gm of Sm per cm^3. However, the density of Sm in its dry, uncompacted form is 0.33 gm/cm^3.[7.3.2] Therefore, use of Sm in slurry form to deliver a given mass of the simulant would require carrying about four times the total weight of material than would be required in using dry, uncompacted material.

7.3.1 General Mills Report No. 2216, Fourth Quarterly Progress Report on Dissemination of Solid and Liquid BW Agents (Unclassified title) August 10, 1961, p. 61 (Confidential).

7.3.2 Ibid, p. 73.

[redacted]

8. PROGRESS ON THE LIQUID DISSEMINATING STORE

8.1 Introduction

In our Fourth Quarterly Progress Report it was pointed out that the disseminating store to be fabricated on this program would be one designed for use on manned aircraft, rather than for the USD-5 Drone. The general configuration of this external store was shown in a drawing, included as part of Appendix B of that report[8.1.1].

The external shape of the store which was selected is known as the Douglas (DAC) shape. This design has a subsonic drag coefficient which is comparable to other good shapes and a very low supersonic drag coefficient, as discussed in Section 5 of this report. The generalized coordinates of this store shape are also given in Section 5.

The disseminator will have a length of 227 inches and a maximum diameter of 26.5 inches. The liquid agent will be contained in an inner tank (filament wound glass fib er construction) which will have a capacity of 180 gallons of liquid agent. The space between the inner tank and the skin will be filled with a low-density, foamed-in-place insulation. A ram air turbine-generator, mounted in the nose of the store will provide 400 cycle, 3-phase power for the other electrical components in the store. The liquid agent will be discharged at a flow rate of 18 gpm through slit-type nozzles located in two booms which extend below the store during operation and are retractable into the store. A motor driven pump will deliver the agent to the booms during

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8.1.1 General Mills, Inc., Report No. 2216, Fourth Quarterly Progress Report, Dissemination of Solid and Liquid BW Agents (Unclassified title), August 10, 1961 (Confidential) p. 28 of Appendix B.

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dissemination and will also provide a recirculation feature during flight before dissemination, to minimize settling of the solids in the agent. The booms and the plumbing compartment will be electrically heated to prevent freezing.

8.2 Design Approach

It has been decided that the detailed design and fabrication of this disseminating store will be performed as an in-house effort at General Mills, Inc. The overall design configuration has been established and layout and detailing is proceeding in all areas of the design. Several of the components will be purchased from other organizations. Orders have been placed for major purchased parts, including the outer tank assembly, the inner glass fiber tank and the ram air turbine-generator. The specifications for these purchased items are included as Appendices A, B and C to this report. The quoted delivery dates on all of these items are compatible with the overall project schedule.

The disseminator will be separable into three sections: (1) the nose section, (2) the center section, and (3) the tail section. The nose and tail sections will be bolted to the center section at section joint rings. The outer aluminum shell and associated structural members for all three sections will be fabricated and assembled by Fletcher Aviation Corporation. Fletcher will also install the inner tank and fill the space between inner tank and outer shell with foam type insulation.

8.2.1 Nose Section

The nose section consists of the ram air turbine generator and the forward compartment. The Allison Division of General Motors will supply the turbine generator which will have a 4.5 KVA capacity. The forward compartment will house electrical connections to the generator, circuit breakers, and the generator voltage regulator. A door in the forward compartment will provide access to the electrical components mounted in the compartment and to the bolts attaching the nose section to the center section.

8.2.2 Center Section

The center section of the liquid agent disseminator extends from station 23 to station 171.5 and includes the inner tank, the lug attachment and "strong back" structure, and the aft compartment housing the plumbing and fluid handling system.

The filament-wound fiberglass inner tank will be supplied by Lamtex Industries, Inc. The space between the inner tank and the outer shell will be filled with foam insulation. This insulation will perform three main functions (1) provide structural support to the outer shell, (2) provide support for the inner tank, and (3) prevent heat loss from the inner tank. The military specifications for aircraft wire and installation have been reviewed, and wire and conduit sizes have been determined for the part of the system which passes through the insulated section of the store. Considerable engineering effort has been devoted to design of the fluid handling system, located in the aft compartment of the center section. Space is limited in this area, requiring careful attention to selection and placement of components.

[redacted]

The severe leak-tightness requirement, as determined by the General Electric H-1 halogen detector has been the most important consideration in selection of components for the fluid handling system.

It has been determined that the pump unit which is most suitable for this application is a rotary vane-type pump manufactured by Lear-Romec. With respect to leak-tightness, the manufacturer has assured conformance to a leakage test using soap solution and air at 20 psig air pressure, but has not performed the halogen test. We have elected to purchase this pump because we believe it to be the best available and subject it to the hologen leakage test in our laboratories. As a back-up measure, we have considered enclosing the entire pump and motor in a sealed casing. This will be done only if tests prove the necessity, since it makes the space problems more critical.

The 28 volt DC solenoid valves will be supplied by the Marotta Valve Co. This manufacturer is confident that these valves will meet the severe leakage tests. However the tests will have to be performed by General Mills, Inc. If these valves do not pass the leakage test, modifications to improve them will be investigated.

Hydropoise, Incorporated will supply the flow indicator. The primary factors considered in selection of the flow indicator were pressure drop across the instrument, size and weight. The meter selected is of the turbine flow transducer type. It will provide the flow/no-flow indication required and will also permit instrumentation to be attached during ground test, which will permit metering of the fluid flow.

[redacted]

The manual valves will be of the packless diaphragm type supplied by Hills-McCanna Company. This type valve is widely used in the chemical process industry.

The plumbing fittings have not as yet been ordered and will not until the more detailed layouts have been completed. Basically, they will be 37° flare and welded or silver soldered fittings with some straight threaded "O" ring fittings to mate the pump and other established bosses.

As an aid to establishing the configuration of the plumbing and fluid handling system a full scale wooden mockup of the aft compartment was made. At the present time detailed drawings are being made to finalize the fitting requirements and to establish the structural support for the plumbing system.

Heating of the plumbing system will be accomplished by heating the aft compartment. The compartment will be insulated with a 0.5 inch thick layer of foam insulation. An inner aluminum shell will serve as a protective covering for the insulation.

Heating requirements for the aft compartment are based on a configuration 22 inches in diameter and 15 inches long. The compartment wall cross section and temperature gradient was assumed to be as shown below. To be on the conservative side it was assumed that the inside and outside surface temperatures were equal to the ambient air temperature in each case. It was further assumed that there is no heat flow to the forward area, i.e., the fluid store area.

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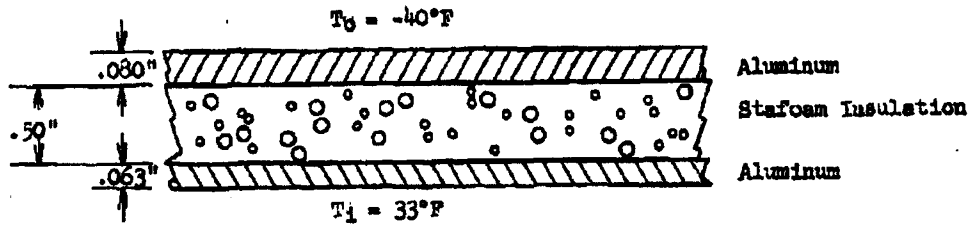

Preliminary calculations based on these assumptions indicate that a heat requirement of 60 to 65 watts will be necessary to maintain temperature levels in the pump and plumbing compartments.

The aft compartment will have two doors, one to permit extension of the filling hoses and the other to provide access to the manual valves.

8.2.3 Tail Section

The tail section houses the actuator system. The actuator system consists of the following major components: (1) actuator, (2) two booms and lever arm attached to a torque tube, (3) support structure for mounting the actuator and booms inside the tank.

The design has progressed to a point where a layout of a workable system is completed. Individual components may have to be changed but the basic geometry of the system has been decided upon.

The actuator will be a modification of one that is presently in production by AiResearch Manufacturing Company of Los Angeles, California. This actuator was chosen because it fits well into the design and the quoted price and delivery time was favorable.

[redacted]

[redacted]

The support structure was designed with the idea of combining the actuator and booms in a structure that can be installed and removed from the tank as a unit. It is believed that this will simplify assembly and servicing.

A wooden mockup of the actuator system is being made and will be installed in a mockup of the tail section. The tail section mockup includes the section between sta. 171.5 to sta. 220. The mockup will closely resemble the actual system as to size and shape so that any clearance and structure problems will become evident. Also the mockup will aid in the final design of the boom well structure.

The booms and lever arm will be welded to the torque tube and pivot as a unit about two bearings mounted in the support frame. The lever arm will be located midway between the bearings. A stress analysis indicated that the bending stress with an 11-inch torque tube span between bearings would be 31,000 psi. It was desired to reduce the stress to approximately 15,000 psi. Therefore, the tube span between bearings was reduced from 11 inches to 6-1/2 inches. In order to do this the booms had to be moved in so that they will be parallel and 4 inches apart. Previously, they were 6-1/2 inches apart at the torque tube and tapered to 4 inches apart at their ends.

A number of problems have been considered in the design and fabrication of the boom. The main problems areas are (1) obtaining suitable boom material, (2) machining of the nozzle slits, (3) boom heating and (4) boom covers.

[redacted]

[redacted]

8.2.3.1 <u>Boom Material</u>

The stress levels in the boom due to the aerodynamic loading will be quite high. Consideration was given to the design of a boom which would have low enough stress levels to allow the use of 300 series of stainless steel tubing. However, with a 300 series yield strength on the order of 35,000 psi, even a boom of 1-1/4 O.D. and 1/4 inch wall would have excessively high stress levels, on the order of 51,000 psi. The contributing factors to this high stress level are first the boom length of 36 inches which provides a substantial moment arm. Fore and aft stresses can be lowered by the addition of stiffener plates. In addition, the lateral forces caused by the von Karman effect and the general air turbulence are an unknown quantity; since the von Karman forces may equal the aerodyanmic drag forces in their worst condition, a conservative approach has been taken in requiring the boom to withstand full drag force in the lateral direction as well.

