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TENTH QUARTERLY PROGRESS REPORT
ON
DISSEMINATION OF SOLID AND LIQUID BW AGENTS

(Unclassified Title)

For Period September 4, 1962 - December 4, 1962
Contract No. DA-18-064-CML-2745

Prepared for:

U. S. Army Biological Laboratories
Fort Detrick, Maryland

Submitted by: G. R. Whitnah
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Report No: 2373
Project No: 82408
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FOREWORD

Staff members of the Aerospace Research Department and Engineering Department who have participated in directing and performing the work reported herein include Messrs. S. P. Jones, Jr., G. Whitnah, M. Sandgren, A. Anderson, R. Lindquist, J. McGillicuddy, J. Upton, C. Hagberg, W. L. Torgeson, S. Steinberg, P. Stroom, G. Morfitt, J. Walters, A. T. Bauman, T. Petersen, D. Harrington, R. Ackroyd, D. Kedl, B. Schmidt, G. Lunde, R. Dahlberg, R. Kendall, E. Knutson, J. Ungs, D. Stender, H. Kuhlman, G. Granley, J. Pilney, A. Johnson, and R. Menard.

ABSTRACT

This Tenth Quarterly Progress Report for the period from September 4, 1962 to December 4, 1962 presents the results of continued work under Contract DA-18-064-CML-2745, "Dissemination of Solid and Liquid BW Agents".

The results of the studies of the mechanics of dry powders are discussed under two headings: compaction characteristics of dry powders, and the behavior of powders in the compacted state. Purely theoretical studies are presented which agree with results of experimental investigations.

Improvements to the aerophilometer used to study properties of aerosols are described. Experimental and theoretical investigations are discussed which demonstrate that agglomeration is of no consequence in the experimental apparatus.

Flow rate data are presented from tests in which the full-scale experimental feeder was used to feed powdered sugar, flour, and talc, with a rate of 91 lb/min being achieved with compacted talc.

Experiments are described in which foamed plastic was used to encapsulate cylinders of compacted powder which were subsequently fed through the experimental feeder. A sufficiently strong package has not yet been obtained.

Successful laboratory and field testing of the E-41 Spray Tank for dry agents is discussed. The structural test report and a preliminary report of the air-worthiness flight tests are presented. Laboratory functional tests are described.

Plans for biological flight tests with both the E-41 and E-42 Spray Tanks at Dugway Proving Ground are discussed.

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TENTH QUARTERLY PROGRESS REPORT
ON
DISSEMINATION OF SOLID AND LIQUID BW AGENTS

1. INTRODUCTION

This Tenth Quarterly Progress Report covers the work performed under Contract DA-18-064-CML-2745 during the three-month period ending December 4, 1962. The scope of this program includes theoretical and experimental studies in several areas related to the dissemination of BW agents, and also the design, fabrication and testing of prototype units of external-store airborne disseminators for liquid and solid BW agents. Because of the broad scope of the program, the types of subjects discussed in this report vary considerably. Additional background information in each area of interest is available in our previous Quarterly Progress Reports on this Contract.

During the period covered by this report, fabrication was completed on the E-41 Spray Tank for dissemination of dry finely-divided BW agents. This prototype unit was shipped to the Patuxent River Naval Air Station where the flight tests to demonstrate the air-worthiness and functional capabilities of the disseminator were conducted. The disseminator performed successfully in these tests and did not produce any unusual effects on aircraft performance. Completion of the fabrication and these tests of the E-41 were two of the major goals of the program.

2. THEORETICAL AND EXPERIMENTAL STUDIES OF THE MECHANICS OF DRY POWDERS

The following sections describe the current status of our coordinated theoretical and experimental efforts in the characterization of particulate materials. We intend that this activity will expand our fundamental knowledge of fine particle technology and will result in the development of both theories and experimenal techniques sufficiently accurate to classify fine powder technology as "exact" science.

Since our experimental activity frequently involves the development of entirely new techniques, we must constantly evaluate our efforts to determine whether the data obtained is a direct measure of a fundamental powder property or represents a value closely related to that property. Both types of information are of significant value, but we should be able to distinguish one from the other. In order to establish that the characterizations we have made are fundamental properties of powders and not a function of apparatus design, we are determining the powder property wherever possible by more than one independent method. This approach is essential to any responsible scientific endeavor.

We are now in the process of determining the energy concentrations that cause powders to shear, to compact, and to fail under tension. We are learning how readily these powders disperse and the modes and rates by which the aerosol so formed decays. Certainly basic to all these characteristics is the nature of the surface of the particle itself. A program of study is now underway which has as its goal the determination of total surface area of the particle as well as its rugosity, adsorptivity, and chemical reactivity.

2.1 Compaction Characteristics of Dry Powders

During our study of the mechanics of powders, it has become apparent that the most distinctive feature of micron-size powders is their ability to be compacted. In contrast to materials such as sand and most soil media that expand while being sheared, finely-ground powders are found to undergo compaction when sheared.

Compaction of these powders is directly related to the fact that the bulk density of a freshly-ground powder is generally a small fraction of the density of the solid material. This may in turn be attributed to the large surface energy of the ground material relative to the gravitational potential energy of the powder mass. The bulk density of a powder may of course be increased by the application of compressive stresses, but this further increases the contact energy of the powder per unit mass. As a result, compacted powder samples are found to possess considerable bulk strength.

This brief discussion suggests that compaction phenomena may well be the key to the behavior of finely-ground powders. For this reason, we have made a considerable effort to develop valid concepts of the compaction process. Our recent theoretical and experimental work in this area is reported below.

2.1.1 Experimental Compaction Studies

Two types of compaction tests have been carried out during the current report period: 1) tests of a number of powders in the Instron compaction unit[I] to determine the absolute compaction characteristics of these powders, and 2) tests to determine the density distribution in a compacted powder column. A number of these compaction tests were carried out in conjunction with shear tests to determine the relationship between the shear strength of a compacted powder sample and the compressive stress employed to compact the sample.

2.1.1.1 Experimental Stress-Density Relationships

Compaction stress as a function of density has been determined for several powders by use of the compaction apparatus shown in Figure 2.1 of the Ninth Quarterly Progress Report.[I] Tests were conducted in an Instron test machine at a strain rate of 0.02 inches per minute (ipm). The stress applied to a Bg powder sample was recorded continuously during compaction, resulting in a stress-deformation curve typified by Figure 2.1.

Results of these tests are shown in Figure 2.2. Because of the wide range in applied stresses, the data are plotted logarithmically. It is apparent from the linearity of these curves that the empirical relationship

$$\sigma = c\rho^m \tag{2.1}$$

accurately describes the compaction process in the range of interest. Departures from this relationship occur at very high stresses, where the stress increases less rapidly with increasing density. It may also be observed that the curve for saccharin steepens at low densities ($\rho < 0.48$ g/cm^3). This may have been caused by the existence of large void spaces in the test powder in this density range. Three tests were carried out at different times for ground Bg (lot 17). In comparing these test data, one should note that the slopes (measured by the exponent m in Equation (2.1)) are identical, but that the curves are subject to scale shifts for reasons not clear at present.

In general, we expect that the compaction curve will shift to the right with increasing particle size. This is exemplified by the curves for ground and unground egg albumin samples with MMD in the range from 3 to 150 microns. Moisture content would also be expected to influence the compaction process. Curve 3 for Bg and the curve for Sm were obtained with powder samples conditioned for over 24 hours at a relative humidity of about 2 percent. In the case of Bg, the appreciable displacement of curve 1 relative to curves 2 and 3 is an incentive for further compaction testing under rigorously controlled environmental conditions and with samples of known size distribution.

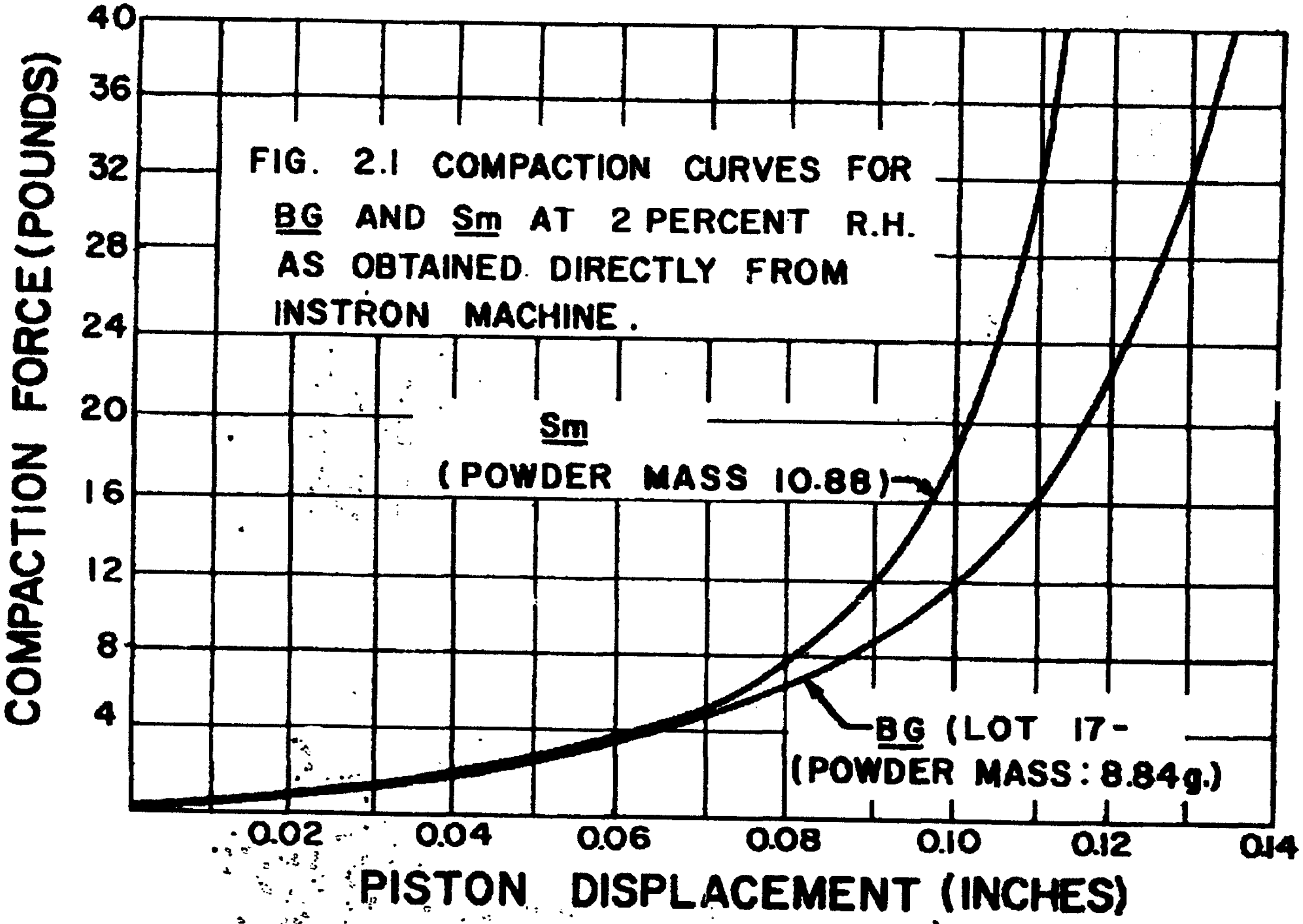

FIG. 2.1 COMPACTION CURVES FOR BG AND Sm AT 2 PERCENT R.H. AS OBTAINED DIRECTLY FROM INSTRON MACHINE.

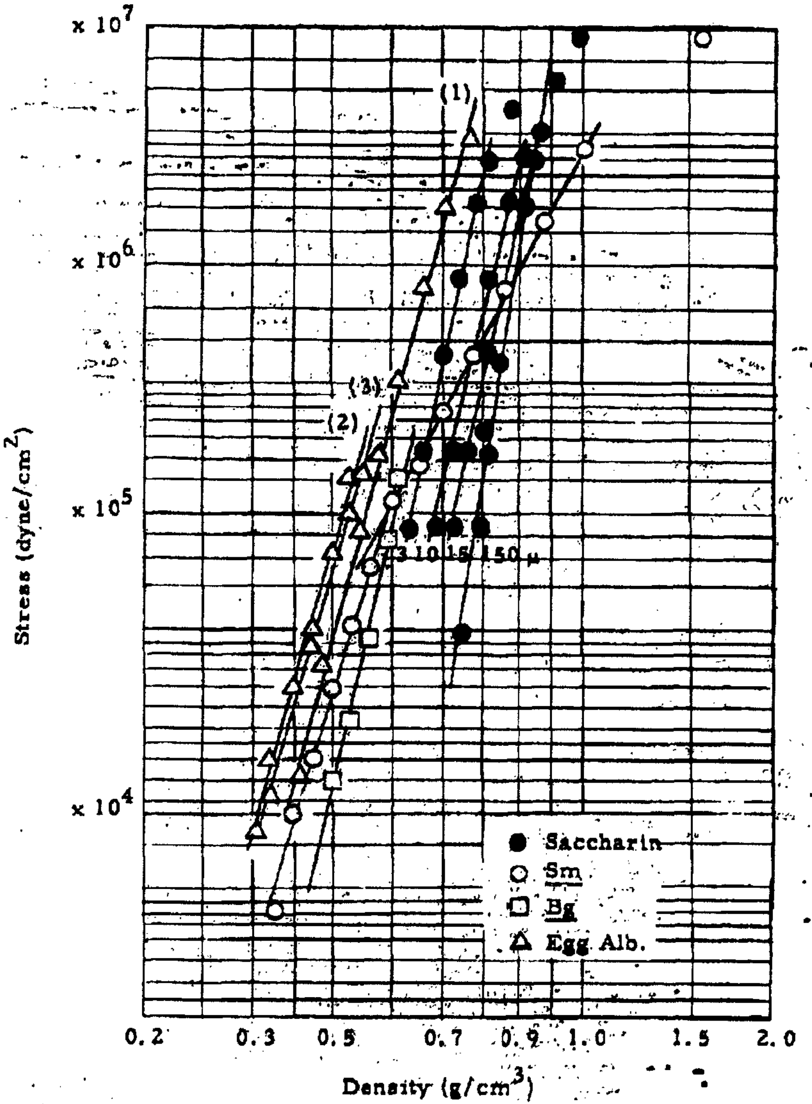

Fig. 2.2 Compaction Stress-Density Relationships for Several Powders

2.1.1.2 Bulk Density of Compressed Powders

Since powdered sugar was considered a possible substitute for Sm in dissemination experiments, it was desirable to obtain information concerning the compaction characteristics and bulk-density variations of this powder under compression. The apparatus and techniques used are identical to those previously described[2] in which the loose bulk powder is used to fill a segmented column 5-3/32-inch ID. Following compression of the powder, the column is cut into 1-inch segments to determine its overall density variation. In the apparatus described, the total column length of uncompacted powder was 20 inches.

The results of this series of experiments are presented in Figures 2.3, 2.4, and 2.5. Since the bulk material is already quite dense, relatively low compressive loads (Figure 2.3) will yield a bulk density of such magnitude that considerable difficulty may be experienced when using this material in the large dissemination equipment. The rate of decrease of bulk density (Figure 2.4) for powdered sugar is comparable to that of saccharin but considerably less than the rate for talc. Figure 2.5 shows the marked effect upon the bulk density of loose powders resulting from different handling techniques. Curve A represents the density variation of the loose powder after filling the bulk-density apparatus in the prescribed way[2] – that is, through a vibrating screen – whereas higher densities represented by curve B are a result of filling the apparatus directly from a 50-pound bag of powdered sugar with a large hand scoop.

In view of the large volumes of powder required, future work with this apparatus will be restricted to powders of specific interest or to specific experiments in controlled-humidity environments. This work will provide a comparison of data obtained with the apparatus and data obtained with other smaller apparatus now in use.

In order to obtain bulk-density information using small amounts of powder in the controlled environment of a glove box, a new bulk-density apparatus (Figure 2.6) has been designed and fabricated. It is not only being used

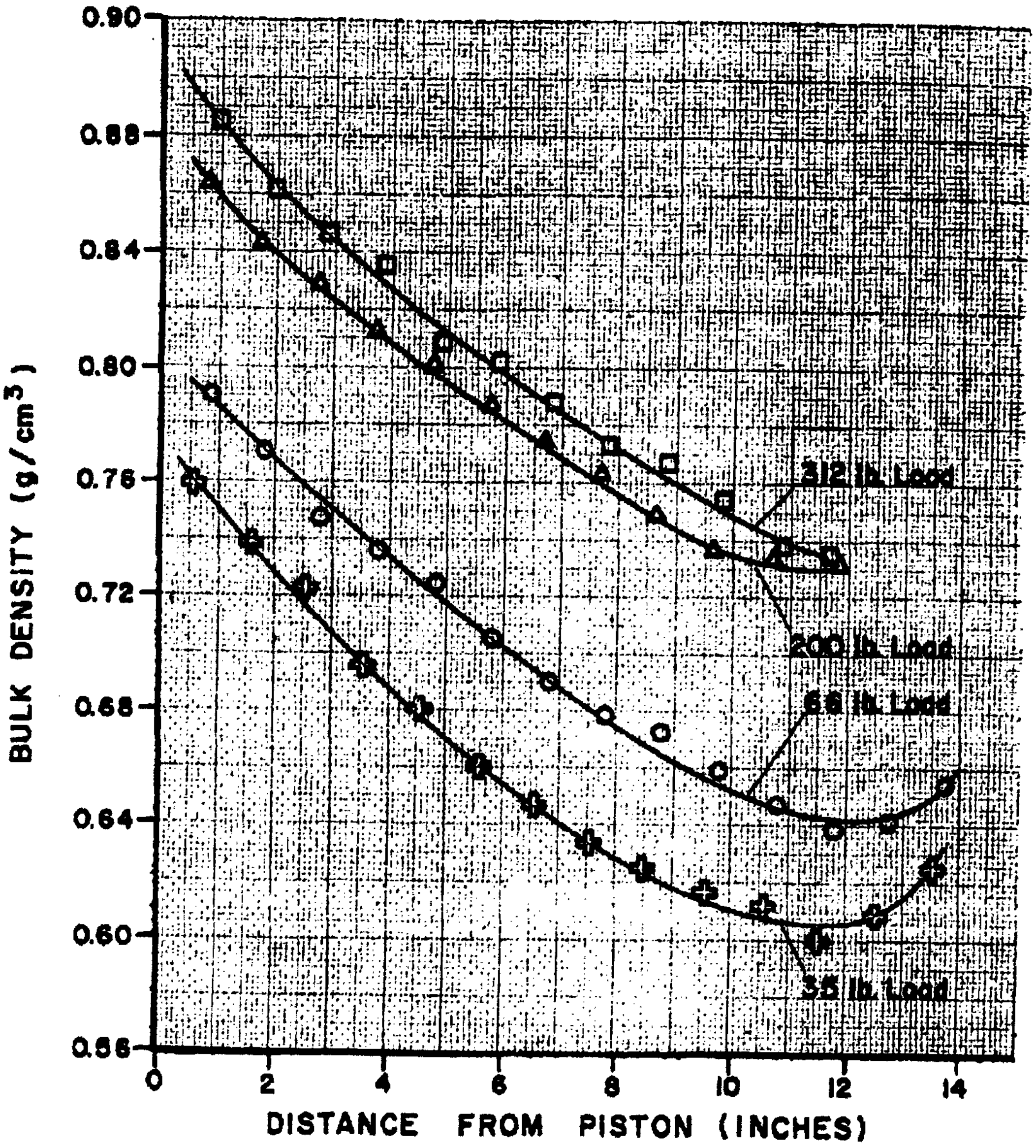

Fig. 2.3 BULK DENSITY OF POWDERED SUGAR AS A FUNCTION OF DISTANCE FROM PISTON AT VARIOUS COMPRESSIVE LOADS.

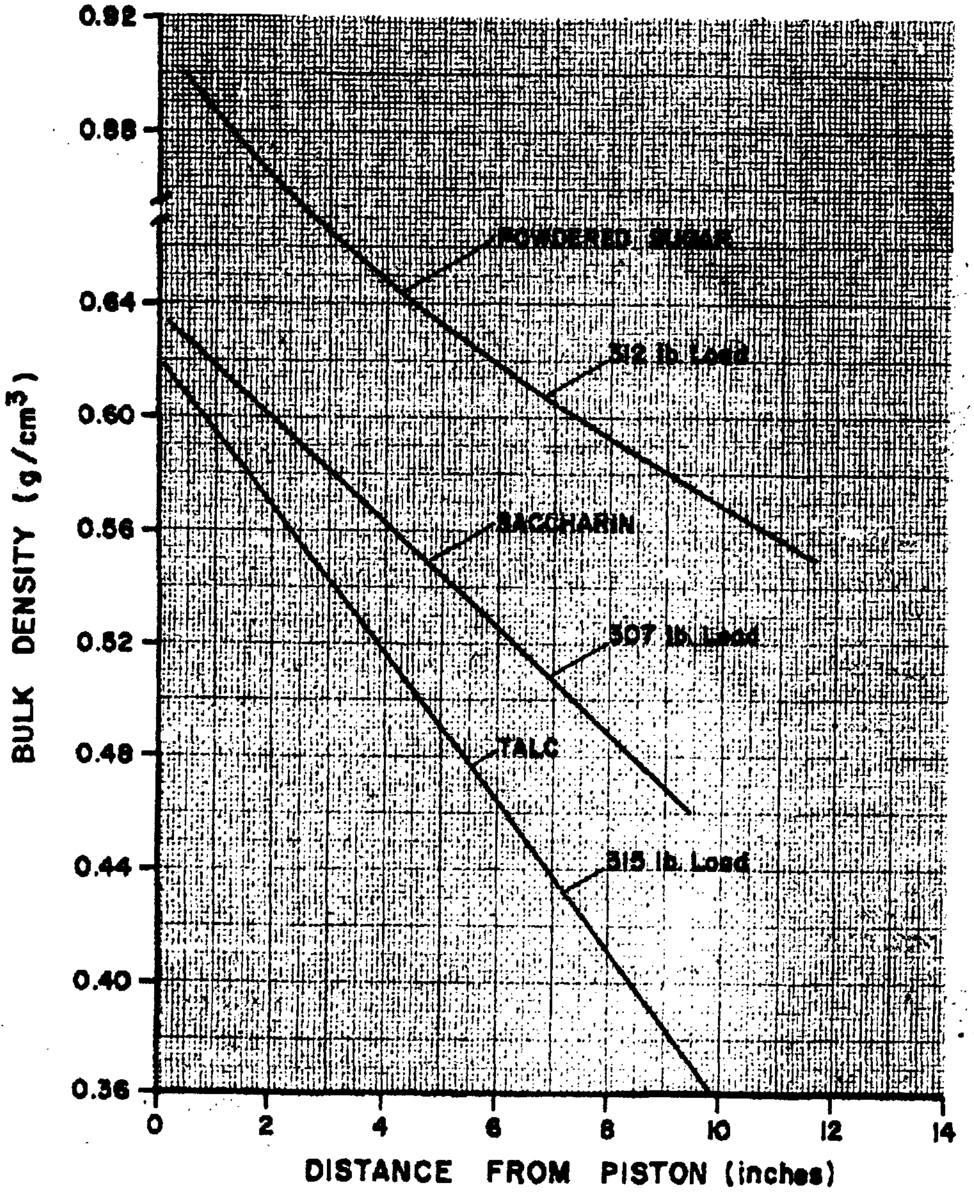

Fig. 2.4 COMPARISON OF THE VARIATION OF BULK DENSITY OF VARIOUS COMPACTED POWDERS AT NEARLY THE SAME COMPRESSIVE LOAD

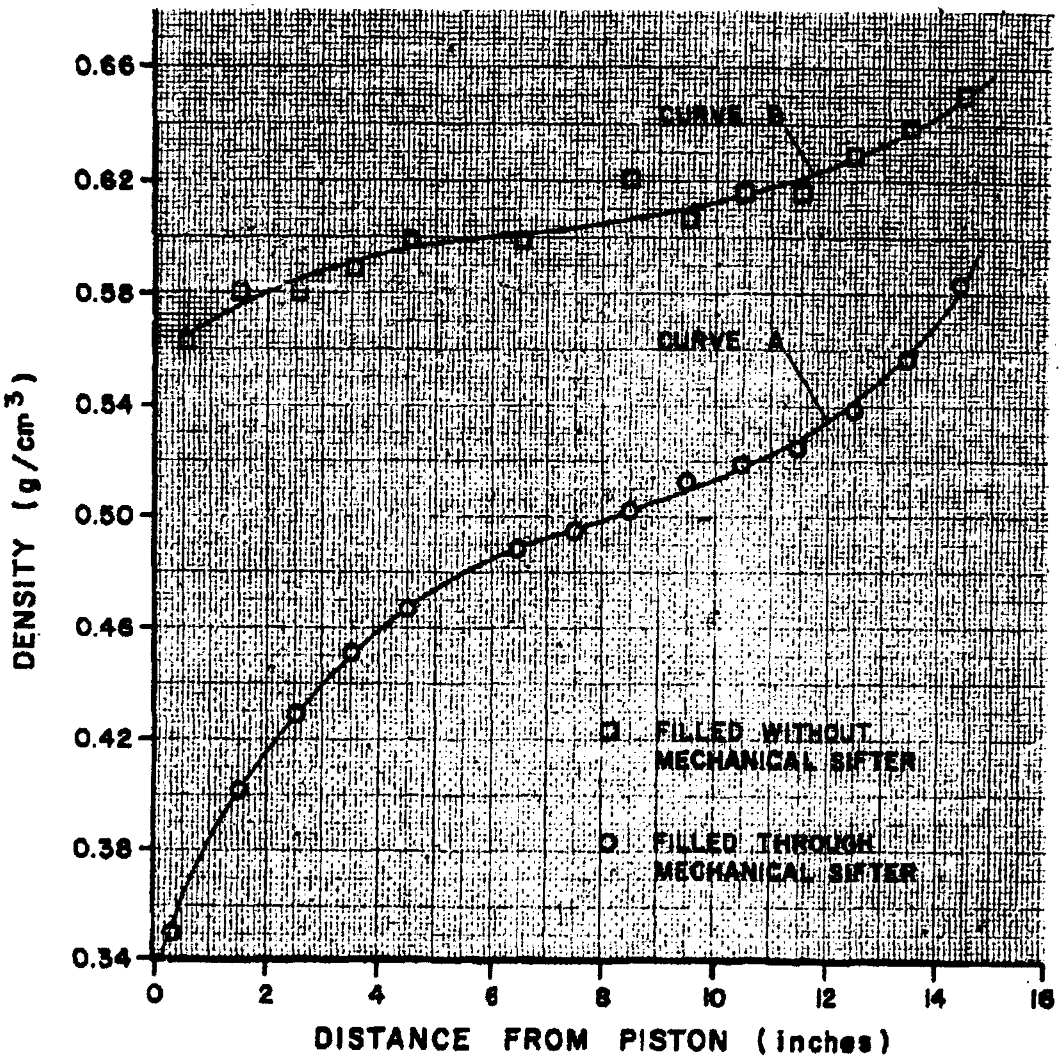

Fig. 2.5 A STUDY OF THE EFFECT OF HANDLING TECHNIQUES ON THE BULK DENSITY OF UNCOMPACTED POWDERED SUGAR

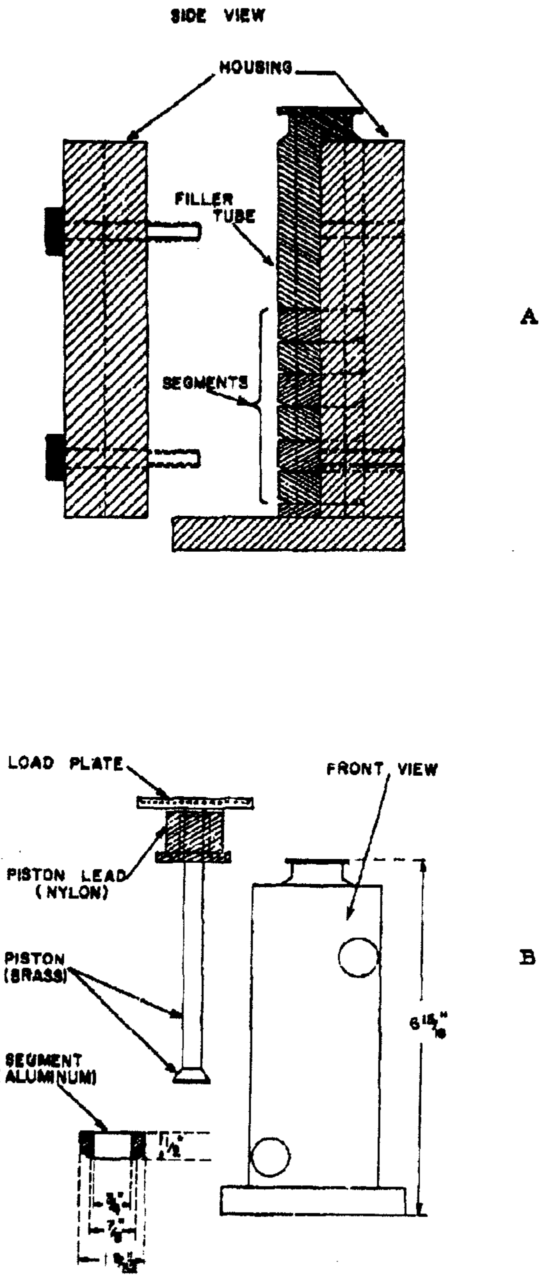
SIDE VIEW
HOUSING
FILLER TUBE
SEGMENTS
A
LOAD PLATE
FRONT VIEW
PISTON LEAD (NYLON)
PISTON (BRASS)
6 15/16"
SEGMENT (ALUMINUM)
1/2"
5/8"
7/8"
1 1/32"
B

Fig. 2.6

as a scaled-down version of our bulk-density apparatus but will also be used to supplement information obtained with the segmented column bulk-tensile-strength apparatus discussed later in this report. The construction of the apparatus is such that the average bulk density of the individual segments corresponds precisely with the fracture plane in the segmented column bulk density apparatus.

2.1.1.3 Compaction Mechanism of Bulk Powders

The large (5-3/32-inch ID) bulk-density apparatus has been used in an interesting way to gain further insight into the mechanism by which a loose bulk powder will compact. In this experiment a portion of a talc sample was colored a medium blue by mixing it with a methylene blue dye solution. The blue talc was then dried and run through a fluid-energy mill to break up any agglomerates formed in the coloring process. The first 1-inch ring of the apparatus was filled with the blue talc, and its weight was recorded. The 15-inch column of rings was subsequently filled with alternate layers of blue and white talc. To insure uniformity of packing, the same weight of powder was used for each layer. Since the weight of the powder caused some compaction, it was necessary to add 19 such layers to fill the 15-inch column. The powder was then compacted into a firm plug with a 270-pound compressive load. Following compaction the entire plug of powder was removed intact from the apparatus and cut vertically in half, revealing the new layer structure shown in Figure 2.7. The "dry river bed" appearance of the surface was caused by the rapid drying of acetone sprayed on the powder's surface to increase the color contrast for photographic purposes.

2.1.1.4 Shear Resistance of Powders During Compaction

Recent progress in the development of theoretical concepts of the compaction process has caused us to adopt a new point of view in interpreting shear-strength characteristics of powders. It is now possible for us to

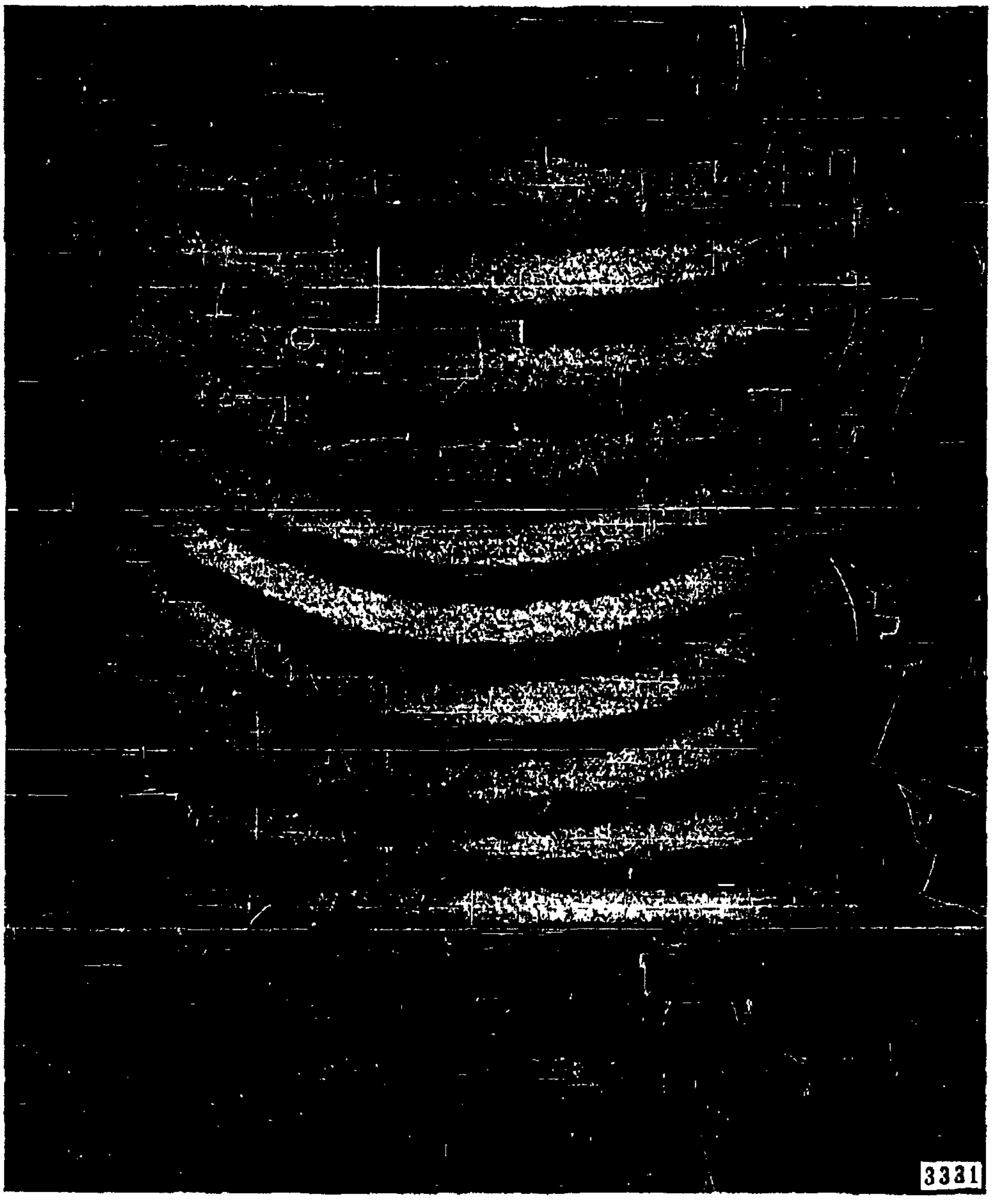

Fig. 2.7 Compaction Mechanism of Bulk Powders

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distinguish between the shear strength of a powder as it undergoes compaction and that of the compacted powder. Most of the shear test data reported earlier, as well as the new test data reported here, can be considered to define the "compaction shear strength" of a powder. The shear strength of compacted powders can best be expressed in terms of the "shear locus" concept, which is considered in Section 2.2 of this report. The close relationship existing between compaction shear strength and shear locus is discussed in Section 2.1.2.

In a series of experiments initiated near the end of the previous quarter, the compaction shear strengths of talc, cornstarch, and two particle sizes of saccharin were determined as a function of compressive stress under various conditions of relative humidity.

The techniques of measurement used were identical to those described in a previous report[3] in which the powder, after exposure for at least 48 hours to a controlled-humidity environment, is caused to shear while under the influence of a compressive stress. The unground saccharin is composed of essentially 20-micron particles, while the other three powders studied are in the < 5-micron range.

The results of these measurements are presented graphically in Figures 2-8 through 2-12. It is obvious from the data that a linear dependence of shear strength on compressive stress exists throughout this range of compressive loads. An increase in the relative humidity of the exposure environment results in a small increase in shear strength. The most significant increase occurs during exposures to relative humidities between 2 and 15 percent. It will be interesting to see how particle rugosity, discussed later in this report, correlates with the relative shear strengths of these powders.

An apparatus has been designed and will soon be fabricated which will both permit more precise measurement of compaction shear strength and improve the data obtainable by measurement of shear strength under reduced loads. Future work will include investigation of the effect of changing the

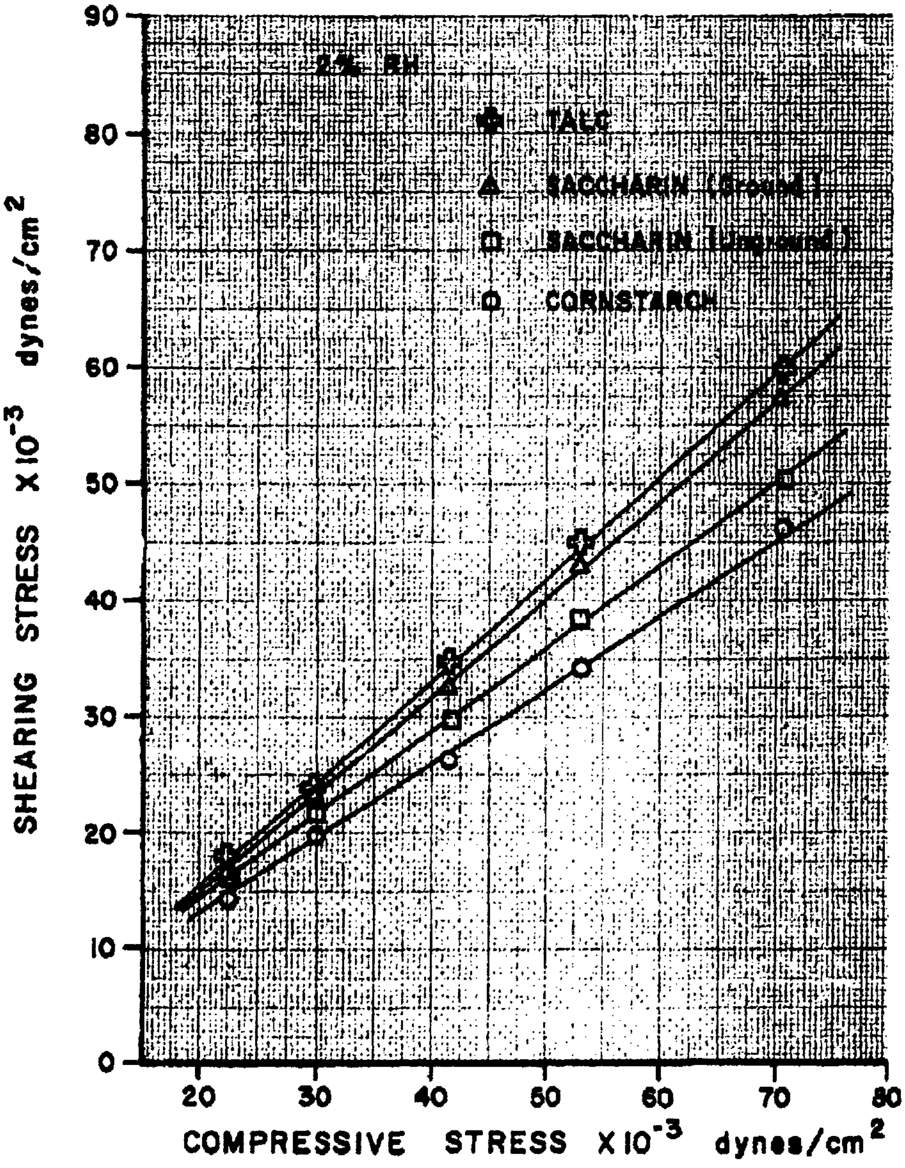

Fig. 2.8 VARIATION OF SHEAR STRENGTH WITH COMPRESSIVE STRESS AT 2 PERCENT RELATIVE HUMIDITY

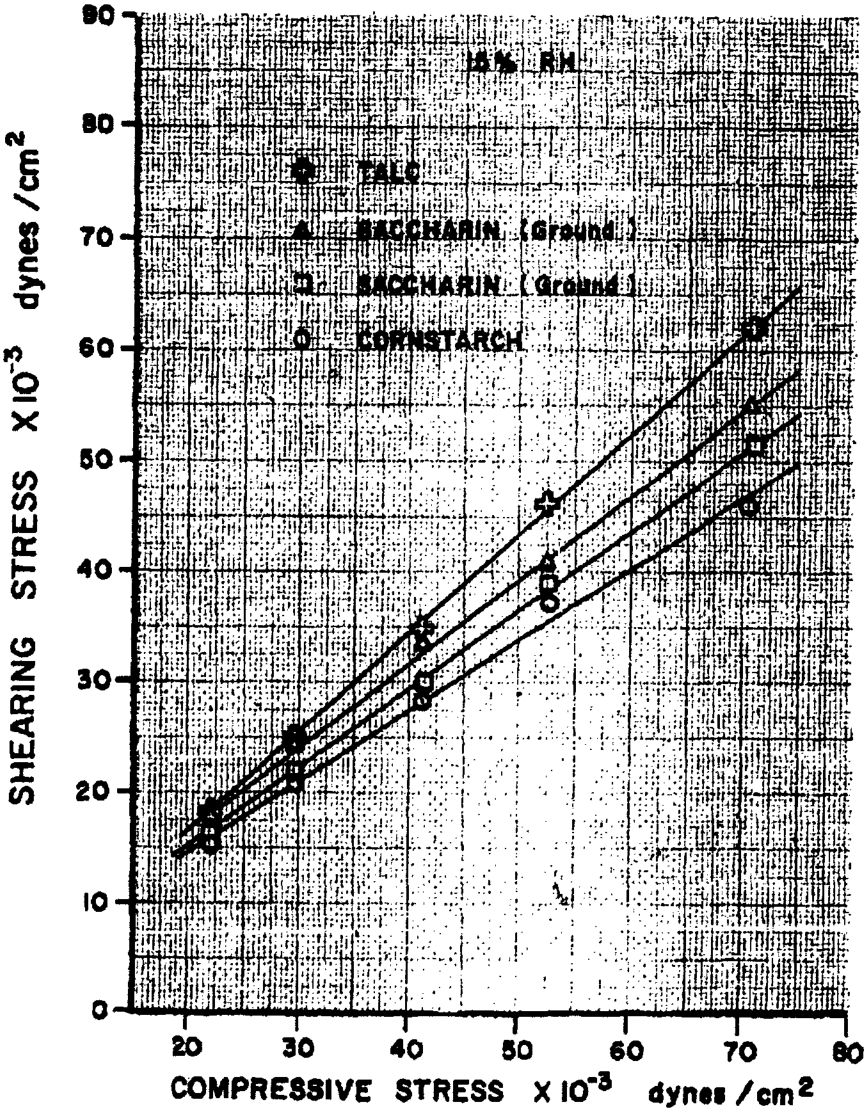

Fig. 2.9 VARIATION OF SHEAR STRENGTH WITH COMPRESSIVE STRESS AT 15 PERCENT RELATIVE HUMIDITY

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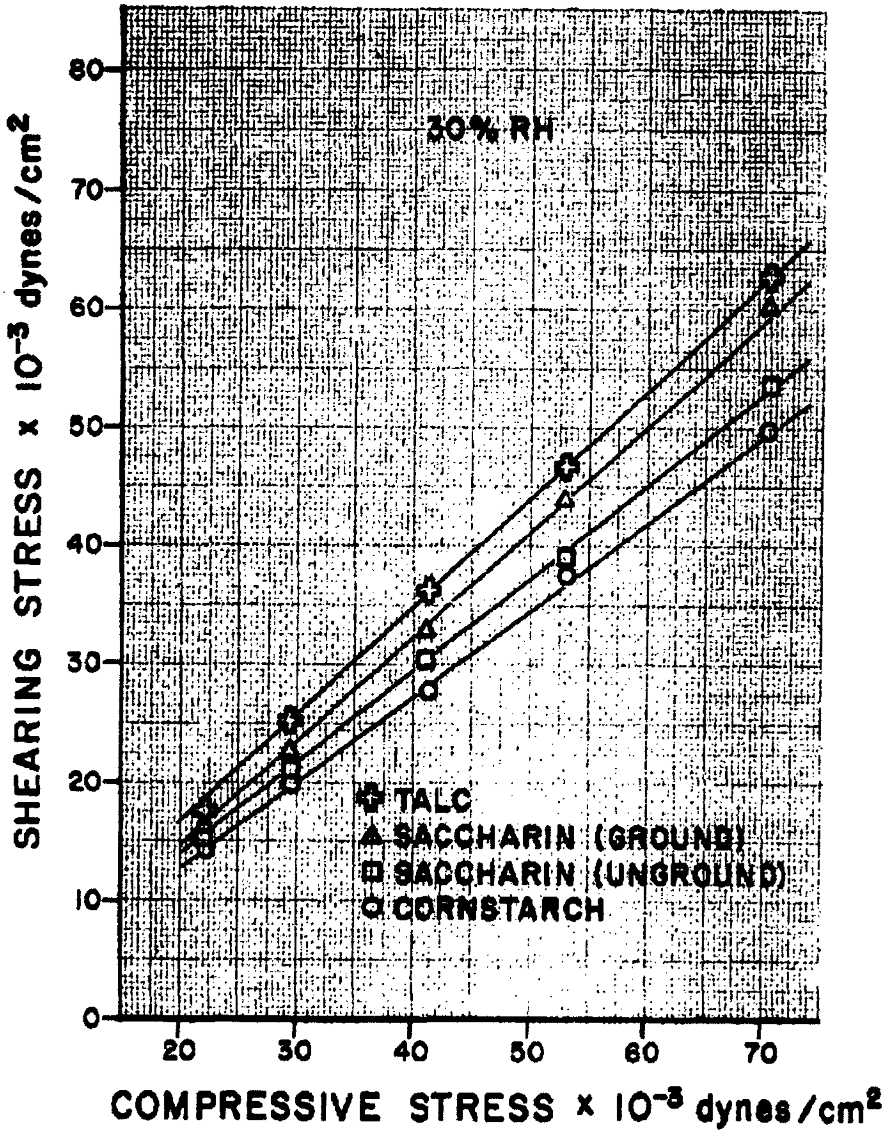

FIG. 2.10
VARIATION OF SHEAR STRENGTH WITH COMPRESSIVE STRESS AT 30% RELATIVE HUMIDITY

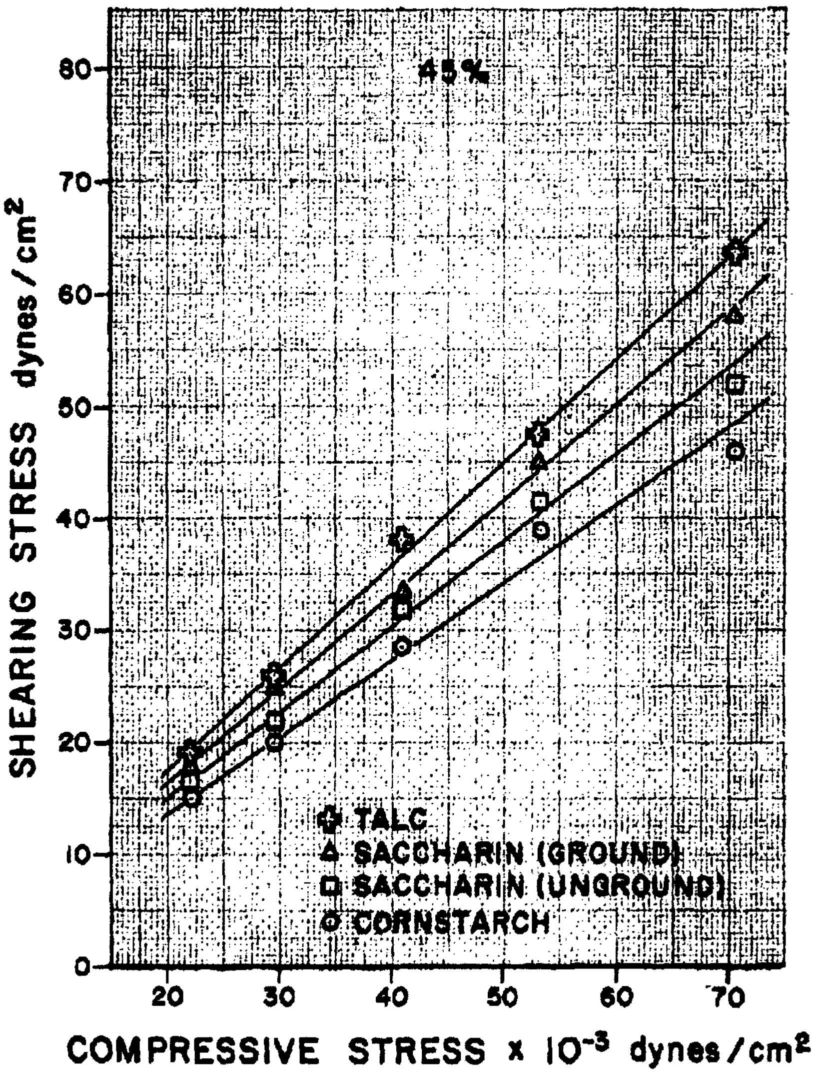

FIG. 2.11
VARIATION OF SHEAR STRENGTH WITH COMPRESSIVE STRESS AT 45% RELATIVE HUMIDITY

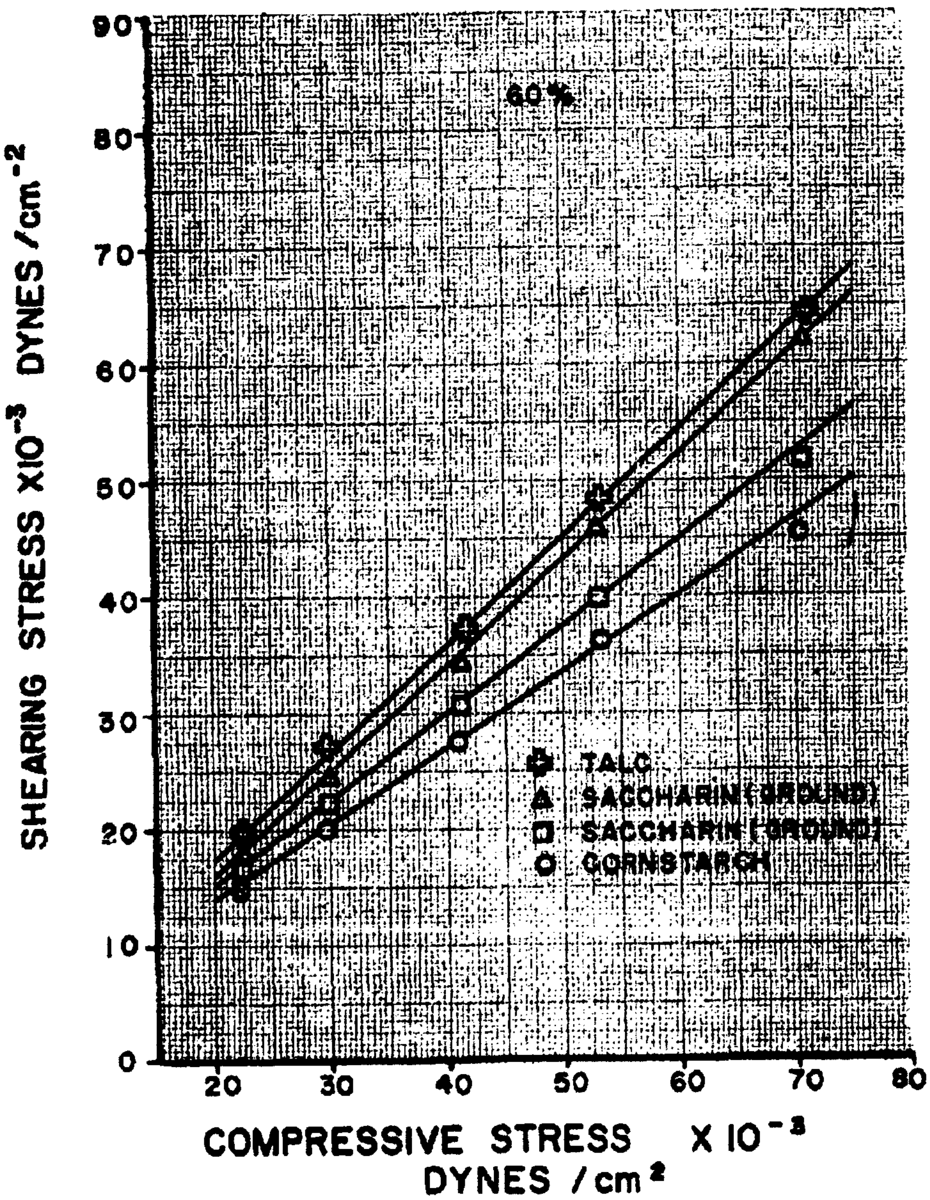

Fig. 2.12 VARIATION OF SHEAR STRENGTH WITH COMPRESSIVE STRESS AT 60% RELATIVE HUMIDITY

geometry of the sliding disk assembly. We will also study the dependence of shear strength on time by maintaining the shearing force slightly below the yield point to determine the extent of stress decay that takes place. The effect of increase in compression time upon shear strength will also be investigated.

2.1.2 Theoretical Considerations in the Compaction of Powders

During the current report period, several new concepts have been introduced into the theory of powder compaction which are of practical as well as theoretical significance. A brief account of these developments is given in this section of the report, although the implications of these concepts are of equal importance to the compacted state considered in Section 2.2.

2.1.2.1 The Dependence of Shearing Strength on Compaction Stress

For a powder undergoing compaction, it is reasonable to expect that the overall shear resistance of the powder is dependent upon two mechanisms: 1) shear resistance due to internal friction, and 2) shear resistance caused by cohesion between particles and agglomerates in the powder. Since the frictional resistance is proportional to the normal stress σ_n on the shear plane, the total shear resistance can be represented by an equation of the form

$$\tau_c = K_1 \sigma_n + f(\rho) \qquad (2.2)$$

where K_1 is a constant and $f(\rho)$ is an explicit function of the density.

The significance of this relationship can be seen by referring to Figures 2.8 through 2.12, which present experimental values of shear strength τ_c as a function of applied normal stress σ_n. These data, obtained by the direct shear technique[4], are in agreement with previous test data[5] in showing that within experimental accuracy the shear strength of a dry powder is proportional to the normal stress – that is,

$$\tau_c = \sigma_n \tan \phi \tag{2.3}$$

where ϕ is the shear angle. As discussed in Section 2.1.1.4, Equation (2.3) is considered to represent the shear strength of a powder as it undergoes compaction.

From Equations (2.2) and (2.3) it is clear that the function $f(\rho)$ is proportional to the applied normal stress σ_n. But it has been shown in the preceding section that in general

$$\sigma = C\rho^m$$

It follows that the shear strength of a powder which behaves in accordance with Equations (2.1) and (2.3) can be expressed in the form

$$\tau_c = K_1 \sigma_n + K_2 \rho^m \tag{2.4}$$

where K_1 and K_2 are constants. These relationships are illustrated in Figure 2.13(a).

The real significance of Equation (2.4) becomes apparent when σ_n is smaller than the stress required to compact the powder to the density ρ. This condition defines the "shear locus"[6] of the compacted powder. If Equation (2.4) correctly defines the shear locus, we should obtain a family of parallel shear loci, with each curve corresponding to a given density as shown in Figure 2.13(b). Thus, the shear strength properties of compacted powders which are implied by Equation (2.4) can be verified by shear tests

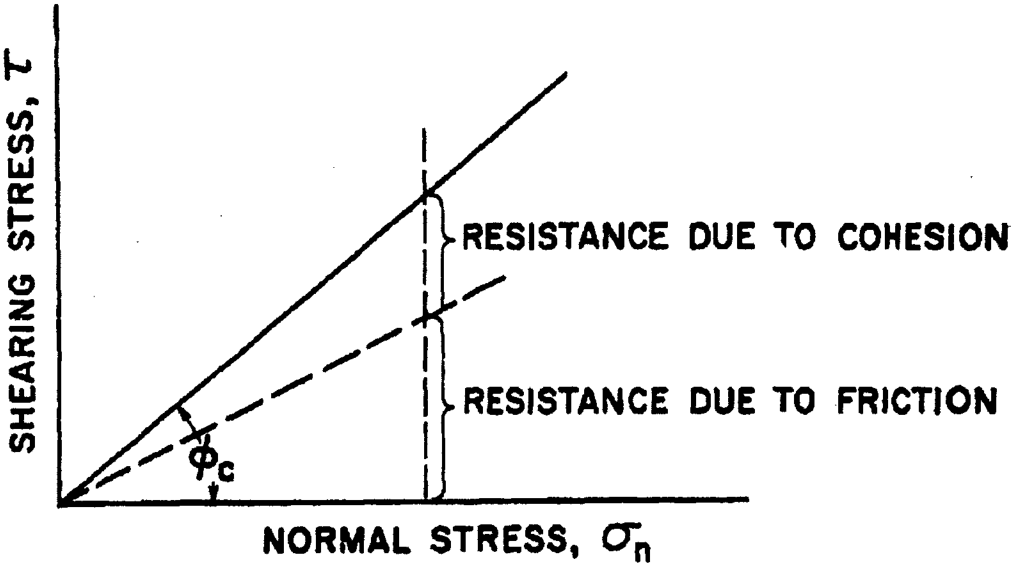

FIG. 2.13a THEORETICAL INTERPRETATION OF THE COMPACTION SHEAR STRENGTH OF A POWDER

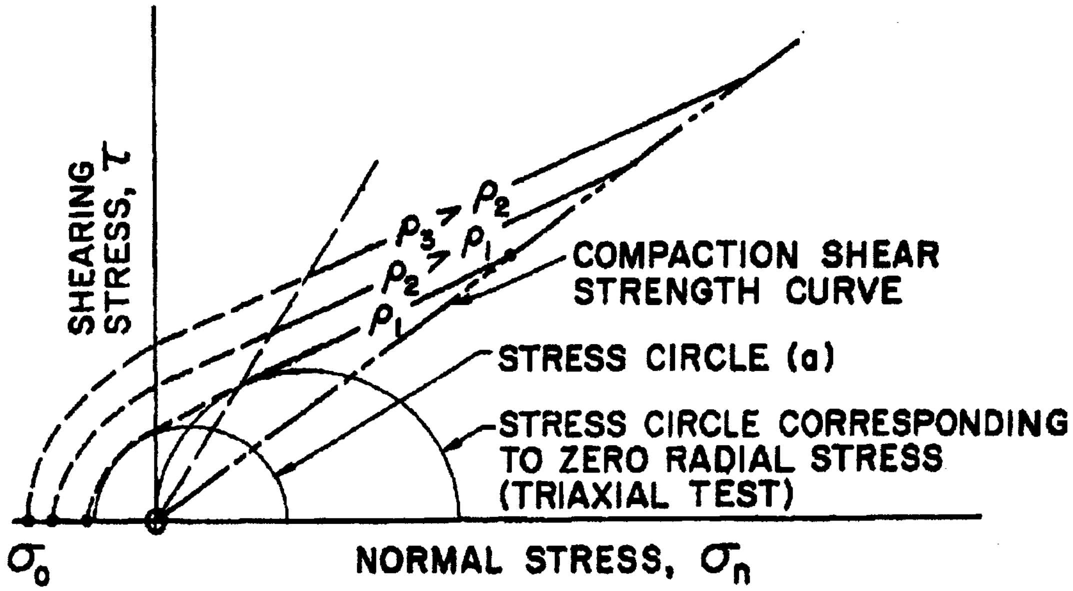

FIG. 2.13b THEORETICAL SHEAR LOCI FOR A COMPACTED POWDER

of compacted powder samples. Tests for this purpose are described in Section 2.2. Although further tests will be required to establish fully the relationships expressed by Equation (2.4), experimental evidence presently available supports the above analysis (see Section 2.2.1.1).

The interpretation of shear strength properties of compacted powder presented here is based on empirical laws - that is, on Equations (2.1) and (2.3). An entirely different and purely theoretical analysis of the shear locus for a compacted powder (see Section 2.2.2) leads to results which are compatible with the conclusions reached here as long as σ_n is positive (that is, for compressive stresses). It can be shown that if σ_n is negative, Equation (2.4) breaks down except in very special cases. However, the theory of Section 2.2.2 affords a basis for extending the shear locus to conditions of tensile loading in the manner indicated by the dashed curve in Figure 2.13(b).

2.1.2.2 Anisotropy of Compacted Powders

It has become apparent during our study of powder mechanics that compaction must take place under conditions of shear equilibrium. This is illustrated by Figure 2.14, which shows stress conditions that the powder can sustain without shearing (circles a, b and c). Each of the stress circles in the figure is defined by the major and minor principal stresses, σ_1 and σ_2. The Mohr stress circle concept has been fully described in an earlier report.[4] Circle d in Figure 2.14, being tangent to the shear locus, represents a condition of shearing equilibrium. The ratio of principal stresses for this condition depends on the shear angle ϕ:

$$\frac{\sigma_1}{\sigma_2} = \frac{1 + \sin \phi}{1 - \sin \phi} . \qquad (2.5)$$

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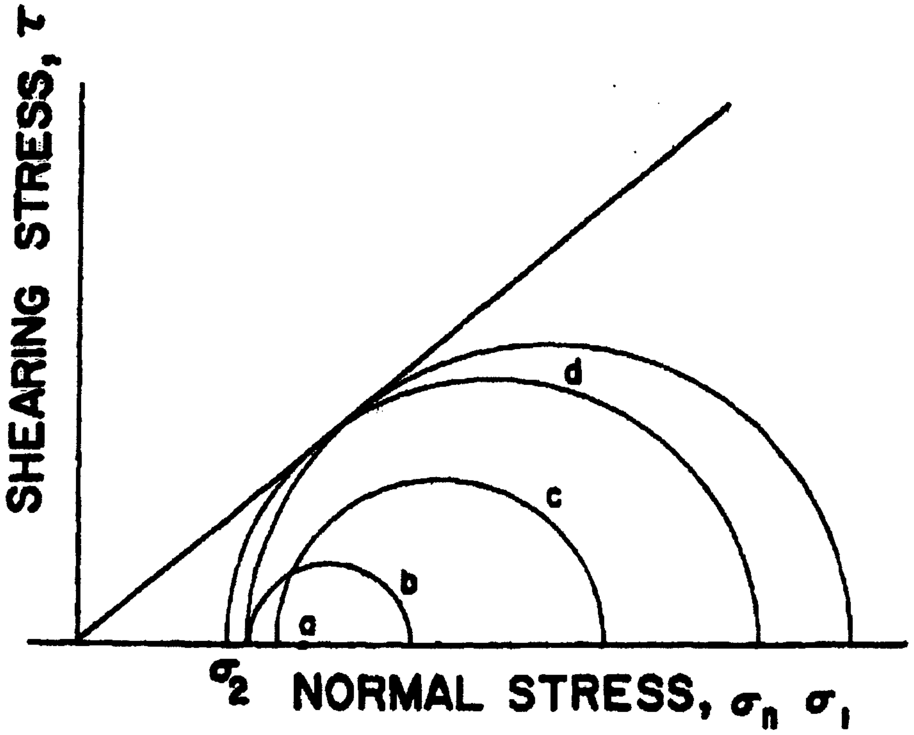

FIG. 2.14 STRESS RELATIONSHIPS DURING COMPACTION OF A POWDER WHICH RESULT IN ANISOTROPIC BEHAVIOR OF THE COMPACTED POWDER

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Now, if σ_1 is further increased, the powder will shear in such a way that Equation (2.5) continues to be satisfied, and the stress circle will grow with increasing σ_1 as shown in the figure.

If a powder sample is compacted in a piston-cylinder device, the major principal stress σ_1 will be directed along the cylinder's axis, and σ_2 will lie in the transverse plane. (The principal stress triad may be represented by vectors σ_1, σ_2, σ_3 which are mutually orthogonal. However, for a powder undergoing compaction, it may be assumed that $\sigma_2 = \sigma_3$ because the powder particles are randomly distributed.) Under these conditions we would expect the powder to compact non-isotropically and to exhibit anisotropic behavior in the compacted state.

Several types of experiments have confirmed the anisotropy of compacted powders. For instance, samples compacted in a piston-cylinder device have been found easier to cut in the transverse direction than in the axial direction, and the decompression tensile test, described in Section 2.2.1.2, has demonstrated that tensile failure invariable occurs first on transverse planes. The effects of anisotropy will be investigated more fully in future experiments.

2.1.2.3 The Role of Elasticity in Powder Compaction

All powders investigated in this study have evidenced elastic properties to some degree. Experimental data on the elasticity of several powders is presented in Section 2.2.1.3, for example. Perhaps the clearest evidence of the elastic behavior of compacted powders was found in the piston-cylinder tests reported some time ago.[5] These tests showed that a powder compacted in a cylinder offered appreciable resistance to sliding, even when the restraining force F_R was zero. This result, as well as other experimental evidence,[7] conclusively demonstrates that the compaction of powders is accompanied by the storage of elastic energy. It appears very likely that the stored elastic energy acts as a potential energy source for the compaction process. From this point of view, powder compaction can be considered to take place in the following way: Suppose that, under initially applied stresses, a number of sites within the powder are at the point of shearing, whereas others are capable of storing energy elastically. With an increase in applied stress, shearing will take place at the weak sites where stored elastic energy will be dissipated through irreversible processes. The remainder of the powder will store additional energy elastically, which will be dissipated as the process continues. These mechanisms may be regarded as functioning simultaneously during compaction to maintain a certain balance between the stored elastic energy and the rate of energy dissipation. This concept is being investigated as a possible basis for a general analytical theory of the compaction process.

2.2 The Behavior of Powders in the Compacted State

Many powdered materials are capable of being poured when in their natural (uncompacted) state. Powders composed of small particles (with MMD around 5 microns) are found to form rather large loosely-bound agglomerates which behave like larger particles when the material is poured or stirred.

After even a slight degree of compaction, however, the powder may lose its capacity to flow freely. This can be explained by the fact that compaction destroys the granular nature of the loose powder that is responsible for its flowability by breaking down the loose agglomerates and forming denser ones. The compacted powder may thus be regarded as a particulate solid, with the particles bound together by chemical or molecular forces. A large number of these interparticle bonds must be broken if the powder is to be restored to a granular state.

The resistance of a compacted powder to fracture when subjected to tensile, compressive, and shear stresses can be expressed in a very general way by means of a "shear locus" as shown in Figure 2.13(b). Stresses defining a stress circle which lies below the shear locus can be carried by the compacted powder. But if the stresses applied to the powder are increased in such a way that the stress circle becomes tangent to the shear locus, the powder will fracture. The general behavior of a given powder can be described by a family of shear loci, each locus of which corresponds to a given density, as indicated in the figure.

Figure 2. 13(b) has been drawn in accordance with our present theoretical concepts of the strength properties of compactible powders, which are discussed in Sections 2. 1. 2 and 2. 2. 2 of this report. A considerable body of experimental data obtained during our study is in essential agreement with these concepts. Recent theoretical and experimental results concerning the properties of powders in the compacted state are described herein.

2. 2. 1 Experimental Evaluation of the Bulk Strength of Compacted Powders

Several experimental techniques have been developed during our study which are useful for investigating the bulk strength characteristics of compacted powders. The triaxial shear test[7] is particularly suitable for this purpose; in fact, our experience has shown that this test is practicable only for compacted powders. The direct or sliding disk shear test can also be used for the studies of the strength of powders in the compacted state. Considerable past work has been done in measuring the tensile strength of compacted powders. This measurement assumes added importance because of difficulties in experimentally defining the shear locus for small values of the normal stress, as discussed below. For this reason, several tests have been under investigation for measuring the bulk tensile strength.

2. 2. 1. 1 Shear Strength

The shear locus for a compacted powder of density ρ can be determined experimentally by either the direct shear technique or the triaxial technique. During the present quarter, both tests have been employed in testing the validity of theoretical concepts outlined in Section 2. 1. 2. The test data also enable a comparison of the two methods of measuring shear strength.

2.2.1.1.1 Direct Shear Test. - The direct shear test has been primarily used to measure the compaction shear strength of powders as described in Section 2.1.1.4. The shear locus may be determined by means of the sliding disk technique in the following way: The initial steps in the test are carried out in exactly the same manner as for the compaction shear test (see Section 2.1.1.4); however, after initially shearing the powder sample with the precompaction normal load P_c applied to the disk, the normal load is reduced to a smaller value P_n. The sample is then sheared by gradually applying a tangential load F to the disk. By repeating this procedure for a series of normal loads P_n, using the same precompaction load P_c in each case, it is possible to construct a shear locus by plotting the shear stress at failure $\tau_c = F_{max}/A$ versus the normal stress $\sigma_n = P_n/A$, where A is the area of the disk.

The results of tests of this type for saccharin are plotted in Figure 2.15. For a precompaction stress σ_c of 71,690 dynes per cm^2, the shear locus is very nearly a straight line as predicted by theory. The shear loci for precompaction stresses of 53,340 and 42,530 dynes per cm^2 are not quite linear, but are nevertheless reasonably in accord with the theory as long as σ_n is not too small.

For small values of σ_n all the experimental points fall appreciably below the expected linear curves. While it cannot be entirely ruled out at this time that these points may lie on the true shear loci, a careful analysis of the test procedure suggests that these data points may be invalid because of defects in the test technique. For one thing, if the shear resistance of the powder is appreciably greater than the applied normal stress, it is possible that the disk may be forced up by the reaction of the powder against the inclined surfaces of the roughened disk, thus permitting failure without complete shearing. A closely related and perhaps more serious defect of the test is the possibility that the shear load may not be applied in the plane of the disk, thus tending to tip the disk and either break or weaken the contact between disk and powder.

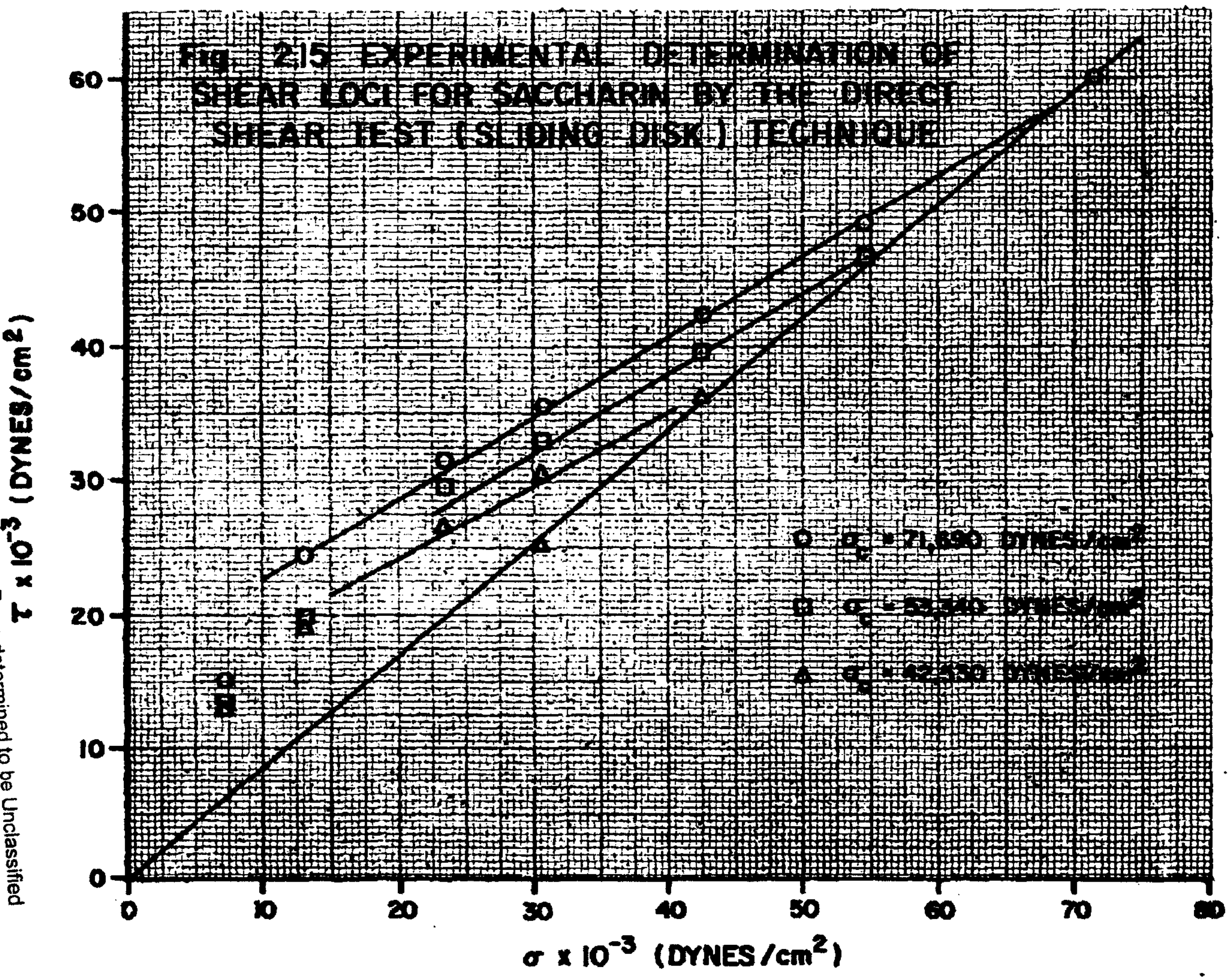

Fig. 2.15 EXPERIMENTAL DETERMINATION OF SHEAR LOCI FOR SACCHARIN BY THE DIRECT SHEAR TEST (SLIDING DISK) TECHNIQUE

This discussion indicates the need for a number of refinements in the direct shear test technique as applied to precompacted powders. Further tests of this type will be carried out after several necessary changes have been incorporated in the test apparatus.

It should be mentioned that the density of the precompacted sample can be determined from the compaction characteristics of Section 2.1.1.1. However, it is essential to take into account the additional compaction which takes place when the sample is presheared. The effective compaction stress is

$$\sigma_{eff} = \frac{P_c}{A} \sqrt{1 + \tan^2 \phi} \ . \tag{2.6}$$

The density may then be found as a function of σ_{eff} from the appropriate compaction curve.

2.2.1.1.2 Triaxial Shear Test. - As mentioned previously, the triaxial test naturally lends itself to an experimental determination of shear loci. This technique has already been used successfully for measurement of the shear strength of compacted talc powder.[2] These tests were conducted primarily for the purpose of evaluating the practicability of the triaxial test for compactible powders. It was found that the triaxial test was feasible, but that the preparation of satisfactory test samples was difficult and time consuming, even when samples were prepared outside a glove box. It should be noted, however, that the results obtained in these preliminary tests support the proposed theory; that is, the shear locus was found to be linear. (See Figure 2.13 of the Eighth Quarterly Progress Report.[2])

During the present report period, efforts were made to simplify the sample-preparation technique, with the ultimate objective of developing a technique which can be used in a glove box. It was considered essential to eliminate the need for using a rubber sleeve in preparing the test sample.

The sample preparation technique described in the last quarterly report was found to meet this requirement successfully.[1] However, considerable manipulation is still required with this technique. A further simplification has been introduced recently in which the powder is compacted from one end rather than from both ends. In this modified technique, the powder sample is compacted into the bottom section of the cylinder, which is split into three segments that can easily be removed after compaction of the sample. An aluminum disk is placed at each end of the sample prior to compaction. These disks remain in contact with the sample throughout the compaction process and during the subsequent triaxial test.

The triaxial test fixture has been modified to permit a thin (1/2-mil polyethylene) plastic bag to be placed over the test specimen. The bag is sealed at the bottom by means of an O-ring and a vent to the atmosphere is provided in the base plate of the test apparatus.

The changes in sample preparation technique described above may make it possible to prepare satisfactory triaxial test specimens in a dry box. A pneumatic system for controlling the application of compaction stresses is currently being investigated for use within the confines of a dry box.

Even though the triaxial shear test procedure was not sufficiently developed to enable tests to be carried out under conditions of controlled humidity during this report period, a series of very informative tests was carried out to establish the dependence of shear strength on sample density. These tests were motivated by a desire to check the validity of the theoretical conclusions of Section 2.1.2 by using the triaxial technique. This was done in the following way: Tests were carried out to determine the stress-density relationship for a given powder in the manner described in Section 2.1.1.1; then a series of shear tests for the powder was conducted over a range of mean sample densities by the triaxial technique at atmospheric pressure. Samples for the latter tests were prepared by the following the procedure described above. Both the compaction and shear tests were carried out in the Instron machine.

If the theoretical assertions of Section 2.1.2 are correct, it follows that the shear strength, as found from the triaxial test, must have the form (see Equations (2.1) and (2.4))

$$\tau_{max} = \text{constant} \cdot \rho^{m} \quad ; \qquad (2.7)$$

i.e., the shear strength must vary with density in precisely the same way that the compaction stress depends on density (Equation (2.1)). Experimental data from these tests are plotted in Figures 2.16 through 2.19. The test materials include saccharin, egg albumin, Sm, and Bg. (The Sm and Bg shear tests were limited to two tests for each powder because of the temporary unavailability of hood facilities for sample preparation.)

Both the compaction stress σ and the shear strength τ_{max} have been plotted versus the sample density. Since these data are plotted logarithmically, we would expect if the theory is correct to find that the two curves are parallel. One can see from the figure that the curves are parallel within the accuracy of the test data, except for Sm. However, since only two test points were obtained for Sm, the discrepancy may be due to experimental error.

The tests described above were not carried out under conditions of controlled sample moisture content; but both the compaction and shear tests were carried out within a short time interval so that humidity effects, if any, would affect both tests in the same degree.

Further triaxial tests will be conducted when the sample compaction apparatus has been adapted for use in a glove box. These tests will of course be carried out for several pressure levels in order to define directly the shape of the shear locus. It may not be possible to define fully the shear locus by means of triaxial tests. The reason for this limitation can be seen in Figure 2.13(b). The portion of the shear locus to the right of the dashed line may be defined by triaxial tests carried out with a chamber pressure

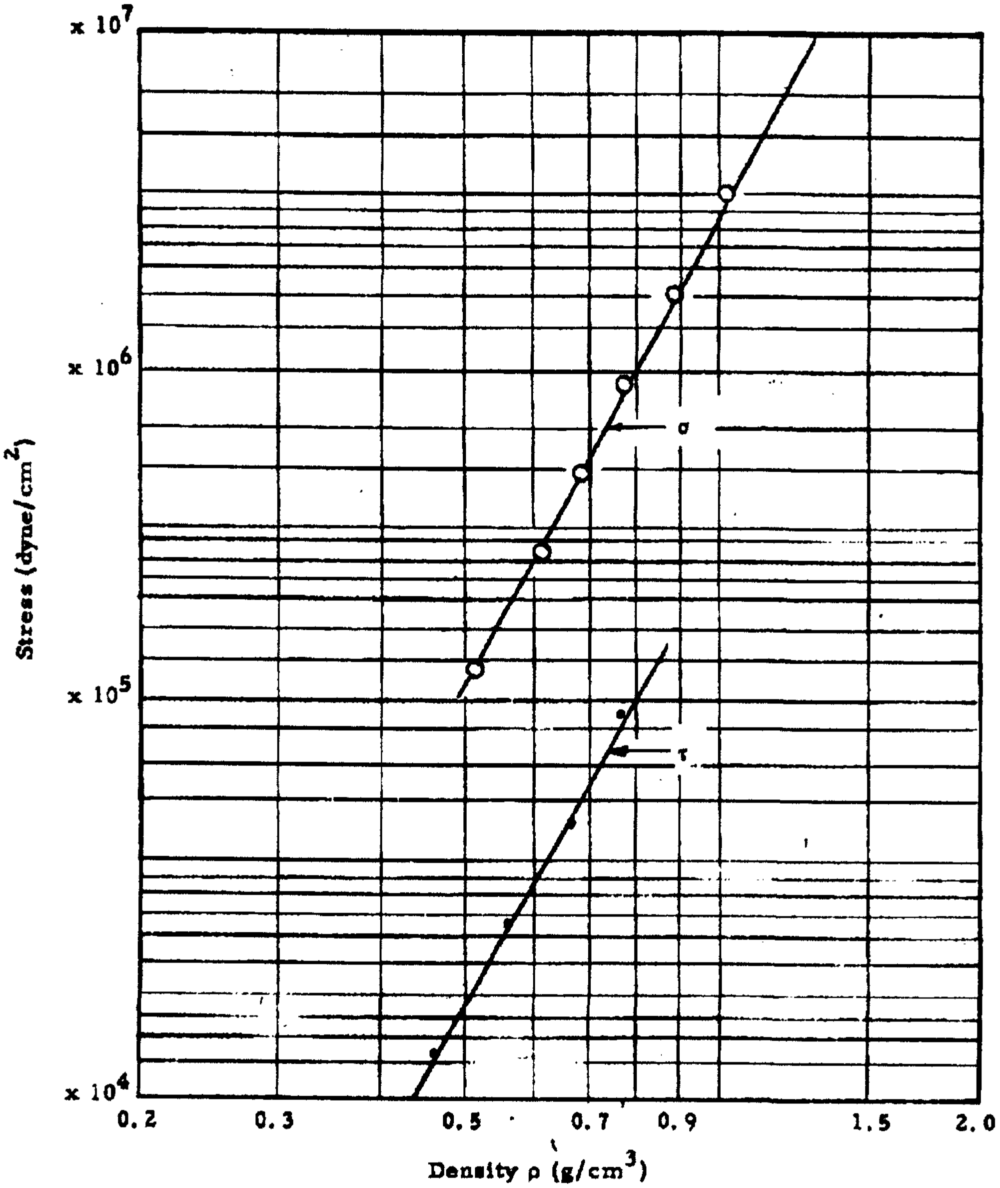

Fig. 2.16 Comparison between Experimental Compaction Data and the Shear Strength of Compacted Powder Samples Determined from Triaxial Tests – Saccharin

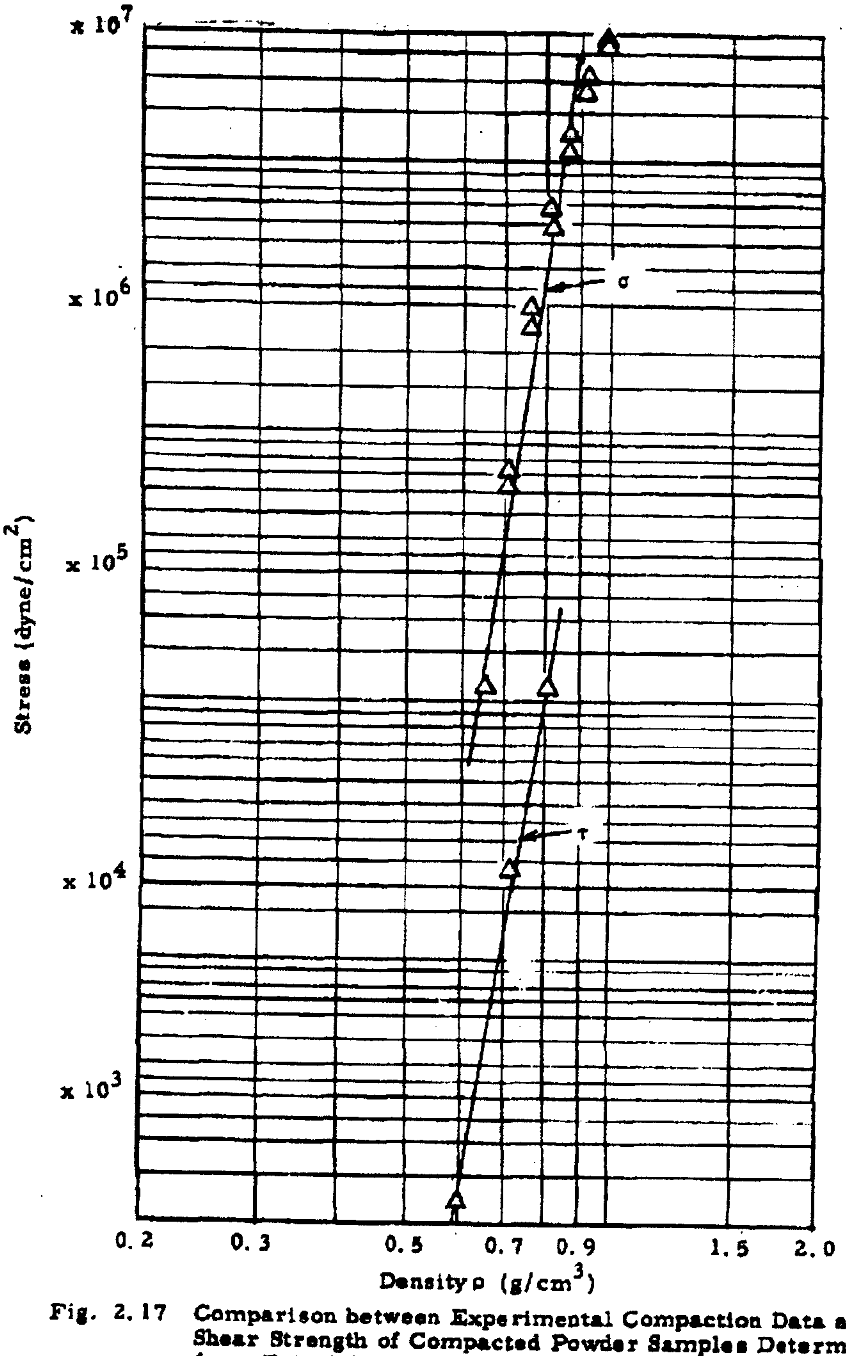

Fig. 2.17 Comparison between Experimental Compaction Data and the Shear Strength of Compacted Powder Samples Determined from Triaxial Tests - Egg Albumin ($d_m \approx 50\mu$)

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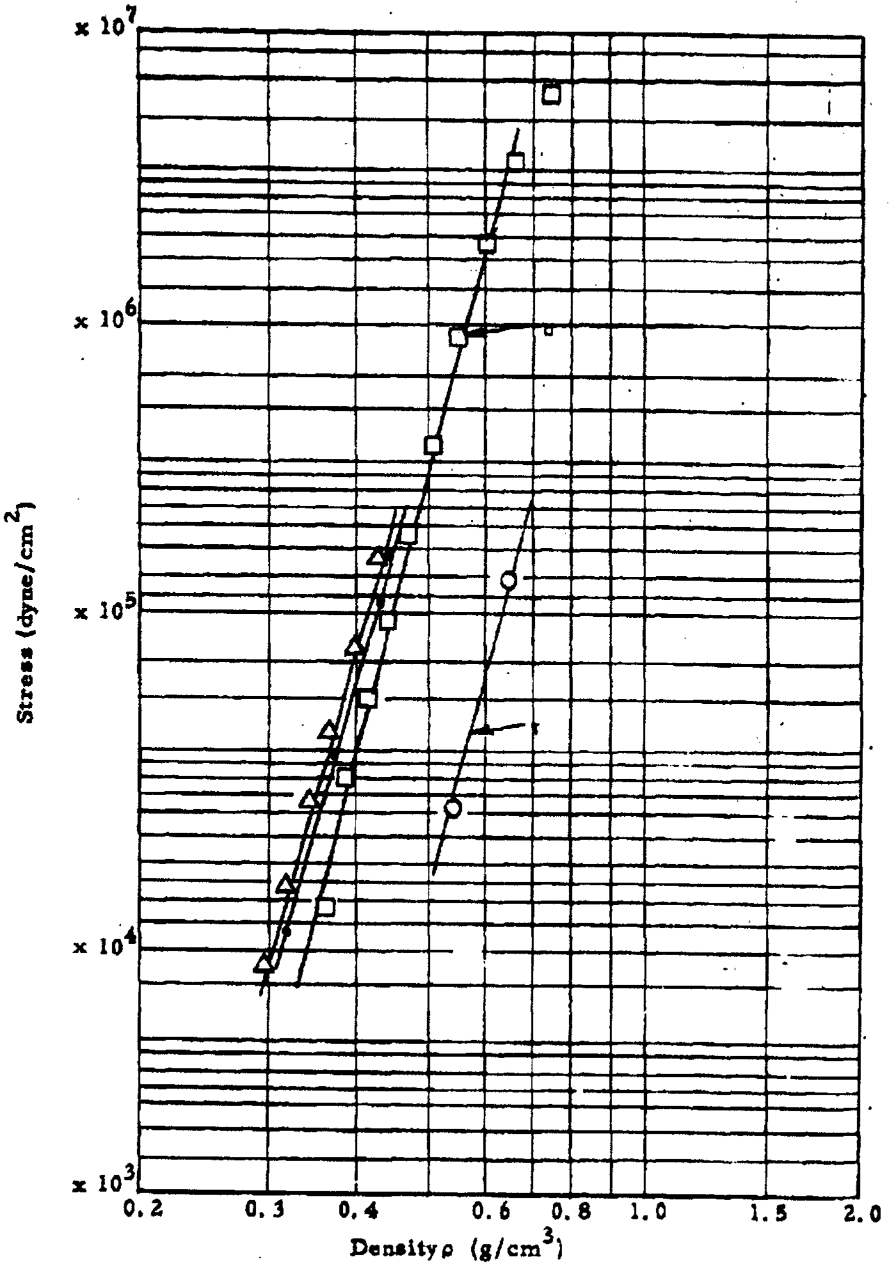

Fig. 2.18 Comparison between Experimental Compaction Data and the Shear Strength of Compacted Powder Samples Determined from Triaxial Tests - Bg

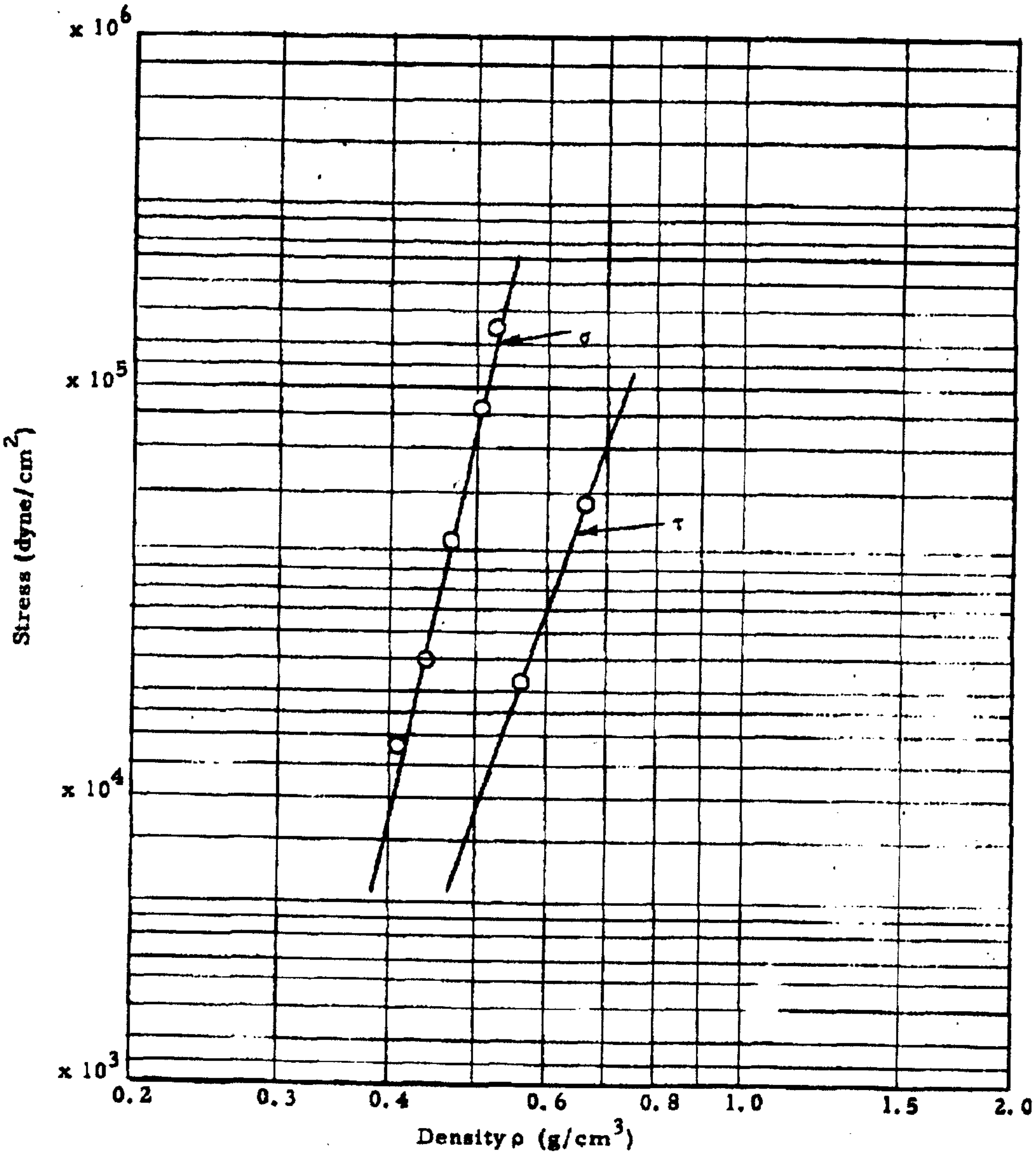

Fig. 2.19 Comparison between Experimental Compaction Data and the Shear Strength of Compacted Powder Samples Determined from Triaxial Tests - Sm

greater than or equal to zero. In order to establish the shear locus to the left of this line, it is necessary to combine tensile and compressive stresses (illustrated by stress circle a). This procedure requires that axial tension be combined with pressurization of the chamber. There are several serious difficulties preventing such a test. One serious problem is that the sample must be sealed within a rubber or plastic membrane, which will tend to carry an undetermined fraction of the applied tensile load. It is also anticipated that the preparation of suitable test specimens for such tests would present formidable problems.