To sustain the high stress levels, a high strength stainless steel tubing is necessary. A check of tubing and steel manufacturers revealed that the size ranges of tubing required were not available from stock and the only way to obtain the material is by a special mill run. The materials considered most suitable are eight 17-7PH or AM350. A mill which will furnish the tubing in the desired quantities was found with the help of the Carpenter Steel Company. From the available choices, a 1.000 inch dia. x 0.083 (wall) tubing was selected.

[redacted]

8.2.3.2 Machining of Nozzle Slits

Several techniques have been considered for machining the 0.005 inch (width) nozzle slits in the booms. Samples have been made by spark erosion machining and by chemical etching. A third sample will be made by ultrasonic grinding. These three samples will be evaluated in the near future by microscopic examination and by flow tests to determine the best technique for this application.

8.2.3.3 Boom Heating

It was pointed out in our Fourth Quarterly Progress Report[8.2.1] that the booms should be heated with 8 watts per square inch to protect against freezing. In contacts with Electrofilm, Inc., (North Hollywood, California) it has been determined that it is feasible to provide heating at this level with film type resistance heaters. The thickness of the total heater installation is expected to be 0.015 to 0.020 inches, which includes the heating film (of thickness 0.005 inches) and an inner and outer coating. Further work is planned on the exact pattern of application of the heaters near the disseminating nozzles.

8.2.3.4 Boom Covers

The problem of protecting the booms when in a retracted position, prior to the dissemination run, centers around providing some type of cover over the storage wells. The desirability of a protective covering is primarily based on preventing the boom discharge slits from becoming clogged with dust, or other foreign material, or iced over during the period prior to the actual dissemination.

8.2.1 General Mills, Inc., Report No. 2216, Fourth Quarterly Progress Report, Dissemination of Solid and Liquid BW Agents (Unclassified title) August 10, 1961 (Confidential) p. 17 of Appendix B.

An examination of several possible solutions to this problem, including retractable doors, expendable doors, flexible doors and film or fabric replaceable covers has indicated that the film or fabric covers would be the simplest and most satisfactory method.

A mockup is being fabricated to investigate the forces required to break various film and fabric covers. It is important that the torque required from the boom actuator for this purpose be well within the available limit.

9. SYSTEMS STUDY

A mathematical model for an infective dose down wind of a release line was introduced in the last quarterly progress report. By means of this model the probability of critical infection of the population was determined as a function of down wind cloud travel for various parameters such as agent concentration to infective dose ratio, discharge rate, wind speed, etc. In this report essentially the same model is used and for the same purpose with additional factors, however, being taken into account. These factors are:

(1) the efficiency of particle retention of a man,

(2) the length of release,

(3) the initial downward cloud displacement.

Previously it was assumed that the efficiency of particle retention is 100%, the length of release is infinite, and the initial cloud displacement is zero.

9.1 Model Development and Basic Assumptions

The number of bacteria available for a man on ground level at a time t due to an instantaneous point source located at the point (o, ℓ, h) for total number of bacteria Q released at t = 0, is governed by the equation

$$D_L = \left(\frac{2}{\pi}\right)^{3/2} \frac{Q\,\bar{E}_r}{(\sigma_z/x_1^{\beta})^3\,(ut)^{3/\beta}}\ \exp.\left[-kt - \left((x - ut)^2 + (y - \ell)^2 + h^2\right)/\sigma_z^2\,(ut/x_1)^{2/\beta}\right] \qquad (9.1)$$

where the nomenclature is defined in Table 9.1 and the coordinate system is shown in Figure 9.1.1. If it is assumed that the time taken by an aircraft to lay out the line source is negligible, the bacteria concentration

[redacted]

TABLE 9.1

Symbol	Definition
b	Breathing rate of a man
C	Agent concentration
d	Agent dosage per person
D_L	Ground level dosage of the agent
E	Dissemination efficiency
E_r	Efficiency of retention of particles with "size" r
$\bar{E}_r$	Mean efficiency of retention
erfc(x)	Complementary error function $\int_x^{\infty} \exp(-\xi^2/2)\, d\xi$
f	Dissemination flow rate
h	Height of an aircraft
h_s	Adjusted height of release
ID_{50}	Number of organisms required to infect 50% of the people
k	Agent decay
L	Half of length of release line
ℓ	Distance along the aircraft path
P	Probability of infection
q	Source strength
r	Particle "size"
t	Time after release
u	Wind speed
v	Aircraft speed
σ	Weather parameter
β	Weather parameter
x_1	Height for which σ and β are determined

[redacted]

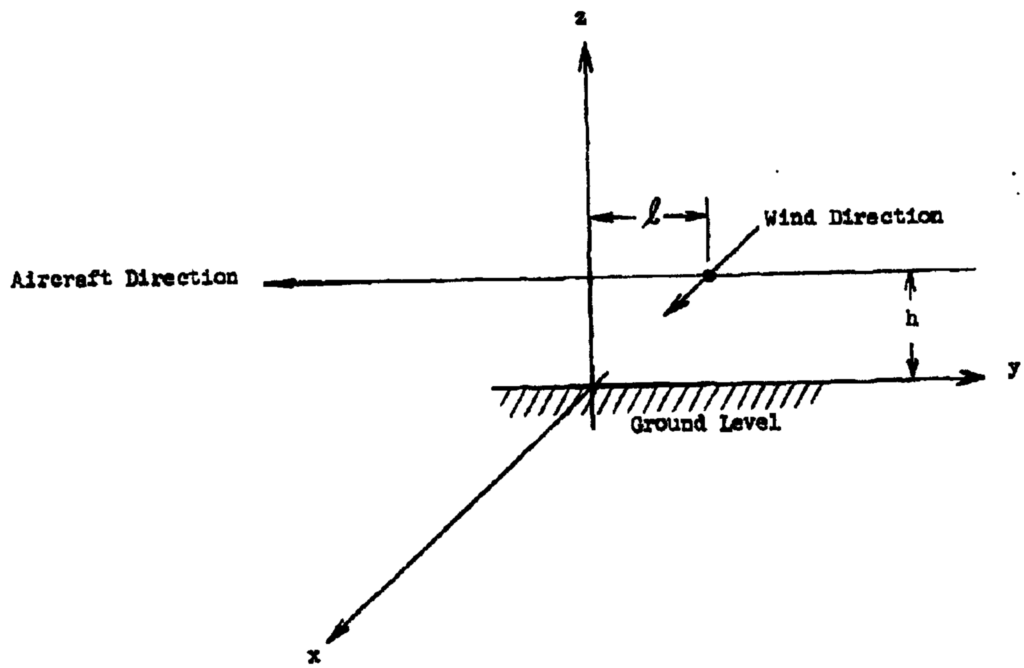

FIGURE 9.1.1 Rectangular Coordinate System

at time t for the assumed instantaneous line source can be obtained from Equation 9.1 by integrating over ℓ from - L to L, which becomes

$$D_L = \frac{\sqrt{2}}{\pi} \frac{q\,\bar{E}_r}{(\sigma_z/x_1^{\beta})(ut)^{2\beta}} \exp. \left\{ - kt - \left[(x - ut)^2 + h^2 \right] / \sigma_z^2 (ut/x_1)^{2\beta} \right\}$$

$$\Delta \operatorname{erfc} \left[\sqrt{2} \; \frac{y - L}{\sigma_z (ut/x_1)^{\beta}} \right]$$

where

$$\Delta \operatorname{erfc} \left[\sqrt{2} \; \frac{y - L}{\sigma_z (ut/x_1)^{\beta}} \right] = \operatorname{erfc} \left[\sqrt{2} \; \frac{y - L}{\sigma_z (ut/x_1)^{\beta}} \right] - \operatorname{erfc} \left[\sqrt{2} \; \frac{y + L}{\sigma_z (ut/x_1)^{\beta}} \right] \quad (9.2)$$

It is noted that q now is the line source strength expressed in units of number of bacteria per unit time. Additional assumptions on which the above equation depends are that:

(1) the wind speed is unidirectional (positive x direction) and constant,

(2) the terrain is smooth, and

(3) the bacterial particles are small enough to exhibit a Brownian motion.

Of these items, (1) is the most serious since in reality wind speed is not a constant but dependent on height as well as other parameters such as time.

The total dosage per man is expressed as $b \int_0^{\infty} D_L (x, y, t)\, dt$. With the assumption that the spread of the cloud is small compared with the cloud displacement, this expression becomes

$$d = \sqrt{\frac{2}{\pi}} \; \frac{bq\,\bar{E}_r}{\sigma_z u \,(x/x_1)^{\beta}} \; \exp. \left[- k \frac{x}{u} - h^2/2\sigma_z^2 \; (x/x_1)^{2\beta} \right] \; \Delta \operatorname{erfc} \left(\sqrt{2} \frac{y - L}{\sigma_z (x/x_1)^{\beta}} \right) \quad (9.3)$$

where the source strength, q, is obtained from the equation

$$q = \frac{fEC}{v} \tag{9.4}$$

Equation 9.3 reduces to 9.2 of the previous quarterly report for E_r equal to unity and L equal to infinity. The probability of infection is related to the lethal dosage by

$$P = 1 - 2^{-d/ID_{50}} \tag{9.5}$$

9.2 The Efficiency of Particle Retention of a Man

For the previous mathematical model it was assumed that a man retains all of the particles that are inhaled. Since only a fraction of particles remain in the lungs, a better model is obtained if this fact is taken into account. This may be accomplished by introducing a mean efficiency of particle retention which would be a function of particle size, r. If $E_r(r)$ is particle retention efficiency for size r and N(r) is the size distribution, then the mean efficiency of all particles is defined as

$$\bar{E}_r = \int_0^\infty E_r N \, dr' \Big/ \int_0^\infty N \, dr' \tag{9.6}$$

For normalized N, $\bar{E}_r = \int_0^\infty E_r N \, dr'$. As a numerical example, let us assume a normal breathing rate and particles on the order of 1.5μ. In this case[9.2.1] E_r is approximated by $E_r = 0.154 r + 0.2$. For $N(r) = \frac{1}{\sqrt{\pi}} e^{-(r - 1.5)^2}$ the mean efficiency becomes 0.33, in which case the probability of infection is diminished considerably as compared to the ideal case of 100% particle retention. For u = 5 mph, $C/ID_{50} = 10^{12}$ ft.$^{-3}$, f = 5 ft.^{3}/min., h = 100 ft.,

9.2.1 Lucien Dautrebande, Studies of Aerosols, AEC Research and Development Report, p. 33.

"weather condition" good, and the "decay factor" as defined in the previous report, the comparison is shown graphically in Figure 9.2.1.