2.2.1.2 Bulk Tensile Strength

The bulk tensile strength of a compacted powder defines the intercept of the shear locus with the σ-axis as shown in Figure 2.13(b). The dashed portion of the shear locus shown in the figure cannot be defined by either the direct shear test or the triaxial shear test for reasons discussed in the preceding section of this report. Accurate measurement of bulk tensile strength thus assumes added importance as a means of "anchoring" the shear locus.

Three methods for measuring the tensile strength of compacted powders have been considered in our study. The segmented-column tensile test[7] was the first to be developed in this program. Although this test provides valuable information relative to the tensile strength of a compacted powder, some question exists as to whether the test results represent pure tensile failure. The uncertainty arises for two reasons: 1) the powder is constrained to fail at the juncture between two rings, and 2) stress concentrations are likely to occur at the periphery of the powder sample since the powder is stressed by means of wall friction; this may tend to cause premature failure.

In an effort to improve the technique for direct measurement of tensile strength, two new tests are currently being investigated. One of these tests, referred to as the triaxial tensile test, is designed to permit unconstrained tensile failure of the test sample. Another test under development uses transient pressure stresses to fracture the test sample. These tests are discussed later in greater detail.

2.2.1.2.1 Segmented Column Tensile Test. - During this quarter we have investigated variations of bulk tensile strength in a column of compressed powdered sugar by the method previously described[1,2,7] in which the powder is preconditioned for at least 48 hours in a controlled environment of 15 percent relative humidity followed by compaction in the segmented column apparatus. Following compaction the tensile strength of the powder is measured at six positions down the column. Tensile strength is, in addition, being determined as a function of bulk density. A dual approach is used in determining bulk density. For powders like ZnCdS, where fracture of the powder column occurs quite evenly, bulk density variation is determined merely by weighing the powder in each segment. To avoid the errors inherent in the uneven fracture typical of many powders and to obtain a measured value of bulk density at the point of fracture, a new apparatus described in the bulk density section of this report (Section 2.1.1.2) was designed and built. The interior geometry of this apparatus is identical to that of the segmented column bulk tensile strength apparatus except that the cutoff point of each segment has been staggered by 1/4-inch so that the average value for the bulk density of the segment corresponds precisely with the position of the fracture plane of the bulk-tensile strength apparatus.

Variation of bulk-tensile strength with distance from the fracture plane of powdered sugar is shown in Figures 2.20, 2.21, and 2.22. Of the powders previously studied,[1] the bulk-tensile strength of powdered sugar is most nearly equal to that of saccharin. The results of our preliminary studies of the variation of bulk-tensile strength with bulk density of powdered sugar and of ZnCdS are shown in Figures 2.23 and 2.24. For efficient handling of bulk-tensile strength data, the tensile strength has previously been reported in grams (g) rather than being converted each time to dynes per square centimeter (dyne/cm^2). In this and future reports, however, data

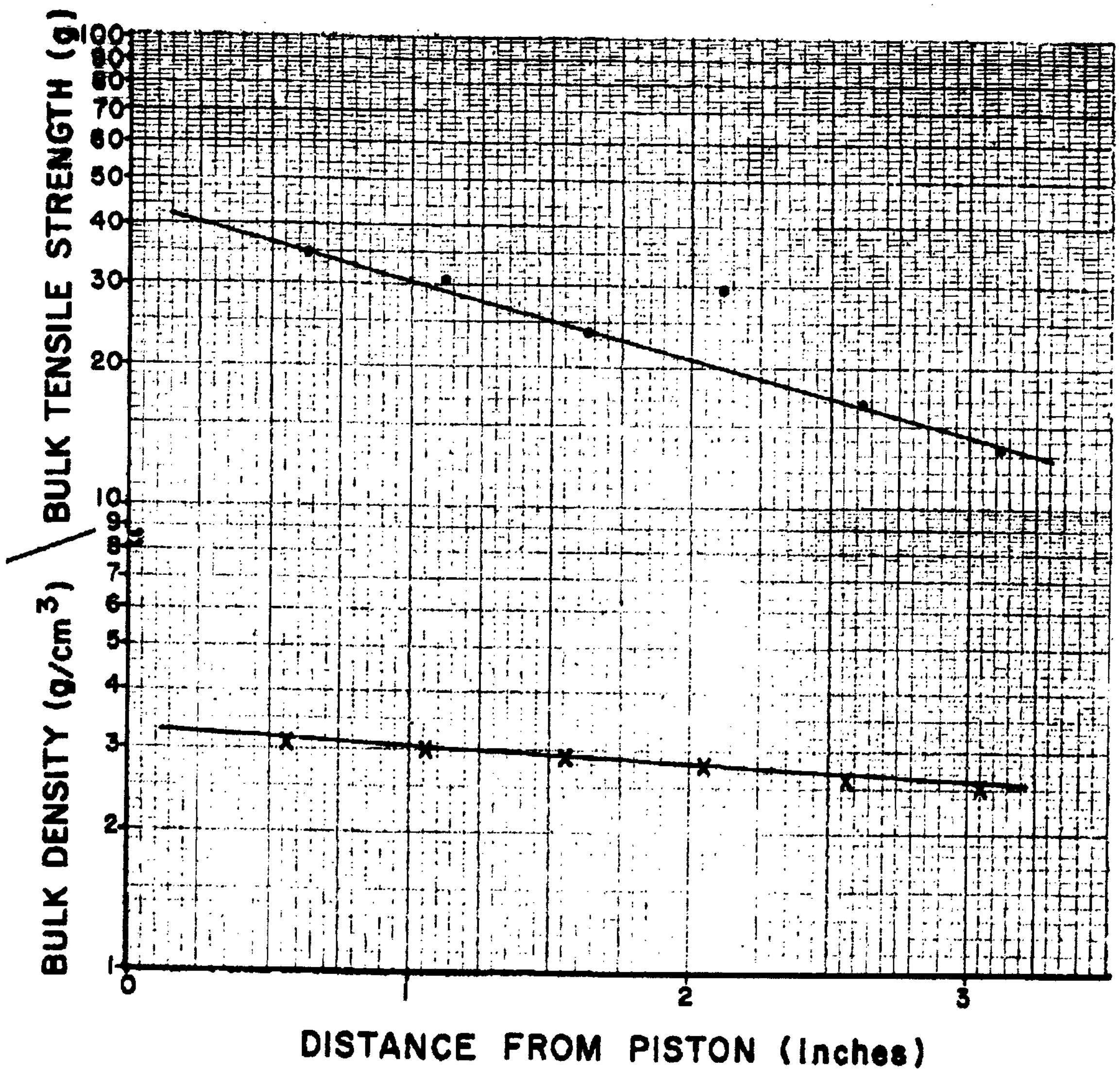

FIG. 2.20
VARIATION OF BULK TENSILE STRENGTH AND BULK DENSITY WITH DISTANCE FROM PISTON FOR POWDERED SUGAR.
COMPRESSIVE LOAD 12.17 × 10^5 dynes / cm^2

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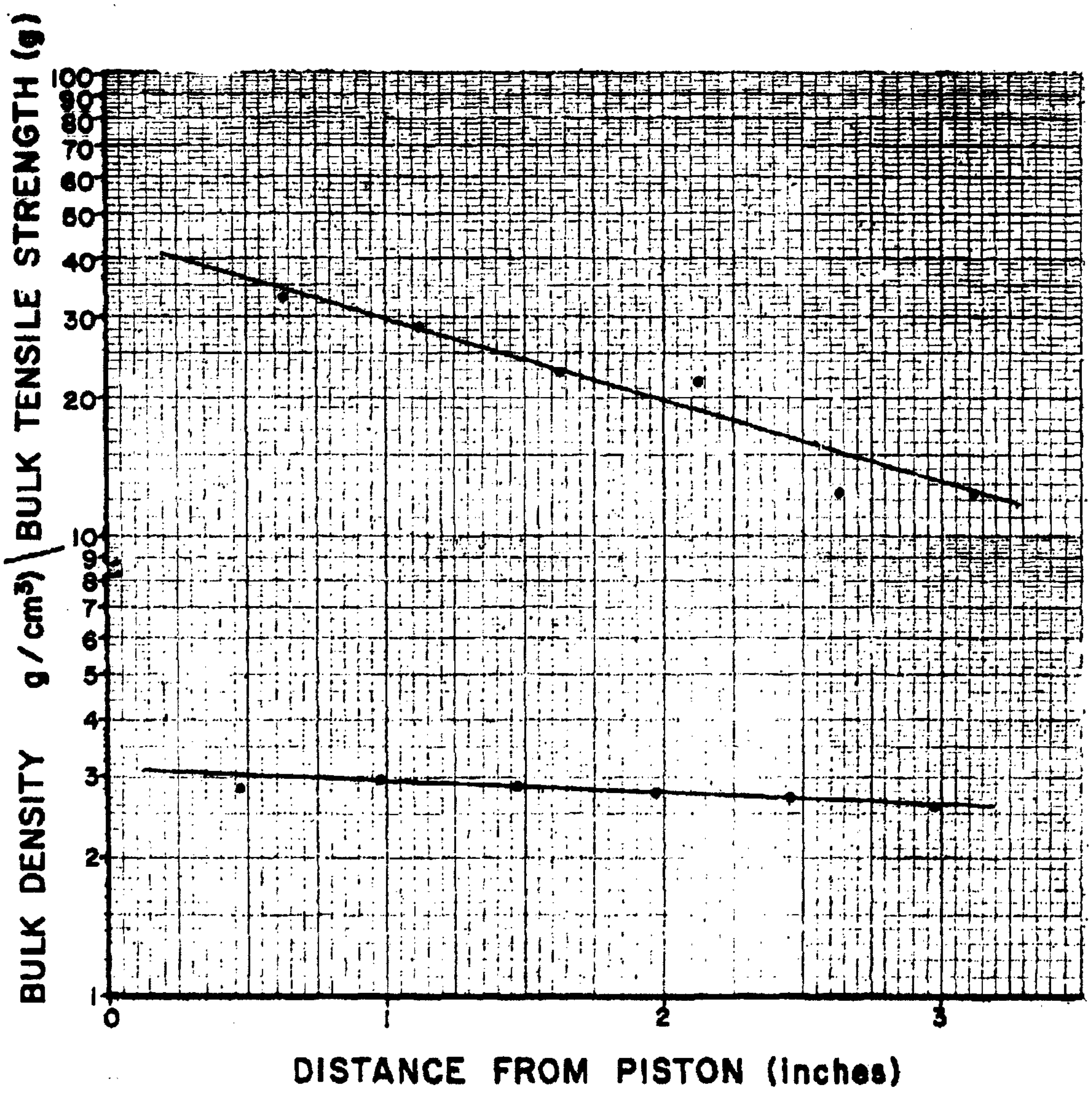


FIG. 2.21
VARIATION OF BULK TENSILE STRENGTH AND BULK DENSITY WITH DISTANCE FROM PISTON FOR POWDERED SUGAR.
COMPRESSIVE LOAD 10.59 x 10^5 dynes / cm²

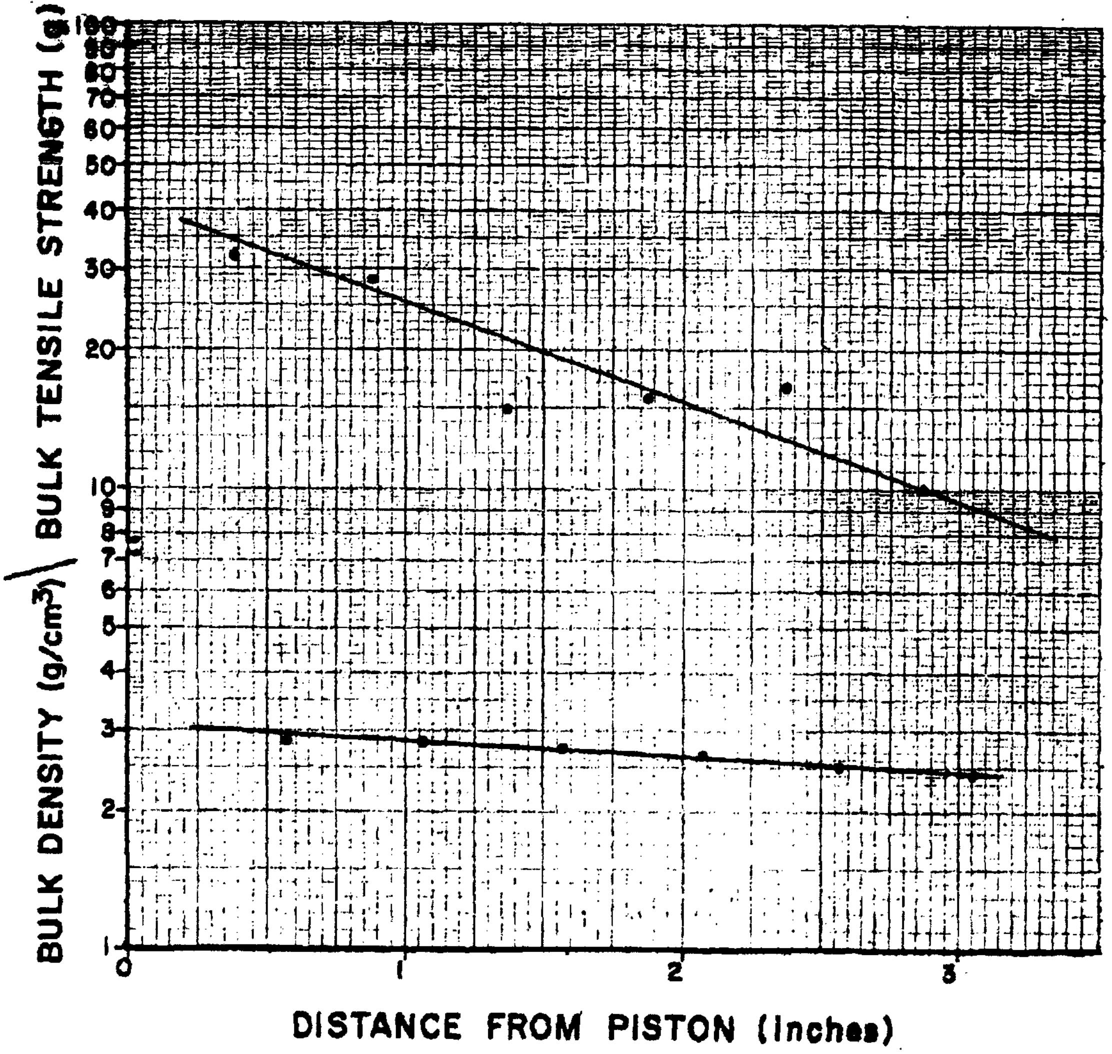


FIG. 2.22
VARIATION OF BULK TENSILE STRENGTH AND BULK DENSITY WITH DISTANCE FROM PISTON FOR POWDERED SUGAR.
COMPRESSIVE LOAD 5.5 × 10^5 dynes / cm^2

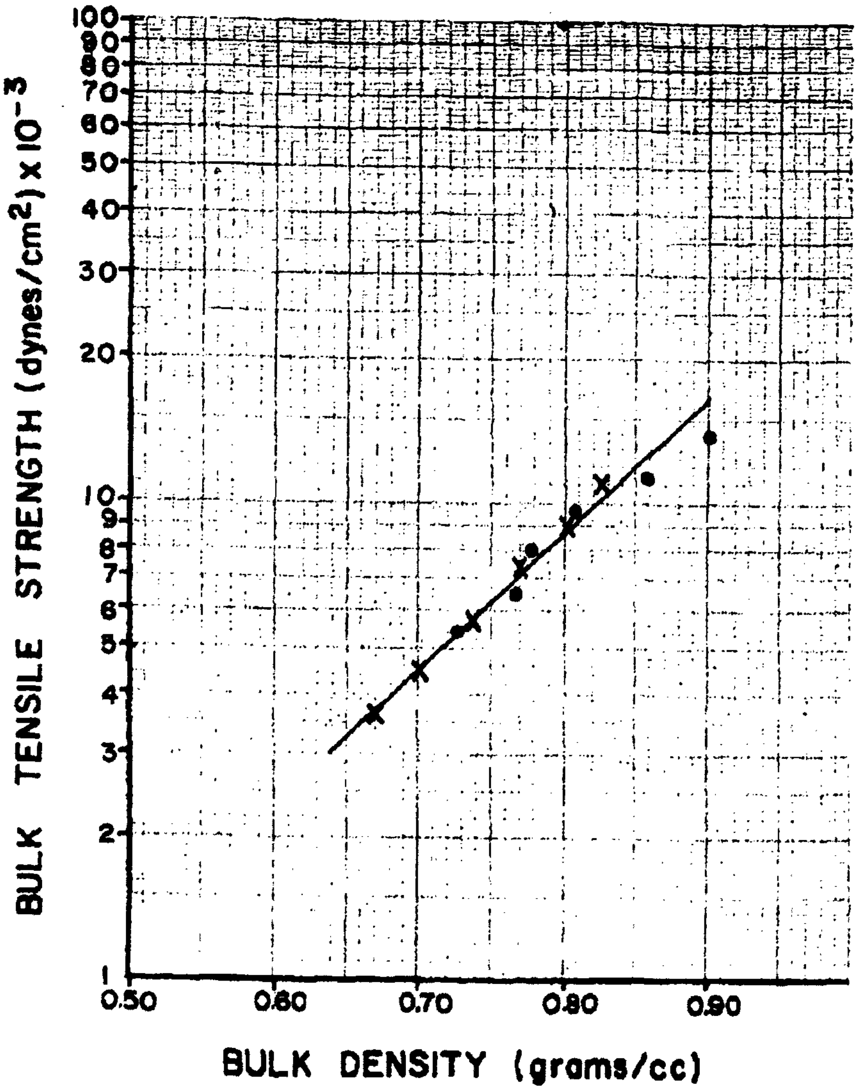
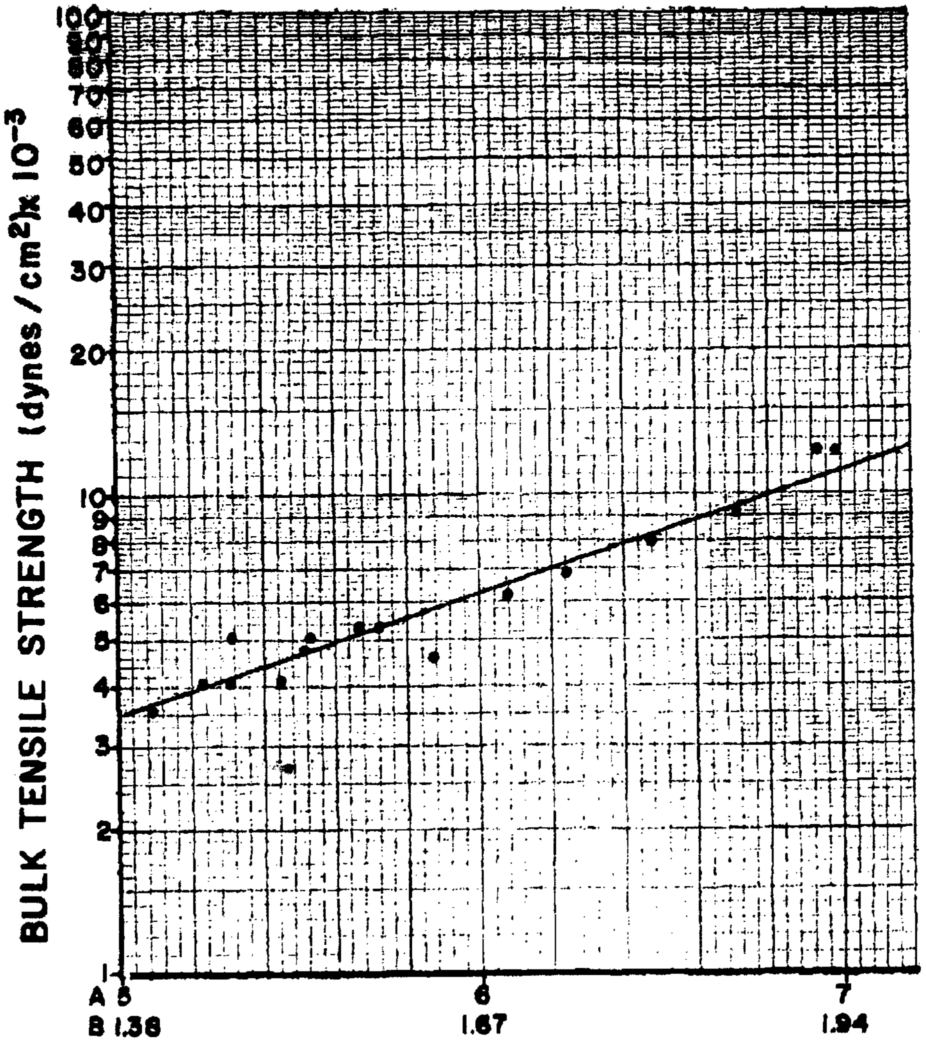


Fig. 2.23

VARIATION OF BULK TENSILE STRENGTH WITH DENSITY FOR POWDERED SUGAR.



A = GMS POWDER PER SEGMENT
B = BULK DENSITY OF POWDER

FIG. 2.24
VARIATION OF BULK TENSILE STRENGTH WITH BULK DENSITY FOR ZINC CADMIUM SULFIDE.

involving bulk-tensile strength will be reported in dyne/cm^2 (cross section of powder column fractured in tensile failure). Data obtained by this method can more readily be compared with that from new methods under development.

The segmented column test for measuring tensile strength has certain limitations. For most powders, the tensile strength at low compressive load is difficult to measure, and at high compressive loads fairly marked changes in tensile strength occur with only minor changes in bulk density, thus requiring a very precise measurement of bulk density.

The results of a preliminary check on the effects of time of compression on tensile strength are shown in Figure 2.25. A 16-hour compression time resulted in a definite increase in tensile strength with no apparent increase in bulk density. Admittedly the test was conducted at a high compressive load to exaggerate the effect; but this phenomenon warrants further investigation. One possible explanation for its existence is an increase in surface bonding between particles with time under compression. This aspect of particle technology will be discussed later in this report.

In addition to the effect that length of compressive time has on bulk tensile strength, future work will include studies at low (< 2 percent RH) humidities, relation of bulk density to bulk-tensile strength, and the effect of particle shape and surface characteristics upon the bulk tensile strength.

2.2.1.2.2 Triaxial Tensile Test. - This is a direct mechanical test that can be carried out in the Instron test machine, in which a specially-prepared test specimen is caused to fail in a region free of external constraint. A test sample produced for initial tests is shown after failure in Figure 2.26. The center section of the sample is necked down to achieve several desired effects: 1) reduced area makes the average stress a maximum in the center section, 2) this configuration causes the powder's density to be higher at the end fittings than in the center, thus tending to increase the tensile strength at the ends of the speciman, and 3) the length of the specimen (20 inches)

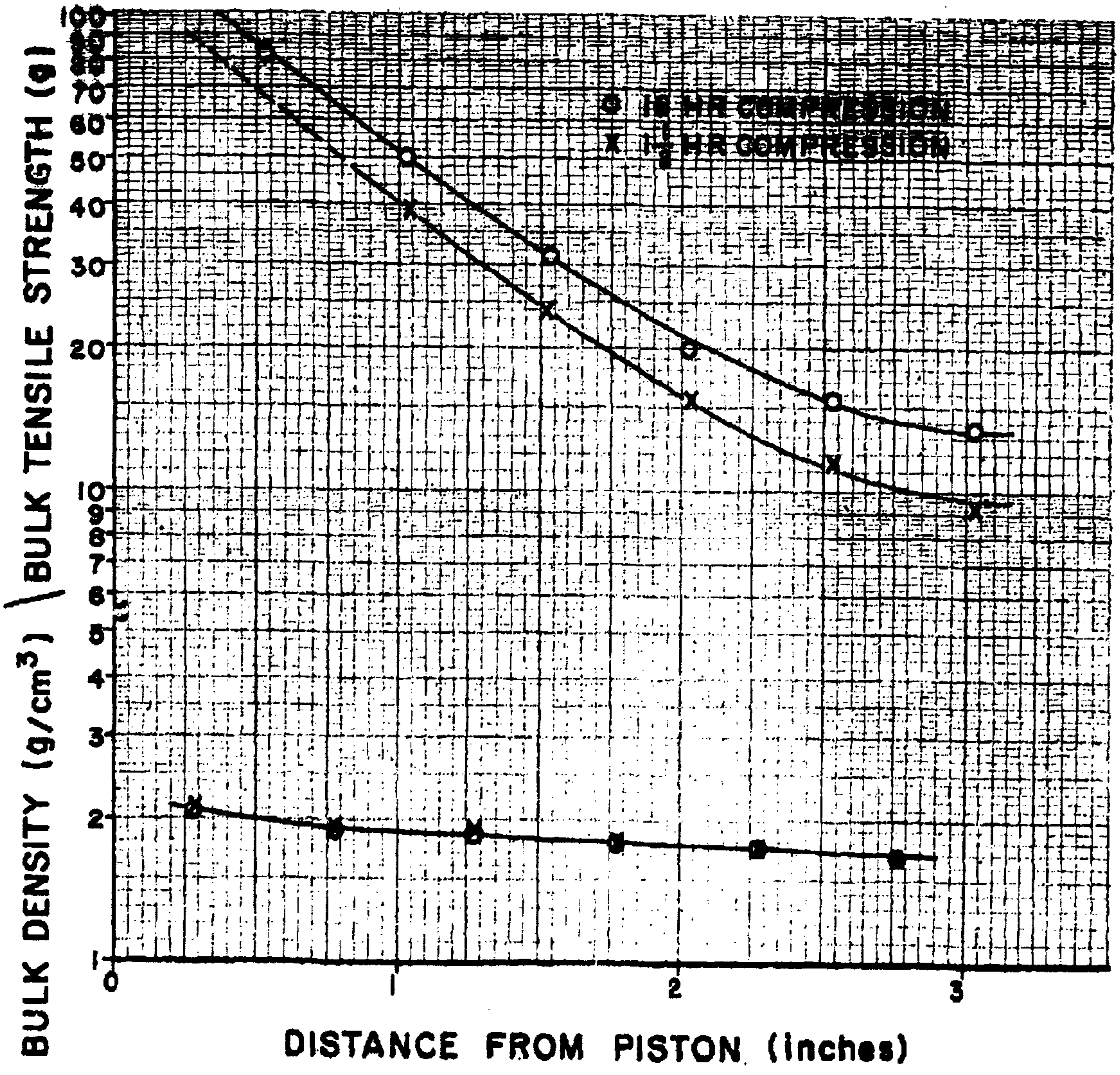


FIG. 2.25
EFFECT OF LENGTH OF COMPRESSION UPON THE TENSILE STRENGTH OF Zn Cd S.
COMPRESSION LOAD 12.17 x 10^5 dynes/cm^2

Fig. 2.26 Triaxial Test Specimen, Shown After Failure

enables an equilisation of tensile stress in the center section due to the elasticity of the powder (see Section 2.2.1.3), thus avoiding stress concentrations prior to failure of the sample.

Sample preparation for the tensile test follows very closely the procedure for the triaxial shear test described in the last Quarterly Report.[1] The only essential difference in the apparatus is that the split central section of the compaction apparatus has been replaced by a flared section to reduce the diameter from 1.2 inch at the end cylinders to 0.8 inch in the center section. Some care is required to produce samples which have a symmetrical density distribution with respect to the center of the sample. It was found that satisfactory samples can be obtained by charging each end of the apparatus with an equal mass of powder and then forcing the powder into the center section by means of pistons to which equal loads are applied.

The density distribution in the center section was determined by means of a duplicate flared section with the central section divided into five equal segments of 0.2 inch long. In initial tests with saccharin powder, samples were prepared with a mean center-section density of 0.38 g per cm^3. The maximum density variation was about 5 percent, with the lowest density occurring in the center.

Several tensile tests were conducted in the Instron machine using saccharin samples of mean density $\rho = 0.38$ g per cm^3. Failure was found to occur in the center section as desired (see Figure 2.26).

Attempts to carry out a series of tensile tests by the triaxial technique were forestalled by difficulties in sample preparation. Very high loads were required to increase the sample density significantly beyond 0.4 g per cm^3. Under these conditions, it was impossible to remove the center-section mould segments without fracturing the sample. It appears likely that these problems can be eliminated by modifying the flared section of the sample-preparation apparatus so as to increase the diameter of the "necked-down" section to about 1.0 inch.

2.2.1.2.3 Decompression Tensile Test. - The decompression tensile test is a unique method for determining the tensile strength of compacted powder specimens. The test consists of subjecting a specimen to a sudden reduction of surrounding gas pressure. This causes the specimen to crack or fracture as gas trapped in its interior seeks to escape following decompression. The pressure drop just necessary to fracture the specimen is a measure of the tensile strength of the compacted powder.

2.2.1.2.3.1 Compaction Apparatus. - Specimens are prepared in the compaction apparatus shown in Figure 2.27. The compaction apparatus is composed of a split compaction chamber A, loading tube B, and piston C. The compaction chamber A consists of two aluminum blocks fitted with alinement pins. In the center of each block is a 90-degree V groove 1-1/4-inch on each side. On top of each block is fastened a 1/4-inch flat aluminum plate with a 90-degree V groove in its center, 1-1/2-inch on each side. This plate forms a sharp-cornered, recessed groove at the top of the block. When the two sides of the chamber are fastened together with pins and thumbscrews they form a square tube with a recess at the top. The loading tube B is a length of square extruded aluminum tubing 1-1/4-inch by 1-1/4-inch (inside dimensions) by 18 inches long. The loading tube is supported by means of a ring stand the clamp. The piston assembly C consists of a beveled square aluminum plate, 1-7/32-inch on a side by 1/4-inch thick, attached to an aluminum rod as shown in the figure. Two Teflon rings are fitted to this rod to maintain proper alinement of the piston assembly.

Specimens are prepared in the following way: The divided chamber A is closed and fastened together with thumbscrews. The loading tube A is then lowered into position directly over the compaction chamber where it fits snugly in the recess at the top of the chamber. A quantity of powder is then poured into the loading tube through a funnel. Piston C is inserted into the loading tube, and weights are placed on the piston to compress the powder slowly into the compaction chamber. Various weights are used to produce specimens of different densities. When the compaction process is completed,

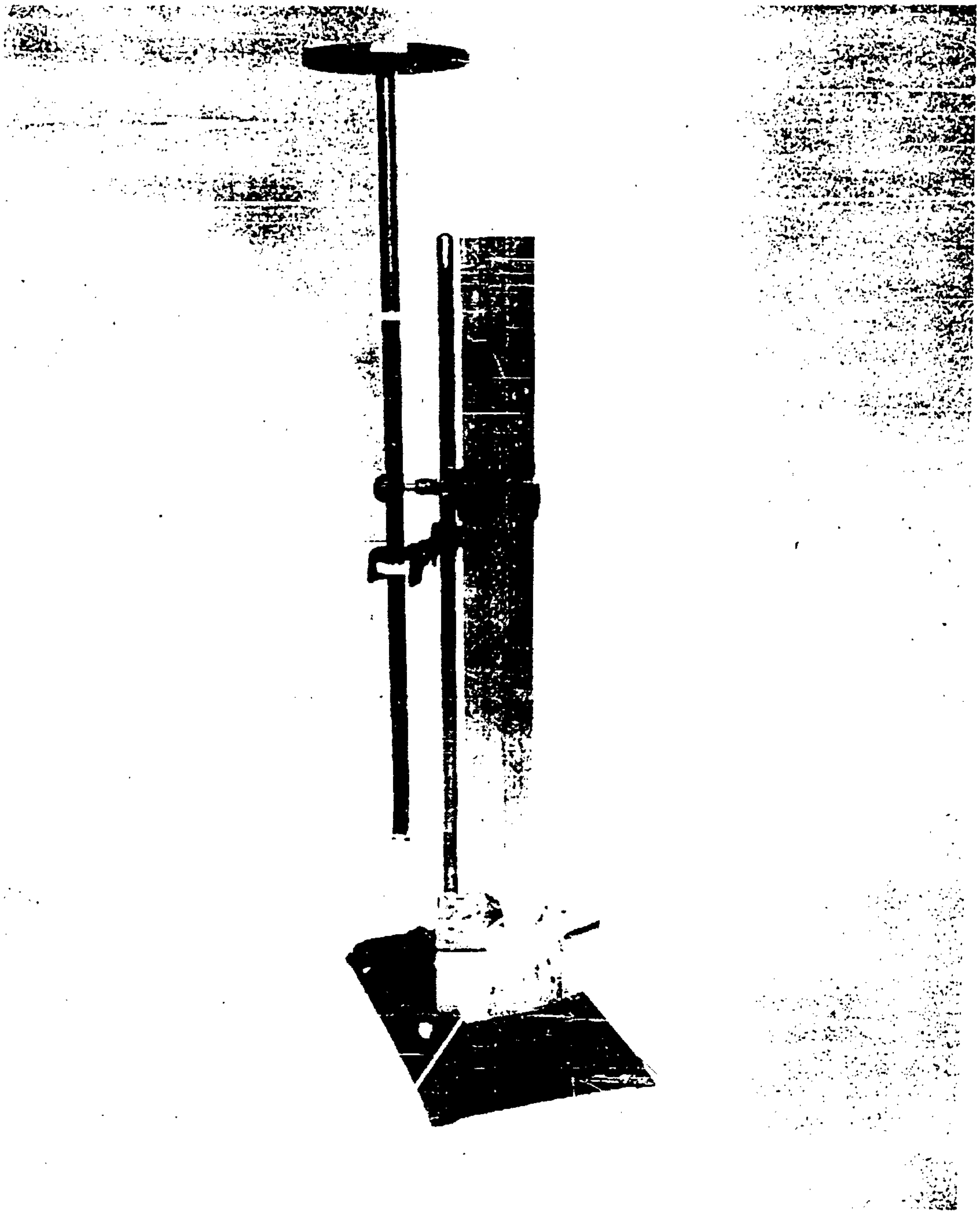


Fig. 2.27 Compaction Apparatus

the piston is removed, the loading tube is raised, and the compaction chamber is opened as shown in Figure 2.27. Sample D is then easily removed. With some powders, a lubricating agent is applied to the sides of the compaction chamber to prevent crack formation at the edges of the cubic specimen. These cracks are evidently caused by friction between the powder and the chamber sides during compression. It has been found necessary to place a thin metal plate at the bottom of the compaction chamber to prevent powder from being extruded from the bottom of the chamber during compression.

2.2.1.2.3.2 Decompression Apparatus. - The decompression test is conducted in the apparatus shown in Figure 2.28. The decompression test chamber A consists of a lucite cylinder 6 inches in diameter by 4 inches high with aluminum plates clamped to both ends. The bottom end plate has a snap valve inlet for the pressurizing gas. The top end plate has a small orifice for a manometer connection and a 2-inch orifice for sudden pressure release. The 2-inch orifice is covered with a thin plastic membrane which can be ruptured easily. A tank of dry nitrogen with high and low pressure regulators B is used to pressurize the test chamber. The pressure in the chamber is measured with a mercury manometer C.

The test is conducted in the following way: First the compacted powder specimen is suspended on the wire frame shown in Figure 2.29. The specimen is held loosely between two plates covered with sponge rubber. The tension between the plates is made as small as possible to avoid stresses due to suspension. The suspended specimen is next placed in the test chamber. The test chamber is then pressurized with dry nitrogen which causes the plastic covering over the 2-inch orifice to bulge slightly outward. A period of 5 minutes is allowed for the gas pressure inside the powder specimen to equalize with the surrounding pressure. At this point the plastic diaphragm is ruptured by pricking it with a needle or by plunging a blunt instrument through it.

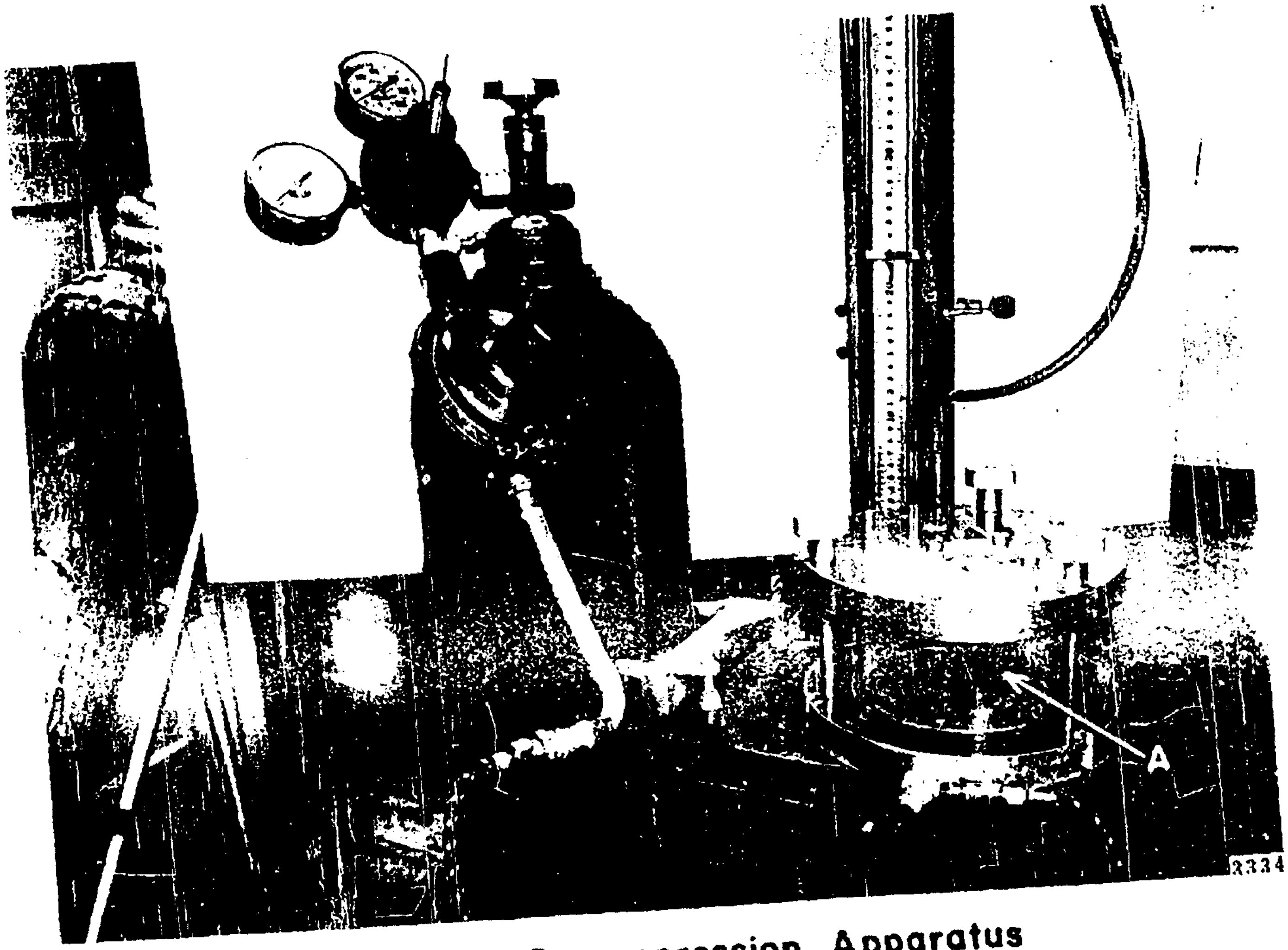


Fig. 2.28 Decompression Apparatus

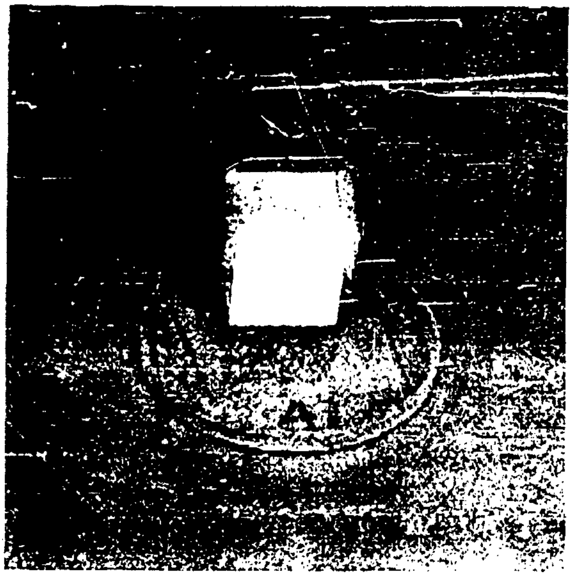


Fig. 2.29 Suspended Powder Specimen

The results of such tests are shown in Figures 2.30 through 2.32. Figure 2.30 shows a specimen which was subjected to subcritical decompression. Gas escaping from the interior cracked the specimen but did not fracture it. The cracks tend to run perpendicular to the direction of compaction. Figure 2.31 shows a specimen which fractured upon being subjected to the critical decompression pressure. Figure 2.32 shows results obtained when the specimen is subjected to a supercritical pressure drop.

These results provide considerable insight into the tensile strength properties of the test powder. It was found that local transverse cracks of the type shown in Figure 2.30 may occur at pressure drop levels considerably below the critical pressure drop. The predominantly transverse configuration of these cracks is a clear indication of the anisotropy of the compacted powder.

The supercritical decompression case (Figure 2.32) shows the striking breakup that can be achieved even with a relatively small pressure drop. Tensile failure under supercritical conditions is characterized by breakup throughout the volume of the sample. This phenomenon may be of significance with respect to the aerosolization of powders from the compacted state. This tensile test technique is being modified so that tests can be carried out with samples having a known moisture content.

2.2.1.3 Elasticity of Compacted Powders

All powders which we have worked with to date have been found to behave elastically in the compacted state. Recent measurements of the shear strength of compacted powders by the triaxial technique have provided as a dividend the data required to determine the elastic modulus of the powder samples. In the shear tests, a continuous stress-strain curve is obtained up to the point of failure. A typical stress-strain curve, as plotted by the Instron machine, was presented in Figure 2.6, page 2-12 of our Ninth Quarterly Report.[1]

Fig 2.30 Cracking caused by subcritical decompression. (Talcum powder, density .68 gm/cc, pressure drop 60 mm Hg)

Fig. 2.31 Break caused by critical decompression. (Talcum powder, density .68 gm/cc, pressure drop 80mm Hg)

Fig. 2.32 Explosive failure caused by supercritical decompression. (Talcum powder, density .68 gm/cc, pressure drop 290 mm Hg)

Stress-strain curves obtained from triaxial tests have been found to be essentially linear; that is, the powder obeys Hooke's law prior to shear failure. Earlier attempts to measure the elasticity of compacted powders led to the erroneous conclusion that the stress-strain curve was nonlinear.[2] It is now apparent that the nonlinearity observed in these tests was due to wall-friction effects.

The elastic modulus of a compacted powder may be determined directly from the definition:

$$E = \frac{\sigma}{\epsilon} = \frac{\sigma}{\left(\frac{\Delta \ell}{\ell}\right)} \quad ,$$

where σ is the applied stress and $\Delta \ell / \ell$ is the corresponding fractional change in length of the test specimen.

Values of the elastic modulus for several sample densities have been determined from the above equation using the shear-test data for saccharin. The results are plotted in Figure 2.33. For purposes of comparison, the compaction stress-density curve is also shown in the figure. It is evident from this figure that within the accuracy of the test data the elastic modulus is proportional to the compaction stress. Future tests will establish whether these elastic properties are generally true of compacted materials.

2.2.2 Theoretical Investigations of the Mechanics of Compacted Powders

During this quarter, considerable progress has been made in defining the mechanical properties of compacted powders. Theoretical developments discussed in Section 2.1.2 are based upon experimental data – on the empirical Equations (2.1) and (2.3). In this section of the report, a parallel treatment of compacted powders is presented that is purely theoretical in nature. It is noteworthy that the conclusions reached are qualitatively in agreement with the empirical theory.

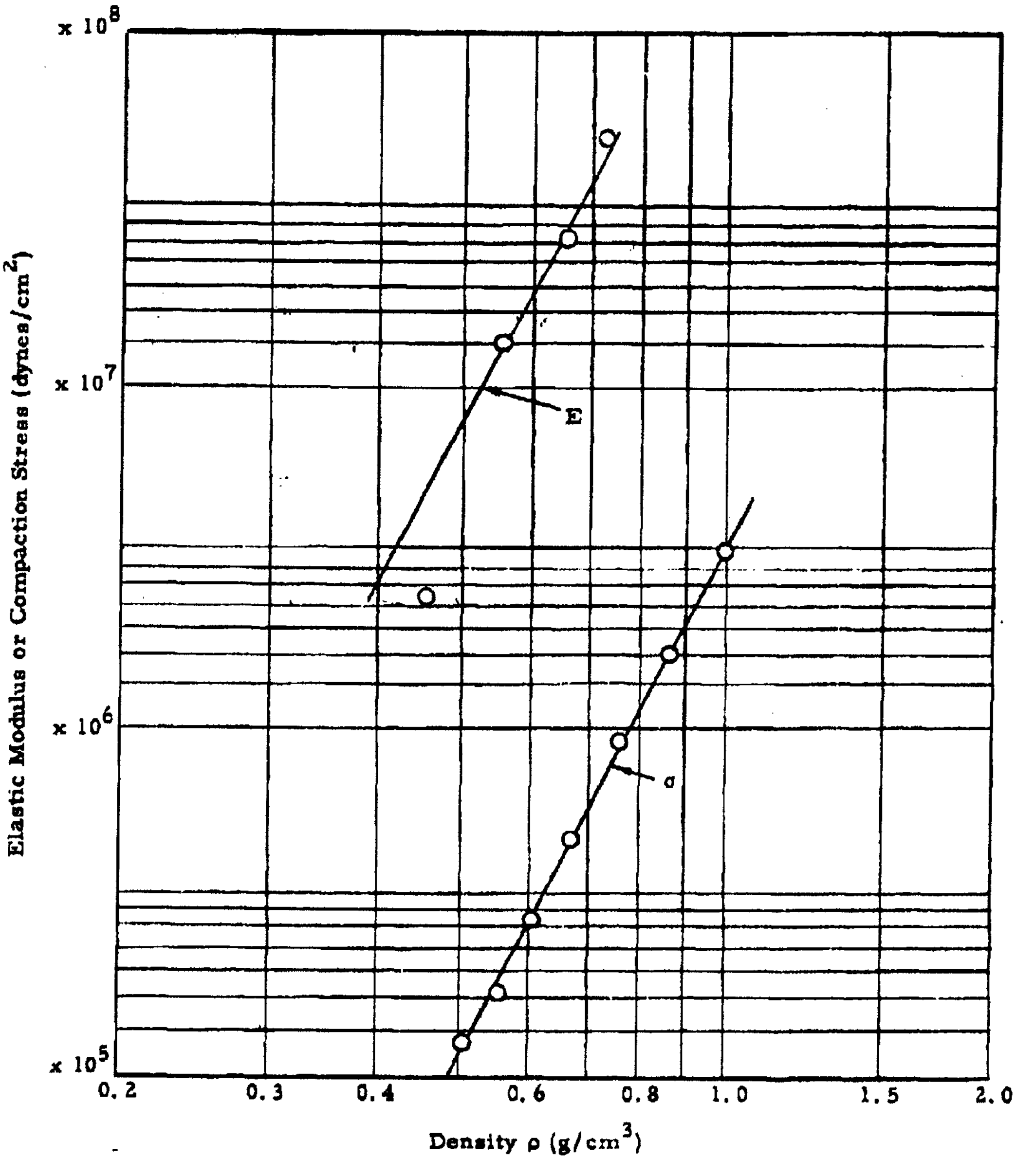


Fig. 2.33 **Elastic Modulus for Compacted Saccharin as a Function of Density (Compaction Stress-Density Curve shown for Comparison)**

Suppose that a powder element has been compacted to a certain density by the application of a compressive stress σ_c (major principal stress). We can consider the conditions for fracture of the element under the application of compressive stresses that are small compared with σ_c. Although the actual configuration of the system of particles is very complex, it may be assumed for purpose of analysis that a "typical" particle or agglomerate configuration exists, which is subjected to applied forces in the manner depicted in Figure 2.34. The forces F and S are, respectively, normal and tangential forces relative to the plane on which shear takes place when the sample fails. These forces are assumed to be applied to the particle by the reactions of neighboring particles above the shear plane. The particle is held in equilibrium by reactions N_L and N_R, acting at an effective angle θ relative to the shear plane.

These forces may be related to the applied stresses by means of the following equations:

$$F = a\sigma_n \tag{2.8a}$$

$$S = b\tau \tag{2.8b}$$

$$N_L = c\sigma_t + e\delta_L \tag{2.8c}$$

$$N_R = c\sigma_t + e\delta_R \quad , \tag{2.8d}$$

where σ_n is the normal stress, σ_t is the transverse stress, and τ is the applied shearing stress. The coefficients a to e are constants which depend on the configuration of the particle ensemble. The terms δ_L and δ_R represent the nonsymmetric increments in the reaction forces N_L and N_R which are required to balance the applied forces F and S. For equilibrium, we must have these relationships (page 2-60):

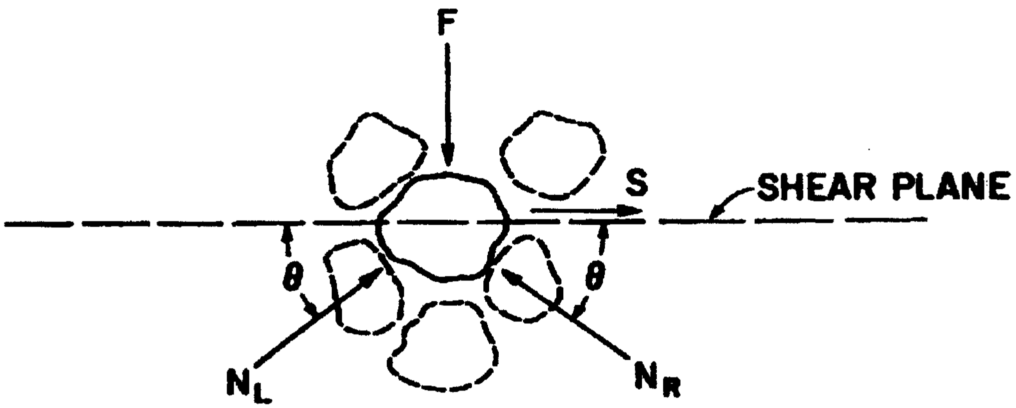


FIG. 2.34 FORCES ACTING ON "TYPICAL" PARTICLE AT SHEAR PLANE

$$F - (N_L + N_R) \sin \theta = 0 \tag{2.9a}$$

$$S + (N_L - N_R) \cos \theta = 0 \ . \tag{2.9b}$$

At the point of fracture, we may assume that $\delta_L = -\delta_t$, where δ_t is the "average" tensile strength of interparticle contacts. Furthermore, the transverse stress at the point of fracture can be expressed as (see Figure 2.35)

$$\sigma_t = \sigma_n + 2\tau \tan \phi_c \tag{2.10}$$

where ϕ_c is the slope of the shear locus curve.

From Equations (2.8) through (2.10), we find on eliminating δ_R and setting $\delta_L = -\delta_t$ that

$$(a \cos \theta - c \sin 2\theta)\sigma_n - (b \sin \theta + 2c \sin 2\theta \tan \phi_c)\tau$$

$$- e\delta_t \sin 2\theta = 0. \tag{2.11}$$

This equation can be expressed in the condensed form

$$- A\sigma_n + B(1 + C \tan \phi_c)\tau = D \ . \tag{2.12}$$

Now, recognizing that $\tan \phi_c = d\tau/d\sigma_n$, we can express the differential equation of the shear locus in the form

$$\tau \frac{d\tau}{d\sigma_n} = \alpha\sigma_n - \beta\tau + \gamma \tag{2.13}$$

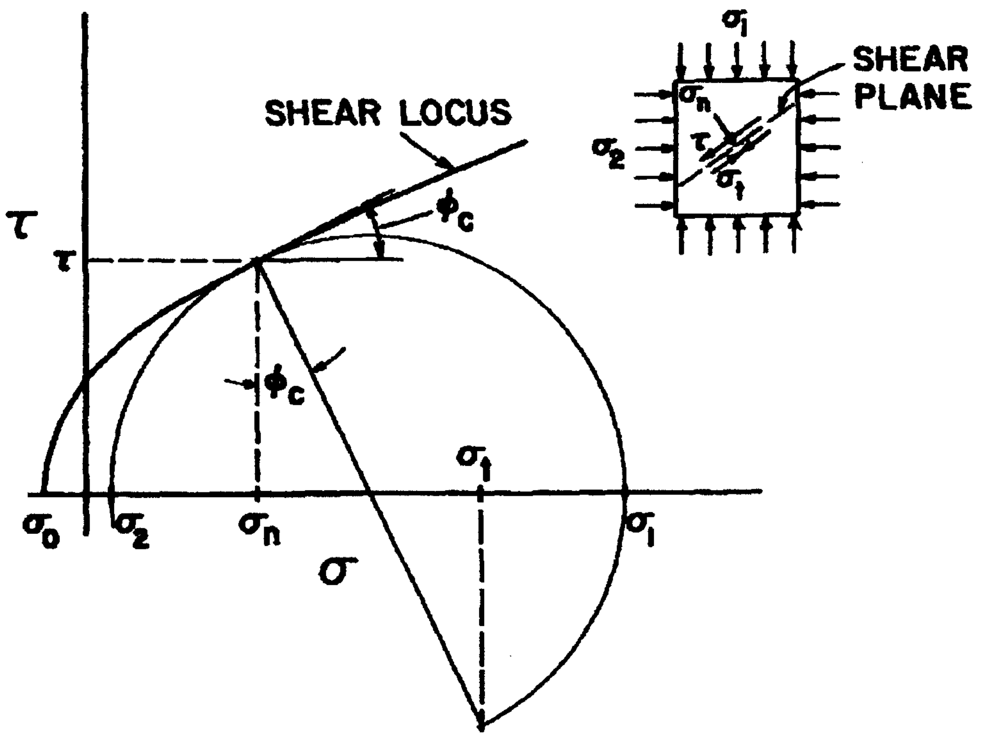


FIG. 2.35 STRESS RELATIONSHIPS AT THE POINT OF SHEAR FAILURE

where the constants α, β and γ are defined by the relationships

$$\alpha = \frac{a}{4c \sin \theta} - \frac{1}{2} \tag{2.14a}$$

$$\beta = \frac{b}{4c \cos \theta} \tag{2.14b}$$

$$\gamma = \frac{e\,\delta_t}{2c} \quad . \tag{2.14c}$$

To solve this equation, we first introduce a new variable $z = \alpha\,\sigma_n + \gamma$ and then make the substitution $\tau = uz$. The transformed equation is

$$\frac{u\,du}{1 - \beta u - \alpha u^2} = \frac{dz}{z} \quad . \tag{2.15}$$

Equation (2.15) may be solved for z to give

$$z = \frac{C e^{-\frac{\beta}{2\alpha q} \tanh^{-1} \frac{1}{q}\left(u + \frac{\beta}{2\alpha}\right)}}{\sqrt{1 - \beta u - \alpha u^2}} \tag{2.16}$$

where C is a constant of integration and $q^2 = (1/\alpha)(1 + \beta^2/4\alpha)$.

The shear locus intercepts the σ-axis at $\sigma = -\sigma_o$ where σ_o is the bulk tensile strength of the compacted powder. This point corresponds to $u = 0$ and $z_o = \alpha|\sigma_o| + \gamma = -\alpha|\sigma_o| + \gamma$. From Equation (2.16) we obtain for $u = 0$

$$z_o = C e^{-\frac{\beta}{2\alpha q} \tanh^{-1} \frac{\beta}{2\alpha q}} \quad . \tag{2.17}$$

Eliminating C from Equations (2. 16) and (2. 17), we obtain

$$\frac{z}{z_0} \equiv f(u) = \frac{e^{\frac{\beta}{2\alpha q}\tanh^{-1}\frac{\beta}{2\alpha q}} - e^{-\frac{\beta}{2\alpha q}\tanh^{-1}\frac{1}{q}\left(u+\frac{\beta}{2\alpha}\right)}}{\sqrt{1-\beta u-\alpha u^2}} \quad . \qquad (2.18)$$

The stresses τ and σ_n are expressible in terms of u, $f(u)$, and σ_o as follows:

$$\frac{\sigma_n}{|\sigma_o|} = \left(\frac{\gamma}{\alpha|\sigma_o|} - 1\right) f(u) - \frac{\gamma}{\alpha|\sigma_o|} \qquad (2.19a)$$

$$\frac{\tau}{|\sigma_o|} = \left(\frac{\gamma}{|\sigma_o|} - 1\right) u f(u) \quad . \qquad (2.19b)$$

The shear locus is defined by the above equations in terms of the constants α, β, and γ. Since γ is proportional to δ_t (Equation (2. 14c)), it is clear that γ must also be proportional to the bulk tensile strength of the powder.

An interesting result can be deduced immediately from Equation (2. 19). It is found from Equation (2. 18) that $f(u) \to \infty$ as $u \to q - \beta/2\alpha$. Therefore, for large values of $f(u)$,

$$\tau \to \left(\alpha q - \frac{\beta}{2}\right)\sigma_n \quad , \qquad (2.20)$$

i.e., the shear locus is linear. The shapes of shear loci determined from this analysis are indicated in Figure 2. 36 for representative values of α, β and $\gamma/|\sigma_o|$. The curves shown correspond to the values of γ: $\gamma = 1.0\,|\sigma_o|$, $1.5\,|\sigma_o|$ and $2.0\,|\sigma_o|$, with $\alpha = 0.8$ and $\beta = 0.4$. From Equation (2. 20) it can be seen that the slopes of the curves for lage values of σ should be identical. Thus, the different values of γ illustrate the effects of cohesion on the shear locus for small values of σ.

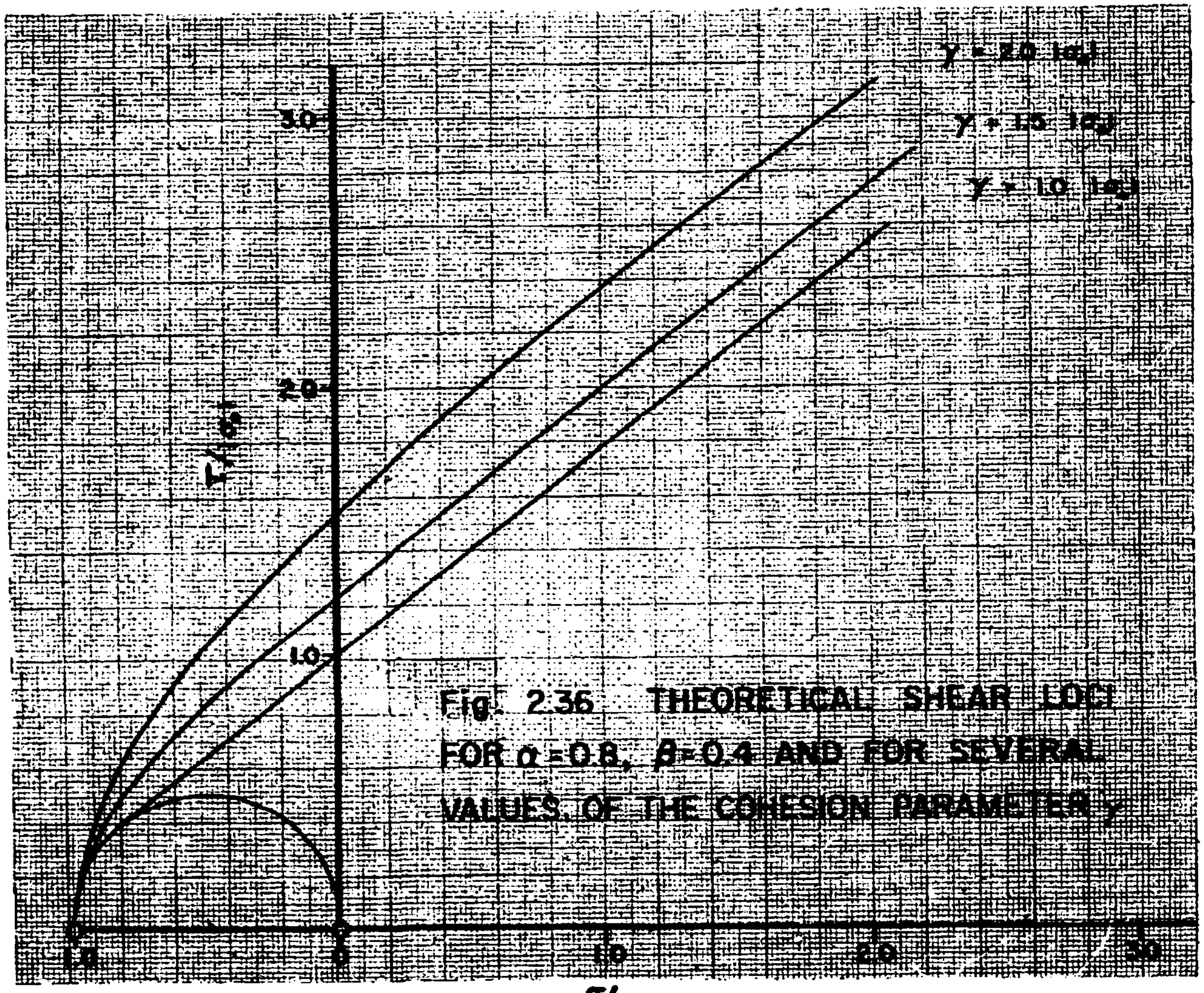


Fig. 2.36 THEORETICAL SHEAR LOCI FOR $\alpha = 0.8$, $\beta = 0.4$ AND FOR SEVERAL VALUES OF THE COHESION PARAMETER γ

It can be seen from Figure 2.36 that all of the curves are very nearly straight lines for $\sigma > 0$, a result which agrees very well with the empirically-based theory of Section 2.1.2. From the figure, one sees that the bulk-tensile strength should be approximately equal to the pure shear strength, according to this theory, if $\gamma/|\sigma_o| < 1.5$.

It should be observed that this analytical treatment is not capable of actually defining the shear locus in absolute terms. The shape of the curves is defined, however, to within a constant factor. A more fundamental approach is required to define the strength of compacted powders uniquely in terms of basic powder parameters, such as particle size, interparticle molecular or chemical bond energies, etc. The most basic avenue of attack on this problem is through development of a general theory of compaction.

2.3 Physical and Chemical Characteristics of the Powder Particle

Behavior of compacted powders is fundamentally determined by the nature of the intermolecular forces (physical or chemical) existing at the contact areas between particles. In the following months, increased emphasis will be placed upon evaluation of the factors which determine these forces and upon relation of these factors to the behavior of the compacted state – specifically their effect on such properties as shear strength, tensile strength, and dispersibility. Among the areas to be studied are particle shape, particle size, crystal habit, surface area, porosity, rugosity, kinetics of the adsorption process, and chemical reactivity.

The total surface area of powders will be determined by the gas adsorption method previously described[2] in which the powder is conditioned to a ground state free of adsorbed gases. Under carefully controlled conditions, a monomolecular layer of a gas will then be adsorbed on the surface. Knowing the weight and cross-sectional area per molecule of adsorbent, the total surface area can then be calculated from the weight gained by the sample during the adsorption process. In addition to setting up of rather complicated high-vacuum apparatus, an extensive literature search is now underway.

In heating the powders to the ground state considerable care must be exercised, particularly with biological materials, since the heat required to remove the last traces of adsorbed gas may structurally change the particle, resulting in possible gross changes in surface. In view of information currently being obtained from the literature, however, it appears quite likely that experimental conditions can be found to bring most powders to an acceptable ground state prior to the monomolecular adsorption process.

By studying the adsorption characteristics of a powder using adsorbents of varying molecular cross sections, the area representative of the external particle surface can be differentiated from the internal pore structure. In this way the porosity of particles can be determined. Particle porosity is of interest in consideration of particle density, its effect upon compaction, and upon the kinetics of water adsorption by the particle. Changes in adsorptivity or in total surface area resulting from the compaction process should yield information concerning the nature of interparticle contacts. In addition, many particles in the compacted and/or uncompacted state will over a period of time form a rigid, cake structure. This surely must be the result of molecular rearrangement into a semi-continuous or cellular structure. Therefore, the resulting changes in surface area or other adsorption characteristics will be of interest.

In our study of powders we are constantly concerned with the effects of adsorption of moisture by a particle. We must for this reason know the kinetics of water adsorption by powders both in the compacted and uncompacted states, or in other words, the rate at which water is picked up and how the moisture content of the sample stays at equilibrium. In addition, the nature of adsorption - whether monomolecular, multimolecular, or capillary - will be investigated as a function of exposure to different atmospheres and as a function of degree of compaction.

Upon determination of particle size distribution and total surface area, the particle rugosity can be calculated. Particle rugosity is defined as the actual total surface area divided by the calculated surface area, assuming that the particles are perfect spheres. Rugosity then becomes a "roughness" index for the particle surface. Particle rugosity should have a relationship to the relative ease of compaction and redispersion of a powder sample.

The chemical properties, particularly relative chemical reactivities of the powders being studied, will be given increased emphasis. This becomes vitally important in the evaluation of relative bonding forces at the interparticle contacts. The chemistry of the powder particles will also play a dominant role in determining the physical properties of a compacted or uncompacted powder after prolonged storage.

A variety of chemically identical particulate materials are available commercially which as a result of their method of manufacture may differ in crystalline habit. Thus a considerable amount of information should be readily attainable by procuring representative samples and subjecting these to the battery of tests already developed.

Determination of these physical and chemical characteristics of the powder particles and correlation of these characteristics with bulk mechanical properties determined by the tests already perfected should permit a realistic evaluation of the relative ease with which powders may be compacted and redispersed, independent of the time lapse involved.

2.3.1 Particle Size Analysis

As discussed in the previous section, it is expected that an important parameter affecting the behavior of a powder is its mean particle size. Consequently, size analyses are being made for the various test powders by using both sedimentation and microscopic counting techniques. Size distributions determined by the Whitby sedimentation technique for saccharin, Sm talc, and cornstarch are shown in Figures 2.37 through 2.40. The sedimentation fluids, feeding liquids, and dispersing agents used in the size analyses of these powders are defined in the figures. The size distributions for other test powders will also be established wherever possible by applying the Whitby technique.

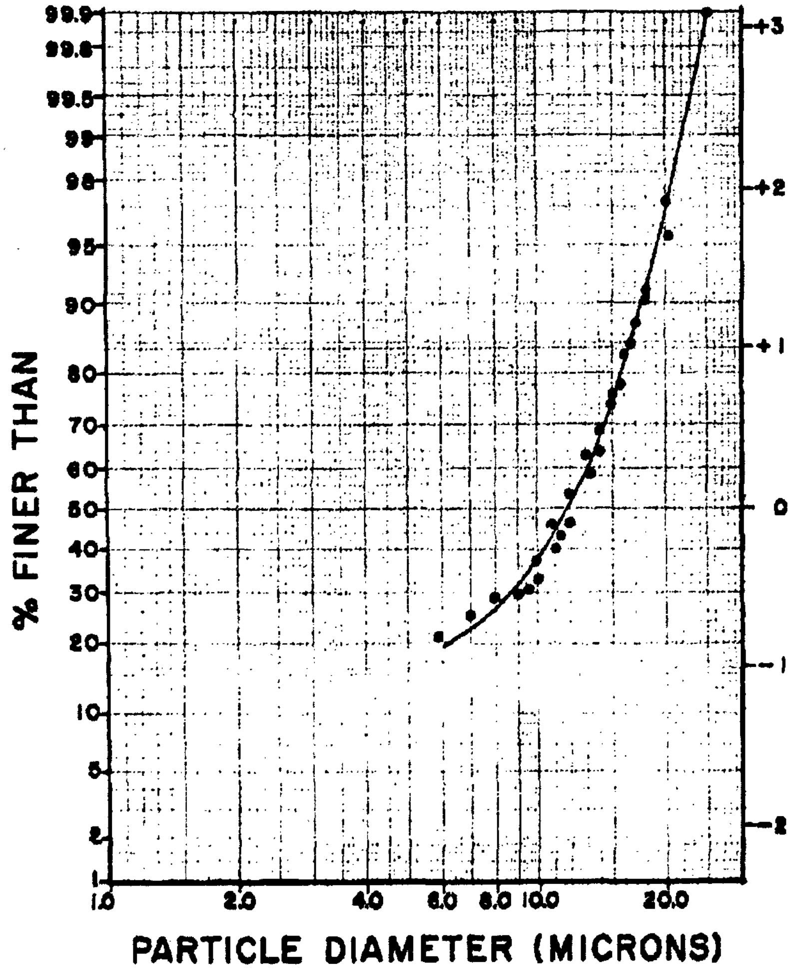


FIG. 2.37

MATERIAL - CORNSTARCH PREPARED IN JET PULVERIZER

SEDIMENTATION LIQUID - WATER

FEEDING LIQUID - 70% WATER 30% ACETONE

DISPERSING AGENT - ALKYL BENZENE SULFONATE

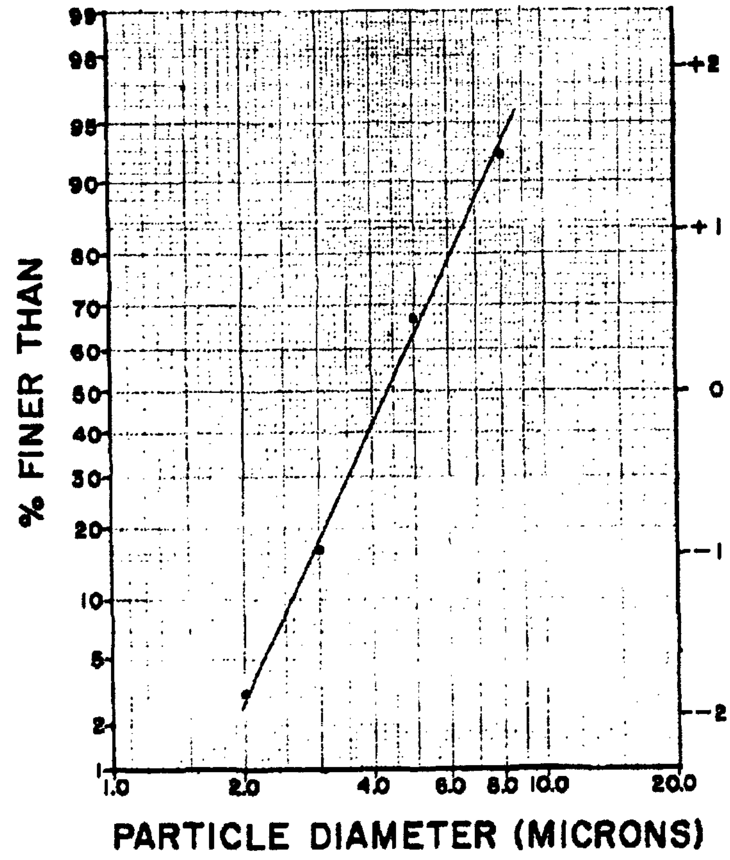


FIG. 2.38
MATERIAL - SACCHARIN PREPARED IN JET PULVERIZER
SEDIMENTATION LIQUID - KEROSENE
FEEDING LIQUID - 15% NAPTHA 85% KEROSENE
DISPERSING AGENT - TWITCHEL

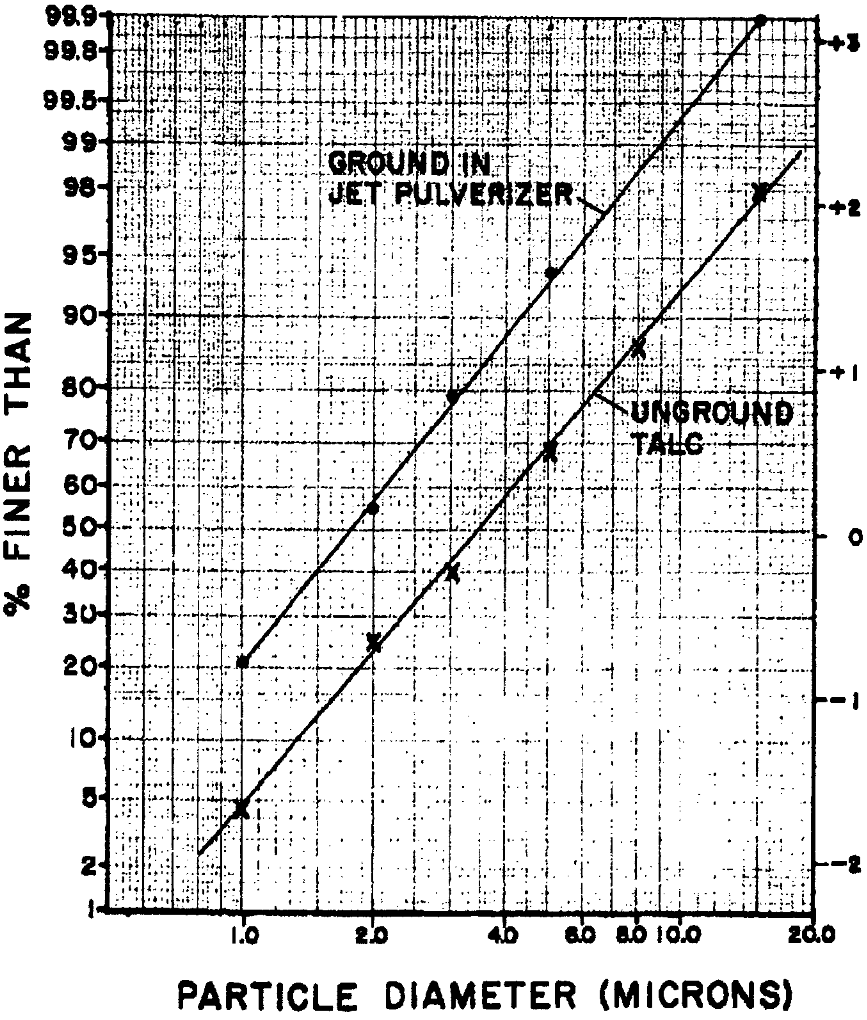


FIG. 2.39
MATERIAL - TALC
SEDIMENTATION LIQUID - WATER
FEEDING LIQUID - 30% ACETONE 70% WATER
DISPERSING AGENT - NONE

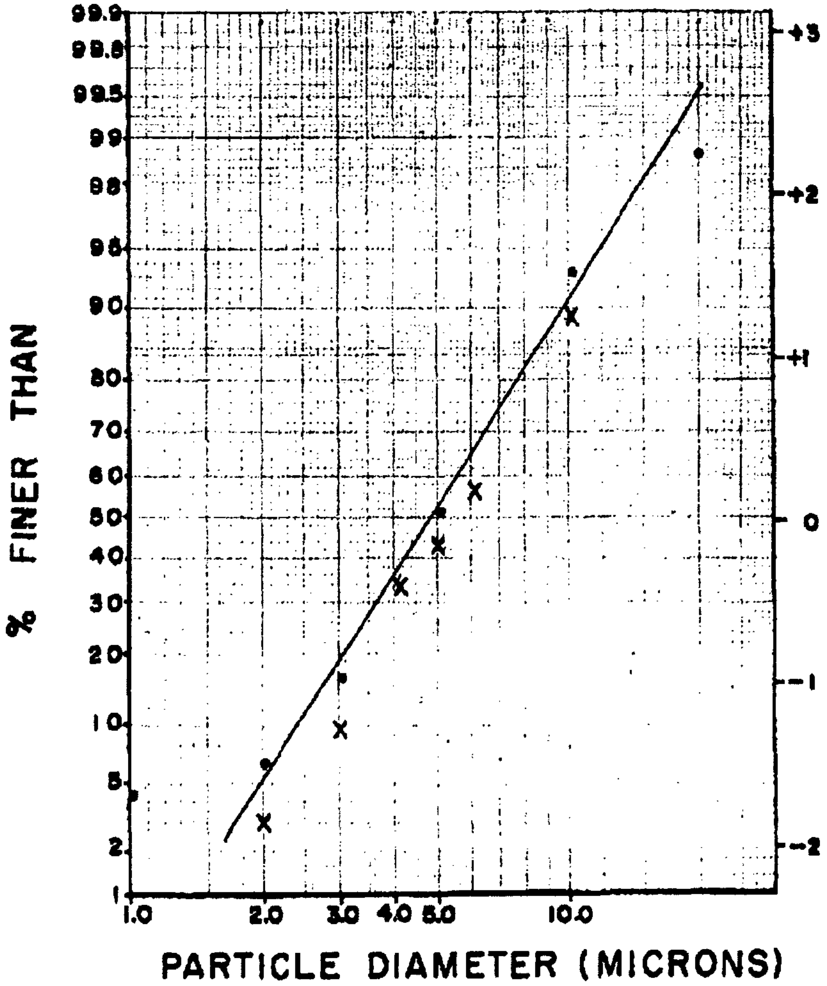


FIG. 2.40
MATERIAL - Sm
SEDIMENTATION LIQUID - BENZENE (11cc)
FEEDING LIQUID - 70% BENZENE, 30% NAPTHA
DISPERSING AGENT - TWITCHEL

3. AEROSOL STUDIES

The experimental work described in this report includes a study of the effects of concentration on the stability of aerosols and the efficiency of two different dispersing systems. For some of the work both the direct sampling system and a fluctuation-measuring system were put into use.

The present report includes certain theoretical estimates bearing on the coagulation process. Four different approaches are suggested; none of these is capable of supplying definitive answers, but each contributes to an understanding of coagulation.

3.1 Experimental Work

The experimental work of the past few months has been devoted to a comparison of methods for dispersing the powder charge in the aerosol chamber, investigation of techniques for improving the quality of the light beam in the chamber, and a study of the effect of particle concentration on aerosol decay.

3.1.1 Comparison of Dispersing Methods

We mention first a series of abbreviated runs comparing the dispersing efficiencies of two dispersing systems. The swirl disperser[8] was generally operated with 250 psi of nitrogen applied to the gas inlets for 5 seconds. A series of runs was also conducted with 60 psi applied pressure. A third series of runs made use of the bursting diaphragm disperser, which was operated as described previously.[9] The room's humidity during this period was between 15 and 25 percent. The amount of powder dispersed was in each case between 90 and 110 mg. The results of these runs are shown in Figure 3.1.

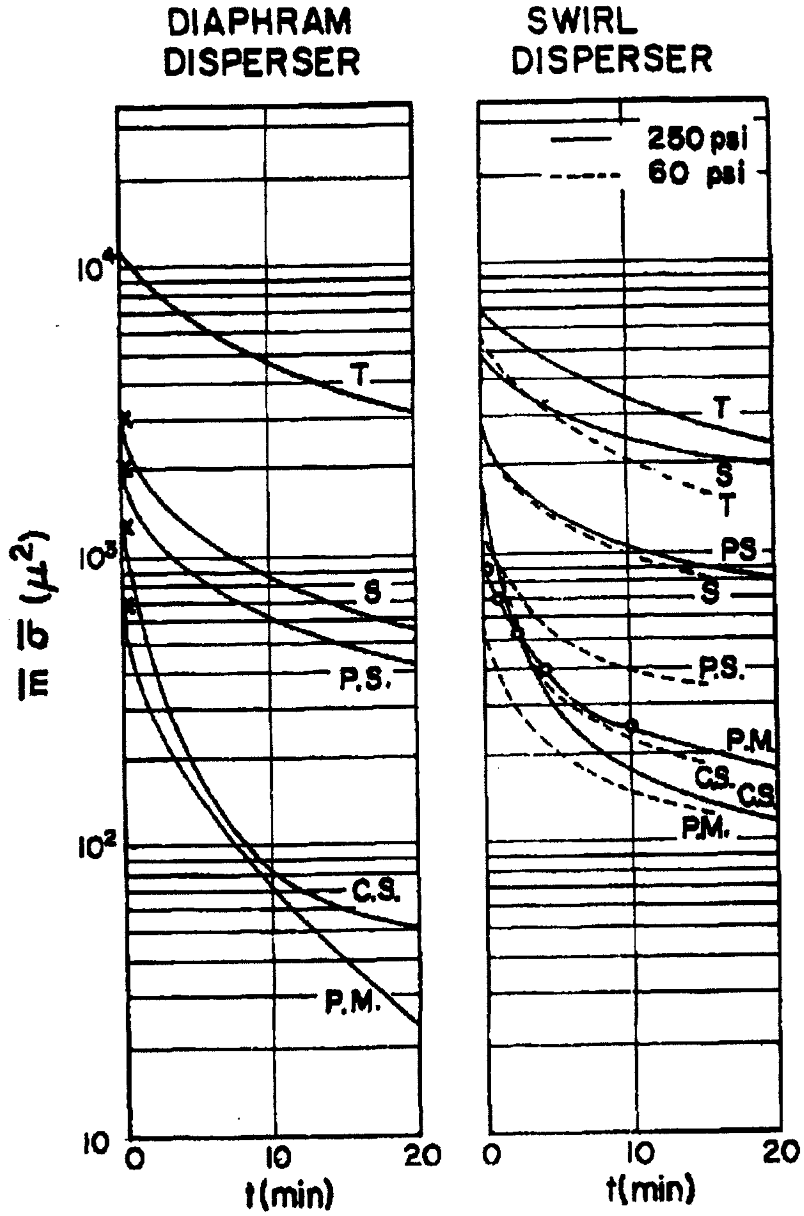


FIG. 3.1 CONCENTRATION OF DISPERSING METHODS (100 mg SAMPLES)

It may be noted from Figure 3.1 that all three methods of dispersing produce curves of essentially the same slope except in the cases of cornstarch and powdered milk. For the latter two powders, the swirl disperser produced markedly more stable aerosols than those from the bursting diaphragm disperser. Note also that comparison of the vertical position of the curves shows that the swirl disperser produced more turbid aerosols for all powders except talc. This can be partially explained by the fact that some talc adheres to the internal surfaces of the swirl disperser.

Another series of runs to determine concentration effects provided further information on the dispersing process. These runs were rather elaborate, and a discussion of instrumentation must precede our report of results.

3.1.2 Modifications to Apparatus

The analysis of light scattering fluctuations[10] assumes a well-defined light beam with uniform intensity across its diameter. Some effort was invested during this quarter in improving the light beam. This improvement was obtained only at the expense of monochromatic qualities of the beam.

The modifications are: 1) the replacement of the projection lamp light source by an automobile tail light bulb (GE 1493), which more nearly approximates a point source; 2) removal of the Corning 7-60 filter; and 3) placing a 1-inch diameter aperture at the entrance window of the chamber. The resulting beam has an intensity variation of about 10 percent across the 1-inch beam diameter. The effective spectral distribution of the light is now determined by a combination of the characteristics of the photomultiplier tube and the light bulb. This effective distribution, plotted in the manufacturer's handbook for the photomultiplier tube, has a maximum at a wavelength of 0.50 micron and a full width at half-maximum, 0.25 micron. Although this represents a considerable sacrifice of the monochromatic qualities of the previous situation,[11] it is probably of no great consequence, because the scattering powers of the particle sizes in question are practically independent of wavelength.[12]

In conjunction with the work on light beam quality, we measured the intensity of the beam. Its average intensity was 2.1×10^6 units/cm^2, expressed in photometer units. The accuracy of this measurement is ±20 percent. This optical arrangement was used for all work reported in the present report.