The curve for the probability of infection, as seen in Figure 9.2.1, has the same form for partial retention of particles as for the total retention; however, there is a considerably greater decreasing rate in the probability from the maximum value in the former case.

9.3 <u>The Length of Release</u>

For most of the flight conditions the length of release can be considered as infinite so that the factor, Δ erfc, in Equation 9.3 assumes unity. In case of large σ_z and β, though, this factor cannot be considered as unity. Near the source it is near unity but for larger down wind cloud travel it dimishes to zero with the rate depending on values of σ_z and β. For average and poor "weather conditions", as defined in Reference 9.3.1, this factor is plotted as a function of cloud travel in Figure 9.3.1 for a center line ($y = 0$). In case of good "weather" the length can be considered as infinite. In general Δ erfc is greater than or equal to 0.999 at the center line when the inequality, $\sqrt{2}\ L/\sigma_z(x/x_1)^{\beta} \geq 3.300$, is satisfied.

9.4 <u>Initial Downward Cloud Displacement</u>

The cloud of particles upon release from an aircraft accelerates downward. The motion is due to displaced air by an aircraft. An estimate has

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9.3.1 North American Aviation, Inc., Report No. NA-5g-632, "Airborne Biological Warfare at Low Altitudes," Vol. 11, 16 June 1959, pp. 165-6 (Secret).

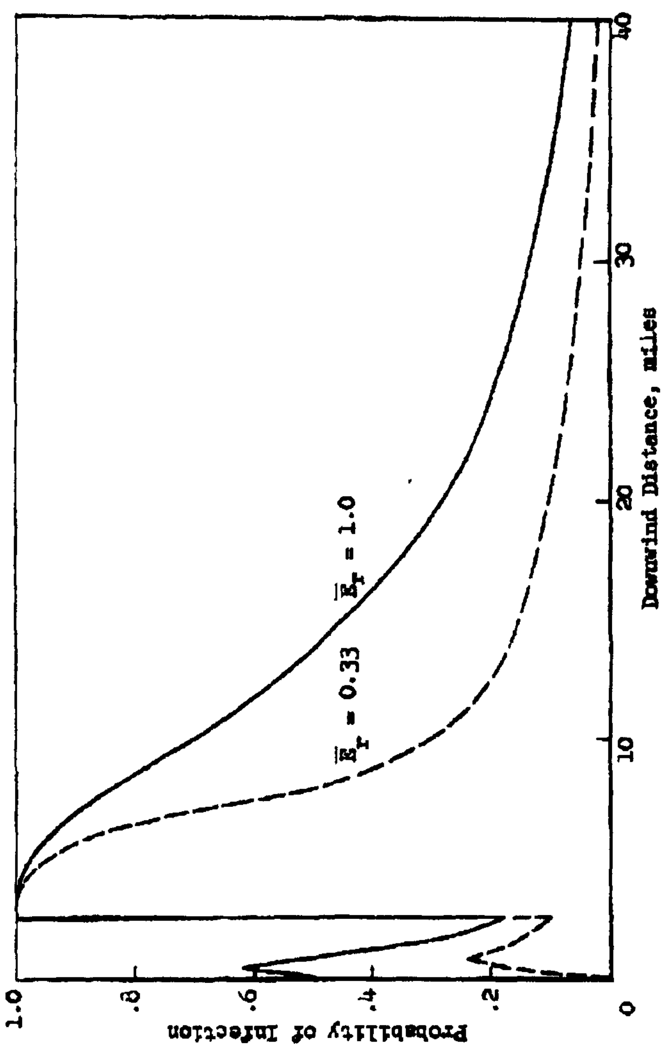

FIGURE 9.2.1 Probability of Infection for Two Different Particle Retention Efficiencies as a Function of Downwind Cloud Travel

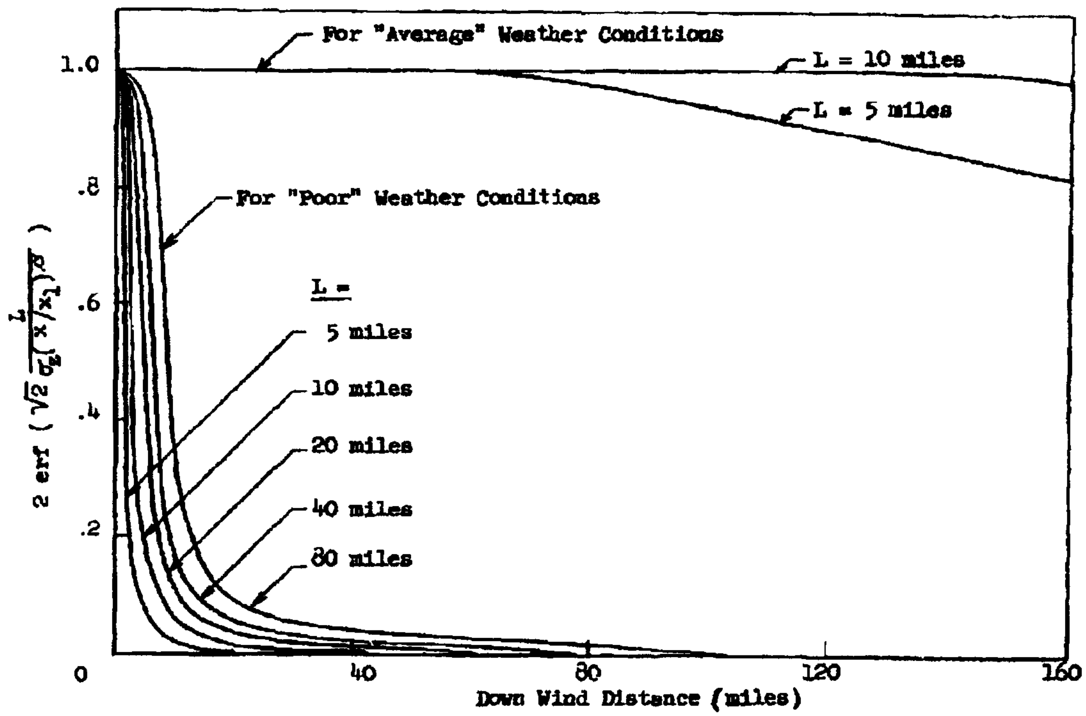

FIGURE 9.3.1 A Diminishing Factor of Lethal Dosage for Finite Length of Line-Source versus Cloud Travel

been obtained by other workers[9.4.1] of the downward velocity of the cloud as a function of time. Initially it is approximately 7 ft/sec but then diminishes exponentially with time to about 1 ft/sec in 20 seconds. This study indicates that the initial displacement of the cloud is about 55 ft, so that the height of an aircraft, h, in our model must be diminished by that amount.

9.5 Numerical Results

To determine the probability of infection as a function of down wind cloud travel, the same values are used for the parameters as in the Fourth Quarterly Report except for particle retention efficiency and the aircraft height, which are taken to be 0.33 and 55 ft, respectively. Equations 9.3 and 9.5 were programmed on a Bendix G-15 digital computer and the results plotted by PA-3 plotter during program execution. These graphs were redrawn and are presented in Figures 9.5.1 and 9.5.2.

9.6 Comparison of Experimental and Theoretical Results

It is of greatest interest to compare the experimental results for bacteria intake per man with the theoretical results. The values for the parameters are taken for trial A-4 conducted by North American Aviation, Inc.[9.4.1] These values are:

Length of release	15 mi.
Height of an aircraft	110 ft.
Wind speed	15 mi./hr.
Bacteria concentration	1.6×10^{10} org./ml.
Flow rate	17.25 gal./min.

9.4.1 See Reference 9.3.1, pp. 165-6.

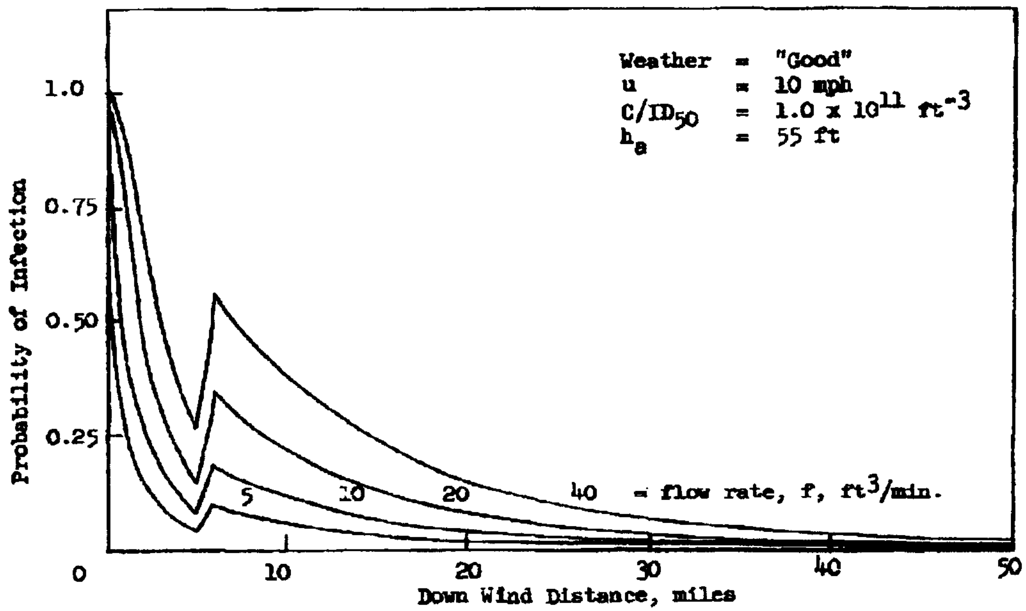

FIGURE 9.5.1 Probability of Infection versus Cloud Travel for $C/ID_{50} = 1 \times 10^{11}$, ft^{-3}

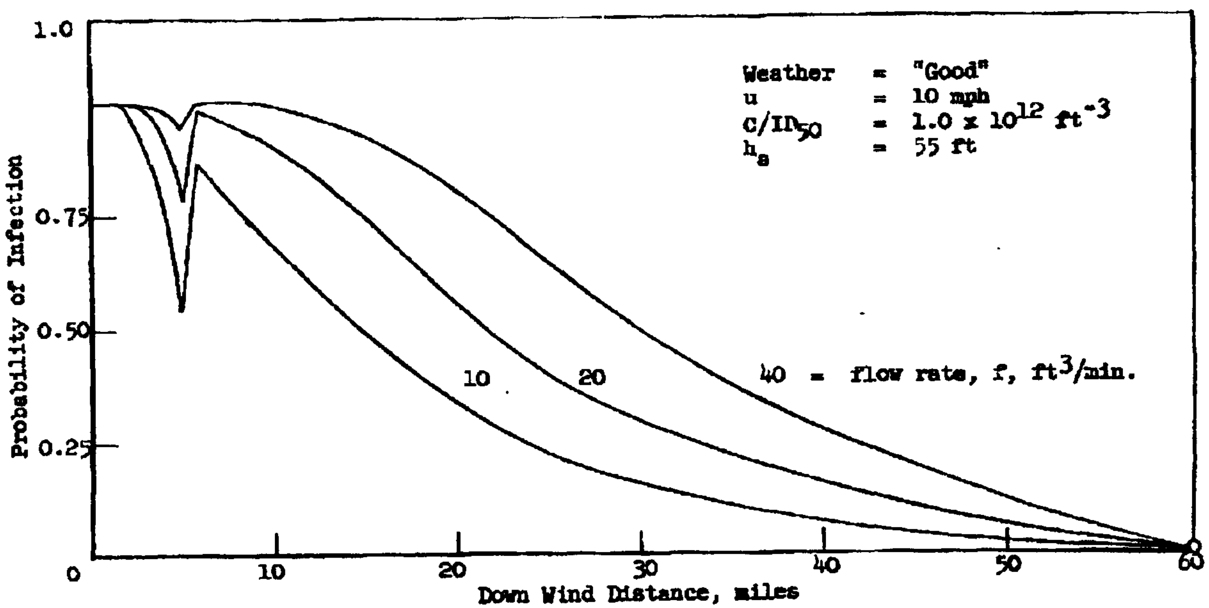

FIGURE 9.5.2 Probability of Infection versus Cloud Travel for $C/ID_{50} = 1 \times 10^{12}$ ft^{-3}

Aircraft speed	400 knots
Nozzle efficiency	11%
Retention efficiency of particles	100%
Breathing rate	.012 m^3/min.

A mild temperature inversion was present in an open terrain so that σ_z = 3.8 m. and β = .66.

Bacteria decay constant	1% per min.

The comparison of the experimental and theoretical results is shown in Fig. 9.6.1. As would be suspected no correlation exists between the theory and the experiments. As pointed out in the last quarterly report and a report on agent characteristics,[9.6.1] k is not a constant so that this fact in itself would lead to a discrepancy. Also the correlations between the temperature and wind speed profiles with parameters σ_z, β, and x_1 are poor. It is likewise not known how much bacteria is lost due to exposure to the jet of an aircraft. The decay constant, k, which enables a least square fit by Equation 9.3 to the data for log d/2 vs. $\log_{10}$ x in this particular trial is

$$k(t) = (4.83 - .411 \log_{10} 14.8\ t)/t$$

That is, if the decay constant is taken to be of the above form rather than 1% per min, then the theoretical result agrees with the experimental in the least square sense. From this result it appears that the decay rate varies even more rapidly than what was originally suspected. More laboratory

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9.6.1 Fort Detrick Report April 1, 1961, Biological Warfare Agents II. Agent Characteristics, No. 61-FDS-392.

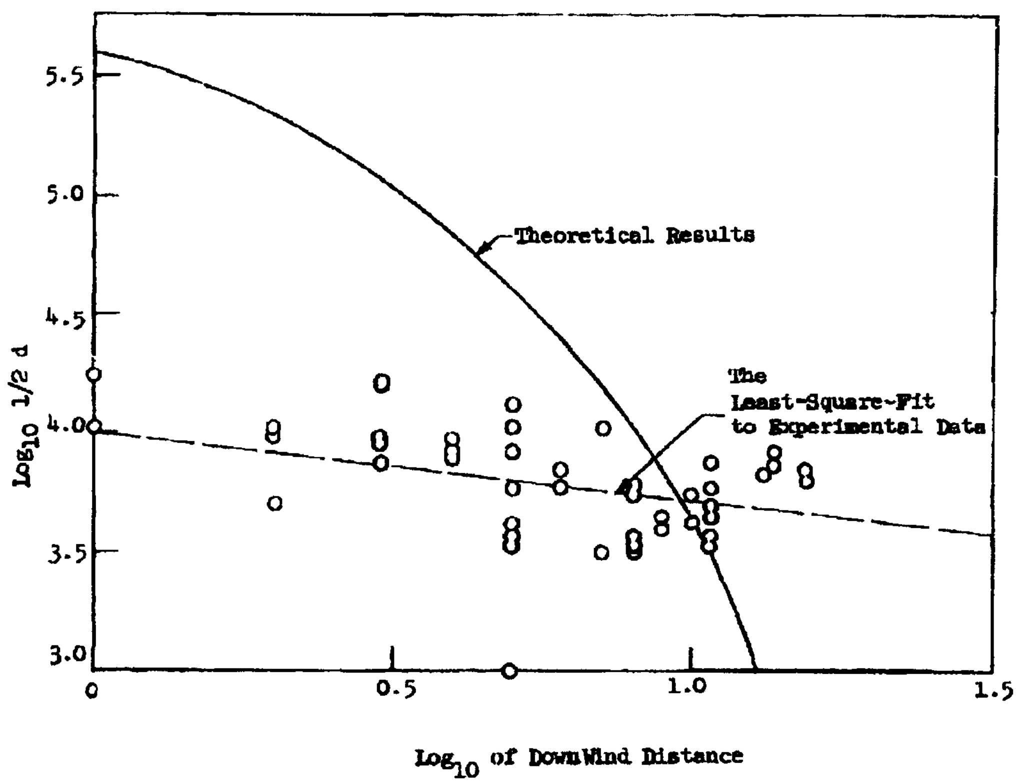

FIGURE 9.6.1 Comparison of Dosage Between Theoretical and Experimental Results

and field experiments are needed in this area so that more precise conclusions can be made.

10. SUMMARY AND CONCLUSIONS

During this reporting period, Phase II work was continued, including research in several areas associated with dissemination of solid BW agents and also the initial work on the detailed design and fabrication of a liquid agent disseminating store.

The theoretical studies of the mechanics of particulate materials were continued. Two specific problems were examined: (1) determination of the force required to displace a plug of powder contained in a cylindrical tube and (2) a preliminary study of the relationship between the energy of compaction and the bulk density of particulate materials. As a result of the first analysis, an equation for the force required to translate a powder plug, which is of the same form as earlier empirical equations, was derived theoretically. Furthermore, limiting values of a resistance parameter, K, were theoretically derived and have been confirmed by experiments of limited scope. With respect to the role of the energy of compaction, the theoretical analysis of J. S. Derr, Jr. was compared with recent experimental data and good agreement was found (Section 2).

As part of the experimental program on the physical characteristics of powders, extensive shear strength measurements were made, which included investigation of the relationship of shear strength to compressive stress and the atmospheric humidity in which the material is stored. It was found that the shear strength increases nearly linearly with compressive stress in the range investigated. Preliminary indications are that more rapid increases in shear strength are found at higher compressive stresses. These will be investigated in the near future. With respect to humidity, it was found that shear strength increases with increasing humidity up to 30 percent, but that it decreases again at 45 percent (Section 3).

The wind tunnel studies of dissemination and deagglomeration were continued, and included investigation of particle size distribution of aerosols generated from loose and compacted <u>Sm</u> simulant, and also a study of the frequency of occurrence of agglomerates in the aerosol. These studies were made by microscopic examination of particles collected on Millipore filters in the isokinetic sampling probe. It was found that the particle size distribution of the collected material agreed very closely with that of the control sample from the bulk material, indicating essentially complete deagglomeration for samples with bulk density up to 0.5 gm/cm^3. Studies of the frequency of occurrence of agglomerates, as a function of the bulk density of the compacted <u>Sm</u>, revealed the existence of a critical region at approximately 0.6 gm/cm^3, above which the number of agglomerates increases rapidly (Section 4).

During this reporting period a design concept for the first dry agent disseminating store was developed. This concept appears to meet the original objectives of providing maximum flexibility of application with respect to agent properties, carrier aircraft capabilities and missions. This design concept is based on the use of compacted dry agents and employs a dual-piston feeding system with provisions for selection of 5 operating speeds. The payload is estimated to be 590 pounds of dry agent compacted to a bulk density of 0.55 gm/cm^3 (Section 5).

Studies of the jet plume problem were continued with further experimental work on determination of the losses of viability in an aerosol generated from a liquid suspension of Sm. It was found that substantial losses occurred for exposure durations as low as 0.6 seconds at temperatures of 50-125°C. An analysis of the jet-plume mixing problem indicates that, for cases where the aerosol is released close to the engine, it is reasonable to expect mixing to expose the aerosol to temperatures which will cause loss of viability (Section 6).

The investigation of the rheological behavior of Sm slurries, made with fluorocarbon liquids, were completed during this reporting period. It was found that the maximum concentration of Sm in the liquid is 25-30 percent by weight. Above these concentrations, the pressures required to extrude the slurry through an orifice is very high and variable. It was concluded that the weight penalty in a system of this type would be too high to permit its use (Section 7).

Considerable progress was made during this period on the design and fabrication of the liquid disseminating store, which is part of the Phase II program. The general design features were established and the approach for fabrication was determined. The external shape of this store is known as the Douglas (DAC) store shape and the principal dimensions are a length of 227 inches and a maximum diameter of 26.5 inches. The liquid capacity is 180 gallons and the flow rate is 18 gallons per minute. The main purchased components have been ordered and detailed work on many of the sub-assemblies has been initiated (Section 8).