Some of the runs discussed included instrumentation for the precise measurement of fluctuations of the light scattering signal. This was conveniently accomplished by connecting a Sanborn amplifier and recorder in parallel with the Brown recorder. The frequency response of the former extends from 1 to 100 cps (on the a-c input), whereas that of the latter extends from dc to about 1 cps. One recorder thus compliments the other: the Brown recorder displays the signal amplitude while the Sanborn displays the superimposed fluctuations. In practice the Sanborn is switched on at selected times and runs for about 20 seconds to produce a fluctuation trace for analysis. One such trace is shown in Figure 3.2.

The fluctuations are analysed in the following way: A 10-second interval is marked off on the trace, and the fractional amount of time that the signal is less than a given value (say -1 mv) is read from the trace. If this process is repeated for several different signal values (say -1/2 mc, 0 mv, +1/2 mv and +1 mv) and the points are plotted on probability paper, a straight line results. The distribution of fluctuations is therefore assumed to be gaussian, and one may read the root mean square (rms) value of the fluctuations from the graph.

As explained in a previous report[13] there is an intrinsic fluctuation in the electronics which is not always small compared to the total fluctuation. A series of runs with other illuminating agencies determined the residual fluctuation, which is to be subtracted "at right angles" from the observed fluctuation to obtain that caused by the aerosol. In equation form,

$$(F\ \text{aerosol})^2 = (F\ \text{observed})^2 - (F\ \text{residual})^2 \quad . \tag{3.1}$$

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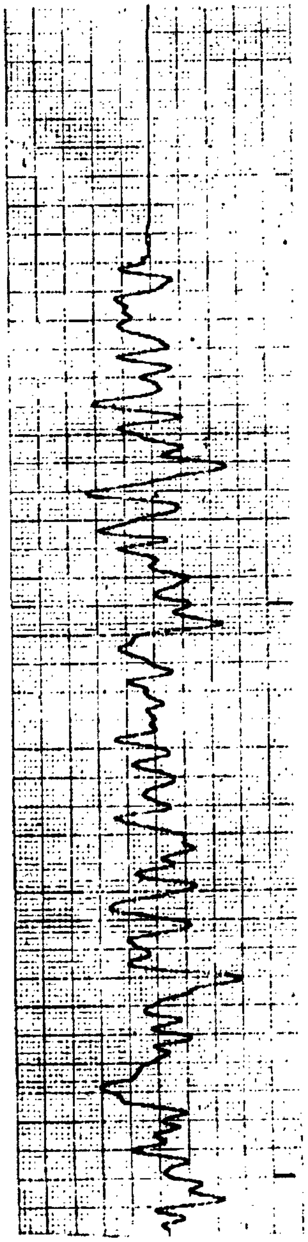

FIG. 3.2 FLUCTUATION TRACE

3.1.3 Study of Concentration Effects

When the swirl powder disperser was first tried, its operation proved so satisfactory that dispersion of large samples was feasible. The planned sequence of work was therefore interrupted to permit a series of runs with varied amounts of powder. The amounts used were 1000 ± 100 mg, 100 ± 10 mg, and 10 ± 1 mg. The humidity during this period was between 15 and 25 percent. The results of these runs are shown in Figures 3.3(a) through 3.7(a).

The units plotted on the ordinates require some explanation. A previous report[14] uses the expression

$$I_s = I \delta\Omega \, \overline{m} \, \overline{\sigma}$$

for the scattered light. We take this opportunity to change an unfortunate notation by replacing I_s by S, the signal. Our measurement of I (which gives I in photometer units per cm^2) then enables us to calculate the ratio

$$\frac{S}{I \delta\Omega} \tag{3.2}$$

which has the dimension of area; $\delta\Omega$ is a geometric factor, the solid angle. The quantity

$$\frac{S}{I \delta\Omega} = \overline{m} \, \overline{\sigma} \; , \tag{3.3}$$

expressed in μ^2, is used on the ordinate of the graphs. Inasmuch as $\overline{\sigma} \approx d_g^2/6\pi \approx 1 \, \mu^2$, we have also

$$\frac{S}{I \delta\Omega} \approx \overline{m} = N \cdot \frac{\delta V}{V} \; . \tag{3.4}$$

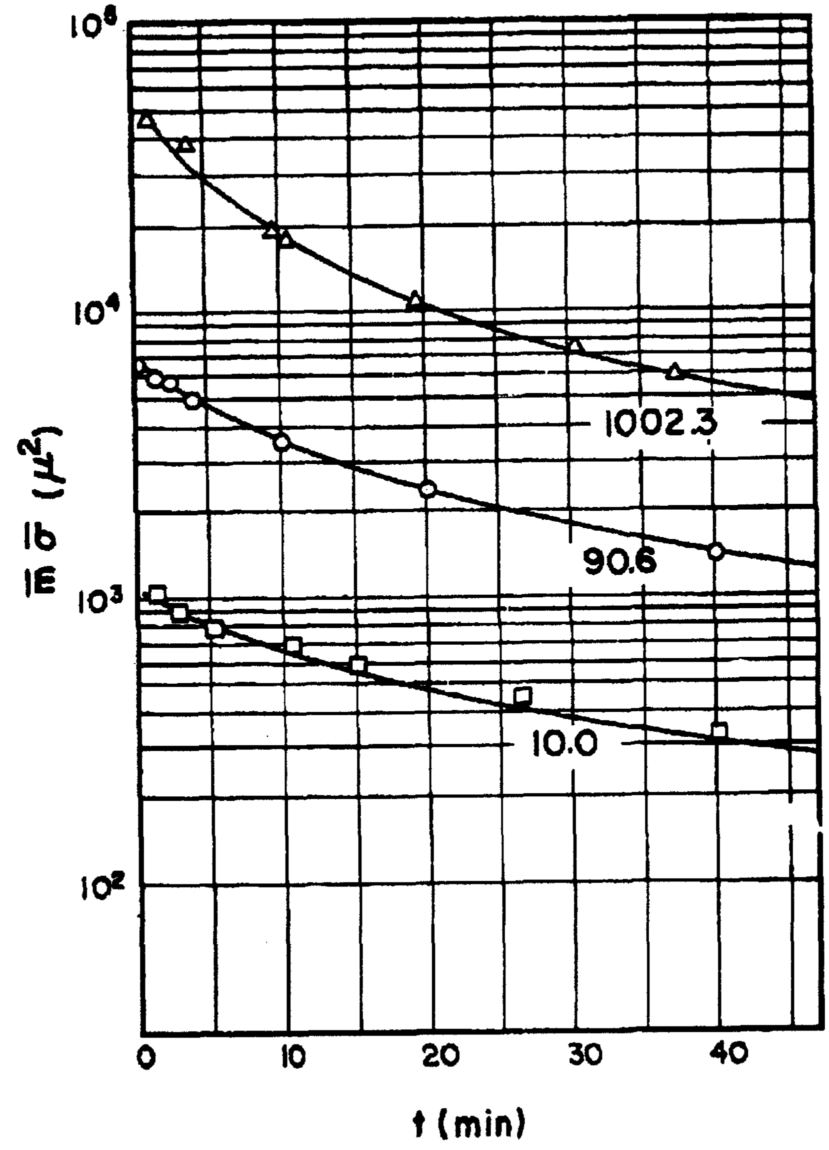

FIG. 3.3(a) CONCENTRATION RUNS FOR TALC

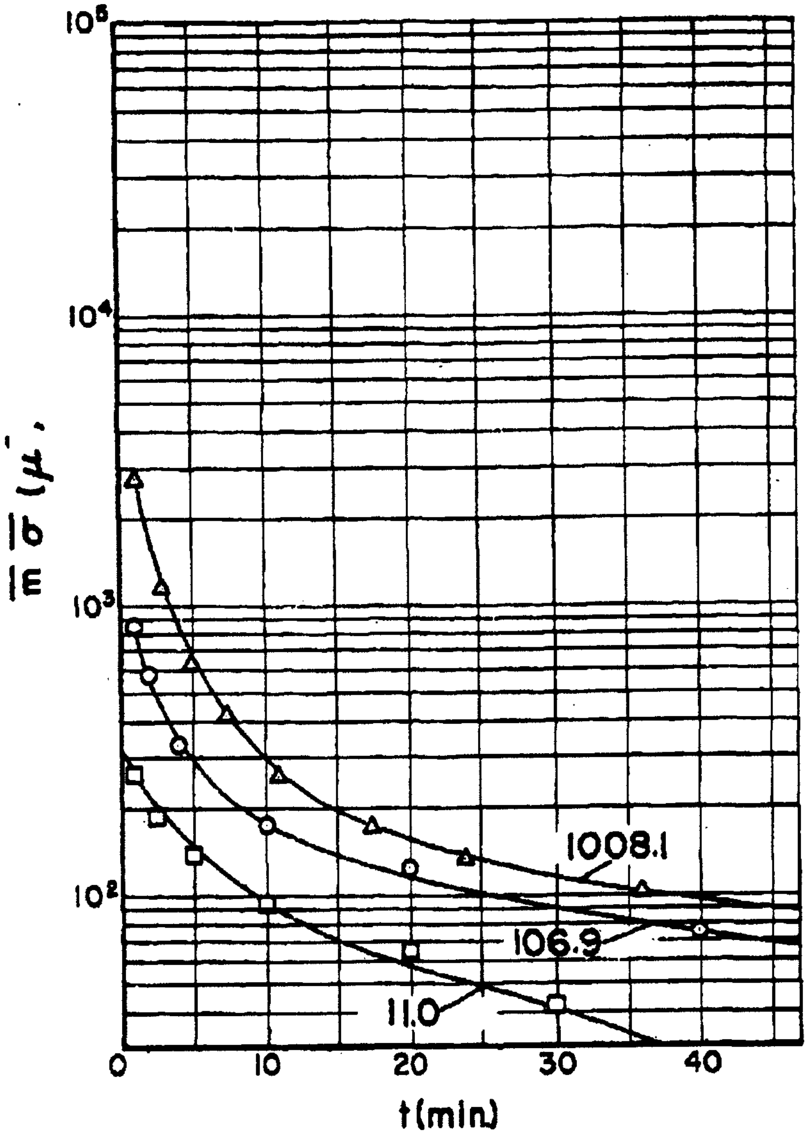

FIG. 3.4(a) CONCENTRATION RUNS FOR CORNSTARCH

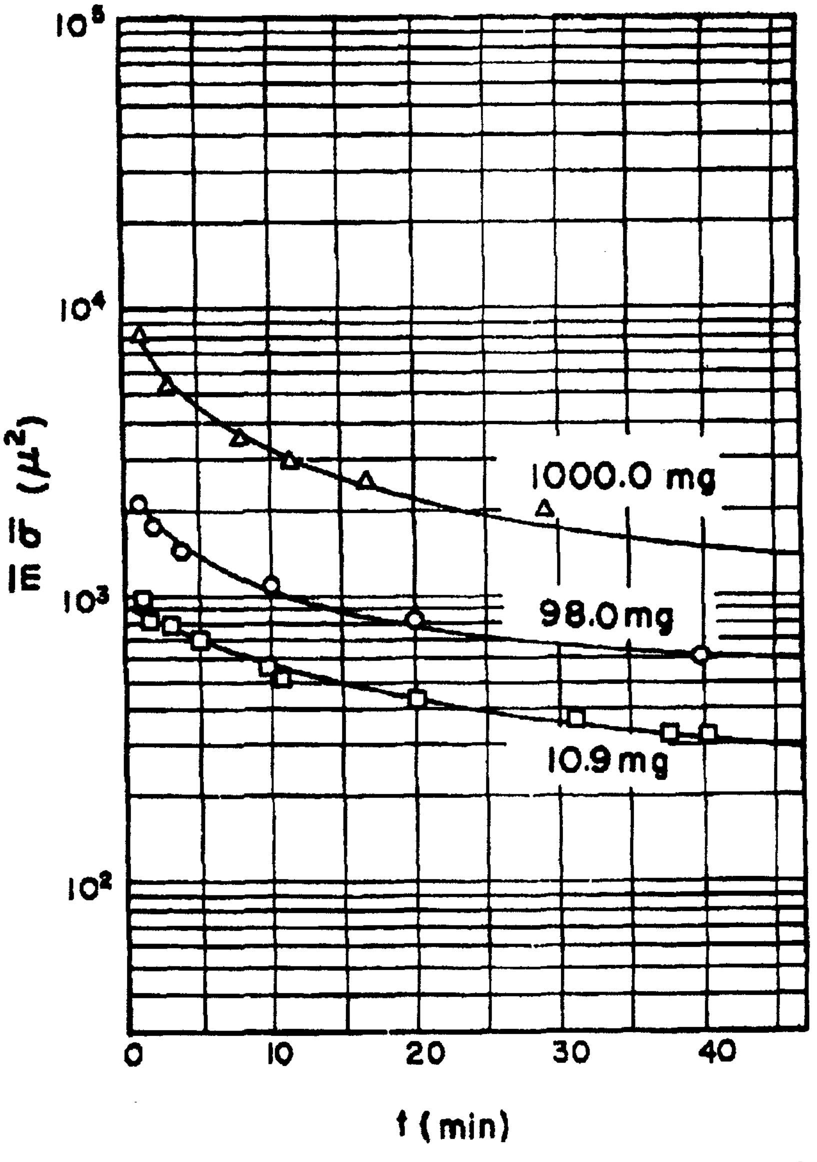

FIG. 3.5(a) CONCENTRATION RUNS FOR POWDERED SUGAR

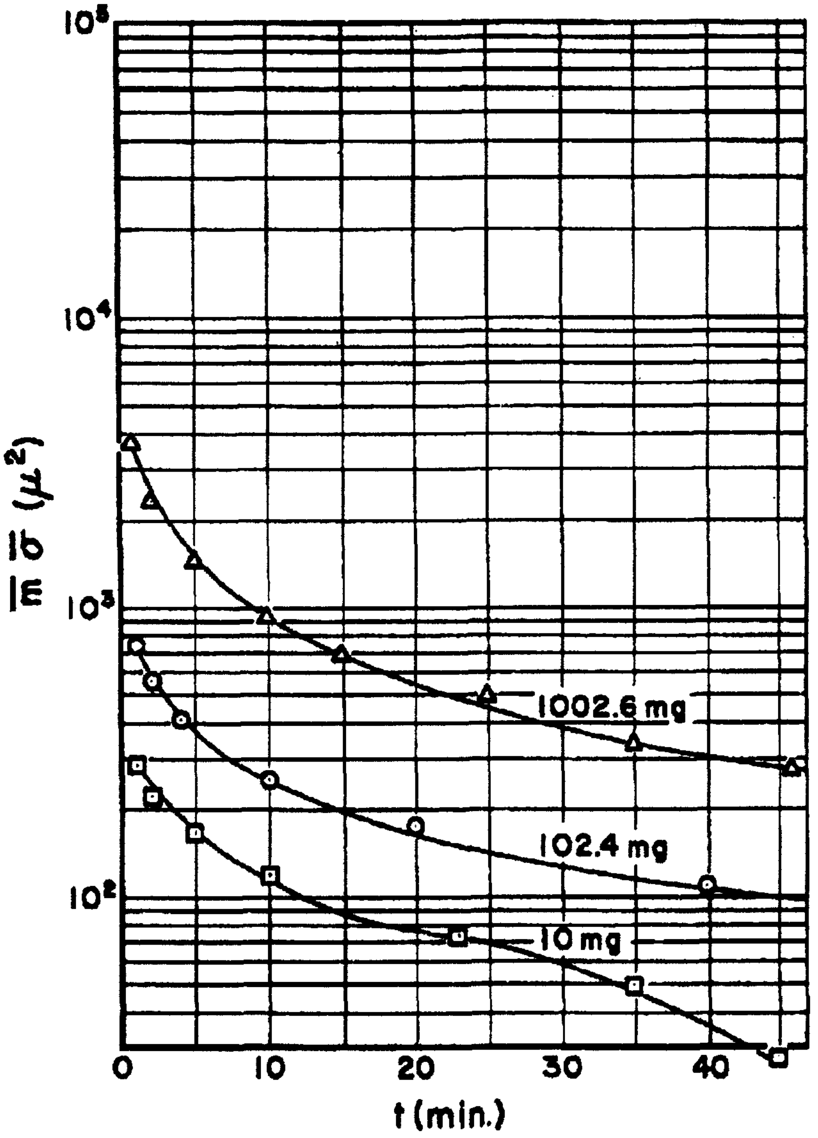

FIG. 3.6 (a) CONCENTRATION RUNS FOR POWDERED MILK

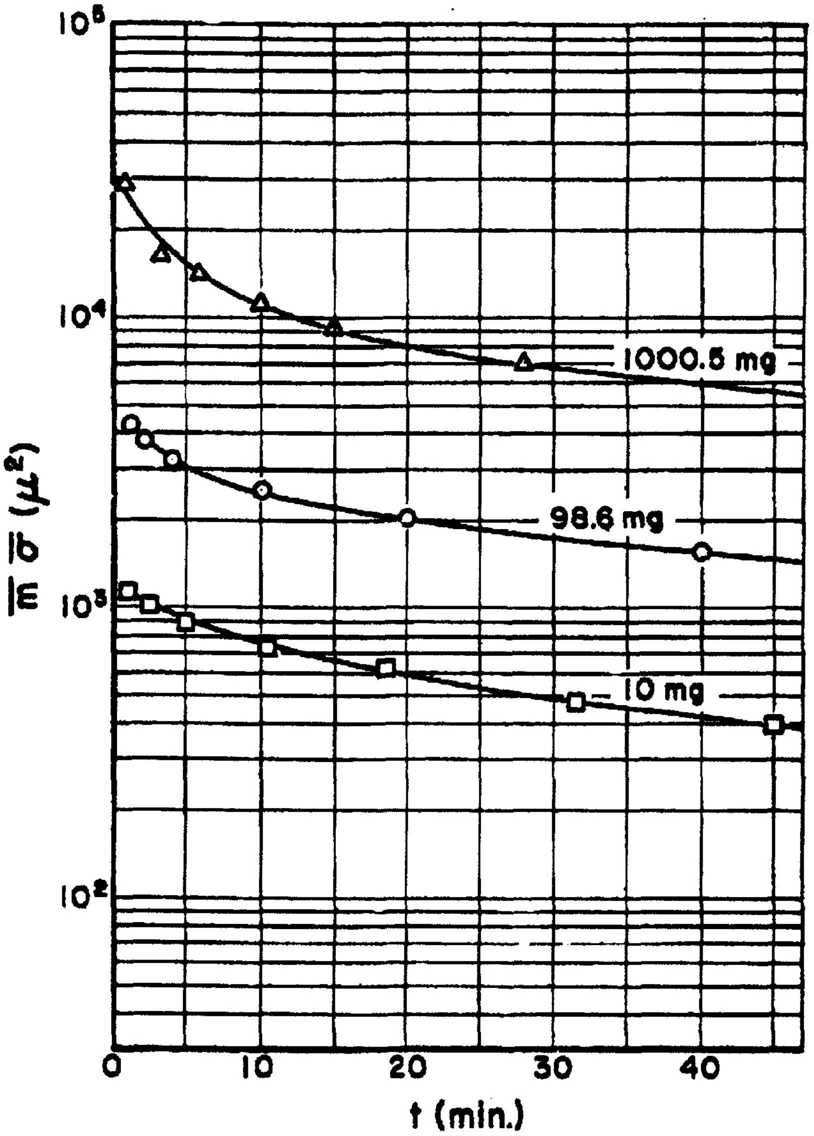

FIG. 3.7(a) CONCENTRATION RUNS FOR SACCHARIN

In a similar way, we shall replace $\overline{I_s^2} - \bar{I}_s^2$ of the reference by F^2, so that there is the expression

$$F^2 = (I\,\delta\Omega)^2\,\overline{m}\,\overline{\sigma^2} \tag{3.5}$$

The same concentration runs are presented in a different manner in Figures 3.3(b) through 3.7(b). Here S/S_o, the signal in percent of initial signal, is plotted versus time on logarithmic normal paper. For the purposes of these plots, the "initial signal" was taken to be the signal one minute after dispersing the powder; this procedure was adopted in view of the fact that some 30 seconds are required for thorough dispersing. The time scale on the "a" series of graphs, then, differs by one minute from that of the "b" series.

It will be noted that many of the curves of the "b" series are very nearly straight lines; the exceptions in most cases are the 10 mg runs. For the latter runs the signal was not far above background (particularly in the late stages of aerosol life), which may account for deviations from a linear plot.

The inference of a straight line on logarithmic normal paper may be seen by reference to the expressions for nonagglomerative aerosol decay.[15] Contingent on the uncertainties stated there, a straight line implies that the aerosol decays without agglomeration; the 50 percent point occurs at $\rho d_s^2 t = 370$, so that the "half life" is inversely proportional to the square of the surface median diameter of the initial aerosol particles.

Figures 3.3 through 3.7 suggest the following two statements:

1) For a given powder, the rate of decay is very nearly independent of the amount dispersed.

2) A ten-fold increase in the amount of powder dispersed does not produce a ten-fold increase in scattered light.

The first statement implies that coagulation plays no important part in the present experiment. For, as indicated by any theoretical treatment, coagulation is a "second order reaction" in which (see page 3-18)

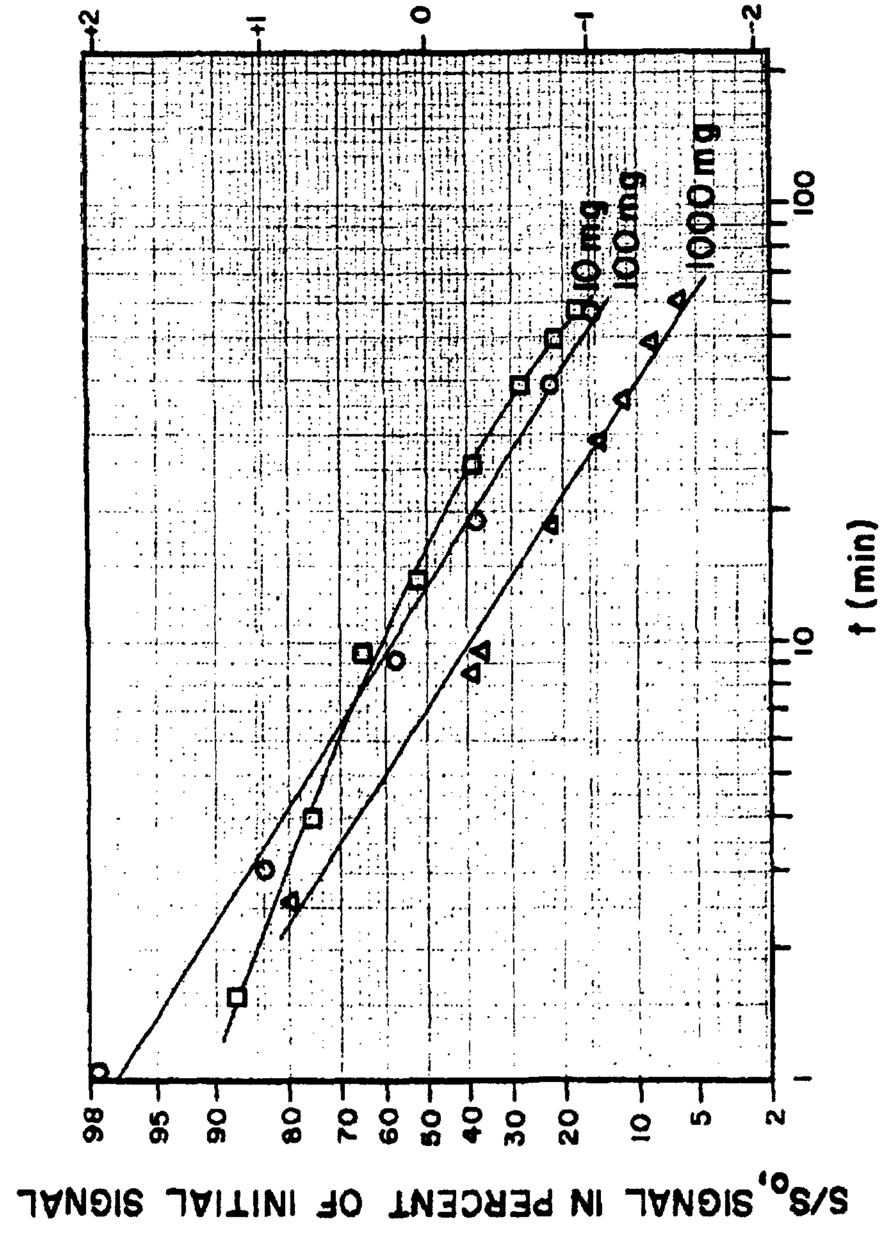

FIG. 3.3(b) CONCENTRATION RUNS FOR TALC

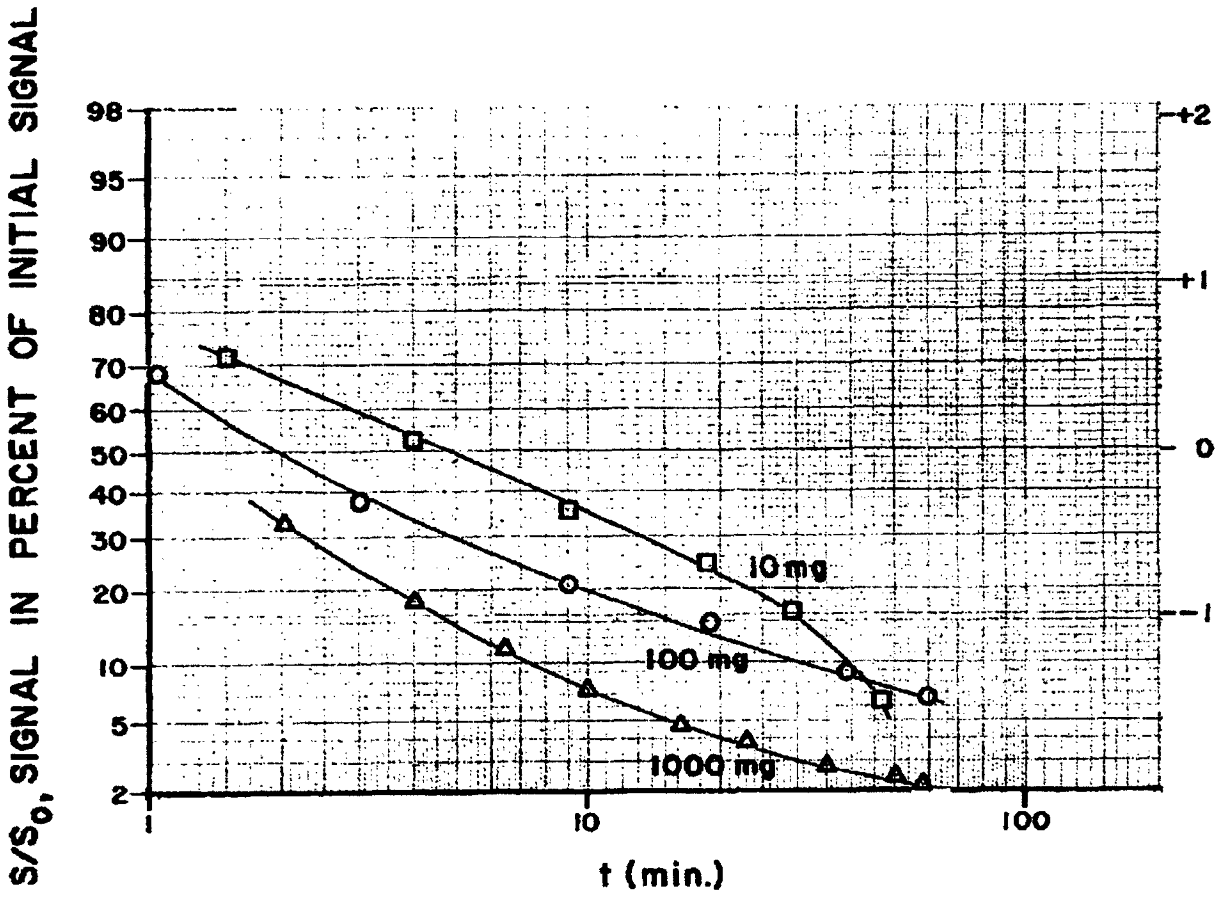

FIG. 3.4(b) CONCENTRATION RUNS FOR CORNSTARCH

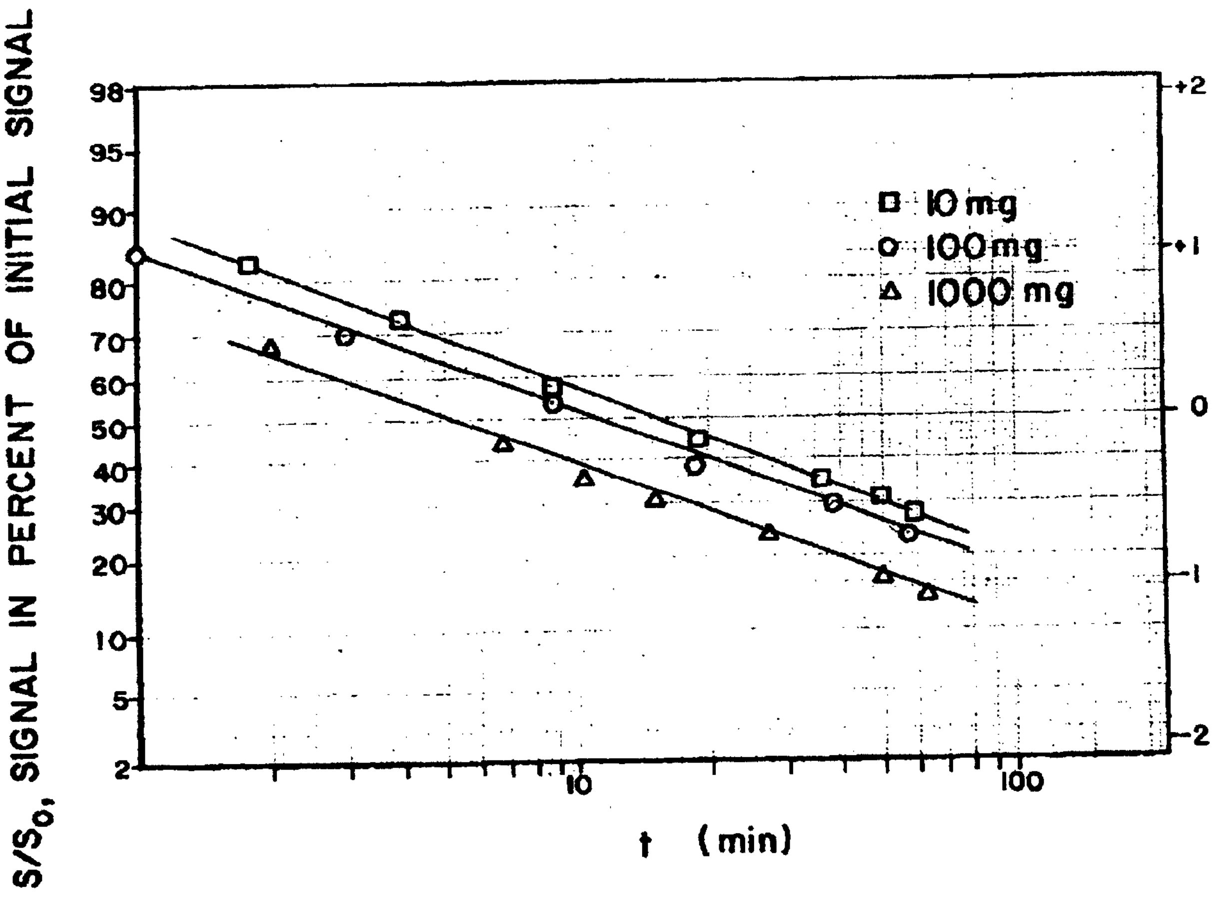

FIG. 3.5 (b) CONCENTRATION RUNS FOR POWDERED SUGAR

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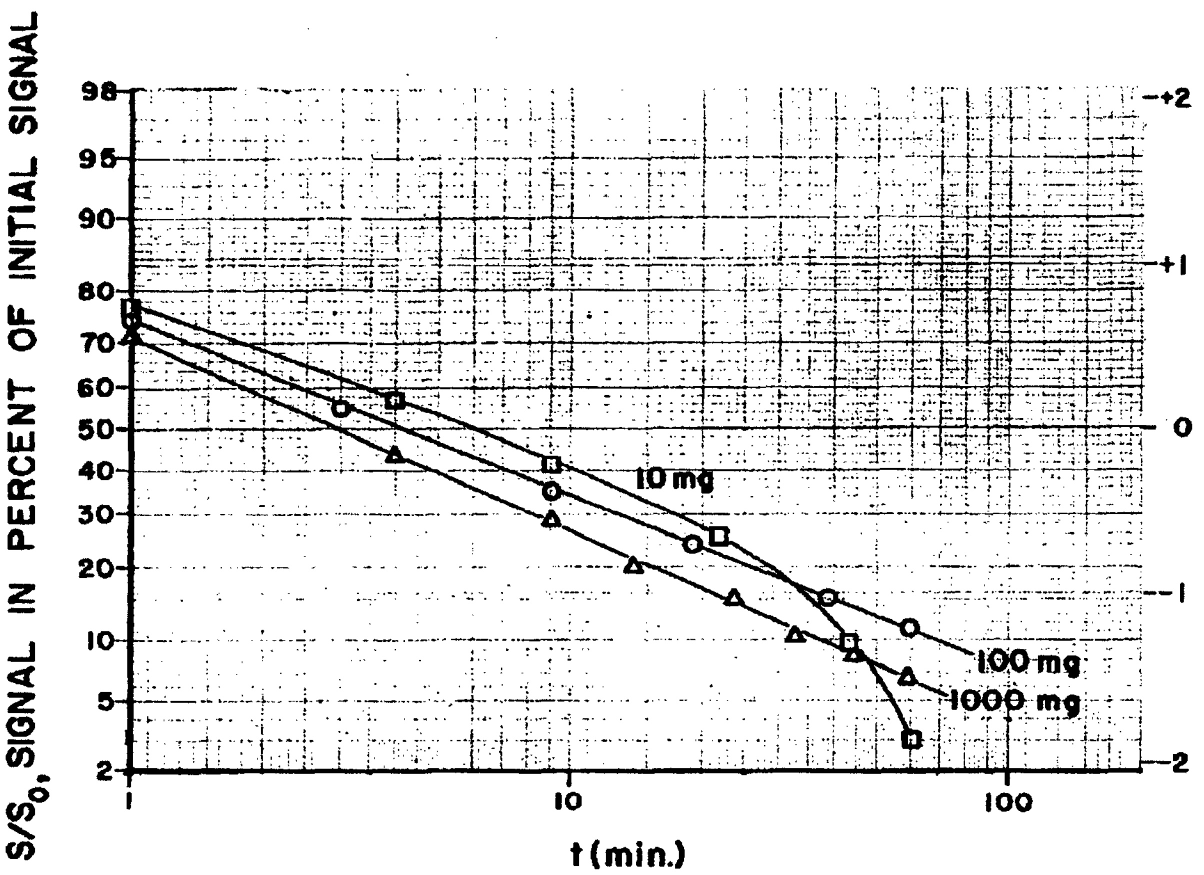

FIG. 3.6(b) CONCENTRATION RUNS FOR POWDERED MILK

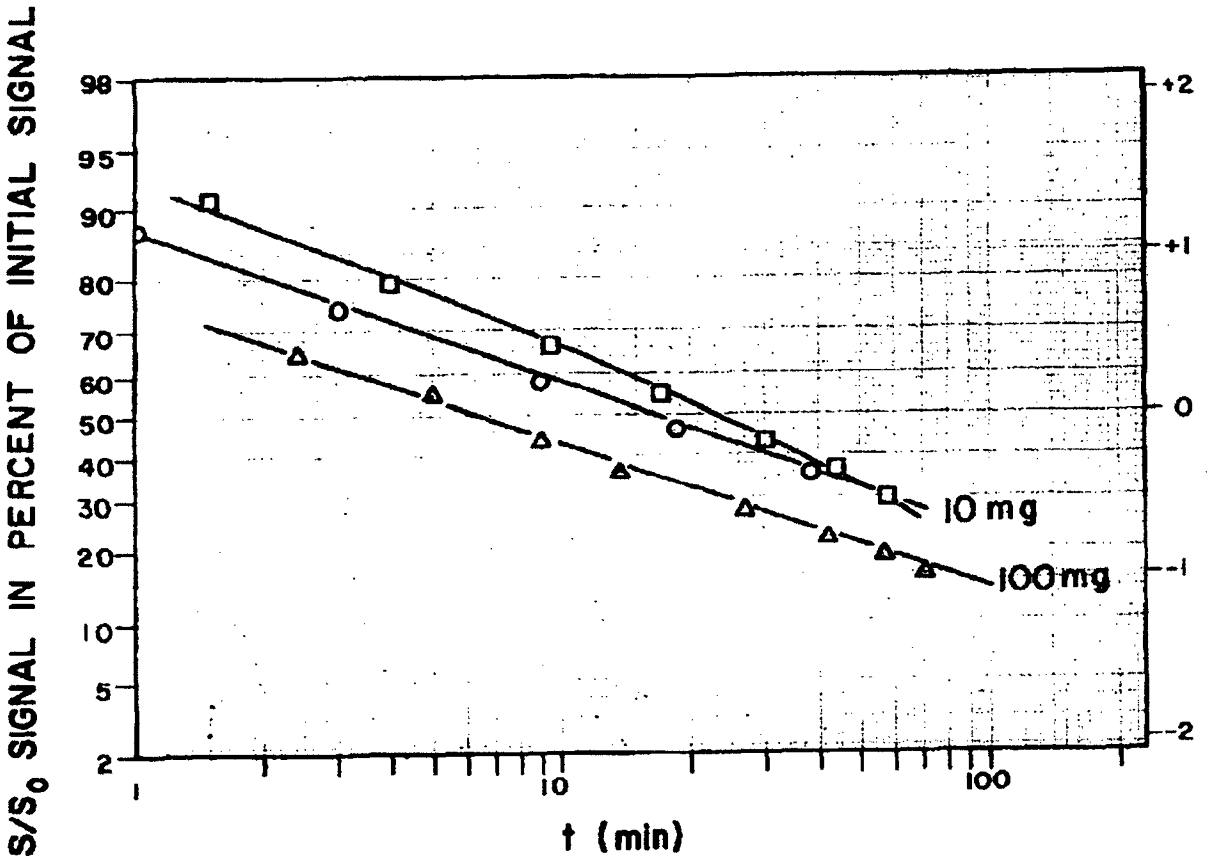

FIG. 3.7(b) CONCENTRATION RUNS FOR SACCHARIN

$$\frac{dC}{dt} = -KC^2 \quad \text{or} \quad \frac{d(\ln C)}{dt} = -KC \tag{3.6}$$

where C is the concentration (particles per unit volume). A ten-fold increase in the concentration causes a ten-fold increase in the logarithmic derivative of the concentration. Now admittedly the scattered light is not a direct measure of concentration; however, Figures 3.3(a) through 3.7(a) do not show anything even remotely approaching a ten-fold increase in slope.

In contrast to coagulation, the rate of settling of particles on internal chamber surfaces is governed by a first order reaction:*

$$\frac{dC}{dt} = -kC \quad \text{or} \quad \frac{d(\ln C)}{dt} = -k \tag{3.7}$$

This logarithmic derivative is independent of concentration. In view of Figures 3.3 through 3.7, it appears that settling must far outweigh coagulation as a mechanism for the removal of particles from an aerosol. This conclusion is reinforced by the figures of series "b" which indicate that in general the decay is nonagglomerative after the first minute of aerosol life.

Statement (2) on page 3-12 implies several things about the dispersing process. Evidently this process becomes less efficient with increasing amounts of powder. But since the powder residue in the disperser does not exceed about 1 mg (except possibly in the case of talc), the discrepancy must be looked for after the powder leaves the dispersing unit. A visual examination of the dispersing process yields a possible explanation: The jet from the disperser appears to carry for about two-thirds the height of the chamber before erupting into turbulence. There is then a lapse of a few seconds before this cloud is furhter dispersed by the fan. During these

---

*Witness the expression $d(\ln C)/dt = -v(d)/H$ suggested previously[12] for a monodisperse aerosol.

few seconds, the cloud volume is approximately one cubic foot, or about one-thirtieth of the volume of the chamber. The concentration is therefore a factor of 30 higher at this point than it is after dispersion is complete, and the agglomeration rate KC^2 may be as much as 1000 times higher. There may thus be considerable agglomeration in this intermediate stage of the dispersion. This statement is well supported by the figures of series "b". In these figures the most striking feature is the shift of the curves toward larger median diameters with increasing amounts of powder dispersed.

The behavior noted above can be considered a failing of the dispersing system, since its function is to fill the chamber with aerosol without fatalities. This criticism of the swirl disperser is, in effect, the same as that advanced against the bursting diaphragm disperser.

The fluctuation recorder was used during the concentration runs, with about eight traces being made for each run. Values of $F_{aerosol}$ were obtained for each trace by the procedure described in Section 3.1.2. These data were further reduced in a manner suggested by the two expressions

$$\begin{aligned} S &= I\delta\Omega\,\overline{m}\,\overline{\sigma} \\ F^2 &= (I\delta\Omega)^2\,\overline{m}\,\overline{\sigma^2}\ . \end{aligned} \qquad (3.8)$$

From these two expressions, there follows

$$\frac{S^2}{F^2}\cdot\frac{1}{\overline{m}} = \frac{\overline{\sigma^2}}{\overline{\sigma}^2}$$

and (3.9)

$$\frac{F^2}{I\delta\Omega S}\cdot\frac{1}{\overline{\sigma}} = \frac{\overline{\sigma^2}}{\overline{\sigma}^2}$$

Making use of the inequality

$$\overline{\sigma^2} \geq \bar{\sigma}^2$$

(where the equal sign holds only for monodisperse aerosols), we find

$$\bar{m} \geq \frac{S^2}{F^2}$$

$$\bar{\sigma} \leq \frac{F^2}{16\Omega S} \quad . \tag{3.10}$$

Accordingly, the ratios S^2/F^2 and $F^2/18\Omega\ S$ were plotted on log-log paper. Unfortunately, the data points so obtained were of very poor quality, the scatter being so great that it was difficult even to pick out trends. To maintain a complete record, however, we present the trends in Figures 3.8 and 3.9.

The curves of Figure 3.8, which are lower limits on the number $\bar{m}$ of particles in the 7.6 cm^3 scattering volume δV, are all in the neighborhood of 10^3. The saccharin curves are characteristically higher (near 10^4), whereas cornstarch is characteristically lower. It is to be kept in mind that the values of Figure 3.8 are to be multiplied by $\overline{\sigma^2}/\bar{\sigma}^2$, which may be as large as 100 or more for sufficiently polydisperse aerosols, to give the actual value of $\bar{m}$.

The curves of Figure 3.9, in which the ordinates are plotted units of μ^2, are all in the neighborhood of 1; the inference here is that the average light scattering cross-section for the powders used is less than $1\mu^2$. This value may be compared with one supplied by the expression

$$\sigma(d) = \frac{d^2}{6\pi}$$

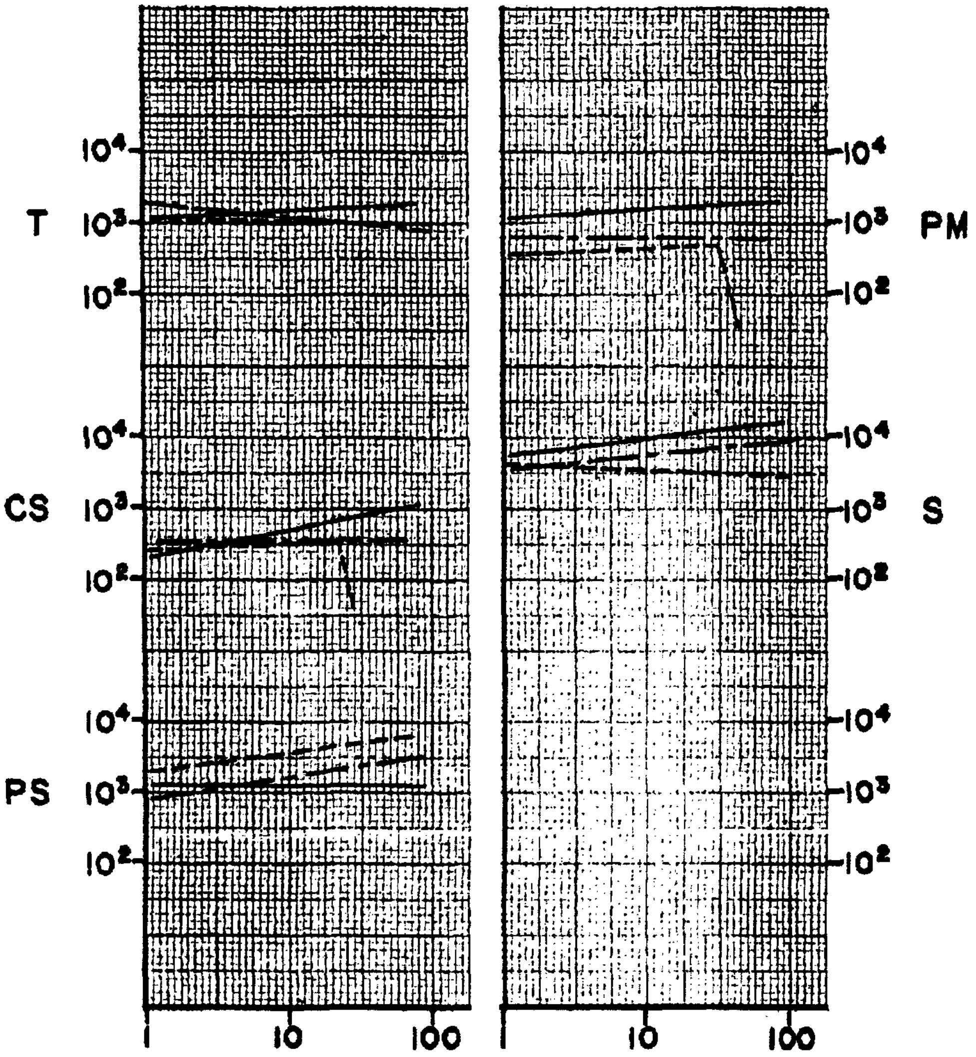

FIG. 3.8 $\frac{S^2}{F^2}$ vs TIME

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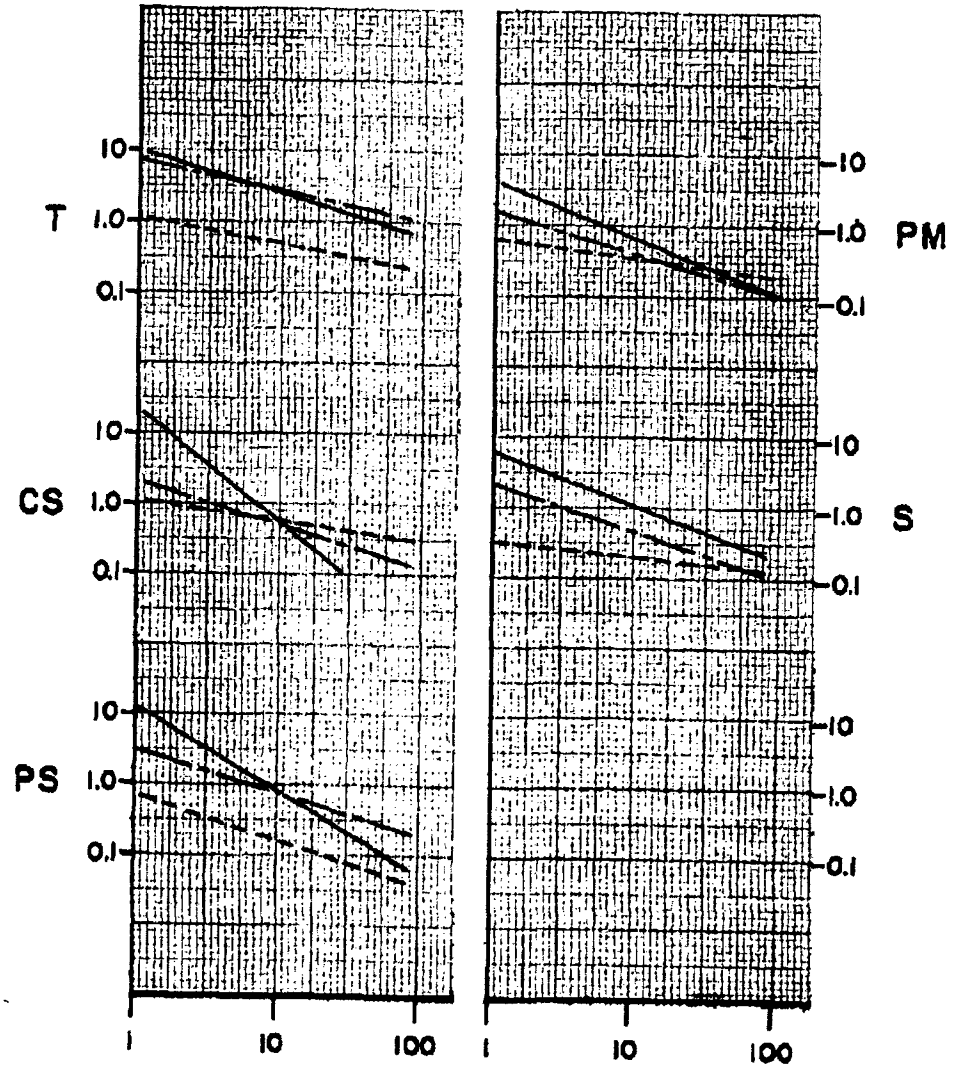

FIG. 3.9 $\frac{F^2}{I8\Omega S}$ vs TIME

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proposed previously for an idealized powder; for a 5-micron particle we have

$$\sigma\,(5) \approx 1 - 1/4\,\mu^2 \quad . \tag{3.11}$$

One surprising feature of Figures 3.8 and 3.9 is that $F^2/100\,S$, related to $\bar{\sigma}$, is more sensitive to concentration that S^2/F^2, which is related to $\overline{m}$.

The direct sampling system was put into operation for the concentration runs, one sample being drawn from each aerosol 10 minutes after firing. The samples were drawn onto black millipore filters, which could conveniently be viewed under a microscope when illuminated with incident white light. The resolving power of this system is about 1 micron, so that only particles of "diameter" larger than 2 microns were recognized. For comparison, the number of particles larger than 8 microns was counted. The results are shown in the accompanying table; in many cases the samples withdrawn were small, so the statistical uncertainty may be as large as a factor of 2.

Table 3.1 Concentration of Particles with Diameters of 2 and 8 Microns (particles per cm^3)

Amount Dispersed	Talc	Cornstarch	Powdered Sugar	Powdered Milk	Saccharin
1 g	---	59/13	500/94	105/16	250/31
100 mg	370/90	12/3	120/20	24/5	49/15
10 mg	77/8	16/1.6	48/2	15/1.1	66/4

3.1.4 Summary of Experimental Work

We have found that aerosol properties depend on the method of dispersion. It seems impossible therefore to confine the scope of the experiment to properties of aerosols per se; the dispersing process must be considered an integral part of each run.

Fluctuation measurements proved unfruitful. The data generated too poor in quality to be of any value.

Concentration runs have been shown to follow the expressions for non-agglomerative decay, provided the discrepancies introduced by the dispersing process are disregarded.

3.2 Theoretical Estimates of Agglomeration

In order to interpret experimental results on the effect of concentration on aerosol decay, it is necessary to have theoretical estimates of the amount of agglomeration which can be expected. Such estimates must be based on the forces operative between particles and on the motion of particles in the settling chamber.

3.2.1 Energy Considerations

In this section we consider various interactions of a pair of neighboring aerosol particles. An aerosol concentration of 10^3 particles per cm^3, for which the average interparticle distance is 0.1 cm, will be taken as typical.

The gross motion of a pair of neighboring particles is determined largely by air currents, so that it is convenient to view their behavior from a coordinate system fixed in the air packet containing the particles. This coordinate system will in general undergo both translation and rotation with respect to a stationary frame; the rotational component of its motion comprises the turbulence of the air.

For the purpose of studying agglomeration, it is the relative rather than the gross motion of the particles that is important. If the air motion is purely translational, the relative motion of the particles is clearly the same as if there were no air motion at all. In this case the relative motion is determined by Browian motion and by the earth's gravitation. If on the other hand the air motion is purely rotational, the particles experience an apparent gravitational field that depends on the angular velocity and radius of the air motion.* It thus appears that, with regard to the relative motion of neighboring particles, the effect of turbulence is to introduce a variable "gravitation constant", which must be evaluated at each instant of time (for a given air packet). The main features of agglomeration may therefore be seen by a consideration of the tranquil air case.

According to Stokes' law, a particle settling in air under the influence of a gravitational field g has the velocity

$$v = \frac{2}{9} \cdot \frac{\rho g r^2}{\mu}$$

where:

r = particle radius

ρ = particle material density

μ = viscosity of air

and the relative velocity of neighboring particles is

$$v_2 - v_1 = \frac{2}{9} \cdot \frac{\rho g}{\mu} (r_2^2 - r_1^2) \quad .$$

---

*If the radius of the air motion is large compared to the interparticle distance, neighboring particles experience essentially the same apparent field. Only this case will be considered - that is, violet turbulence is ruled out.

The kinetic energy of relative motion is*

$$\frac{1}{2} \cdot \frac{m_1 m_2}{m_1 + m_2} (v_2 - v_1)^2 \quad .$$

With $r_1 = 1\mu$, $r_2 = 3\mu$, $\rho = g/cm^3$, $g = 980$ cm/sec, and $\mu = 1.83 \times 10^{-4}$, the relative velocity is 0.19 cm/sec and the kinetic energy of relative motion is 2.9×10^{-13} ergs.

The particles also have kinetic energy by virtue of their Brownian motion. The average energy of such motion is equal to the average energy of the gas molecules, which is

$$(\tfrac{3}{2})\, kT = 4.2 \times 10^{-14} \text{ ergs at } 300 \text{ K} \quad .$$

It may be mentioned also that the laws of mechanics allow the transference of this amount of energy in a single collision.

We next consider some possible mutual energies of a pair of particles. The gravitational attraction gives rise to the energy

$$\phi(x) = \frac{G\, m_1\, m_2}{x} \tag{3.12}$$

where x is the center-to-center separation distance. Since $G \doteq 6.67 \times 10^{-8}$ in cgs units and m is approximately 10^{-10} g for 5μ particles,

$$\phi(x) \approx \frac{6.7 \times 10^{-28}}{x} \text{ erg} \quad ,$$

which is insignificant even with the particles in contact ($x = 10^{-4}$ cm).

---

* This definition of kinetic energy appears in the classical two-body problem in mechanics. The result is that binding is possibly only if the mutual energy is larger than the relative kinetic energy.

Charge on the particles gives rise to an interaction energy; if each particle has unit charge, we have

$$\phi(x) = \pm \frac{q_1 q_2}{x} = \pm \frac{(4.8 \times 10^{-10})^2}{x} \text{ ergs} \quad .$$

The electrostatic energy may become appreciable if there are large numbers of unit charges on each particle.

Another generally existent force is that of Van der Waal. This force contributes[16]

$$\phi(x) = - \frac{Q}{6x} \left(\frac{2}{z} + \frac{z-1}{z-2} + \frac{z+1}{z+2} - z \ln \frac{z^2}{z^2-4} \right) \qquad (3.13)$$

where $z = x/r$. Q is said to be approximately equal to kT — that is, comparable to the energies of Brownian motion.

The three interparticle energies considered above are "long-range", their influence extending over several particle diameters. To make the survey complete, we must consider possible the formation of chemical or physical bonds between molecules in the surfaces of the particles. Such forces would evidently be short range, extending only over a few molecular diameters of separation of the surfaces.

Molecular bonds may be estimated from

1) heats of vaporization
2) heats of reaction
3) heats of sorption

Tables in physical chemistry textbooks provide the following ranges of value for these heats:

1) 10^{-14} to 10^{-12} ergs/molecule

2) 10^{-12} to 10^{-11} ergs/bond

3) 10^{-13} to 10^{-11} ergs/molecule

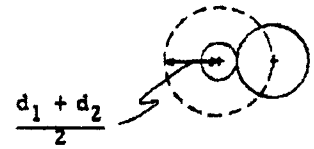
3.2.2 An Estimate of Agglomeration in the Case of Tranquil Settling

In this treatment of agglomeration we shall neglect long-range forces and assume that the short-range forces are strong enough to bind particles together once they are in contact. The problem then becomes one of finding the probability of collisions between particles.

Let attention be fixed on those particles in an aerosol which have diameters in the range $(d_1, d_1 + \delta d_1)$. This whole class of particles moves vertically downward with a velocity $v(d_1)$. It is convenient to view matters from a system of coordinates which is at rest with respect to these particles; let z be the vertical coordinate in this system. The number of particles of the class under consideration in unit area of the horizontal slice dz is

$$C(d_1)\,\delta d_1 \cdot dz \tag{3.14}$$

where $C(d_1)$ is the concentration. Suppose that a particle of diameter $d_2 > d_1$ passes through the slice dz. A collision will occur if this particle passes within a distance $(d_2 + d_1)/2$ of a particle in dz;



that is, each particle in dz effectively blocks off an area

$$\pi\left(\frac{d_2 + d_1}{2}\right)^2 \tag{3.15}$$

The probability of a collision is then simply the fraction of the unit area effectively blocked off, namely

$$\pi \left(\frac{d_1 + d_2}{2} \right)^2 C(d_1)\, \delta d_1\, dz \quad . \tag{3.16}$$

These considerations may now be extended to the entire class of particles d_2, of which there are $C(d_2)\,\delta d_2$ per unit volume. In our chosen frame of coordinates these particles move vertically downward with a velocity

$$v(d_2) - v(d_1) \quad .$$

Therefore, if a cylinder of unit area and height $v(d_2) - v(d_1)$ is erected on dz, all particles d_2 within this cylinder pass through dz in unit time. Since there are

$$C(d_2)\, \delta d_2\, [v(d_2) - v(d_1)] \tag{3.17}$$

such particles, the probable number of collisions in unit area of the slice dz per unit time is

Number per unit area per unit time =

$$C(d_2)\,\delta d_2\, [v(d_2) - v(d_1)]\, \frac{\pi (d_1 + d_2)^2}{4}\, C(d_1)\,\delta d_1\, dz \tag{3.18}$$

or

Number per unit volume per unit time =

$$C(d_2)\,\delta d_2\, [v(d_2) - v(d_1)]\, \frac{\pi (d_1 + d_2)^2}{4}\, C(d_1)\,\delta d_1 \tag{3.19}$$

The result of the above line could now be extended to include all particles d by suitable integrations over d_1 and d_2. Thus, the number of collisions (per unit volume and time) suffered by particles of diameter d is

(collisions with particles larger than d) + (collisions with particles smaller than d) =

$$C(d)\,\delta d \int_d^\infty [v(d') - v(d)]\,\frac{\pi(d' + d)^2}{4}\,C(d')\,\delta d'$$

$$+\; C(d)\,\delta d \int_0^d [v(d) - v(d')]\,\frac{\pi}{4}\,(d' + d)^2\,C(d')\,\delta d' \quad . \qquad (3.20)$$

The total number of collisions would result from another integration, where care would have to be taken to avoid counting each event twice. As may be seen, however, the expressions become rather complicated. We therefore content ourselves with an estimate based on the simpler Equation (3.19).

Suppose that an aerosol is composed of particles of two classes, with diameters 2 and 5 microns. Let the concentration of each type be 10^3 particles per cm^3; thus,

$$C(d_1)\,\delta d_1 = C(d_2)\,\delta d_2 = 10^3 \text{ per cm}^3 \quad .$$

We then find approximately

$$10^{-2} \text{ events per cm}^3 \text{ per sec} \quad .$$

The complete picture would of course involve the aforementioned integrals. But, it is likely that the integrals would modify the above estimate only by a factor of order unity, so that the simpler Equation (3.19) may be taken as characteristic of this type of agglomeration process. It may be noted for example that the rate of agglomeration is proportional to the product of $C(d_1)$ and $C(d_2)$; in the complete picture, both factors would be proportional to C (the concentration without regard to particle size), so that the rate of agglomeration is proportional to C^2 as mentioned before.

According to the considerations of Section 3.2.1, the same sort of analysis would hold, with a variable gravitation constant, for the turbulent case. The question of importance here, however, can be more succinctly stated as: "How much does turbulence increase relative motion of particles?" This question will be left open for the present.

3.2.3 Coagulation Due to Brownian Motion

A certain number of collisions between the particles of an aerosol undoubtedly arise because of the Brownian motion of the particles. If it is assumed that the short-range forces between particles are strong enough to bind them together in the face of the same Brownian bombardment, then these collisions result in agglomeration. For aerosols of particles in the 5-micron range, it is to be expected that collisions due to Brownian motion would be few compared to collisions due to gravitational settling; for displacements due to the former are small when compared with those due to the latter. (This statement is to be amended for the case of a monodisperse aerosol, where there is no relative particle motion due to settling; for the sake of this case especially, some comments on Brownian coagulation will be included.)

The theory of coagulation due to Brownian motion was worked out by Smoluchowski.[17] This article treats coagulation in a colloidal suspension, but one finds that the conditions assumed are very similar to those taken in Section 3.2.2 – that is, only short-range forces are important.

Smoluchowski's treatment of the problem is very complete: starting with a monodisperse colloidal suspension, he finds and solves differential equations for the quantities ν_1, ν_2, ν_3, ... , where ν_i is the concentration of agglomerates consisting of i particles. In the process an expression for $\Sigma \nu_i$ (total number of particles per unit volume) is generated. The differential equation is

$$\frac{d(\Sigma \nu)}{dt} = -4\pi DR(\Sigma \nu)^2 \qquad (3.21)$$

where D is the "diffusion constant" and R the "radius of action" of the particle. D is inversely proportional to the particle radius, and R is assumed proportional to the same (with proportionality constant of order unity), so that the expression is independent of particle size. For this reason, the expression may be extended with confidence to polydisperse aerosols.[18] Note that the differential equation is again one of a second order reaction.

Smoluchowski's value* for D is

$$D = \frac{kT}{6\pi \mu r}$$

so that

$$\frac{d(\Sigma \nu)}{dt} \approx -\frac{2}{3} \cdot \frac{kT}{\mu} (\Sigma \nu)^2 \quad . \qquad (3.22)$$

with $(\Sigma \nu) = 10^3$ per cm^3, $2/3\, kT \approx 2 \times 10^{-14}$ ergs, $\mu \approx 1.8 \times 10^{-4}$ poise, we find

$$\frac{d(\Sigma \nu)}{dt} \approx -10^{-4}\ \mathrm{cm}^{-3}\ \mathrm{sec}^{-1}$$

---

*More recent values differ by a factor of 2.

3.2.4 Effects of Particle Charge on Agglomeration

The energy considerations of Section 3.2.1 indicated that particle charge could become large enough to overcome kinetic energies and therefore affect agglomeration. Further information is presented in this section.

A treatment similar to that set down in Section 3.2.2, with the elaboration that particles may be deflected from vertical motion by interparticle forces due to electric charge, is presented in the literature.[19] The conclusion is that a particle of charge q does not affect agglomeration if the condition

$$|qq_0| \frac{C}{r} < 10^{10}$$

is satisfied. Here q_0 is the average particle charge of one sign in electron units, C is concentration, and r is the radius in microns.

In related experimental work,[20] Kunkel has measured particle charge by a Millikan oil drop type of experiment. It was found that the average charge on a 5-micron particle is approximately 100 electron units; but there were a large number of particles of either much higher or much lower charge. This figure was found to characterize aerosols without regard for the type of powder or for the method of their dispersion.

Kunkel's conclusion is that for particles of 5-micron size, charge plays no role in agglomeration until the concentration reaches 10^6.

3.2.5 Summary of Agglomeration Estimates

In Section 3.2.1, we indicated that all interparticle forces of any consequence were of short range, with the possible exception of those forces due to particle charge. No interparticle forces are therefore capable of bringing particles together; and collisions are left to chance. The estimate of Section 3.2.4 says that particle charge does not influence agglomeration for concentrations less than 10^6. The short-range interparticle forces, however, are probably sufficient to bind particles into stable agglomerates, particularly if chemical bonds form between surface molecules. The criterion for stability, from Section 3.2.1, is that the binding energy be large compared with the kinetic energies.

Assuming a 5-micron count median diameter, the number of particles per g of powder is, at most, 2×10^{10}. If 1 g of powder is dispersed into a 1 m^3 chamber, the concentration is therefore 2×10^4 per cm^3 or less.

Section 3.2.2 presents an estimate of the number of collisions per unit volume and time due to the relative particle motion of settling. Section 3.2.3 deals with collisions due to Brownian motion. With an assumed concentration of 10^3, the former section estimates that 10^{-2} particles are involved in collisions per cm^3 per second, while the latter one yields a figure of 10^{-4}. The logarithmic derivatives of the concentration are therefore 10^{-5} and 10^{-7} per second, respectively.

A look at Figures 3.2 through 3.7 yields values for the logarithmic derivative of the light-scattering signal. In Figure 3.2 (for talc) it is found that the light signal decreases about 3 percent per minute late in the life of an aerosol; earlier slopes and slopes of other curves are higher. The corresponding value of the logarithmic derivative is

$$5 \times 10^{-4} \text{ per sec} \quad .$$

The relation between the logarithmic derivatives of scattered light and of concentration may be seen from

$$S = I \delta \Omega \, \overline{m} \, \overline{\sigma}$$

$$= I \delta \Omega \, C \frac{\delta V}{V} \cdot \overline{\sigma} \quad .$$

There results

$$\frac{d(\ln S)}{dt} = \frac{d(\ln C)}{dt} + \frac{d(\ln \bar{\sigma})}{dt} \quad . \tag{3.23}$$

For purely agglomerative aerosol decay, the two terms on the right would have opposite signs. Simple geometrical consideration, however, shows that

$$\left|\frac{d(\ln C)}{dt}\right| > \left|\frac{d(\ln \bar{\sigma})}{dt}\right|$$

so that

$$\left|\frac{d(\ln S)}{dt}\right| < \left|\frac{d(\ln C)}{dt}\right| \quad .$$

Since observed rates of decrease for the light scattering are orders of magnitude higher than estimated agglomeration rates, it seems that agglomeration is of no consequence in the present experimental apparatus. It is conceivable, however, that the agglomeration rate could become important in experiments where a larger chamber is used. This is so because the rate of nonagglomerative decay depends on chamber size.

3.3 Future Work

During the eleventh quarter, further work on humidity effects will be undertaken. This matter has become especially important because results of the recent quarter in some cases contradicted those previously reported. The work with ion concentration (mentioned in the last quarterly report) will get underway.

In the broader view, we hope that during the next quarter the aerosol studies may be more strongly related to other aspects of the program, such as the dispersibility studies. This attitude is in part forced by the dependence of aerosol properties on dispersing methods.

4. CONTINUATION OF EXPERIMENTS WITH THE FULL-SCALE FEEDER FOR COMPACTED DRY AGENT SIMULANT MATERIALS

Experiments were conducted using powdered sugar and "Jet" flour in the experimental feeder, which is a prototype of the inner tank assembly for the first-generation dry agent disseminating store. Operation of the unit with compacted Mistron Vapor talc was continued with some runs being made at a feeding rate of 91 lb/min. Satisfactory performance of the full-scale experimental feeder has now been demonstrated over a range of feed rates from 20 to 91 lb/min and a range of powder densities from 0.25 to 0.69 g/cm^3.

4.1 Powdered Sugar and "Jet" Flour Tests

All of the experimental feeding experiments previously reported for the full-scale feeder were conducted with Mistron Vapor talc. In order to demonstrate performance of the feeder when filled with other compacted dry powders, the unit was operated with powdered sugar and with General Mills, Inc. "Jet" flour. Powdered sugar was selected primarily because of the difference between the amount of void space in compacted sugar and that in talc. Powdered sugar at a density of 0.69 g/cm^3 has approximately 57 percent void space; whereas Mistron Vapor talc at a density of 0.55 g/cm^3 has about 80 percent void space. Because of the smaller amount of air occupying the reduced void space in the powdered sugar, this material could possibly feed less readily than talc.

"Jet" four was selected because the amount of void space in this flour (when it is compacted) agrees well with that in Sm compacted by the same force. The average bulk density of the flour is approximately 15 percent greater than that of Sm under the same compaction force.

The feeder was observed to function very well with both the powdered sugar and the flour. Driving torques were low, and gas-flow rates similar to those for talc could be used. Flow-rate curves for the tests are presented in Figure 4.1.

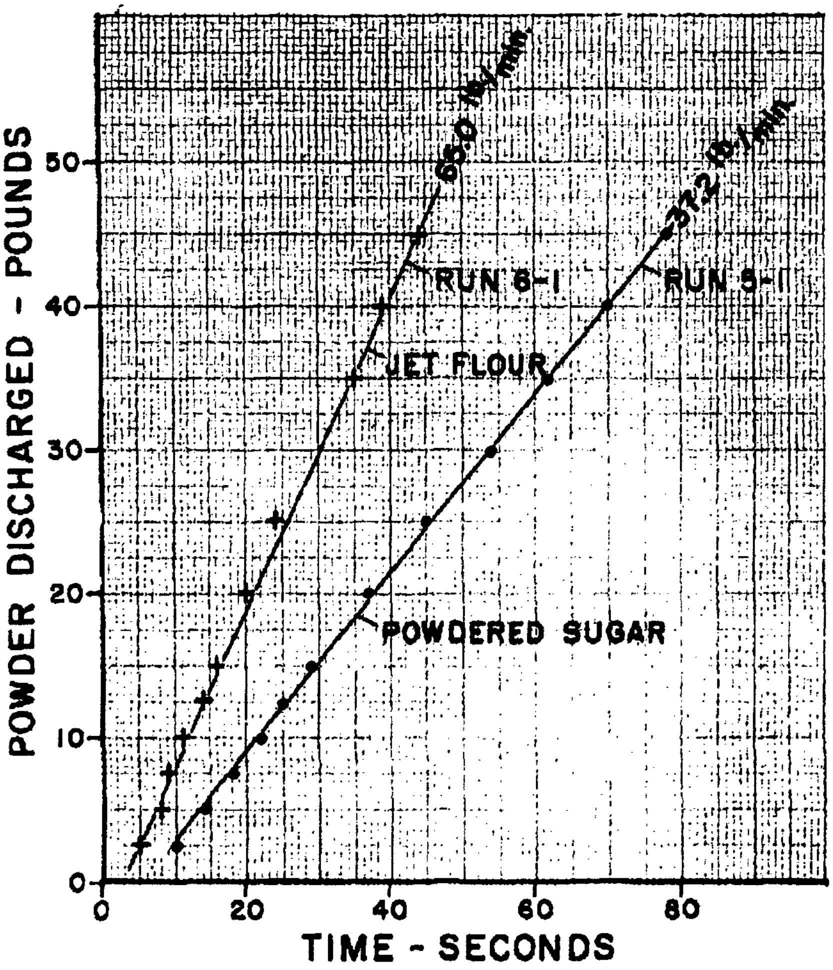


FIG. 4.1
POWDER FLOW RATE CURVES FOR SECOND EXPERIMENTAL UNIT FEEDING FLOUR AND POWDERED SUGAR

For the feeding tests using powdered sugar, the unit was partially loaded with sugar at a density of 0.69 g/cm^3. On the first run the driving speed was 18.5 rpm and the gas (nitrogen) flow rate was 4.4 std cfm. A powder flow rate of 37.2 lb/min was measured. These flow rates resulted in a gas-to-powder weight ratio of 0.0087.

On the second run the speed was approximately 35 rpm, and the gas flow was increased to 7.5 std cfm. The feeder functioned satisfactorily; but accurate flow-rate data were not obtained due to difficulties with the measuring equipment. The flow rate as calculated from the speed of 35 rpm and the density of 0.69 g/cm^3 is 74.9 lb/min.

For the test using Jet flour at a density of 0.60 g/cm^3, the gas-flow rate was 7.9 std cfm. A powder flow rate of 65.0 lb/min was measured. The gas-to-powder weight ratio determined with these flow rates is 0.009.

4.2 Feeding Talc at 90 lb/min

In feeding experiments reported in previous progress reports,[21] Mistron Vapor talc has been discharged at flow rates ranging from 20 to 53 lb/min with filling densities ranging from uncompacted talc at 0.25 g/cm^3 to compacted talc at 0.65 g/cm^3. Higher flow rates were not obtainable with the existing experimental drive system. At the end of October, 1962, a rotary actuator for the first-generation dry agent disseminating store was completed and used in place of the experimental drive system. This made it possible to operate at a maximum drive speed of 48 rpm as compared to 35 rpm with the former system. Correspondingly higher feed rates were obtained with the rotary actuator.

In one of the series of runs made with compacted talc in the second experimental unit, the unit was operated at 48 rpm with 13.4 std cfm of air flowing. The feeder discharged 42.5 lb of talc in 28 sec for an average powder feed rate of 91 lb/min. The gas-to-powder weight ratio calculated from these flow rates is 0.0113.

The density of the compacted talc in the feeder in this case was 0.6 g/cm^3. (It should be explained that the first-generation dry agent disseminator does not have the same piston drive screw as the experimental feeder and that powder feed rates at identical driving speeds for the two units do not therefore correspond. The prototype disseminator has a screw with seven threads per inch, whereas the experimental feeder has a screw with five threads per inch. Consequently, when the disseminator is operated at the top speed of 48 rpm with 0.6 g/cm^3 density fill, its discharge rate is approximately 65 lb/min instead of 91 lb/min.)

5. FILLING THE DRY AGENT DISSEMINATING STORE (E-41 SPRAY TANK)

Effort was continued on the investigation of techniques for filling the E-41 spray tank with compacted particulate material. Experiments were conducted using foamed plastic to encapsulate compacted talc into packages 16.5 inches in diameter and 9 inches high. For laboratory and field tests, the disseminator has been filled with compacted talc by means of the special loading device described in the Ninth Quarterly Progress Report.[22]

5.1 Encapsulation Using Foamed Plastic

The investigation of methods to encapsulate dry particulate materials previously reported in the Ninth Quarterly Progress Report (GMI Report No. 2344) was continued during the present reporting period. Of the three methods proposed in the previous report the foamed-in-place plastic packaging appeared to show most promise, and we therefore concentrated effort on this method.

Although many conditions are imposed on the encapsulating material, the primary ones are strength and friability. The package must be strong enough to withstand normal handling and yet must remain sufficiently friable to be shaved by the blades of the disaggregator in the disseminator in particles small enough to pass through the discharge orifice.

The Chemical Activity of General Mills' Central Research Laboratory has recommended a type of foamed-in-place plastic which has properties that approach the above-mentioned requirements. The basic material used is a rigid polyether-based polyurethane foam. The chemical compounds have the trade name of Pleogen and are manufactured by the Mol-Rez Division of American Petrochemical Corp. The Chemical Activity formulated the following combination of Pleogen compounds to make up the urethane foam: First combine 1000 g of Pleogen 4052 with 72 g of distilled water and then add this combination to Pleogen 4020B in a ratio of 134 g of A (Pleogen 4052 and water) to 280 g of B (Pleogen 4020B).

Urethane foams are basically a reaction product between a hydroxyl-rich material (Pleogen 4052 is a polyether resin) and polyisocynate (Pleogen 4020B is a prepolymer containing toluene diisocyanate). The foaming action occurs when carbon dioxide gas is formed by the chemical action of the water with the toluene diisocyanate. The reaction time, which to a certain degree determines the strength of the material, may be decreased with the addition of a catalyst such as N-ethylmorpholine. The catalyst tends to increase the liberation of carbon dioxide gas. The process is exothermic and the heat promotes bonding of individual cells, which are formed from the resin material.

General combinations of the Pleogen compounds were investigated prior to arriving at the formula previously outlined. During the investigations we discovered that small changes in the chemical compositions of the urethane foam did not affect the characteristics of the final foam as much as did the changes in the initial temperature of the molds and the temperature maintained during the aging process. Previous experience with foamed-in-place urethane foams indicated that in order to obtain a high strength, rigid, non-friable material, it was necessary to preheat the molds prior to pouring the foam material and to maintain a high temperature during the aging process. Normally, the heat of reaction produces a sufficiently high temperature. The most successful approach to obtain a friable, low-strength material for our application has been to pour with the molds at room temperature, and to cool the foam as quickly as possible by removing the casting as soon as the foaming is completed. Another way of minimizing the heat retention in the material is to reduce the wall-thickness of the shell. However, it is necessary to retain sufficient thickness to preserve the required strength. Several of the packages constructed had friable outer surfaces but tough inner core material. The inner core problem was reduced considerably when an aluminum bar was used as a heat sink in the inner mold.

Two types of urethane foam capsules were investigated for use in the dry agent disseminator. The first series made used the foam shell as the container into which the powder was compacted. This required that the foam

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shell be molded with extremely thick walls causing excessive loss of potential powder capacity. A maximum density of 0.41 g/cm^3 (with talc) was achieved in filling the containers tested. Although the shell was 1-1/4 to 1-1/2 inches thick, extreme care was necessary when handling the containers loaded with powder.

Eight of these units were successfully digested by the experimental disseminator. However, it was necessary to incorporate a screen at the entrance to the discharge nozzle to prevent large pieces of foam material from clogging the orifice.

The second series of capsules incorporated an aluminum shell around the foam material to provide added strength to the container during handling. The capsules were formed by placing the aluminum shell around a cylinder of compacted talc powder and pouring the foam directly over the powder and into the space between the powder and the aluminum shell. Wall thicknesses varying from 1/2 to 3/4 inches were tried. The density of the talc was approximately 0.55 g/cm^3.

Because the foam adhered to the aluminum, it was necessary to free the shell at the time the capsule was placed in the disseminator. Several of these units were fabricated and tested. The capsules could be handled without breakage, but difficulty was encountered in inserting the units into the disseminator. The foam material was too friable and cracked open during loading.

The second method of forming the capsule by pouring the foam material over a cylinder of compacted dry powder raises two questions:

1) Is the heat generated during the foaming action detrimental to compacted agent materials?

2) Are the chemicals and materials compatible with the agents to be used?

A preliminary investigation of the temperature question was conducted using a compacted slug of talc to determine the temperature rise in the bed during foaming action. A copper constantine thermocouple was placed in the powder

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bed approximately 0.25 inches from the edge of the foam material. A total temperature rise of 10°F was observed during the entire foaming operation. This rise in temperature does not appear to be excessive. However, the heat transfer coefficients of talc and agent materials may differ, and the experiment should either be repeated with actual agents or coefficients should be obtained for these agents.

The packaging investigations have not yet produced a suitable solution to the problem. The urethane foam shows the most promise of the methods under study, but several problems remain unsolved. If a good encapsulating technique is developed, it will be necessary to investigate compatibility of packaging materials and agents.

5.2 Loader for Filling with Compacted Powder

The Ninth Quarterly Progress Report[22] describes the loading fixture which has been fabricated for use in filling the prototype E-41 disseminator with compacted powders. This unit has been used successfully in several filling operations in which talc was used as the simulant material. It is planned that this device will also be used when filling the disseminator with Bg for the Dugway tests.

As part of the preparations for the tests at the Naval Air Test Center, extra inner tubes were fabricated for use with the loader. Two of these tubes were filled with compacted talc and shipped to the Test Center in the event that it became necessary to refill the disseminator in the field. Because of the successful performance of the disseminator, the initial filling sufficed, and the spares were returned unused.

6. ASSEMBLY AND TEST OF THE PROTOTYPE DRY AGENT DISSEMINATING STORE (E-41 SPRAY TANK)

During the past three-month period significant work was accomplished on the development of the dry agent disseminating store which has been designated the E-41 Spray Tank. The prototype was assembled and subjected to laboratory and field testing. Structural and functional tests were conducted in the laboratory at General Mills, Inc. and at Fletcher Aviation Company. Static functional tests and flight tests were conducted at the Naval Air Test Center, Patuxent River, Maryland. The disseminator passed all of these tests with a high degree of success.

6.1 Fabrication and Assembly

The first-generation prototype dry agent disseminating store was assembled in the Development Engineering Shop at Plant 5 of the General Mills' Electronics Division. Wherever possible, as components and subassemblies were fabricated and assembled in the shop or received from outside vendors, they were inspected and tested for conformance with drawings and specifications before being incorporated in the prototype unit. A few engineering specifications are appended to this report as examples of engineering procedure related to fabrication of this unit.

The fabrication and assembly of the prototype have closely followed the basic design described in previous progress reports,[23] and no further discussion of design details will be provided here.

As the design and development work progressed, the need for certain items of support equipment became apparent. Design, fabrication, and procurement of these items also progressed during the past quarter so that they were available when needed in the assembly and test program. Included in the category of support equipment are the following items:

1) nose cone cart

2) tail cone cart

3) lifter

4) support frame

5) high-pressure nitrogen cylinders

6) electrical test fixtures

7) flight recorder

The nose cone and tail cone carts are used to facilitate assembly of the end cones to the center section of the store. They also serve as cradles to hold the end cones when they are being worked on apart from the center section. Each cart is made so that the nose cone can be rotated about its longitudinal axis to engage or disengage the bayonet latching rings by which the cone and the center section are joined. A commercial half-ton load lifter is used to raise the cart and end cone to the elevation of the center section.

A special support frame was constructed to hold the store during assembly in the shop. The attachment lugs in the store are used to attach it to the support frame.

The gas bottle in the disseminator is charged with nitrogen to a pressure of 3000 psi. To achieve this pressure, the bottle is filled by a cascading process in which the "topping", or final filling, is accomplished with 6000 psi nitrogen cylinders. The cylinders are not available from local suppliers of the standard 2400 psi cylinders, but were ordered from the Air Reduction Company, Inc., Los Angeles, California.

A small recorder was procured for monitoring and recording the operation of the dry agent disseminator during flight testing. This instrument is a Century Electronics and Instruments, Inc., Model 409E4, miniature light-beam oscillograph with Model 409D9 recording paper magazine. It is a compact, shock-mounted unit ideally suited for mounting in an airplane.

For the flight tests, the oscillograph will be powered from the disseminator's 28 vdc power supply and will commence recording upon application of power to the disseminator.

On-off type recording is achieved by actuating the appropriate recorder galvanometer through the relay associated with the condition in question. Following is a tabulation of the eight conditions monitored, together with their associated relays:

Condition	Sensor
3-phase a-c undervoltage	undervoltage detector relay
nitrogen supply heaters on	heater relay
cylinder pressure above 2 psi	cylinder pressure relay
line pressure above 20 psi	line pressure relay
nitrogen flow pressure below 28 psi	gas flow relay
discharge valve fully closed	discharge valve switch
piston extended to limit	actuator extend limit relay
squibs fired	arm relay

In addition to the above events, the disseminator's 28 vdc circuit is monitored and recorded in analog form.

Detailed analyses of these conditions and of the sequence of various events during as long as one hour of disseminator flight operation are possible through examination of the permanent paper record.

Two electrical test boxes were made for the purpose of simplifying pre-flight check-out procedures. One of these is called the "Ground Operating Box" and the other the "Aircraft Checkout Box".

The ground operating box is used to operate the E-41 spray tank when a ground power source is used and the cockpit control panel is not connected to the disseminator. This test box has a "Ground Operating Cable" which connects the box to the disseminator through a receptacle in the top of the store. The following switches and indicator lamps are mounted on the box and correspond with those in the airplane cockpit:

Switches	Lamps
master	generator off
arming	orifice open
disseminate	flow
photo light	

The aircraft checkout box is used to check the cockpit control panel and the aircraft wiring associated with the E-41 spray tank. This box has indicator lamps and switches to simulate various components in the disseminator. It is connected to the pylon connector in place of the disseminator. As various switches on the cockpit control panel are operated, the appropriate indicators on the checkout box light up if the system is normal. The indicator lamps on the cockpit panel can be made to light up by using the appropriate switches on the checkout box. The following indicators and switches are incorporated in the aircraft checkout box:

Switches	Lamps
generator indicator	28 vdc power
orifice open	arming
flow indicator	disseminate
	photo light on
	photo light on-disseminate

In addition to the above switches and indicator lamps, there are nine pushbuttons which are used to check the nine channels of the recorder used in flight testing. To check the recorder, a ground glass screen is inserted in place of the recording paper magazine, and movement of the light-beam is observed visually as the galvanometer shifts when the appropriate button is pushed.

6.2 Laboratory Structural Tests

In order to insure that the dry agent disseminator is structurally qualified for use as an external store on high-performance aircraft, a tank assembly was subjected to a series of structural qualification tests. The structural test assembly was identical to the prototype disseminator except that operational components such as the ram air turbine generator, rotary actuator, valves, etc. were simulated by blocks of metal of identical weight and center of gravity.

The tests were conducted by the Fletcher Aviation Company, El Monte, California. Mr. A. T. Bauman and/or R. T. Dahlberg, representatives from General Mills, Inc., witnessed all tests. Since some tests required that the unit be loaded, the two GMI representatives assumed the responsibility for filling the store. A portable compaction stand was shipped to Fletcher Aviation Co. for this purpose. General Mills, Inc. "Jet" flour was used as the simulant material because it compacts to a density of 0.6 g/cm^3 with less force than is required for talc, the usual simulant material.

The assembly was tested using essentially the same procedure as is normally employed in the qualification testing of removable external auxiliary fuel tanks for aircraft. The following tests were conducted:

1) examination of product
2) weight
3) center of gravity
4) pitch and vibration
5) static structural
6) leakage
7) ejection

The test report "Qualification Tests, General Mills Tank Assembly, P/N 21-150-48032", included in Appendix A, describes the tests and their results. The assembly successfully passed all of its structural qualification tests.

6.3 Laboratory Functional Tests

The dry agent disseminating store was operated in the laboratory at General Mills, Inc. to insure that the unit functioned properly before shipping it out of the plant for field testing. In addition, a rough-handling test was conducted with the second experimental unit to investigate the possibility of malfunction in the powder feeding phase of operation which might result from transportation.

When the store was completely assembled it was first operated empty while minor adjustments were made. A laboratory power source was used, since the ram-air turbine generator was not operating, and the ground operating box was used in place of the cockpit control panel. The high-pressure nitrogen source was operable during these trials.

Then the store was loaded with compacted talc and operated at all five feed-rate settings. Powder flow rates were determined by weighing the talc as it was discharged into a collection tank mounted on a platform scale. The photograph in Figure 6.1 was taken during one of the trial runs and shows the powder collection system. Flow rates determined during these runs are tabulated below:

Speed Selector Setting	Flow Rate, lb/min
1	16.7
2	24.5
3	33.8
4	51.6
5	66.8

The density of the compacted talc as calculated from the data for this test is 0.61 g/cm^3.