The systems analysis, employing a variable-decay-rate mathematical model has been continued. Calculations have been made, comparing the predictions of this model with available field data. It appears that the variable-decay-rate approach offers some improvement in mathematical models for this complex problem (Section 9).

APPENDIX A

Specification for
External Aircraft Tank Assembly

ELECTRONIC DIVISION

[redacted]

1620 CENTRAL AVENUE, MINNEAPOLIS 13, MINNESOTA

General Mills

RELEASE DATE Sept. 8, 1961

ENGINEERING DEPARTMENT

SPECIFICATION GMS - 29100-027

LTR.

STATEMENT OF WORK

EXTERNAL REMOVABLE AIRCRAFT TANK ASSEMBLY

FOR GENERAL MILLS ELECTRONICS GROUP

	A	Add sheets 7+8	9/14/61	[illegible]
ECO NO.	REV	REMARKS	DATE	INIT

APPROVED BY

ENGINEER

[illegible signature] PROJECT ENGINEER

CHIEF PROJECT ENGINEER

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ELECTRONIC DIVISION

[redacted]

1620 CENTRAL AVENUE, MINNEAPOLIS 13, MINNESOTA

General Mills

RELEASE DATE Sept. 8, 1961

ENGINEERING DEPARTMENT

SPECIFICATION GMS - 29100-027

LTR.

STATEMENT OF WORK

EXTERNAL REMOVABLE AIRCRAFT TANK ASSEMBLY FOR GENERAL MILLS ELECTRONICS GROUP

1.0 SCOPE

This document describes the design, performance and delivery requirements for the engineering and manufacturing of an external, removable aircraft tank assembly and the accompanying requirements for documentation.

2.0 APPLICABLE DOCUMENTS

2.1 Conference at Fletcher Aviation Corp. attended by J. McGillicuddy and H. Benjamin on August 7th and 8th, 1961.

2.2 Quotation from Fletcher Aircraft Corporation (T. Derlachter) to General Mills dated August 17, 1961.

2.3 Specifications MIL-A-8591B, MIL-T-7378A, MIL-T-18847A.

2.4 General Mills, Inc. drawings No. SK29100-018 and SK29100-026.

3.0 REQUIREMENTS

3.1 The contractor is to supply assemblies consisting of the outer tank or shell, various structural elements, access doors, and an inner filament wound tank foamed in place; hereinafter these assemblies will be referred to simply as tank assemblies, or tank assembly. Each tank assembly will consist of three subassemblies designated the nose section, the center section, and the tail section. Construction shall be such as to allow repeated disassembly of the main tank assembly into the three subassemblies and reassembly. Design and construction is to be in accordance with the requirements of this work statement including referenced portions of the applicable documents.

3.2 The tank assembly when carrying the loads designated on General Mills, Inc. drawing SK29100-026 shall be suitable for flight on the F-100, F-105, B-66, A-4D, and the A3J aircraft, including arrested landing and catapult take off conditions, and at speeds of up to 0.95 Mach number at sea level. Load factors no less stringent than those in MIL-A-8591B and MIL-T-7378A shall be used. The tank assemblies shall satisfactorily withstand the full range of environments the above listed aircraft are designed to withstand. The tank assembly shall be suitable for installation at wing station 106 on the F-100D aircraft.

3.3 The weights and locations of loads for which mounting provisions must be made and which the tank assembly must be suitable for carrying are shown in General Mills drawing SK29100-026.

3.4 The inner filament wound tank is to be supported in place and insulated from the outer skin or shell by the foamed-in-place insulation designated on GMI SK29100-026 unless the contractor's structural analysis reveals an inadequacy in this insulation. In such case, the contractor is to notify General Mills, Inc.

3.5 The maximum weight of the tank and assembly including the outer skin, all structural elements, access doors, and all parts described in paragraph 4.0 excluding the inner filament wound tank shall not exceed 275 pounds.

3.6 The contractor shall provide all materials exclusive of the filament wound tank (GMI drawing SK29100-018) electrical conduit, and electrical connectors which will be supplied by General Mills, Inc.

3.7 The tank assembly shall meet the requirements of all applicable portions of MIL-T-18847A. The applicable portions are limited only to those requirements that exist if the liquid carried is water instead of fuel and with no requirements made for handling the water but only for storing it in varying quantities in the inner tank to be supplied by General Mills, Inc. This excludes all requirements that result from the peculiar characteristics of aviation fuel in contrast to the characteristics of water, that arise from direct contact of a liquid load with any part of the skin and structure and that arise from the provisions that must be made for handling fuel. No consideration need be given to the freezing characteristics of the liquid load.

3.8 The tank assembly is to meet the requirements of the following paragraphs of MIL-T-7378A. Wherever reference in those paragraphs is made to "fuel tanks" it shall be construed to refer to the tank assembly that is the subject of this work statement. Also, the interpretation of paragraph 3.7 of this work statement applies to the applicable paragraphs of MIL-T-7378A.

3.3, 3.3.1, 3.3.2, 3.4, 3.4.1, 3.4.1.1

3.5 Design (Modified) - Tanks with access doors attached shall be so designed as to not admit water during flight in rain and during washing by hosing with water. The tank assembly including the exterior skin, the structural elements, the foamed-in-place insulation, and the interior tank shall comprise the necessary strength to provide adequately for combined loads and stresses as outlined in Paragraph 3.5.6.

3.5.2 Weight (Modified) - Emphasis shall be placed on design to create the lightest weight tank that will meet the requirements of this specification.

3.5.3, 3.5.3.1

3.5.6 with 3.5.6.d deleted

3.5.6.1, 3.5.6.2, 3.5.6.3, 3.5.6.4, 3.5.6.5

3.5.6.6 with "load" substituted for "fuel"

3.5.6.8 with "or its internal components" deleted

3.5.7, 3.5.7.1

3.5.7.2 Flutter (Modified) - The tank assembly shall be designed to have safe flutter characteristics throughout the speed and altitude ranges and for all attitudes and maneuvers which the aircraft will perform with the tank installed. Full and empty internal tank conditions as well as partially full, level flight conditions shall be considered. In addition, for partially full conditions, the forward center of gravity condition caused by all the load moving forward and the aft center of gravity caused by aft shift of the load, shall be considered. In the event that the design appears to have low flutter speeds or marginal flutter safety due to adverse frequency ratios, General Mills, Inc. shall be informed of this before further work is carried on.

3.5.7.3, 3.5.7.3.1, 3.6, 3.6.1, 3.6.2, 3.7

3.8, 3.8.1, 3.8.1.1, 3.10, 3.10.1, 3.12

4.4.1 Examination of Product (Modified) - Each tank assembly shall be examined to determine conformance with all the paragraphs and modifications of paragraphs of MIL-T-7378A herein listed.

5.2 Class 2 Tanks (Modified) - All Class 2 tanks unless otherwise specified, shall be packed in wooden crates conforming to Specification MIL-C-9437 or equivalent in unit quantities of 1 each. Contrary to the requirements of MIL-C-9437 no samples are required, no identification markings and no tests are required.

5.2.2, 5.5

3.9 The lug spacing on the hangar fittings shall be 30 inches in accordance with MIL-A-8591B.

3.10 Any holes made and used for the purpose of installing the foamed-in-place insulation are to be neatly and smoothly covered with a durable material.

4.0 DESCRIPTION

The tank assembly will consist of the following and will incorporate structural provisions for equipment to be mounted:

4.1 Nose Section

4.1.1 Turbine Generator Support Ring Station 15.5

4.1.2 Access Door and Frame

4.1.3 Section Joint Ring Station 23.5

4.1.4 Outer Shell Assembly Station 15.5 to Station 23.5

4.2 Center Section

4.2.1 Section Joint Ring Station 23.5

4.2.2 Forward Bulkhead Station 23.5

4.2.3 Main Support Structure Including Lug Attachments, Sway Brace and Ejection Areas, and Inner Tank Support Rings.

4.2.4 Cradling Area Reinforcement

4.2.5 Inner Tank Attachment Ring Station 156.5

4.2.6 Aft Bulkhead and Bulkhead Attachment Ring Station 159

4.2.7 Two Access Doors and Frames

4.2.8 Aft Compartment Inner Shell Station 159 to Station 171.5

4.2.9 Section Joint and Bulkhead Attachment Ring Station 171.5

4.2.10 Brackets in Aft Compartment to support pump, valves, tubing, etc.

4.2.11 Two 3/4 " Diameter Conduits - One from Station 23.5 to Station 159 and a second from Station 159 to a Station suitable for Umbilical connection provisions.

4.2.12 Installation of Inner Tank

4.2.13 Insulation in Space Between Inner Tank and Outer Shell Station 23.5 to Station 159.

4.2.14 Insulation in Space Between Inner and Outer Shells of Aft Compartment Station 159 to Station 171.5.

4.2.15 Outer Shell Assembly Station 23.5 to Station 171.5.

4.3 Tail Section

4.3.1 Section Joint Ring Station 171.5

4.3.2 Access Door and Frame

4.3.3 Two Boom Structure Support Rings - One at Station 178.5 and the second at Station 204.25.

4.3.4 Boom Aperture Covers

4.3.5 Boom Access Door and Frame

4.3.6 Outer Shell Assembly Station 171.5 to Station 227

4.4 Additional Structural Members

4.4.1 Any structural reinforcement members in addition to those listed in 4.1, 4.2 and 4.3 which may be required in order for the tank assembly to meet the specified loading and flight conditions.

5.0 STRUCTURAL ANALYSIS

Three copies of the analysis of structural characteristics of the tank assembly shall be supplied General Mills, Inc. at least ten days prior to the running of any structural tests, or at least 10 days before shipment of the first item to General Mills, Inc./ whichever is earlier. The analysis shall include:

(a) A list of loading conditions considered
(b) A list of any assumptions made
(c) Formulae and equations used with source references
(d) Actual calculations
(e) Tabulation of results

6.0 TESTING

Requirements for testing will be made the subject of a separate work statement.

7.0 DRAWINGS

A reproducible and two prints of each assembly and detail part drawing for the tank assembly and its constituent assemblies and parts shall be submitted to General Mills fifteen days after delivery of the hardware. The drawings shall depict the final design condition of the hardware supplied.

The top assembly drawing shall be approved by General Mills, Inc.

8.0 INSPECTION

General Mills, Inc. shall have the right to monitor at any time between letting of the contract and the delivery of the hardware, the fabrication of parts, processes, assembly work, and any testing required to be done, this monitoring to be done through a representative designated by General Mills, Inc.

9.0 DELIVERY

Tank assemblies ordered shall be shipped to General Mills, Inc. within 90 days of receipt of order.

ELECTRONIC DIVISION
[redacted]
1620 CENTRAL AVENUE, MINNEAPOLIS 13, MINNESOTA

General Mills

RELEASE DATE September 14, '61

ENGINEERING DEPARTMENT

SPECIFICATION GMS - 29100-027

LET. A

CHANGES TO SPECIFICATION GMS - 29100-027

1 Para. 2.3: Delete MIL-T-18847A

2 Para. 3.6. shall read: "The Contractor shall provide all materials exclusive of the filament wound tank, G.M.I. Drawing SK29100-018, wire, and the electrical connectors for the lower conduit which will be supplied by General Mills Inc."

3 Para. 3.7 shall read: "Requirements of referenced portions of applicable specifications are limited only to those that exist if the liquid carried is water instead of fuel and with no requirements made for handling the water but only for storing it in varying quantities in the inner tank to be supplied by General Mills, Inc. This excludes all requirements that result from the peculiar characteristics of aviation fuel in contrast to the characterists of water, that arise from direct contact of a liquid load with any part of the skin and structure and that arise from provisions that must be made for handling fuel. No consideration need be given to the freezing characteristics of the liquid load."

4 Para. 3.5.7.2 (Modified), MIL-T-7378A, shall contain the following exclusion: "The Contractor shall not be responsible for flutter problems arising from pylon or aircraft characteristics."

5 Delete Para. 3.5.7.3.1, MIL-T-7378A

6 Para. 3.6.1, MIL-T-7378A, delete "riveting through the tank wall shall not be permitted".

7 Para. 3.6.2, MIL-T-7378A, delete second sentence.

8 Para. 3.7., MIL-T-7378A, Performance (Modified) - The tank assembly shall satisfy the performance requirements of Para. 3.7.3 (Modified), 3.7.7, and, 3.7.8 but testing to these requirements is not required by this work statement.

9 Add Para. 3.7.3 (Modified), MIL-T-7378A, deleting "or evidence of leakage".

10 Add Para. 3.7.7 and 3.7.8 of MIL-T-7378A

11 Para. 3.10.1, MIL-T-7378A, delete "plus" from line 7 and delete completely lines 8 thru 12.

12 Para. 3.10 delete "and used" from first line.

CHANGES TO SPECIFICATION GMS - 29100-027 (Continued)

13 Para. 4.1.1 - Station 13.0 instead of Station 15.5.

14 Para. 4.1.4 - Station 13.0 instead of Station 15.5.

15 Add 4.1.5 "Bracketry in forward compartment.

16 Para. 4.2.11, add "The umbilical connection conduit shall be installed complete with wiring and quick disconnect connector for connection to the pylon. G.M.I. will supply wire for the umbilical conduit.

17 Add Para. 4.5 Section joint connections are to be bolt secured.

18 Add Para. 4.6 Access doors are to be secured with quick disconnect fasteners and are to be chain secured to the tank assembly.

19 Add Para. 10.0 Spare Parts: One (1) spare set of aperture doors is to be provided.

20 Add Para 4.7 Drain fittings shall be provided as called out on Drawing 29100-026.

APPENDIX B

Specification for
Filament Wound Fiberglass Tank

ELECTRONIC DIVISION

General Mills

[illegible]

1620 CENTRAL AVENUE, MINNEAPOLIS 13, MINNESOTA

SHEET 1 OF 1

RELEASE DATE Sept. 6, 1961

ENGINEERING DEPARTMENT

SPECIFICATION GMS - 29100-022

LET.

TANK, FILAMENT WOUND, FIBERGLASS

ECO NO	REV.	REMARKS	DATE	INIT

APPROVED BY: ENGINEER | PROJECT ENGINEER | CHIEF PROJECT ENGINEER

TANK, FILAMENT WOUND, FIBERGLASS

Lamtex Industries, Inc., will design, fabricate and deliver to General Mills two filament wound fiberglass tanks conforming to the following requirements:

1. Tank dimensions and configuration will be in accordance with General Mills drawing No. SK29100-018. Tank dimensions not specified on drawing No. SK29100-018, such as wall thicknesses, are to be determined by Lamtex so as to be compatible with tank design and performance requirements.

2. The volume of the tank shall be the maximum volume compatible with the space envelope shown on drawing No. SK29100-018 and strength requirements, but should not be less than 185 gallons. The residual liquid should not exceed 7 gallons when the aircraft is in level flight at the end of a dissemination run.

3. Anti-slosh bulkheads will be provided as shown on drawing No. SK29100-018.

4. A stainless steel ring will be provided at the larger end of the tank. The dimensions and configuration of the part of the steel ring external to the tank shall be as shown on drawing No. SK29100-018.

5. The tank (empty, partially full or full) must be able to withstand the following loading conditions in any combination without damage or leakage:

   (a) Inertia load factors in accordance with MIL-A-8591 for a 2000 pound store including arrested landing and catapult take off.

   (b) Slosh and vibration conditions as specified in MIL-T-7378.

   (c) Internal pressure up to 15 psi due to altitude change.

6. The tank shall be capable of being subjected to the following temperature environments without damage or deterioration:

   (a) When full or partially full, under flight or storage conditions, 33° F to 70° F.

   (b) When empty, under flight or storage conditions, -65° F to 160° F.

(c) For decontamination exposure to st am at 250° F for 4 hours.

(d) Thermal shock, interior surface of tank at 65° F exposed to steam at 250° F.

7. The tank weight shall be the minimum weight consistent with volume and strength requirements.

8. The operating, proofing, and bursting pressures of the tank shall be compatible with the loading requirements given above.

9. The tank, when full and mounted in the under wing store as shown in drawing No. SK29100-017, shall not rupture or develop a leak if the store is dropped 10 feet onto a concrete surface.

10. The tank will be constructed of Lamtex "Hystran" material.

11. The mold release material used in the fabrication of the tank shall be the Stoner Rubber Company Buna base product SMR1.

12. Lamtex will furnish to General Mills a complete set of engineering design drawings for the tank including a reproducible and two prints of each drawing.

13. Lamtex will furnish to General Mills three copies of the design and stress analysis calculations made on the tank.

14. Lamtex will furnish to General Mills in triplicate data on any tests, such as pressure tests, made on the tank as part of their normal design procedure. General Mills does not require that any special tests be made on the tank.

15. Packing of tanks for shipment to General Mills shall be in a manner suitable for train or truck transportation.

APPENDIX C

Specification for
Ram Air Driven Generator

ELECTRONIC DIVISION [redacted] 1620 CENTRAL AVENUE, MINNEAPOLIS 13, MINNESOTA — General Mills	SHEET 1 OF 111 RELEASE DATE Sept. 21, 1961
ENGINEERING DEPARTMENT	SPECIFICATION GMS-29100-020

GENERATOR, RAM AIR DRIVEN

ECO NO.	REV.	REMARKS	DATE	INIT.

APPROVED BY: ENGINEER | PROJECT ENGINEER | CHIEF PROJECT ENGINEER

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GENERATOR, RAM AIR DRIVEN

1.0 SCOPE

1.1 Scope - This specification covers the requirements for a ram air-driven generator. Specifically, the specification pertains to the Allison Division of General Motors Corporation, Model GA124GH-92.

1.2 Classification - The GA124GH-92 generator assembly consists of a ram air turbine assembly driving a 4.5 KVA generator intended for use as a primary power source.

2.0 APPLICABLE DOCUMENTS

The following documents of the date specified shall form a part of this specification to the extent specified herein:

Specifications:

MIL-E-5272A	Environmental Testing, Aeronautical and Associated Equipment, General Specification for, dated 16 September 1952
MIL-G-6099	Generators and Regulators, Aircooled A-C, Aircraft General Specification for, dated 19 April 1950
MIL-S-7742A	Screw Threads, Standard Optimum Selected Series, General Specification for, dated 3 December 1959
MIL-E-7894A	Electrical Power, Aircraft Characteristics of, dated 17 May 1955
MIL-D-70327(1)	Drawings, Engineering and Associated Tests, dated 1 July 1959

Standards:

MIL-STD-130A	Identification Markings of U.S. Military Property, dated 8 September 1958
MIL-STD-210A, Chg. 1	Climatic Extremes for Military Equipment dated 30 November 1958

Drawings:

GMI SK29100-019	Generator-Ram Air Driven dated 9/21/61 Revision A

3.0 REQUIREMENTS

3.1 Components - The generator assembly shall consist of a ram air turbine drive unit coupled to a 115/200 volt, 400 cps, 3-phase, wye connected generator.

3.1.1 Ram Air Turbine - The ram air turbine shall be a two blade unit with a self-contained mechanical governor. The governor shall be housed in the turbine spinner and act to change the turbine blade pitch to maintain the generator rpm between 11,400 and 12,900 rpm.

3.1.2 Generator - The generator shall be rated at 4.5 KVA at .75 power factor and a nominal 115/200 volts. The electrical characteristics of the generator shall be identical to the Allison Model PGA124GH-D4 generator assembly. The generator shall be made up of a three-phase, "wye" connected stator and a built-up permanent magnet rotor and it shall have no brushes, slip rings, or rotor windings. The output voltage shall be controlled by a solid state voltage regulator.