Another test related to the functioning of the disseminator was conducted using the experimental model of the inner tank assembly. This test was a rough-handling test in which the experimental unit was filled with compacted

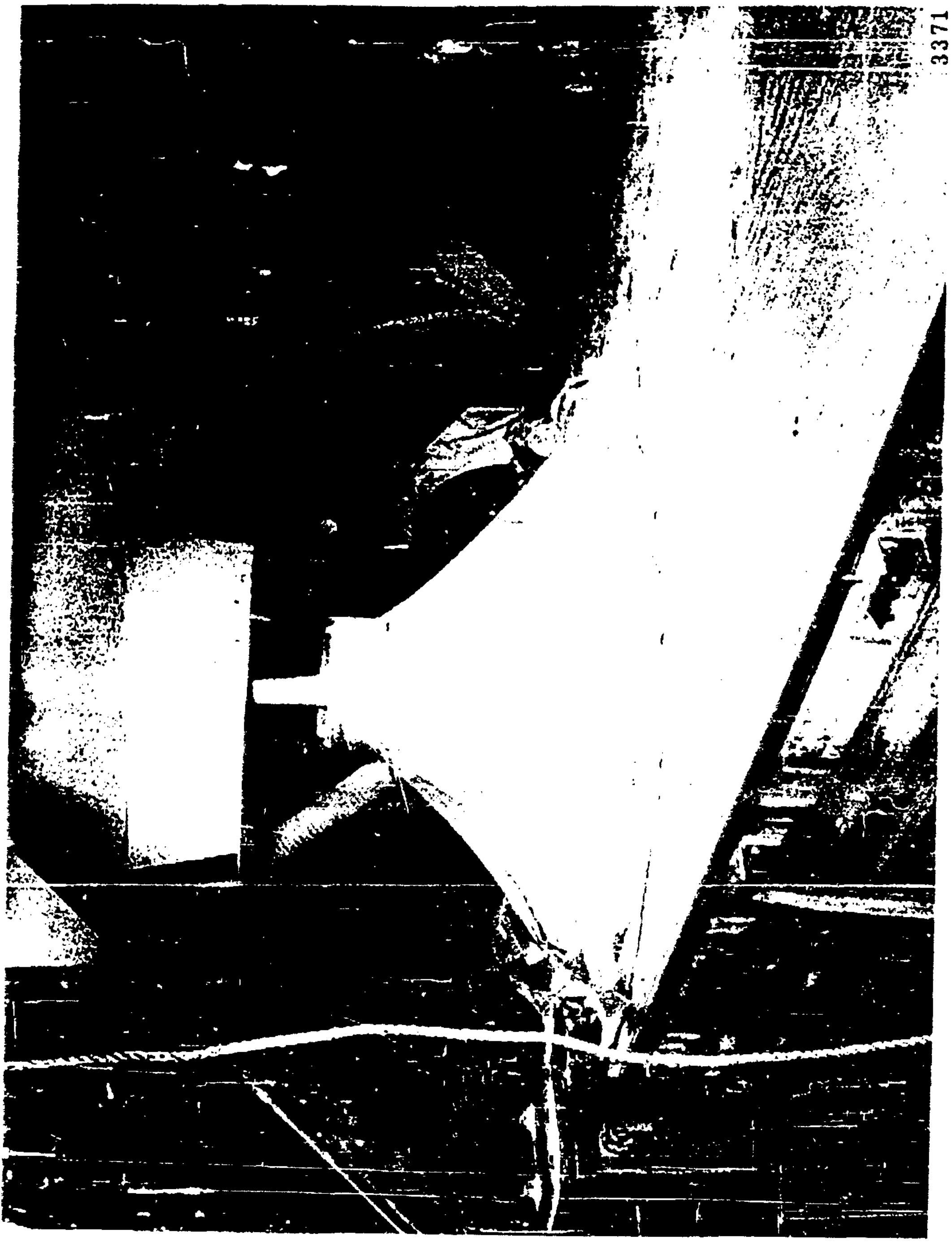

FIG. 6.1 LABORATORY OPERATION OF THE E-41 SPRAY TANK

talc and trucked over 147 miles of rough roads. The unit was then returned to the laboratory and operated in the test stand. The forces encountered during the rough ride produced no noticeable change in performance of the unit.

This ability to withstand handling and transporting was later confirmed when the prototype E-41 spray tank was trucked to the Naval Air Test Center, Patuxent River, Maryland, and flown on an A-4B (A4D-2) airplane. But we had felt it important to investigate this aspect of performance before the flight tests at Patuxent so that any problems discovered could be corrected before the prototype unit left Minneapolis.

6.4 Flight Tests at Naval Air Test Center, Patuxent River, Maryland

On November 27, 1962, the prototype E-41 spray tank was flight tested on an A-4B (A4D-2) airplane by the Weapons System Test Division of the Naval Air Test Center, Patuxent River, Maryland. The tests were conducted under Navy Wep Task No. RA 1200001/2011/F012-15-02, Problem Assignment No. RMMO-334-153. An interim report on the tests issued by the Naval Air Test Center has been reproduced and included as Appendix B.

The E-41 was first attached to an Aero 7A rack in a support structure for static tests on the ground. A ground power source was used, and the disseminator was operated by means of the ground operating box. Motion pictures were taken by photographers from Fort Detrick.

The unit was then mounted at the centerline station of the A-4B, and the cockpit controls for the disseminator were used to arm the unit and to feed out a short burst of powder while the airplane was still on the ground.

The airplane was then flown through a series of maneuvers so that the E-41 spray tank was subjected to aerodynamic and flight loads. The maximum flight speed was 0.895 indicated Mach number, and the maximum acceleration imposed during maneuvers was 6 G. The talc in the unit was disseminated in a series of twelve dissemination runs at altitudes from 300 to 3000 feet and from 350 to 520 knots indicated airspeed. Dissemination periods of 45 and 60 seconds were used. Four of these runs at 300-foot altitude and high speed were made within view of observers on the ground at the Weapons System hangar. The talc was visible from the ground and appeared as an ever-widening ribbon trailing out behind the airplane.

When the airplane returned, it was examined visually for contamination, but no talc could be found on it. Three strips of ordnance tape had been placed on the bottom of the fuselage aft of the disseminator and coated with silicone grease with the idea that they would hold talc which hit this area. Unfortunately, the tapes were stripped off in flight.

The disseminator was found to be heavily contaminated with talc. The talc appeared to be emanating from the joint where the shroud for the discharge tube attaches to the surface of the disseminator. Upon removing the shroud it was learned that approximately one cup of talc had somehow made its way into the shroud. It was suspected that the talc entered through the small hole for the squib wires in the arming device since the squib cavity communicates with the discharge tube where talc was flowing.

For the Patuxent tests the E-41 was filled with compacted talc in Minneapolis and transported by truck to the Naval Air Test Center. It was also returned by truck to Minneapolis where it was disassembled and cleaned out in preparation for loading with Bg for the test program at Dugway Proving Ground. During this process the unit was examined for evidence of any damage or excessive wear which might have occurred during transport or flight test. As stated above, with the exception of the contamination of the store itself, there was no evidence that the disseminator was affected in any way by the flight test or shipping.

7. PREPARATIONS FOR BIOLOGICAL FLIGHT TESTS AT DUGWAY PROVING GROUND

During the quarter, preparations were made for biological flight tests to be conducted at Dugway Proving Ground with the E-41 and E-42 Spray Tanks. A planning meeting was held at Dugway, and preparations for filling the disseminators began.

7.1 Planning Meeting at Dugway Proving Ground

On 17 October 1962, Mr. G. Whitnah and Mr. J. McGillicuddy of General Mills, Inc., together with Mr. J. Qualey and Mr. M. Chertoff of Fort Detrick, participated in a meeting at Dugway Proving Ground for the purpose of discussing plans for a series of flight tests of the E-41 and E-42 Spray Tanks. Dugway was represented by Mr. Cole D. Neff, Director of Test Operations, and several members of the technical staff.

A presentation covering the characteristics of the E-41 and E-42 in considerable detail was given by the General Mills representatives. Results of previous flight tests of the E-42 at Eglin Air Force Base and at the Patuxent River Naval Air Station were summarized. The subjects of filling, handling, operation, flow-rate calibration, and decontamination were discussed.

Some modifications to the E-42 Spray Tank were suggested by the Dugway staff. These included the installation of an in-line liquid agent filler in an accessible location to facilitate cleaning in case this became necessary, and the revision of the lower end of the booms to eliminate residual liquid below the nozzles which could cause dripping of agent when the booms are retracted. Both of these modifications were made by General Mills, and a new packless pump was purchased for use by Dugway personnel in filling the E-42.

Operation of the E-41 dry agent disseminator was discussed with emphasis on the controllability of agent flow rate and the starting and stopping characteristics. No problems which would require modification of the design were found.

Plans were made to ship the E-41 and E-42 units to Dugway as soon as possible after completion of the air-worthiness flight tests of the E-41 at Patuxent River Naval Air Station.

7.2 Preparations for Filling Disseminators with Biological Materials for Flight Tests

It was decided that the E-41 Spray Tank would be filled by General Mills, Inc. and that the E-42 would be filled by Dugway Proving Ground personnel. The dry Bg to be used in the E-41 was shipped to General Mills, Inc. from the U. S. Army Biological Laboratories last August. The biological materials for use in the wet condition with the E-42 are to be shipped from the U. S. Army Biological Laboratories to Dugway Proving Ground.

A quantity of 125 lb of dry Bg was received at General Mills, Inc. The material received was from two lots: 105 lb from lot 17 and 20 lb from lot 18. Rather than mix lots, we will fill the disseminator with 100 lb of the lot 17 material.

It will be necessary to minimize the amount of contamination of the building with Bg during the filling operation. For this reason, it is planned that the rules listed below will be followed.

1) The filling will be done in the dry room which has been used for the full-scale powder feeding experiments.

2) Personnel entering the room will don coveralls, gloves, caps, shoe covers, and face masks which will be removed in the air lock upon leaving the dry room. Fresh clothes will be donned upon re-entering the room.

3) The used caps and shoe covers will be burned, and the coveralls, gloves and face masks will be washed and re-used.

4) Expendable burnable materials used in the dry room will be placed in plastic bags for removal to the incinerator.

5) The disseminator and other equipment will be thoroughly washed with germicide before removal.

6) Filters in the room air circulation system will be replaced and the entire room will be thoroughly washed with germicide after the filling operation is completed.

The materials, supplies and wearing apparel needed to implement this plan are being procured.

During the planning meeting at Dugway Proving Ground in October, it was agreed that General Mills' responsibility for filling the E-42 with wet agent would be limited to providing a suitable pump.

The pump for this purpose was procured from the Vanton Pump and Equipment Co. The specifications for this Vanton Sealless Chemical Pump are as follows:

1) size 30 (5 gpm at 0 psi discharge)

2) stainless steel body

3) hypalon flexiliner

4) 3/4-inch NPT inlet and outlet

5) 1/4 hp, totally enclosed, 110-volt motor

6) Close coupled with capacitor start

A special hose was also procured to connect the pump discharge to the disseminator filling line.

This equipment will be shipped to Dugway with the disseminators.

8. SUMMARY AND CONCLUSIONS

Our program of research and development on the dissemination of solid and liquid BW agents is broad and varied. The progress in the various areas of work is summarized in the following paragraphs.

Most powder samples being used in the study of fundamental properties are now being processed in a fluid energy mill to eliminate any possible effects related to previous history of the powder. We now believe that the sliding disk test measures the shear resistance of the powder during compaction, whereas the triaxial test provides a true measure of the shear strength of a compacted powder. A purely theoretical treatment of compacted powders results in conclusions which are qualitatively in agreement with empirical theory. Three methods of determining tensile strength are being evaluated. These are the triaxial method, segmented column method and a new decompressive breakup test, which involves aerodynamic breakup of a compacted powder specimen through rapid depressurization. The Instron tester is being employed to obtain data relating stress and energy to average bulk density of compacted powders. A technique involving filling a long 5-inch diameter tube with alternate layers of natural and dyed compacted powder has revealed how the powder distributes itself during compaction. An extensive study of the characteristics of the powder particle has been initiated. Factors of interest include particle shape, porosity, total surface area, surface energy, adsorptivity, chemical reactivity and rugosity (Section 2).

The experimental work with aerosols conducted in the aerophilometer has revealed that aerosol properties depend upon the method of dispersion employed. Improving the light-beam failed to provide data of sufficient quality to permit an analysis of light-scattering fluctuations. Concentration runs have been shown to follow the expressions for nonagglomerative decay. Theoretical estimates of agglomeration, based on forces operative between particles and on the motion of particles in the settling chamber, have shown that agglomeration is of no consequence in the present experimental apparatus but could become important in a larger chamber. Areas needing further study are the effect of humidity, static charge, energy of dispersion, and particle rugosity on dispersibility and decay, as well as the effect of compacting the powders to higher bulk densities prior to dispersal in the aerophilometer (Section 3).

The full-scale experimental feeder, which is actually a prototype of the inner tank assembly of the E-41 spray tank, was used successfully to feed powdered sugar and flour. In additional tests with compacted talc, a flow rate of 91 lb/min was achieved (Section 4).

Techniques for encapsulating compacted particulate material were investigated in which foamed plastic was used to contain the powder. Packages of this type were successfully fed through the disseminator, but the methods employed thus far have not produced a sufficiently strong package. A special loading device in which compacted material is transferred from a compaction cylinder into the disseminator has been used to fill the prototype E-41 spray tank for laboratory and field tests (Section 5).

The prototype dry agent disseminating store (E-41 spray tank) was completed and subjected to a series of tests. A structural test model successfully passed the structural tests conducted at Fletcher Aviation Company. Laboratory functional tests and a rough-handling test were conducted at General Mills, Inc. In November the E-41 was successfully flown and operated with compacted talc on an A4-B (A4D-2) airplane at the Naval Air Test Center, Patuxent River, Maryland. With the exception of contamination of the bottom of the disseminator, the unit and its cockpit controls proved to be quite satisfactory. The disseminator was returned to General Mills, Inc. for examination and refilling preparatory to the flight tests scheduled for Dugway Proving Ground (Section 6).

Preparations were made for biological flight tests to be conducted at Dugway Proving Ground. A planning meeting was held at Dugway on 17 October 1962. Arrangements were made for filling the E-41 spray tank with dry Bg at General Mills, Inc. and equipment was procured for filling the E-42 with liquid agents at Dugway (Section 7).

9. REFERENCES

1) General Mills, Inc. Electronics Group. Report No. 2344. Dissemination of solid and liquid BW agents (U), by G. R. Whitnah. Contract DA-18-064-CML-2745. Ninth Quarterly Progress Report (October 19, 1962) (Confidential).

2) ----. Report No. 2322. Dissemination of solid and liquid BW agents (U), by G. R. Whitnah. Contract DA-18-064-CML-2745. Eighth Quarterly Progress Report (August 22, 1962) (Confidential).

3) ----. Report No. 2249. Dissemination of solid and liquid BW agents, by G. R. Whitnah. Contract DA-18-064-CML-2745. Fifth Quarterly Progress Report (November 30, 1961) (Confidential).

4) ----. Report No. 2200. Dissemination of solid and liquid BW agents, by G. R. Whitnah. Contract DA-18-064-CML-2745. Third Quarterly Progress Report (May 15, 1961) (AD 323,598) (Confidential).

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7) General Mills, Inc. Electronics Group. Report No. 2300. Dissemination of solid and liquid BW agents, by G. R. Whitnah. Contract DA-18-064-CML-2745. Seventh Quarterly Progress Report (June 22, 1962).

8) ----. Report No. 2344, op. cit., p. 3-20.

9) ----. Report No. 2322, op. cit., p. 3-11.

10) ----. Report No. 2344, op. cit., p. 3-10.

11) ----. Report No. 2300, op. cit., Figure 3.5.

12) ----. Report No. 2322, op. cit., p. 3-6.

13) ----. Report No. 2344, op. cit., p. 3-8.

14) Ibid., p. 3-14.

15) ----. Report No. 2322, op. cit., p. 3-4.

16) Green, H. L. and W. R. Lane. Particulate clouds: dusts, smokes, and mists; their physics and physical chemistry and industrial and environmental aspects. London, E. and F. N. Spon, 1957. p. 139. A simpler expression is given on p. 51.

17) Smoluchowski, M. v. Versuch einer mathematischen theorie der Koagulationskinetik kolloider losungen, Z. Physik. Chem. 92: 129-68 (1917).

18) The effect of polydispersity has been estimated in particular cases; it is found that a homogeneous distribution over 1 to 7 units increase the coagulation rate by 24 percent. See: Indiana, University. Department of Chemistry. The coagulation of aerosols, by F. T. Gucker. Contract AF 19(122)-375. Scientific Report No. 2 (July 31, 1953) (AD 25, 729).

19) Kunkel, W. B. Growth of charged particles in clouds. J. Appl. Phys. 19: 1053-55 (1948).

20) ----. The static electrification of dust particles on dispersion into a cloud. J. Appl. Phys. 21: 820-32 (1950).

21) General Mills, Inc. Electronics Group. Reports No. 2300, 2322, 2344, op. cit.

22) ----. Report No. 2344, op. cit., pp. 7-2 thru 7-5.

23) ----. Reports No. 2322 and 2344, op. cit.

APPENDIX A

ENGINEERING SPECIFICATIONS

REPORT NO. 43.304 **DATED 9/28/62**

FLETCHER aviation company
A DIVISION OF A. J. INDUSTRIES, INC. LISTED N.Y.S.E. AND P.C.S.E.
[illegible] WEST FLAIR DRIVE • EL MONTE, CALIFORNIA • CUMBERLAND 3-7171—GILBERT 3-7171

QUALIFICATION TESTS
GENERAL MILLS TANK ASSY
P/N 21-150-48032

APPROVED

Wayne Callahan
Test Engineer

H. W. Walker
Project Engineer

Chief Engineer

MODEL 21-150

COPY NO.

REFERENCE General Mills Specification
No. GMS 29100-610

ISSUED

FORM F 828

	NAME	DATE	FLETCHER AVIATION COMPANY	PAGE	TEMP.	PERM.
PREPARED	W. Callahan	9-28-62				A
CHECKED	R. Hill	10-31-62	TITLE QUALIFICATION TESTS GENERAL MILLS TANK ASSEMBLY	MODEL 21-150		
APPROVED	H. W. Mal	10-31-62		43.304 REPORT No.		

②

INTRODUCTION

This report covers a portion of the qualification tests conducted on General Mills (G.M.I.) special tank assembly, Part No. SK 29100-610. The test assembly is identical to the final assembly except that operational components such as the ram air turbine generator, pistons, actuator, valves, etc., were models of identical weight and center of gravity. Further qualification testing will be conducted by G.M.I. to substantiate the operational capabilities of the complete assembly.

This document presents the qualification testing conducted in accordance with the requirements of specification MIL-T-7378A, and G.M.I. Specification GMS 29100-783.

Qualification tests described herein were conducted at the Fletcher Aviation Company test facility.

REFERENCES:

Specification MIL-T-7378A	...	Tank, Fuel Aircraft, External Auxiliary, Removable
G.M.I. Specification Drawing	...	SK 29100-698
G.M.I. Specification GMS 29100-610	...	External Removable Tank Assy for G.M.I. Electronics Group
G.M.I. Specification GMS 29100-783	...	Testing of External Removable Aircraft Tank Assembly described by GMS 29100-610 for General Mills Electronic Group
F.A.C. Drawing 21-150-48032	...	Tank Assembly, G.M.I. Specification

②

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Ejection Test. 7.0

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REVISIONS

SYMBOL 1

REVISED PAGES: 5.5, 5.9, 5.10, 5.11, 5.12, 5.13, 5.17 — DATE 10-12-62

ADDED PAGES

5.11.1, 5.11.2, 5.13.1,
5.13.2

APPROVED: Wayne Callahan

2

REVISED PAGES

A, B, C, 2.0, 3.0, 3.2, 4.0, 4.2,
4.3, 4.4, 4.5, 4.6, 4.7, 5.0, 5.9,
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7.0, 7.3

ADDED PAGES

3.2, 4.8, 4.9, 5.9.1, 5.11.3, 5.13.3,
5.17, 7.4, 7.5, 7.6, 7.7, 7.8

APPROVED:

3

REVISED PAGES

4.2, 4.6, 5.10, 5.12, 6.1

APPROVED:

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APPROVED		10-4-62		43.304 REPORT NO.		

②

ADMINISTRATIVE DATA

PURPOSE OF TEST:

To determine that the assembly conforms to the applicable drawings.

MANUFACTURER:

Fletcher Aviation Company

MANUFACTURER'S MODEL NO:

21-150

ASSEMBLY DRAWING:

21-150-48032

QUANTITY OF ITEMS:

One

SECURITY CLASSIFICATION:

None

TEST DATE:

10-16-62

TEST CONDUCTED BY:

Wayne Callahan

DISPOSITION OF SPECIMEN:

Use for Weight Test

ABSTRACT:

The assembly successfully met all of the requirements of the test.

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CHECKED	R. Hill	10-5-62		43.304
APPROVED		10-11-62		REPORT NO.

FACTUAL DATA

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

REQUIREMENTS:

1. That the assembly and accessible components thereof conform to their applicable engineering drawings.
2. That the assembly and all components conform to aircraft quality standards for workmanship.

TEST EQUIPMENT:

1. Standard inspection tools; linear scales, micrometers, calipers.

TEST PROCEDURE:

1. Inspect the complete assembly for general conformance to F.A.C. drawing no. 21-150-48032.
2. Remove nose and tail sections and inspect all compartments for metal chips, filings, or other foreign material.
3. Inspect all mating components for alignment, fit, sealing capabilities and general workmanship.
4. Inspect tank surfaces for evidence of damage or undue abrasion.
5. Inspect for loose bolts, rivets, or other fastening devices.
6. Inspect for parts not treated for corrosion resistance.
7. Inspect for misalignment of mating components.
8. Remove inner tank cover plates and inspect inner tank for general cleanliness, workmanship, and conformance to G.M.I. requirements.
9. Generally inspect simulated components (G.M.I. furnished) for fit and security of installation.

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②

TEST PROCEDURE: (Contd)

10. Install nose and tail sections and inspect entire tank contour for surface irregularities.

RESULTS OF TEST:

Satisfactory

RECOMMENDATIONS:

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

F.A.C. TEST ENGINEER Warren Callahan

F.A.C. QUALITY CONTROL

CUSTOMER REPRESENTATIVE A. D. Bauman

Best Available Co

FAC Form F508

	NAME	DATE	FLETCHER AVIATION COMPANY	TEMP.	PERM.
PREPARED	W. Callahan	9-28-62		PAGE	2.0
CHECKED	R. Hill	10-5-62	TITLE WEIGHT TEST GENERAL MILLS TANK ASSY	MODEL 21-150	
APPROVED		10-4-62		43.304 REPORT NO.	

ADMINISTRATIVE DATA

②

PURPOSE OF TEST:

To determine the empty and full weights of the complete assembly.

MANUFACTURER:

Fletcher Aviation Company

MANUFACTURER'S MODEL NO.

21-150

ASSEMBLY DRAWING:

21-150-48032

QUANTITY OF ITEMS:

One (1)

SECURITY CLASSIFICATION:

None

TEST DATE:

10-17-62

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

TEST CONDUCTED BY:

Wayne Callahan

DISPOSITION OF SPECIMEN:

Use for Center of Gravity Test

ABSTRACT:

The assembly successfully met all of the requirements of the test.

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APPROVED		10-4-62		REPORT NO.	43.304	

FACTUAL DATA

②

REQUIREMENTS:

1. To determine the total weight of the empty assembly.

2. To determine the total weight of the full assembly.

TEST EQUIPMENT:

1. Certified platform scales.
2. Tank cradle.
3. Simulated filler material (powder).

TEST PROCEDURE:

1. The cradle is weighed.

2. The empty tank and cradle are weighed and the cradle weight is deducted from the total weight.

3. The tank is filled with filler material (powder).

4. The full tank and cradle are weighed and the cradle weight is deducted from the total weight.

TEST RESULTS:

Weight of empty assembly	697.0	lbs.
Weight of full assembly	1049.5	lbs.

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

F.A.C. TEST ENGINEER Wayne Callahan

F.A.C. QUALITY CONTROL

CUSTOMER REPRESENTATIVE Bowman

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APPROVED		10-4-62		43.304 REPORT NO.		

ADMINISTRATIVE DATA

③

PURPOSE OF TEST:

To determine the location of the center of gravity of the assembly in both the full and empty conditions.

MANUFACTURER:

Fletcher Aviation Company

MANUFACTURER'S MODEL NO.

21-150

ASSEMBLY DRAWING:

21-150-48032

QUANTITY OF ITEMS:

One (1)

SECURITY CLASSIFICATION:

None

TEST DATE:

10-19-62

TEST CONDUCTED BY:

Wayne Callahan

DISPOSITION OF SPECIMEN:

Use for Pitch & Vibration Test

ABSTRACT:

The assembly successfully met all of the requirements of the test.

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FACTUAL DATA

TEST REQUIREMENTS:

To determine the location of the center of gravity of the assembly in both the empty and full conditions.

TEST EQUIPMENT:

1. Two (2) platform scales.
2. Tank cradle.
3. Rocker bar.
4. Simulated filler material (powder).

TEST PROCEDURE:

1. The cradle is weighed.

2. The tank and cradle are weighed and the cradle weight is deducted from the total weight.

3. The cradle is balanced on the rocker bar.

4. The tank is placed on the cradle in the "balance" position. The c.g. station is recorded.

5. The tank is filled with the simulated filler material.

6. The tank is placed on the cradle in the "balance" position. The c.g. station is recorded.

	NAME	DATE	FLETCHER AVIATION COMPANY	PAGE	TEMP.	PERM.
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②

TEST RESULTS:

C.G. Location of Empty Tank T.S. 82.97

C.G. Location of Full Tank T.S. 82.17

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

F.A.C. TEST ENGINEER Wayne Callahan

F.A.C. QUALITY CONTROL

CUSTOMER REPRESENTATIVE

FAC Form 7508

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APPROVED	H. G. MALM	[illegible]		REPORT NO. 43.304		

	NAME	DATE	FLETCHER AVIATION COMPANY	PAGE	TEMP.	PERM.
PREPARED	N.Callahan	9-28-62				4.0
CHECKED	R. Hill	10-4-62	TITLE PITCH & VIBRATION TEST GENERAL MILLS TANK ASSY	MODEL 21-150		
APPROVED		10-3-62		43.304 REPORT NO.		

②

ADMINISTRATIVE DATA

PURPOSE OF TEST:

To demonstrate the tank will withstand vibration and pitching forces encountered in service.

MANUFACTURER:

Fletcher Aviation Company

MANUFACTURER'S MODEL NO.:

21-150

ASSEMBLY DRAWING:

21-150-48032

QUANTITY OF ITEMS:

One (1)

SECURITY CLASSIFICATION:

None

TEST DATE:

10-20-62

TEST CONDUCTED BY:

Wayne Callahan

DISPOSITION OF SPECIMEN:

Use for Leakage Test

ABSTRACT:

The assembly successfully met all of the requirements of the test.

	NAME	DATE			TEMP.	PERM.
PREPARED	W.Callahan	9-28-62	FLETCHER AVIATION COMPANY	PAGE		4.1
CHECKED	R. Hill	10-4-62	TITLE PITCH & VIBRATION TEST GENERAL MILLS TANK ASSY	MODEL 21-150		
APPROVED		10-5-62		43.304 REPORT NO.		

FACTUAL DATA

REQUIREMENTS:

1. Test Conditions: The tank complete with all simulated components and parts shall be mounted in the support jig and installed on the vibrator and rocker assembly. The centerline of the tank when mounted on this assembly shall be a minimum of 20 inches above the axis of rotation. The tank shall be pitched and vibration tested in accordance with the following conditions.

    A. The vibration displacement shall be a minimum double amplitude of 0.020 inch measured at the attachment points of the tank. The average amplitude between the top and bottom of the tank at the supporting rings shall be a minimum of 0.020 inch. A suitable electronic vibration measuring instrument shall be used to measure vibration displacement while the tank assembly is being tested. The average peak value, at the point being measured during a 30 second interval shall be taken as the value to be recorded.

    B. The vibration frequency shall be 2000 + 0 - 60 cycles per minute.

    C. The tank shall be mounted in such a manner that the major horizontal axis of the tank shall be 90° to the centerline of the axis of the shaft of the rocker assembly platform.

    D. The pitch rocking angle shall be 30° total, approximately 15° on either side of the horizontal position.

    E. The tank shall be unpressurized.

    F. The tank when filled shall be pitch-vibrated for 25 hours at 16 to 20 pitch cycles per minute.

③

REQUIREMENTS: (Contd)

G. At the conclusion of the pitch vibration test the tank shall be emptied. The inner tank shall be checked for leakage in accordance with the procedure of section 6.0 of this report.

H. After completion of the above tests the tank assembly shall be inspected visually for evidence of failure, such as structural damage to the inner or outer tanks.

2. Following the above inspection the empty tank with the inner tank pistons at the forward extreme of their travel shall be pitch-vibrated for 10 minutes at 16 to 20 pitch cycles per minute. Any resonant vibration behavior of the pistons or drive screw will be noted.

3. With the tank in the same condition as in para. 2 a vibration survey shall be made over a range of frequencies from 0 to 50 cycles per second. Any resonant vibration behavior of the pistons or drive screw (GMI provided parts) will be noted.

TEST EQUIPMENT:

1. Slosh and vibration machine.
2. Tank support fixture.
3. Strobotac or equivalent.
4. Vibration meter.
5. Vibration pickup.
6. Pressure gage.

TEST PROCEDURE:

1. The test assembly is mounted on the slosh and vibration machine by means of a support fixture. The centerline of the assembly is a minimum of 20 inches above the slosh axis.

2. The tank is filled with G.M.I. provided material (powder).

TEST PROCEDURE: (Contd)

of frequencies from 0 to 50 cycles per second. Any resonant vibration behavior of the pistons or drive screw (G.M.I. provided parts) are noted.

	NAME	DATE	FLETCHER AVIATION COMPANY	PAGE	TEMP.	PERM.
PREPARED	W. Callahan	9-28-62				4.3
CHECKED	R. Hill	10-4-62	TITLE PITCH & VIBRATION TEST GENERAL MILLS TANK ASSY	MODEL 21-150		
APPROVED	H. W. Whalen	10/5/62		43.304 REPORT NO.		

TEST PROCEDURE:

3. The pitch and vibration machine is put into cyclic pitching of the longitudinal axis from 15° nose up to 15° nose down.

4. The motor drive for the eccentric weights producing vibration is activated and brought up to 2000^{+0}_{-60} CPM.

5. Vibration readings are taken and the eccentric weights adjusted to produce the required values of vibration displacement.

6. The pitch rate is checked to be 16 to 20 per min.

7. The rotation speed of the eccentric weights is measured to be 2000^{+0}_{-60} R.P.M.

8. Simultaneous pitch and vibration is continued for 25 hours.

9. The tank is emptied and the inner tank is checked for leakage in accordance with Section 6.0 of this report.

10. The tank assembly is visually inspected for evidence of failure such as structural damage to the inner or outer tank.

11. The inner tank pistons are advanced to the forward extreme of their travel toward center.

12. The assembly is pitch vibrated for 10 minutes in accordance with steps 4 through 8. Any resonant behavior of the pistons or drive screw are noted.

13. With the assembly in the same condition as step 12, a vibration survey is made over a range

	NAME	DATE	FLETCHER AVIATION COMPANY	PAGE	TEMP.	PERM. 4.4
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CHECKED	R. Hill	10-31-62		43.304 REPORT NO.		
APPROVED		10-3-62				

②

TANK NO. 2 MODEL 21-150

TEST CONDUCTED BY: Wayne Callahan DATE: 10-20-62

VIBRATION

TANK CAPACITY: 350 pounds TEST: 350 pounds

OPERATING PRESSURE: 0 TEST PRESSURE: 0

TANK AT 90° TO PITCH AXIS

ECC. WT. SETTING			PITCH RATE	VIBRATION MEASUREMENT/IN.					
In./Overlap		Speed		At Lugs		Fwd. Ring		Aft. Ring	
Fwd.	Aft	R.P.M.	C.P.M.	Fwd	Aft	Upper	Lower	Upper	Lower
1.50	1.50	1990	17	1.8	2.0	1.8	2.2	1.5	1.4
1.50	1.75	1990	17	2.1	2.2	1.8	2.6	1.7	2.2

START OF RUN: DATE: 10-20-62 TIME: 11:10 A.M.

LOG: Frequency and displacement measurements taken every 2-3 hours.

END OF RUN: DATE: 10-21-62 TIME: 12:10 P.M.

REASON: End of 25-hour test.

	NAME	DATE	FLETCHER AVIATION COMPANY	PAGE	TEMP.	PERM.
PREPARED	W. Callahan	9-28-62				4.5
CHECKED	R.H.ll	10-31-62	TITLE PITCH-VIBRATION TEST GENERAL MILLS TANK ASSY PISTONS EXTENDED	MODEL 21-150		
APPROVED		10-3-62		43.304 REPORT No.		

②

TANK NO. 2 MODEL 21-150

TEST CONDUCTED BY: Wayne Callahan DATE: 10-22-62

VIBRATION

TANK CAPACITY 350 pounds TEST: 0 pounds

OPERATING PRESSURE: ---- TEST PRESSURE: ----

TANK AT 90° TO PITCH AXIS

ECC. WT. SETTING			PITCH RATE	VIBRATION MEASUREMENT/IN.					
In./Overlap		Speed		At Lugs		Fwd. Ring		Aft Ring	
Fwd.	Aft	R.P.M.	C.P.M.	Fwd	Aft	Upper	Lower	Upper	Lower
1.50	1.75	1970	17	1.9	2.0	1.9	2.6	2.0	2.4

START OF RUN: DATE: 10-22-62 TIME: 1:00 P.M.

LOG: There was no resonant behavior observed on any part of the assembly.

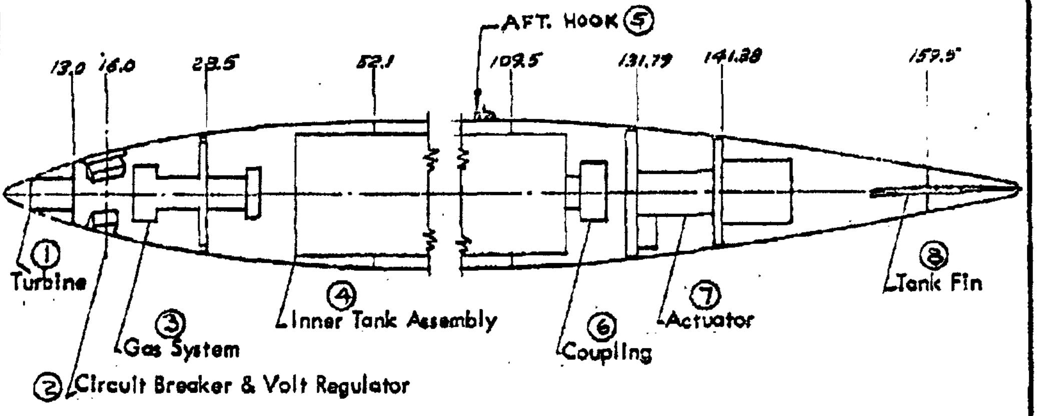
END OF RUN: DATE: 10-22-62 TIME: 1:10 P.M.

REASON: End of 10-minute test.

	NAME	DATE			TEMP.	PERM.
PREPARED	W. Callahan	10-25-62	FLETCHER AVIATION CORPORATION	PAGE		4.6
CHECKED	R. Hill	10-31-62	TITLE PITCH-VIBRATION TEST VIBRATION SURVEY GENERAL MILLS TANK ASSY	MODEL 21-150		
APPROVED		10/31/62		43.304 REPORT No.		

TEST RESULTS ② ③

ECC. WT. SETTING INCHES Fwd.	OVERLAP Aft	FREQ. C.P.S.	RESONANCE OCCURRED AT POINT -	LIGHT	SEVERE
1.50	1.75	5	None	-	-
1.50	1.75	10	None	-	-
1.50	1.75	15	5, 8	x	-
1.50	1.75	20	5	x	-
1.50	1.75	25	None	-	-
1.50	1.75	30	None	-	-
1.50	1.75	35	8	x	-
1.50	1.75	40	1, 3, 5, 6, 7, 8	x	-
1.50	1.75	45	1, 3, 5, 6, 7, 8	-	x
1.50	1.75	50	1, 3, 5, 6, 7, 8	-	x



	NAME	DATE	FLETCHER AVIATION COMPANY	PAGE	TEMP.	PERM. 4.7
PREPARED	W.Callahan	9-28-62	TITLE PITCH & VIBRATION TEST GENERAL MILLS TANK ASSY	MODEL 21-150		
CHECKED	R. Hill	10-31-62		43.304 REPORT No.		
APPROVED		10-3-62				

②

RESULTS OF TEST

Pitch Vibration per steps 1 through 10

Results: Satisfactory

Leakage per step 11

Results: Satisfactory

Inspection per step 12

Results: Satisfactory

Pitch Vibration pistons extended per steps 13 and 14

Results: Satisfactory (see Note 1)

Vibration Survey per step 15

Results: Satisfactory (see Notes 1 and 2)

Note 1:
Resonant behavior of pistons could not be observed since they are in a sealed enclosure. Resonant behavior of tank assembly indicated no resonance in this area at any of the frequencies.

Note 2:
See page 4.6 for additional results.

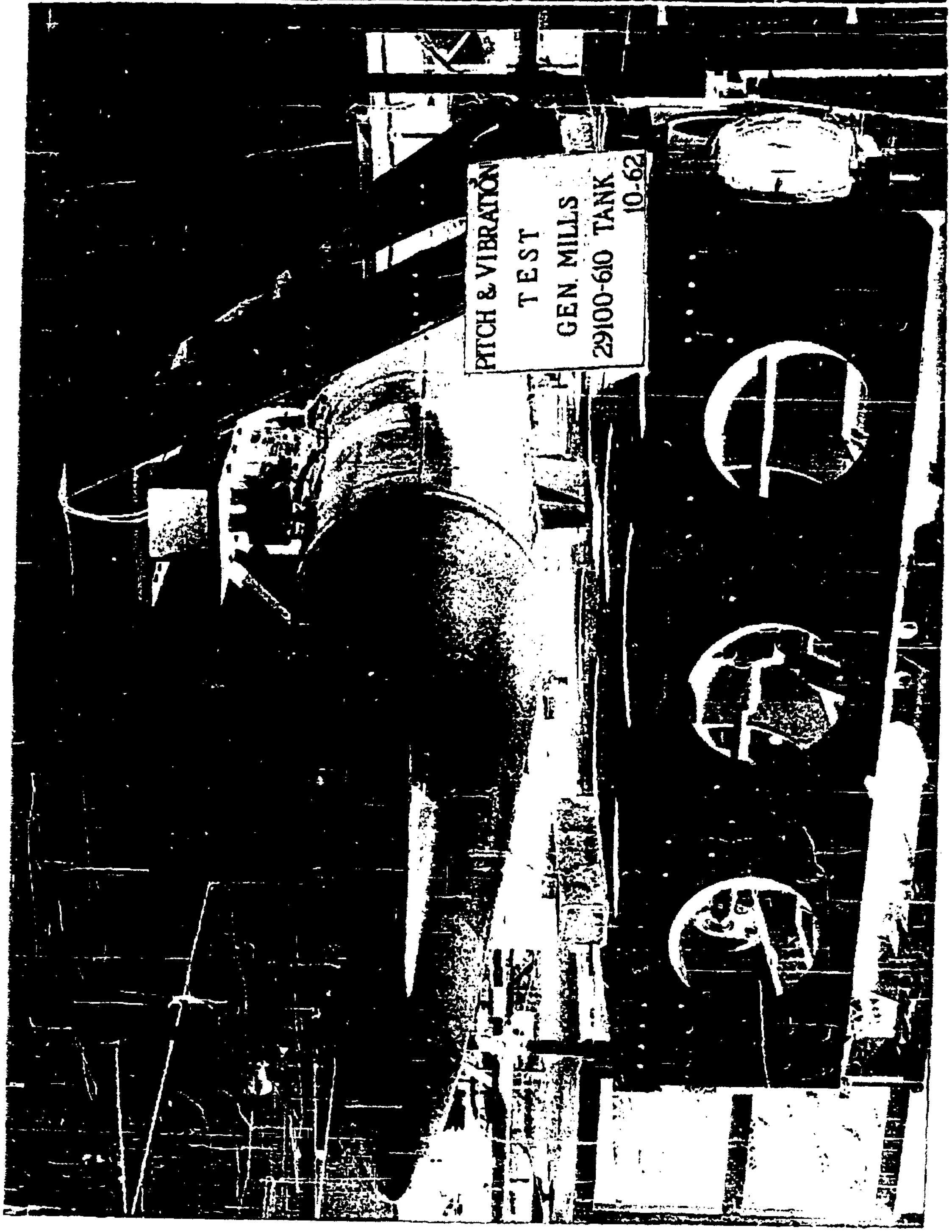
Page determined to be Unclassified
Reviewed Chief, RDD, WHS
IAW EO 13526, Section 3.5
Date: JUL 19 2013

F.A.C. TEST ENGINEER Wayne Callahan

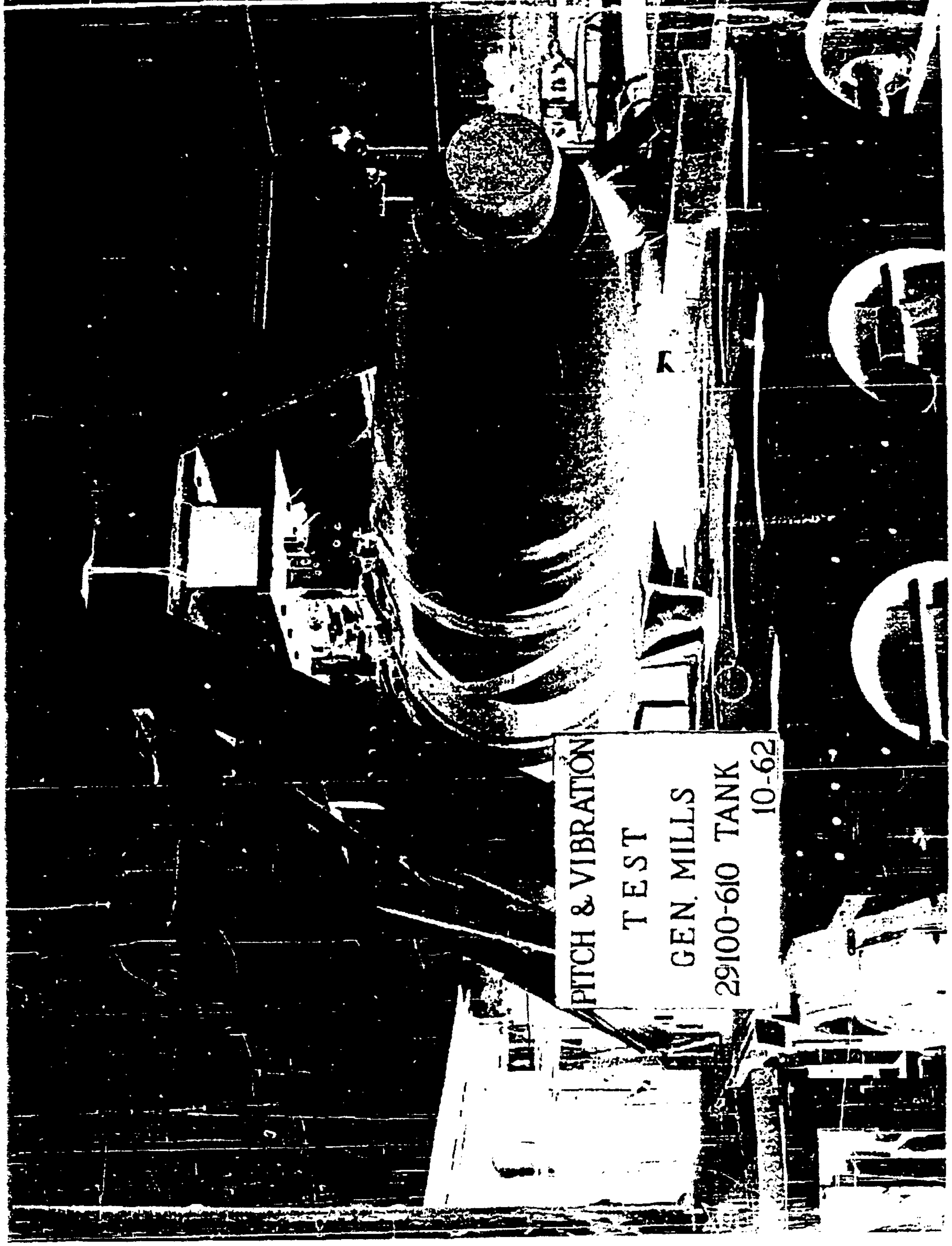
F.A.C. QUALITY CONTROL

CUSTOMER REPRESENTATIVE

	NAME	DATE	FLETCHER AVIATION CORP.	PAGE	TEMP.	PERM. 4.8
PREPARED	G. FORD	10-31-62	TITLE PITCH-VIBRATION TEST	MODEL 21-150		
CHECKED		10-31-62		REPORT NO. 43.304		
APPROVED		10-31-62				



	NAME	DATE	FLETCHER AVIATION CORP.	PAGE TEMP.	PERM. 49
PREPARED	G. FORD	10-31-62	TITLE PITCH-VIBRATION TEST	MODEL 21-150	
CHECKED	D. Callahan	10-31-62		REPORT No. 43-304	
APPROVED	R.W. MALM	10-31-62			



Best Available Copy

	NAME	DATE	FLETCHER AVIATION COMPANY		TEMP.	PERM.
PREPARED	W. Callahan	9-28-62		PAGE		5.0
CHECKED	R. Hill	10-31-62	TITLE STRUCTURAL TEST GENERAL MILLS TANK ASSY	MODEL	21-150	
APPROVED	H W Walker	10-31-62		REPORT NO.	43.304	

②

ADMINISTRATIVE DATA

PURPOSE OF TEST:

To demonstrate the structural integrity of the tank.