3.1.2.1 Voltage Regulator - The voltage regulator shall be a solid state device. The entire voltage regulator assembly shall be encapsulated in a material designed to withstand the environmental conditions outlined in MIL-STD-210A Chg. 1. The voltage regulator shall be housed in a moisture-proof container suitable for mounting on a flat heat conductive surface. The physical dimensions of the regulator shall not exceed the following:

Length - four inches
Width - Three and one-half inches
Height - three inches

The weight of the regulator shall not exceed three pounds. A Bendix Scinflex P/N 10-42220-7P type connector shall be used to provide necessary electrical connections.

3.2 Standard Parts - AN and MS standard parts shall be used where suitable for the purpose. These parts shall be identified by the standard parts number.

3.3 Material and Processes - The materials and processes used shall be of high quality, suitable for the purpose, and shall conform to government specifications where applicable. Material conforming to Allison or AMS specifications may be used. Approved materials or processes shall be those materials or processes used in the manufacture of the unit which passes the official qualification test specified herein or are subsequently approved through a material change.

3.3.1 Protective Treatment and Coatings - All parts not in constant contact with oil, except working surfaces, threads, or drive pad faces, shall be corrosion resistant or suitably protected.

3.4 Design and Construction

3.4.1 Operation - The generator assembly provides electrical power by means of a ram air turbine consisting of blades, hub, spinner, shaft, and a fly-weight spring governor which maintains approximately constant rpm by controlling blade pitch.

3.4.1.1 Operating Speed - The ram air turbine governor shall be capable of maintaining turbine speed within the range of 11,400 to 12,900 rpm (380-430 cps) under steady state operating conditions with ram air inlet velocities within the range of 300 to 650 KTAS at an altitude of 500 feet.

3.4.1.1.1 Overspeed - During load transients and during starting the ram air turbine governor shall maintain turbine speed within the range of 10,800 to 13,500 rpm (360-450 cps). Following a load transient or starting, steady state operation shall be established within 3 seconds.

3.4.1.2 Direction of Rotation - When viewed from the rear the direction of rotation of the air turbine and the alternator shall be counter-clockwise.

3.4.2 Balance - The amount of unbalance of rotating components shall not exceed 0.01 oz. in.

3.4.3 Lubrication - All lubrication points shall be permanently lubricated at assembly.

3.4.4 Connectors - The electrical connectors on the generator shall be as shown on the outline drawing, (GMI SK29100-019).

3.4.5 Structure

3.4.5.1 Mounting Provisions - Generator mounting provisions shall be as shown on the outline drawing, (GMI SK29100-019).

3.4.5.2 Overspeed Integrity - The unit shall be capable of operation at 15000 rpm for a period of one minute with no output load.

3.4.5.3 Ultimate Structural Load - The generator unit and its mounting provision shall be capable of withstanding an ultimate acceleration of 40 g's parallel to the mounting base and along the transverse axis and a simultaneously applied air load drag based upon an airspeed of 800 Kts EAS.

3.5 Performance - The performance specified herein is based upon operation of the generator with its axis of rotation within ±1 degree of the direction of airflow: All air velocities specified are free stream velocities.

3.5.1 Ratings - The performance ratings shall be as follows:

Standard Conditions

Rating	Airspeed Kts, EAS	Turbine Rotor Speed rpm	Electrical Load KVA (Min.)	Power Factor
Continuous	300 - 650	12,000	4.5	.75
Condition I	300 - 650	12,000	10.0	.65
Condition II	300 - 650	12,000	4.8	.65

During power transients a peak load as defined by Condition I shall be permitted for 50 milliseconds followed by a secondary load, Condition II, the duration of which shall not exceed 12 seconds.

3.5.2 Altitude - Temperature Limits for Operating - The generator assembly shall be capable of operation at all altitudes between sea level and 45,000 feet pressure-altitude, at all airspeeds between 300 and 650 Kts EAS, and throughout the temperature range specified in MIL-STD-210A Chg. 1.

3.5.3 Drag - The drag force of the ram air turbine generator shall be the minimum value compatible with good turbine design and in no case shall it exceed 100 lbs. at 650 Kts EAS.

3.5.4 Environment - The ram air turbine generator shall be capable of passing the requirements of paragraph 4.1.3 after being subjected to the environmental tests of paragraphs 3.5.4.1 through 3.5.4.9. However, testing to paragraphs 3.5.4.1 through 3.5.4.9 is not required if previous ram air turbine generator units of the same design and materials have passed these tests.

3.5.4.1 Temperature Shock - (Ref. Para. 4.3.1 of MIL-E-5272) - The turbine generator assembly shall be capable of being subjected to (3) three temperature cycles consisting of four (4) hours in a chamber maintained at 185° F and four (4) hours in a chamber maintained at -40° F with a maximum of five (5) minutes between temperature changes. Within one (1) hour of completion of this test, the unit shall be capable of meeting requirements of paragraph 4.1.3.

3.5.4.2 Salt Spray - The turbine generator assembly shall be capable of being subjected to a salt spray test which meets the conditions outlined in paragraph 4.6 of MIL-E-5272. The test period shall be for a duration of 100 hours at a temperature of 95° F. Upon completion of the test the unit shall pass the requirements of paragraph 4.1.3.

3.5.4.3 Shock - (Ref. Para. 4.15.2.1 of MIL-E-5272) - The turbine generator assembly shall be capable of withstanding 18 impact shocks of 15 G, consisting of three shocks applied in each direction along each of the three mutually perpendicular axes. Each shock impulse shall have a time duration of 11 ±1 milliseconds. The "G" value shall be within ±10 percent when measured with a 100 cps filter and the maximum "G" value shall occur at approximately 5.5 milliseconds. There shall be no mechanical failure. The unit shall be capable of meeting the requirements of paragraph 4.1.3 upon completion of this test.

3.5.4.4 Sand and Dust - The turbine generator assembly shall be capable of being placed in a test chamber and subjected to a sand dust concentration for six hours. The conditions in the test chamber shall be as follows:

a. The relative humidity shall not exceed 30 percent.
b. The sand dust concentration shall be raised to and maintained at 0.3 ±0.2 grams per cubic foot.
c. The internal temperature shall be 77° ±3° F.
d. The sand and dust laden air velocity shall be 100 to 500 feet per minute.

The sand and dust mixture shall have the characteristics outlined in paragraph 4.11.1 of MIL-E-5272. This test shall be repeated with an internal temperature of 160° ±3° F. The unit shall pass the requirements of paragraph 4.1.3 upon completion of this test.

3.5.4.5 Humidity - The turbine generator assembly shall be capable of being placed in a suitable test chamber (per paragraph 4.4.1 of MIL-E-5272) and subjected to 15 cycles (360 hours). Each cycle shall consist of the following:

(a) The internal test chamber temperature shall be uniformly raised from 84° ± 16° F to 160° F during a 2 hour period.

(b) The 160° temperature and relative humidity of 95 percent shall be maintained during the following six hour period. Distilled or demineralized water having a pH value of 7 ±0.5 at 77° F shall be used to obtain the desired humidity.

(c) The internal test chamber temperature shall be uniformly reduced to 84° ± 16° F during the following 16 hour period.

The unit shall pass the requirements of paragraph 4.1.3 upon completion of this test.

3.5.4.6 Fungus - The turbine generator assembly shall be capable of being sprayed or dipped in a spore suspension prepared in accordance with the requirements of paragraph 4.8.1 of MIL-E-5272, and then placed in a test chamber capable of maintaining the relative humidity at 95 percent and the internal temperature at 86° F for a test period of 28 days. The unit shall pass the requirements of paragraph 4.1.3 upon completion of this test.

3.5.4.7 Vibration - (Ref. Para. 4.7.1 of MIL-E-5272) - The turbine generator assembly shall be capable of being subjected to the tests defined in (a) and (b) below. The unit shall not be operated during these tests.

(a) Resonance The unit shall be scanned along each of its three (3) mutually perpendicular axes for resonant frequencies throughout the range of 10 to 500 cps at an applied double amplitude of .036 inch or an applied acceleration of ±10 G, whichever is the limiting value. The unit shall be vibrated at the resonant frequency along each axis as follows:

(1) 60 minutes at 77° F.
(2) 15 minutes at 160° F.
(3) 15 minutes at -65° F.

When more than one resonant frequency is encountered with vibration applied along any one axis, the test period may be accomplished at the most severe resonance or the period may be divided among the resonant frequencies, whichever is considered most likely to produce failure. When resonant frequencies are not apparent within the above range of frequencies, the generator shall be vibrated for periods twice as long as those specified in (1), (2), and (3) above at a frequency of 55 cps and an applied double amplitude of .060 inch.

(b) Cycling The unit shall be cyclic vibrated along each of its three mutually perpendicular axes between 10 and 500 cps in 15 minute cycles at an applied double amplitude of 0.036 inch or an applied acceleration of ±10 G, whichever is the limiting value. The testing period and temperatures shall be the same as specified in paragraph 3.5.4.7 (a), (1), (2), and (3). The linear acceleration along either of the other two mutually perpendicular axes shall not exceed 15% of the linear acceleration along the axis being excited. The angular acceleration shall not exceed 2.5% of the linear acceleration along the axis being excited, per inch, as measured along a radius of the angular acceleration. (For example: If the linear acceleration is 10 G's along the axis being excited, no angular acceleration can exceed .25 G's at a one inch radius from the axis of the angular acceleration.) The above linear and angular acceleration limits apply to the fixture surface against which the unit mounts, over the area of contact between the unit and this surface. There shall be no indication of damage or mechanical failure. The unit shall pass the requirements of paragraph 4.1.3 upon completion of this test.

3.5.4.8 Low Temperature Start - The unit shall be capable of being mounted in a suitable wind tunnel at a stabilized ambient temperature of -65° F and undergo the following tests:

(a) With the turbine rotor blocked, establish within 30 seconds a steady state air velocity of 360 Kts EAS and remove blockage. The unit shall start and accelerate to 11,400 rpm with a 4500 VA (at .75 P.F.) load applied within 4 seconds from removal of blockage. The unit shall complete ten such starts. In place of blocked rotor operation it shall be permissible to suddenly eject the unit into the established airstream.

(b) Upon completion of ten starts, the unit shall meet the requirements of paragraph 4.1.3.

3.5.4.9 <u>High Temperature Start</u> - The unit shall be capable of being mounted in a suitable wind tunnel at a stabilized ambient temperature of 160° F and undergo the following tests:

(a) With the turbine rotor blocked, establish within 30 seconds a steady state air velocity of 360 Kts EAS and remove blockage. The unit shall start and accelerate to 11,400 rpm with a 4500 VA (at .75 P.F.) load applied within 4 seconds. The unit shall complete 10 such starts. In place of blocked rotor operation it shall be permissible to suddenly eject the unit into the established airstream.

(b) Upon completion of 10 starts, the unit shall meet the requirements of paragraph 4.1.3.

3.5.5 <u>Generator Performance</u>

3.5.5.1 <u>Wave Form</u> - The crest factor and harmonic content line-to-line and line-to-neutral of the output voltage shall conform to the requirements of specification MIL-G-6099.

3.5.5.2 <u>Short Circuit Capacity</u> - The generator shall be capable of supplying 300 percent rated current during a single or three-phase fault condition for three seconds without impairment of generator characteristics.

3.5.5.3 <u>Unbalanced Load</u> - The generator shall be capable of meeting the following unbalanced load requirements at 400 cps, 115 volts nominal and 12,000 rpm. The percent unbalance of line voltage shall be defined as 100 times the maximum deviation of the line voltage from the average of the three line voltages divided by the average of the three line voltages.

(a) With a 1500 VA, 1.0 P.F., 3 phase load applied and an additional single phase 1.0 P.F. line to neutral load of 500 VA and 1000 VA added individually, the maximum value of voltage unbalance shall not exceed 6.0 percent.

(b) With the generator carrying no three phase load, a single phase line to neutral 1.0 P.F. load of 500 VA and 1000 VA shall be added individually. The maximum value of voltage unbalance shall not exceed 6.0 percent.

(c) With a 3000 VA, 1.0 P.F. 3 phase load applied and an additional single phase line to neutral 1.0 P.F. load of 500 VA and 1000 VA added individually, the maximum value of voltage unbalance shall not exceed 6.0 per cent.

3.5.5.4 Generator Cooling - Generator cooling during operation shall be obtained by providing a suitable means for conducting the heat from the generator to the outer shroud. Heat removal by means of ram air cooling, cooling ports, will not be utilized. The maximum allowable surrounding air ambient temperature when not operating will be 250° F. The maximum allowable operating temperature will be 160° F.

3.5.5.5 Voltage Regulation - The voltage regulator shall maintain the generator voltage within the limits of ±2.5% during steady state conditions and between the following voltage limits and load conditions for all designed operating speeds and environments as defined in MIL-STD-210A Chg. 1.

Conditions	Voltage
4.0 KVA, p. f. = .75-1.0	108-121
4.5 KVA, p. f. = .75-1.0	108-124

3.6 Interchangeability - All parts having the same manufacturer's part number shall be functionally and dimensionally interchangeable. The drawing number requirements of specification MIL-D-70327 shall govern changes in manufacturer's part numbers.

3.7 Drawings - Allison Division of General Motors will furnish to General Mills, Inc. a complete set of engineering design drawings for the ram air turbine generator, (Model GA 124GH-92) including a reproducible and two prints of each drawing.

3.8 Weight of Complete Unit - The maximum weight of the complete ram air turbine generator assembly shall not exceed 43 pounds.

3.9 Identification of Product - Equipment assemblies, and parts shall be marked for identification in accordance with standard MIL-STD-130.

3.10 Screw Threads - All conventional straight screw threads shall be in accordance with the requirements of specification MIL-S-7742.

3.11 Workmanship - The workmanship and finish on all parts shall be in accordance with high grade aircraft practice.

4.0 QUALITY ASSURANCE PROVISIONS

4.1 Acceptance Tests - Acceptance tests are those tests conducted by Allison Division of General Motors, on the ram air turbine generator assembly (required by General Mills, Inc.) to demonstrate suitable quality control, correct assembly and performance.

4.1.1 Accuracy of Data - All instrumentation shall be suitable for the testing to be conducted and shall not be detrimental to test tolerances.

4.1.2 Test Conditions

4.1.2.1 Operating Test Conditions - All tests shall be conducted at approximately sea level altitudes and all data used to establish power output shall be corrected to NACA Standard Day sea level conditions. All air velocities specified herein are free stream and all tunnel air velocities used for testing shall be equivalent to free stream velocities. The test shall be conducted at ambient temperatures.

4.1.2.2 Mounting - The unit shall be mounted in a suitable wind tunnel with its axis of rotation parallel within 1° to the direction of air flow. Mounting facilities are to have negligible effect on power performance.

4.1.2.3 Generator Loads - The following loads shall be used for determining the performance of the unit during testing.

Load I	-	No load,
Load II	-	Balanced 3 phase, 4000 VA at .80 PF
Load III	-	Balanced 3 phase, 4800 VA, at .65PF

4.1.3 Test Methods - The following tests shall be performed on the unit.

4.1.3.1 Balance - The unit shall be tested for dynamic unbalance. The amount of unbalance of rotating components shall not exceed 0.01 oz. in. The measured vibration acceleration of the unit when operated at 12,000 $\pm$0.5% rpm and Load I applied shall not exceed 40.0 G's.

4.1.3.2 Governing - The unit shall be subjected to the following test operation:

(a) With Load I applied to the unit, increase the air velocity to 650 Kts EAS minimum. The unit rotational speed shall not exceed 12,900 rpm.

(b) With Load II applied to the unit, decrease the air velocity from 650 Kts EAS to 300 Kts EAS maximum. The unit rotational speed shall not be less than 11,400 rpm.

(c) With Load II applied to the unit operating in an air velocity of 650 Kts EAS minimum, suddenly apply Load I. The transient rotational speed of the unit shall be within the limits of 10,800 to 13,500 rpm and shall return to steady state conditions within 3 seconds after load change. The steady state rotational speed shall be within the limits of 11,400 to 12,900 rpm.

(d) With Load I applied to the unit operating in an air velocity of 300 Kts EAS minimum, suddenly apply Load III. The transient rotational speed of the unit shall be within the limits of 10,800 to 13,500 rpm and shall return to steady state conditions within 3 seconds after load change. The steady state rotational speed shall be within the limits of 11,400 to 12,900 rpm.

(e) With Load II applied to the unit, slowly increase the air velocity to 650 Kts. EAS minimum, then slowly decrease the air velocity at a uniform rate. There shall be no evidence of governor oscillation above 300 Kts EAS minimum.

4.1.3.3 Voltage Regulation - The unit shall be subjected to the following test operation:

(a) With Load I applied to the unit, and with an air velocity of 650 Kts EAS, the steady state line to neutral voltage of any of the three phases shall not exceed 118 volts.

(b) With Load III applied to the unit and with an air velocity of 300 Kts EAS, the steady state line to neutral voltage of any of the three phases shall not fall below 112 volts.

4.1.4 Rejection and Retest. - If the unit does not pass the requirements of paragraph 4.1.3 it shall be rejected. A rejected unit may be reworked or have parts replaced to correct the defects, and resubmitted for acceptance. Before resubmitting, full particulars concerning previous rejection and the action taken to correct the defects found in the original unit shall be furnished General Mills, Inc.

4.2 Qualification Tests - Qualification Tests are those tests accomplished on the generator assembly to demonstrate suitability for production. The generator assembly to be sold to General Mills, Inc. shall be identical in material and workmanship to similar generator assemblies which have passed qualification tests for production thereby precluding any requirement for such tests on this model.

4.3 Reports - A complete record shall be kept of the progress and results of all tests. Upon completion of testing, a complete test report shall be prepared and three copies submitted to General Mills, Inc. for approval. General Mills, Inc. also reserve the right to provide a witness for any or all acceptance tests.

5.0 PREPARATION FOR DELIVERY

5.1 Packaging and Packing - The unit shall be packaged to assure arrival at the destination in a clean and undamaged condition. Where applicable all openings, mounting faces, and external exposed parts shall be provided with suitable temporary coverings to exclude dirt and prevent damage. All protective covers must be of a configuration that prohibits assembly with mating parts without removing the cover.

The following paragraphs of General Mill's Specification No. 29100-020 shall be changed as indicated below:

Paragraph	Change
2.0	MIL-G-6099, dated 10 April 1950 to MIL-G-6099A, dated 25 March 1957.
3.1.2.1	Change "Length" from "four inches" to "five and one-fourth inches".
3.4.1	Change "provides electrical power by means of" to "provides electrical power, being driven by means of".
3.5.4	Change "units of the same design and materials" to "units of similar design and material".
3.5.5.1	Change "MIL-G-6099" to "MIL -G-6099A".
3.5.5.5	Delete "4.0 KVA, p.f. = .75-1.0 108-121" Change "108-124" to "108-122".
4.1.2.3	Change "during testing" to "during wind tunnel testing". Change "4000 VA at .90PF to 1700 VA at 1.0PF". Change "4000 VA at .95PF to 3400 VA at 1.0PF".
4.1.3.1	Change "when operated at 12,000 ± 0.5% rpm and Load I" to "when operated within the specified governing rpm range, at 300 KEAS, and Load I."
4.1.3.2	(b) Change "Load II" to "Load III". (c) Change "Load II" to "Load III".
4.1.3.3	Change entire paragraph to read as follows:
	Voltage Regulation - The voltage regulator shall maintain the generator voltage within the limits of ± 2.5% during steady state conditions and between the specified voltage limits 108-122V during all loads and operating speeds specified during testing as outlined in paragraph 4.1.

Page determined to be Unclassified
Reviewed Chief, RDD, WHS
IAW EO 13526, Section 3.5
Date: JUL 19 2013

ELECTRONIC DIVISION

[redacted]

1620 CENTRAL AVENUE, MINNEAPOLIS 13, MINNESOTA

General Mills

RELEASE DATE

ENGINEERING DEPARTMENT

SPECIFICATION CMS 29100-020

Paragraph	Change
4.1.4	Change, "Before resubmitting, full particulars concerning previous rejection, and the action taken to correct the defects found in the original unit shall be furnished General Mills, Inc." to "Full particulars concerning test rejections and the action taken to correct the defects found in the original unit shall be furnished General Mills, Inc., upon completion of the testing."