MANUFACTURER:

Fletcher Aviation Company

MANUFACTURER'S MODEL NO:

21-150

ASSEMBLY DRAWING:

21-150-48032

QUANTITY OF ITEMS:

One (1)

SECURITY CLASSIFICATION:

None

TEST DATE:

10-25-62

TEST CONDUCTED BY:

Wayne Callahan

DISPOSITION OF SPECIMEN:

Use for Ejection Test

ABSTRACT:

The assembly successfully met all of the requirements of the test.

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	NAME	DATE	FLETCHER AVIATION COMPANY	PAGE	TEMP.	PERM.
PREPARED	W. Callahan	9-28-62				5.1
CHECKED	R. Hill	10/31/62	TITLE STRUCTURAL TEST GENERAL MILLS TANK ASSY	MODEL 21-150		
APPROVED		10-31-62		43.304 REPORT NO.		

FACTUAL DATA

②

TEST REQUIREMENT:

The tank is subjected to the following test conditions and should support these conditions without failure.

The static test tank shall be a complete structure, less such non-structural elements as turbine generator and electrical components. The static test tank shall be of the same quality workmanship as the flight tank delivered on the contract and shall be structurally identical to the flight tank as indicated in the reports and drawings submitted.

The test techniques of the tank is as follows:

The tank support jig shall be constructed to duplicate the attach point locations of the Aero 7A rack to produce the most critical hook and sway brace reactions.

Loads shall be introduced into the test tank by means of external straps. Care shall be taken to insure that the load application devices do not materially affect the strength of the test tank by introducing artificial stiffness, etc.

All applied test loads are suitably monitored by calibrated equipment (pressure gages, load dynamometers, etc.) so that acceptable test accuracy is obtained.

	NAME	DATE			TEMP.	PERM.
PREPARED	W.Callahan	9-28-62	FLETCHER AVIATION COMPANY	PAGE		5.2
CHECKED	R. Hill	10-30-62	TITLE STRUCTURAL TEST GENERAL MILLS TANK ASSY	MODEL	21-150	
APPROVED		10-3-62		REPORT No.	43.304	

<u>TEST REQUIREMENT</u>: (Contd)

Tare weight of store and all load application devices shall be accounted for in all test loadings. Independent application of load components (that is vertical, side, and aft loads) are used to facilitate maintaining correct relationship of load components with each other for full range of load from zero to ultimate.

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	NAME	DATE	FLETCHER AVIATION COMPANY	PAGE	TEMP.	PERM.
PREPARED	W.Callahan	9-28-62				5.3
CHECKED	R. Hill	10-30-62	TITLE STRUCTURAL TEST GENERAL MILLS TANK ASSY	MODEL 21-150		
APPROVED		10-3-62		43.304 REPORT NO.		

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TEST EQUIPMENT:

1. Static test frame.
2. Tank support fixture.
3. Loading pads, whiffle trees, etc., per applicable test conditions.
4. Hydraulic pumps.
5. Hydraulic cylinders (jacks) with net areas as listed on test data sheets.
6. Hydraulic test gages - as necessary.
7. Four 24-inch Starrett steel engine marked scales reading to .010 inch.
8. Surveyor's level.

TEST PROCEDURE:

All test conditions are run with the test tank mounted in the horizontal position in the test jig. The test procedure is identical in each case and consists of the following steps:

1. The system of loading jacks and whiffle trees is installed, checked functionally, and inspected for proper location.

2. Readings of deflection at zero load is taken by means of a series of steel scales hung along the length of the tank, and a surveyor's level. Lateral deflections are measured from a wire stretched alongside of the tank.

3. The load is then applied in increments of 25% of limit load, and the deflection readings taken at 25, 50, 75, and 100%.

4. The jack loads are then reduced to zero, and deflection readings taken to check possible permanent set.

5. Load is again applied in 25% increments up to 100% of limit load.

	NAME	DATE			TEMP.	PERM.
PREPARED	W. Callahan	9-28-62	FLETCHER AVIATION COMPANY	PAGE		5.4
CHECKED	R. Hill	10-30-62	TITLE STRUCTURAL TEST GENERAL MILLS TANK ASSY	MODEL	21-150	
APPROVED		10-3-62		REPORT No.	43.304	

TEST PROCEDURE: (Contd.)

6. The static load is increased to 125% of limit load.

7. Deflection readings are taken.

8. The static load is increased to 150% of limit load, and deflection readings are taken. (150% of limit load = ultimate load.)

9. The jack loads are reduced to zero and deflection readings are taken.

	NAME	DATE	FLETCHER AVIATION COMPANY	PAGE	TEMP.	PERM. 3.5
PREPARED	R.W. Hill	8-28-62	TITLE STRUCTURAL TESTS GENERAL MILLS TANK	MODEL 21-150		
CHECKED	R.W.H.	10-30-62		REPORT NO. 43.304		
APPROVED	H W Mal	10/31/62				

STRUCTURAL STATIC TESTS

A review of F.A.C. Report 43.300, "Loads and Stress Analysis - Solid Fuel Tank", shows that structural static tests must be run for three design conditions. These are:

Condition #3 - Flight (with loads increased
by 2.9%)
Condition #5
& #7 - Flight
Condition #11- Arrested Landing

Test loads for these three conditions are developed on the following pages.

All loads are on an ultimate basis, (1-1/2 x limit load,) and the tank itself will be tested empty and unpressurized.

	NAME	DATE	FLETCHER AVIATION CORPORATION	PAGE	5.3.1
PREPARED	R W Hill	9-10-62	TITLE	MODEL	21-150
CHECKED	WC	10-3-62			43.304
APPROVED		10-3-62	STATIC TESTS	REPORT NO.	

FIN AIRLOAD DISTRIBUTION

The center of pressure of the airload on each fin is on the mean aerodynamic chord (10.5" from tank ℄) at T.S. #160.0. (Ref. G.M.I. letter to F.A.C. dated 7-27-62.)

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IAW EO 13526, Section 3.5
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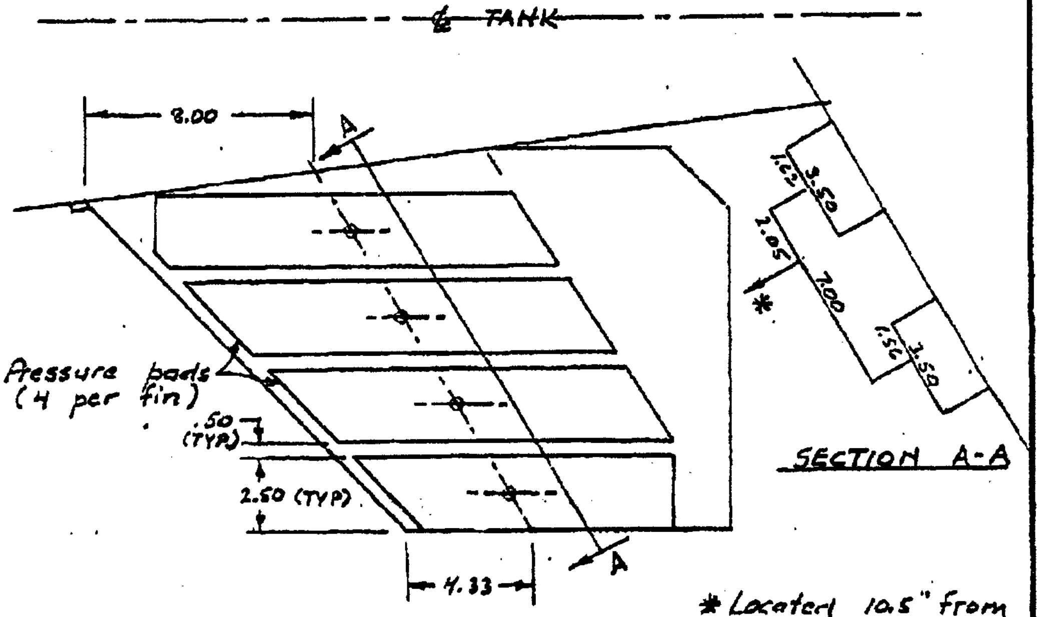

* Located 10.5" from ℄ tank @ T.S. #160.

	NAME	DATE	FLETCHER AVIATION CORPORATION	PAGE	5.6
PREPARED	R. W. Hill	8-27-62	TITLE	MODEL 21-150	
CHECKED	W. C.	10-3-62	STATIC TESTS	43.304	
APPROVED		10-3-62		REPORT NO.	

Test Loads ~ Cond. #3 (With loads increased by 2.9%. Ref. pg. 27 of Rep. #43.300.)

$n_z = 1.50$ $P_x = -2764$
$n_y = 9.75$ $M_x = -2160$
$M_{y_{CG}} = 44\,820$
$M_{z_{CG}} = 0$
} Basic Loads Pg. 12, Rep. #43.300

Airload distribution from pg. 22 of Rep. #43.300.

Vertical Loads

1	2	3	4	5	
T.S	$\frac{P}{n}$	$\frac{P}{10^{-3} M_{y_{CG}}}$	$P_{z_{AIR}}$	P_z	
	Ref. above	Ref above	Ref. above	1.544 ② +46.12 ③ +1.029 ④	
10	61.80	3.237	−361	−127	
33	78.80	2.809	−707	−476	
56	210.70	3.985	−521	− 27	
79	403.90	+ .894	−129	+ 532	
102	225.60	−3.282	+ 96	296	
125	94.40	−2.953	260	277	
148	78.80	−3.784	313	269	
171	14.00	−.906	209	195	
160 (FIN)	—	—	−3795	−3905	
			−4635	−2966	

Lateral Loads

1	2	3	4	5	
T.S.	$\frac{P}{n}$	$\frac{P}{10^{3} M_{z_{CG}}}$	$P_{y_{AIR}}$	P_y	
	Ref above	Ref above	Ref above	10.033 ② +1.029 ④	
8	53.80	−2.926	185	731	
31	66.30	−2.486	413	1091	
54	208.70	−4.296	314	2416	
77	404.70	−1.495	+ 68	4130	
100	229.10	+3.030	− 79	2217	
123	104.00	3.134	−180	858	
146	85.50	4.022	−218	633	
169	15.90	1.017	−158	− 3	
			345	12073	

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Date: JUL 19 2013

PREPARED	R. W. Hill	8-28-62	FLETCHER AVIATION CORPORATION	PAGE 5.7
CHECKED	Callahan	10-31-62	TITLE STATIC TESTS	MODEL 21-150
APPROVED		11-3-62		43.304 REPORT NO.

WHIFFLE-TREE LOADING

Load Condition No. 3 ~ Flight (With loads increased 29%)
Reference Diagram Pages ____

[N] = Gauge no.

VERTICAL LOADS + = UP − = DOWN

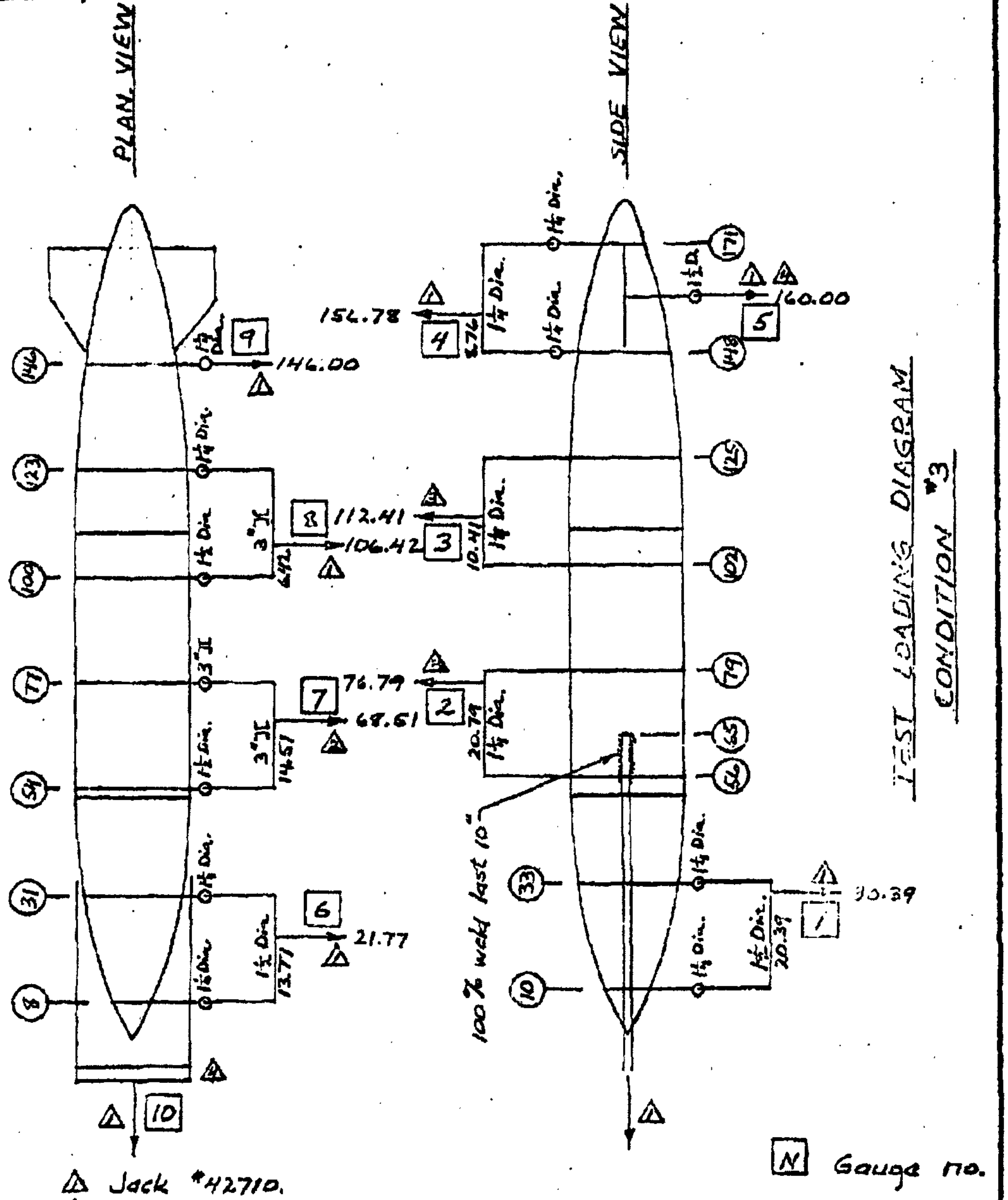
Sta.	Ult. Ld.	Dead Wt. (EMPTY)	Tare	Net Ld.	Comb.	Sta.	Comb.	Sta.
10	−127	62	15	−50	−440	30.39	1	
33	−476	71		−390				
56	−27	103		+91	+946	76.79	2	
79	+532	308		855				
102	296	118		429	784	112.41	3	
125	277	63		355				
148	269	79		363	587	156.78	4	
171	195	14	15	224				
FIN (160)	−3905			−3905	−3905	160.00	.57" off center to the right 5	
	−2966	819	120 =	2027 2029				

HORIZONTAL LOADS (ALL TO LEFT)

	Sta.	Ult. Ld.	Comb.	Sta.	Comb.	Sta.
Lateral Loads	8	731	1822	21.77	6	
	31	1091				
	54	2416	6546	68.51	7	
	77	4130				
	100	2217	3075	106.42	8	
	123	858				
	146	630	630	146.00	9	
		12073	12073			
Nose Pull	Tank ℄	2834	(Acting fwd)		10	

FAC Form 1108

	NAME	DATE	FLETCHER AVIATION CORPORATION	PAGE	TEMP.	PERM. 5.8
PREPARED	R.W. Hill	10-1-62	TITLE	MODEL 21-150		
CHECKED		10-31-62	STATIC TESTS	43.304		
APPROVED		10-3-62		REPORT NO.		



TEST LOADING DIAGRAM
CONDITION #3

N Gauge no.

△1 Jack #42710.
△2 Jack #50639LH-1.
△3 One jack #H-5A50 on each side of tank.
△4 See details on separate sketch.

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Date: JUL 19 2013

	NAME	DATE	FLETCHER AVIATION CORPORATION	PAGE	TEMP.	PERM. 5.9
PREPARED	N.Callahan	10-5-62	TITLE STATIC TEST GENERAL MILLS TANK	MODEL 21-150		
CHECKED	R. Hill	10-5-62		43.304 REPORT NO.		
APPROVED		10-5-62				

LOAD CONDITION NO. 1 TEST DATE 10-25-62 ②

REFERENCE DIAGRAM PAGES 5.8

GAGE NO.	JACK AREA	PRESSURE GAGE READINGS IN PERCENT OF LIMIT LOAD								
		0	25	50	75	100	0	125	150	0
1	2.795	0	0	14	50	85	0	121	157	0
2	1.596	276	329	382	434	487	276	540	593	276
3	1.596	132	192	252	311	371	132	431	491	132
4	2.795	44	72	99	127	155	44	182	210	44
5	2.795	0	233	466	698	931	0	1164	1397	0
6	2.795	0	109	217	326	435	0	543	652	0
7	5.498	0	198	397	596	794	0	992	1191	0
8	2.795	0	183	367	550	733	0	917	1100	0
9	2.795	0	38	75	112	150	0	188	225	0
10	2.795	0	169	338	507	676	0	845	1014	0
PRESSURE										

TANK STATION	VERTICAL DEFLECTION READING IN INCHES								+=UP -=DN.
40.0	0	.02	.03	.04	.06	0	.07	.07	.02
90.0	0	-.01	-.02	-.04	-.06	-.01	-.07	-.08	-.01
.140	0	-.03	-.10	-.16	-.22	-.02	-.29	-.34	-.03

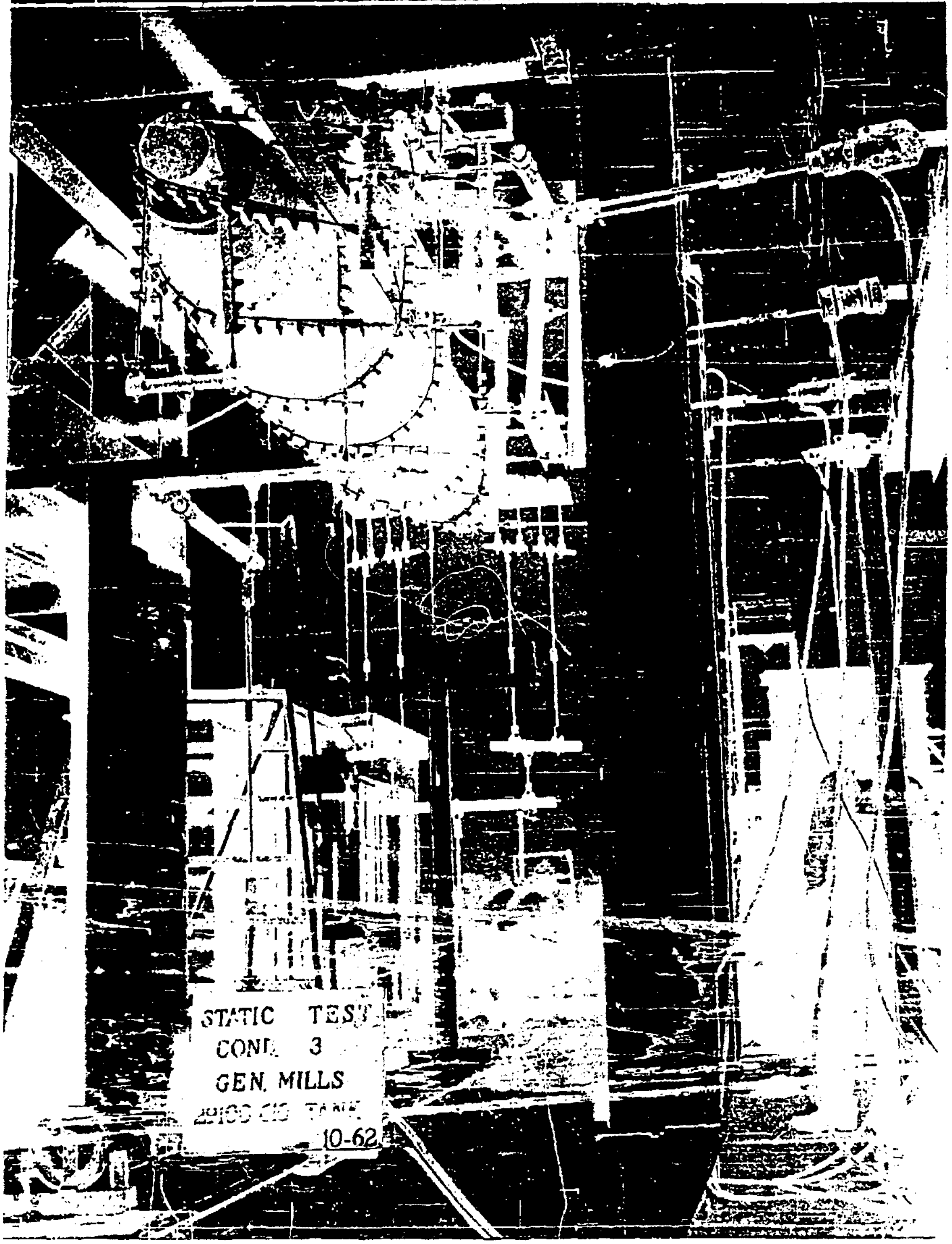
TANK STATION	HORIZONTAL DEFLECTION READING IN INCHES								+= TO L. -= TO R.
45.0	0	.01	.10	.17	.30	.01	.47	.59	.04
85.0	0	.03	.09	.18	.30	.02	.41	.51	.02
142.0	0	.05	.12	.19	.30	.01	.38	.47	.02

ENGINEERING: Wayne Callahan

QUALITY CONTROL:

CUSTOMER: A. T. Bauman

	NAME	DATE	FLETCHER AVIATION CORP.	PAGE	TEMP.	PERM.
PREPARED	G. FORD	[illegible]	TITLE STATIC TEST			59.1
CHECKED	[illegible]	[illegible]		MODEL	21-150	
APPROVED	[illegible]	[illegible]		REPORT NO.	43.304	



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JUL 19 2013

	NAME	DATE	FLETCHER AVIATION CORPORATION	PAGE 3.10
PREPARED	R.W. Hill	10-10-62	TITLE	MODEL 21-150
CHECKED	W.S. Collins	10-31-62		43.304
APPROVED		10-31-62	STATIC TESTS	REPORT No.

③

Test Loads ~ Cond. #5 Flight

$n_z = -9.00$ $P_x = -2904^{\#}$
$n_y = 9.75$ $M_x = -4860$
$M_{y_{cg}} = 44820$
$M_{z_{cg}} = 0$
} Basic Loads, pg. A2, Rep. #43.300

Airload distribution from pg. A5 of Rep. #43.300.

Vertical Loads

1	2	3	4	5
T.S.	$\frac{P}{n_z}$	$\frac{P}{10^{-3} M_{y_{cg}}}$	$P_{z_{AIR}}$	P_z
	Rep. 43.300 pg. 11	Rp. 43.300 pg. 11	Ref. above	−9.00② +44.82③ +④
10	61.8	3.237	−128	−539
33	78.8	2.809	−244	−827
56	210.7	3.985	−172	−1890
79	403.9	+.894	−17	−3612
102	225.6	−3.282	+68	−2109
125	94.4	−2.953	123	−859
148	78.8	−3.784	143	−736
171	14.0	−.906	87	−80
160 (FIN)	—	—	−2115	−2115
			−2255	−12767

Lateral Loads

1	2	3	4	5
T.S.	$\frac{P}{n_y}$	$\frac{P}{10^{-3} M_{z_{cg}}}$	$P_{y_{AIR}}$	P_y
	Ref. above	Ref. above	Ref above	9.75② +④
8	53.8	−2.926	185	710
31	66.3	−2.486	413	1059
54	208.7	−4.296	314	2360
77	404.7	−1.495	+68	4014
100	229.1	+3.030	−79	2155
123	104.0	3.134	−180	833
146	86.5	4.022	−218	615
169	15.9	1.017	−158	−3
				11733

	NAME	DATE	FLETCHER AVIATION CORPORATION	PAGE	TEMP 5.11	PERM.
PREPARED	R. W. Hill	10-11-62				
CHECKED	W. Callahan	10-31-62	TITLE	MODEL	21-150	
APPROVED	R W Malin	10-31-62	STATIC TESTS	REPORT NO.	43.304	

WHIFFLE-TREE LOADING

Load Condition No. 5 Flight

Reference Diagram Pages

[N] = Gauge No.

VERTICAL LOADS + = UP, − = DN

Sta.	Ult. Ld.	Dead Wt.	Tare	Net Ld.	Comb.	Sta.	Comb.	Sta.
10	−539	62	15	−462	−1203	24.17	[1]	
33	−827	71		−741				
56	−1890	103		−1772	−5061	70.95	[2]	
79	−3612	308		−3289				
102	−2109	118		−1976	−2757	108.52	[3]	
125	−859	63		−781				
148	−736	79		−642	−693	149.69	[4]	
171	−80	14	15	−51				
160 (FIN)	−2115	—	—	−2115	[5]			

HORIZONTAL LOADS + = L, − = R

	Sta.	Ult. Ld.	Comb.	Sta.	Comb.	Sta.
Lateral Loads	8	710	1769	21.77	[6]	
	31	1059				
	54	2350	6364	68.51	[7]	
	77	4014				
	100	2155	2988	106.41	[8]	
	123	833				
	146	615	612	145.89	[9]	
	169	−3				
Drag Load	Tank ℄	−2904	Acting	fwd.	[10]	

FAC Form 7803

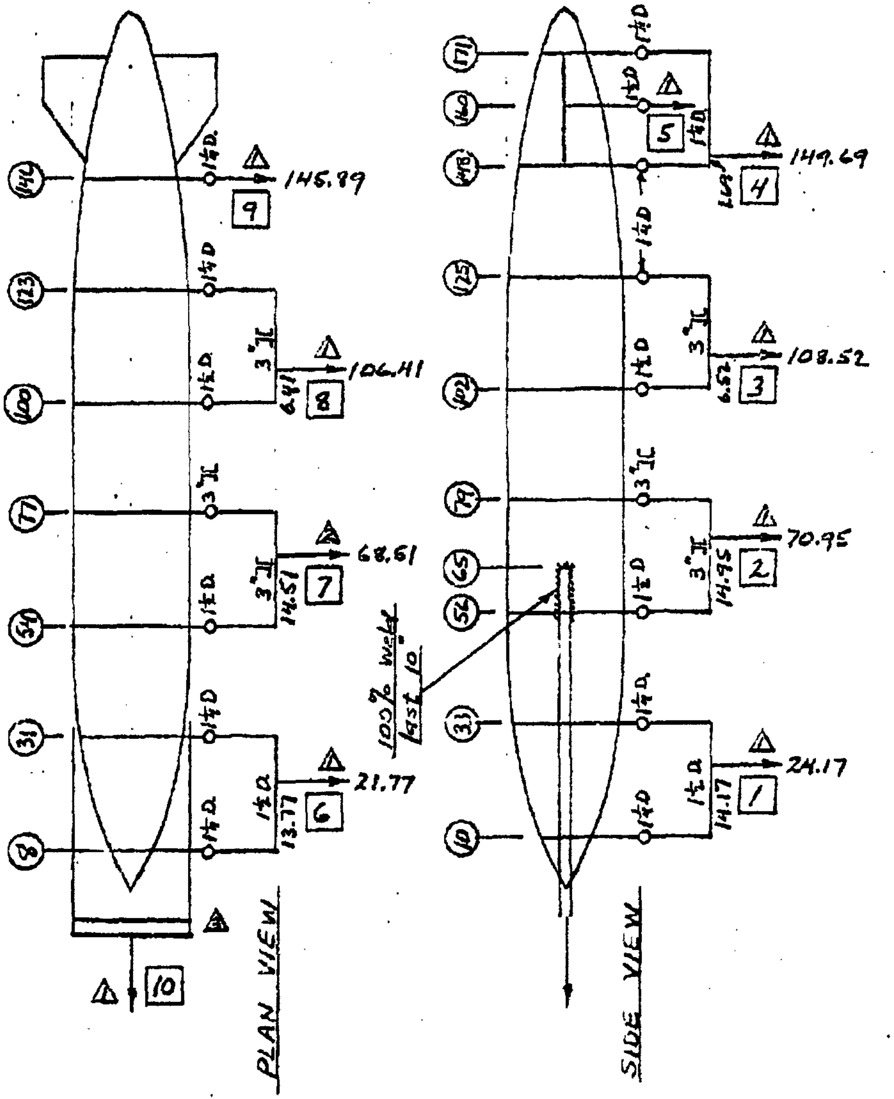
	NAME	DATE	FLETCHER AVIATION CORPORATION	PAGE	5.11.1
PREPARED	R.W. Hill	10-11-62	TITLE	MODEL	21-150
CHECKED		10-31-62	STATIC TESTS	REPORT NO.	43.304
APPROVED		10-31-62			

△ Jack #42710

▲ " #5062964-1

⚠ See details on separate sheet

☐N Gauge no.



TEST LOADING DIAGRAM

CONDITION #5

FAC Form 1508-1

	NAME	DATE	FLETCHER AVIATION CORPORATION	PAGE 5.11 2
PREPARED	W. Callahan	10-12-62		
CHECKED	R.HILL	10-31-62	TITLE STATIC TESTS	MODEL 21-150
APPROVED	H W Malm	10-31-62		43.304 REPORT NO.

LOAD CONDITION NO. (5) TEST DATE 10-25-62 ②

REFERENCE DIAGRAM PAGES 5.11.1

GAGE NO.	JACK AREA	PRESSURE GAGE READINGS IN PERCENT OF LIMIT LOAD							
		0	25	50	75	100	0	125	150	0
1	2.795	0	23	105	186	267	0	349	430	0
2	2.795	0	170	498	826	1155	0	1483	1811	0
3	2.795	0	101	278	455	632	0	809	986	0
4	2.795	0	5	54	102	151	0	200	248	0
5	2.795	0	126	252	378	505	0	631	757	0
6	2.795	0	106	211	316	422	0	528	633	0
7	5.498	0	193	386	579	772	0	965	1158	0
8	2.795	0	178	356	534	713	0	891	1069	0
9	2.795	0	36	73	110	146	0	182	219	0
10	2.795	0	173	346	520	693	0	866	1039	0
PRESSURE										

TANK STATION	VERTICAL DEFLECTION READINGS IN INCHES + = UP − = DN.							
40.0	0	.04	.04	.04	.05	.02	.06	.08	.02
90.0	0	−.09	−.14	−.16	−.20	−.11	−.24	−.24	−.14
140.0	0	−.09	−.22	−.30	−.40	−.09	−.54	−.64	−.16

TANK STATION	HORIZONTAL DEFLECTION READING IN INCHES + = TO L. − = TO R.							
45.0	0	.06	.14	.24	.40	0	.51	.65	.02
85.0	0	.08	.14	.25	.36	.01	.52	.62	.02
142.0	0	.04	.10	.21	.32	.01	.45	.57	.01

ENGINEERING: Wayne Callahan

QUALITY CONTROL: W. H. Hillard

CUSTOMER: A. T. Bauman

FAC Form F808

	NAME	DATE
PREPARED	G. FORD	[illegible]
CHECKED	[illegible]	[illegible]
APPROVED	[illegible]	[illegible]

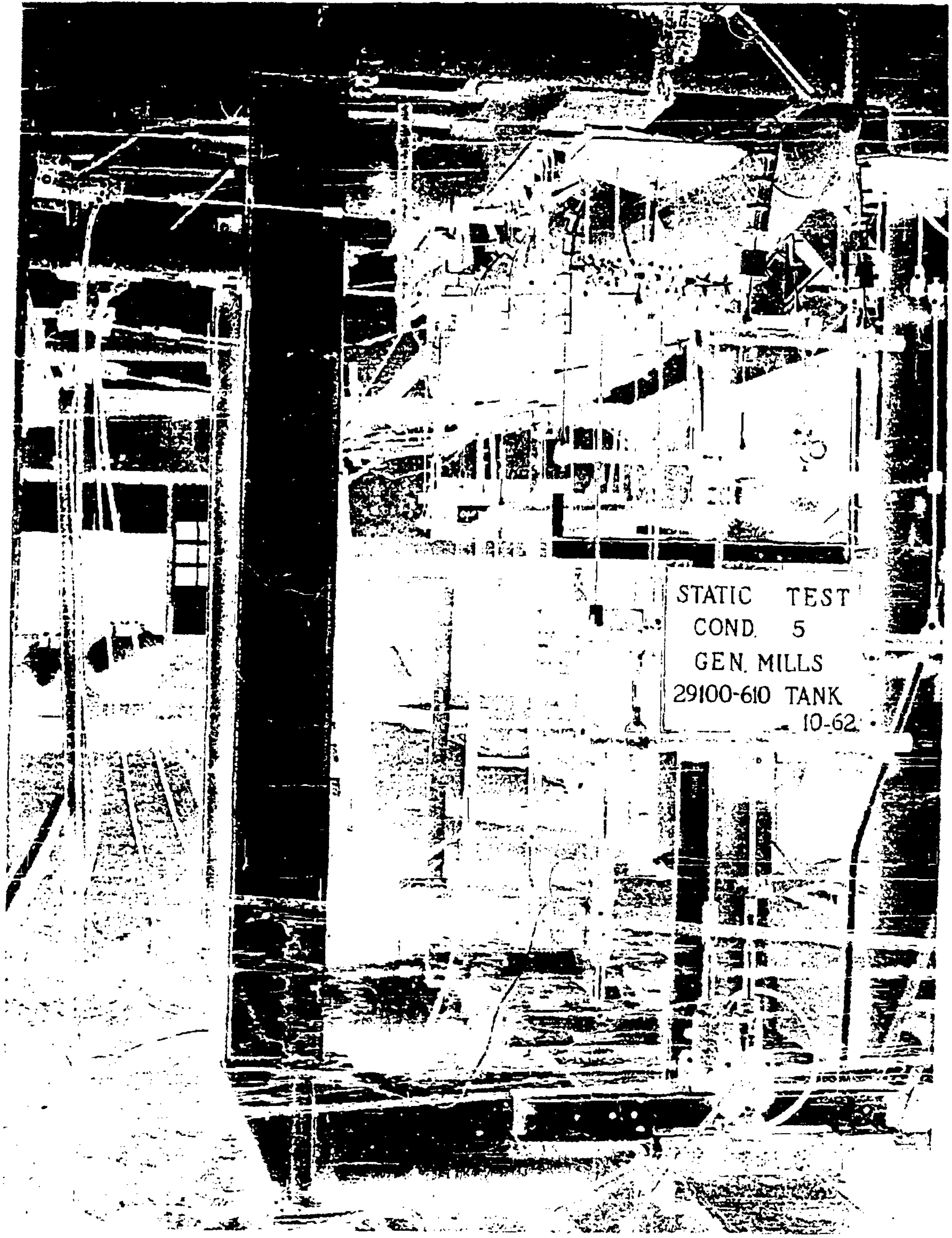
FLETCHER AVIATION CORP.

TITLE STATIC TEST

	TEMP.	PERM.
PAGE		5.1.3

MODEL 21455

REPORT NO. 43,304



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Reviewed Chief, RDD, WHS
IAW EO 13526, Section 3.5
Date: JUL 19 2013

	NAME	DATE	FLETCHER AVIATION CORPORATION	PAGE	5.12
PREPARED	R. W. Hill	10-10-62	TITLE	MODEL 21-150	
CHECKED	D. S. Callahan	10-31-62	STATIC TESTS	REPORT No. 43.304	
APPROVED	H W Walen	10/31/62			

③

Test Loads ~ Cond. #7, Flight

$n_z = -15.00$ $P_x = -2904$*
$n_y = 2.25$ $M_x = -180$
$M_{y_{cg}} = 44,820$
$M_{z_{cg}} = 0$

} Basic Loads, Appendix "A", Rep. #43.300, pg. A2

Airload distrib. from Appendix pg. A5, above.

Vertical Loads

1	2	3	4	5
T.S.	$\frac{P}{n_z}$	$\frac{P}{10^{-3}M_{y_{cg}}}$	$P_{z_{AIR}}$	P_z
	Rep. 43.300 pg. 11	Rep. 43.300 pg. 11	Ref above	-15.00 ② +44.82 ③ + ④
10	61.8	3.237	- 128	- 910
33	78.8	2.809	- 244	-1300
56	210.7	3.985	- 172	-3154
79	402.9	+ .894	- 17	-6035
102	225.6	-3.282	+ 68	-3463
125	94.4	-2.953	123	-1425
148	78.8	-3.784	143	-1208
171	14.0	- .906	87	- 164
160 (FIN)			-2115	-2115
			-2255	-19774

Lateral Loads

1	2	3	4	5
T.S.	$\frac{P}{n_y}$	$\frac{P}{10^{-3}M_{z_{cg}}}$	$P_{y_{AIR}}$	P_y
	Ref. above	Ref. above	Ref. above	2.25 ② + ④
8	53.8	- 2.926	44	165
31	66.3	- 2.486	106	255
54	208.7	- 4.296	73	542
77	404.7	- 1.495	+ 4	915
100	229.1	+ 3.030	- 29	486
123	104.0	3.134	- 55	179
146	55.5	4.022	- 68	124
169	15.9	1.017	- 45	- 9
			30	2657

FAC Form 1508-1

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IAW EO 13526, Section 3.5
Date: JUL 19 2013

	NAME	DATE	FLETCHER AVIATION CORPORATION		ITEM	
PREPARED	R W Hill	10-11-62		PAGE	5.13	
CHECKED		10-31-62	TITLE	MODEL	21-150	
APPROVED	A W Mahn	10/31/62	STATIC TESTS	REPORT NO.	43.304	

WHIFFLE-TREE LOADING

Load Condition No. 7 Flight
Reference Diagram Pages 1

N Gauge No,

VERTICAL LOADS
+ = UP
− = DN.

Sta.	Ult. Ld.	Dead Wt.	Tare	Net Ld.	Comb.	Sta.	Comb.	Sta.
10	−910	62	15	−833	−2047	23.64	1	
33	−1300	71		−1214				
56	−3154	103		−3036	−8748	71.02	2	
79	−6035	308		−5712				
102	−3463	118		−3330	−4677	108.62	3	
125	−1425	63		−1347				
148	−1208	79		−1114	−1249	150.48	4	
171	−164	14	15	−135				
160 (FIN)	−2115	—	—	−2115	5			

HORIZONTAL LOADS
+ = L
− = R

	Sta.	Ult. Ld.	Comb.	Sta.	Comb.	Sta.
Lateral Loads	8	165	420	21.96	6	
	31	255				
	54	542	1457	68.44	7	
	77	915				
	100	486	665	106.19	8	
	123	179				
	146	124	115	144.20	9	
	169	−9				
Drag Load	Tank ℄	−2704	Fwd. acting		10	

FAC Form 7808

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Date:
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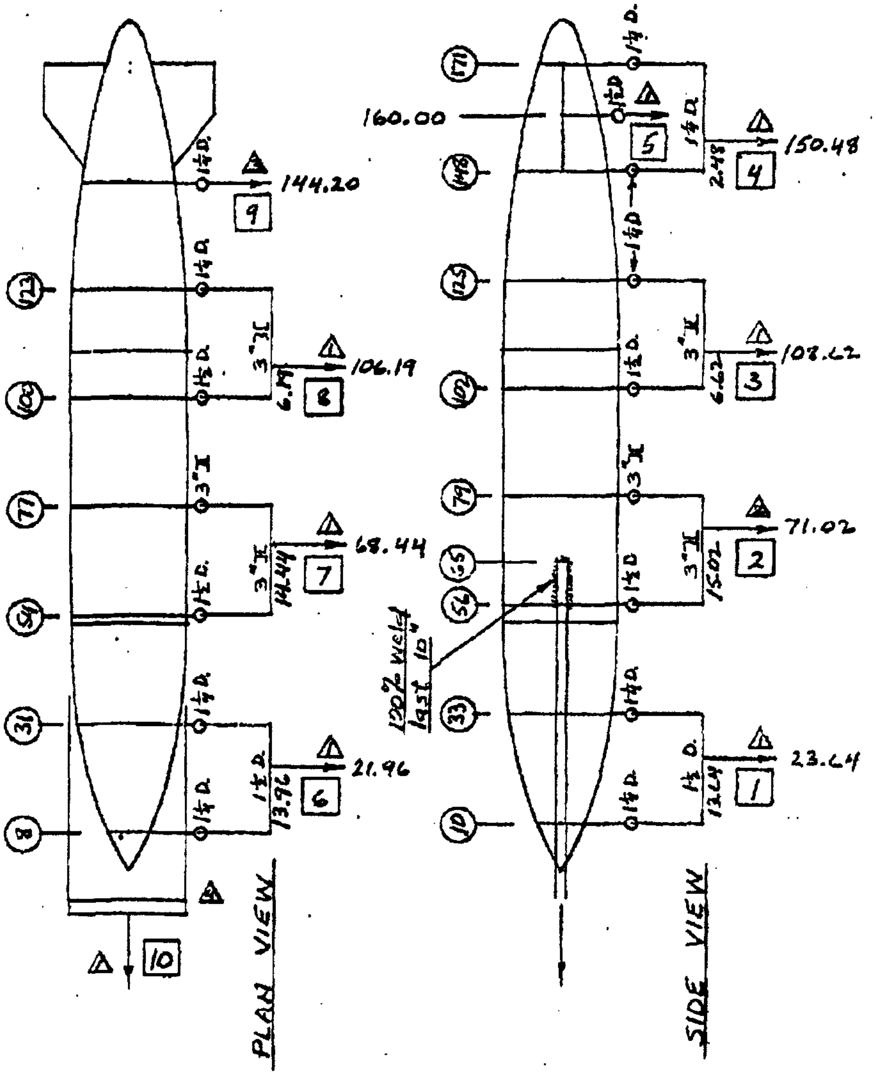
	NAME	DATE	FLETCHER AVIATION CORPORATION	PAGE 5.13.L
PREPARED	R.W. Hill	10-11-62	TITLE STATIC TESTS	MODEL 21-150
CHECKED	D. Callahan	10-31-62		43.304 REPORT NO.
APPROVED		10-31-62		

N Gauge no.
△ Jack #42710
▲ Jack #5063964-1
▲ Jack #H-5A50
△ See details on separate sheet



TEST LOADING DIAGRAM
CONDITION #7

FAC Form 1505-1

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IAW EO 13526, Section 3.5
Date: JUL 19 2013

	NAME	DATE	FLETCHER AVIATION CORPORATION	TEMP.	PERM.
PREPARED	W. Callahan	10-5-62		PAGE	5.13.2
CHECKED	R. Hall	10-6-62	TITLE STATIC TESTS	MODEL	21-150
APPROVED		10-6-62		REPORT NO.	43.304

LOAD CONDITION NO. (7) TEST DATE 10-25-62 ②

REFERENCE DIAGRAM PAGES 5.13.1

GAGE NO.	JACK AREA	PRESSURE GAGE READINGS IN PERCENT OF LIMIT LOAD								
		0	25	50	75	100	0	125	150	0
1	2.795	0	74	205	337	469	0	600	732	0
2	5.498	0	198	477	756	1034	0	1312	1591	0
3	2.795	0	216	507	798	1090	0	1382	1673	0
4	2.795	0	38	120	202	283	0	365	447	0
5	2.795	0	126	252	378	505	0	631	757	0
6	2.795	0	25	50	75	100	0	125	150	0
7	2.795	0	87	174	260	347	0	434	521	0
8	2.795	0	40	79	119	159	0	198	238	0
9	.798	0	24	48	72	96	0	120	144	0
10	2.795	0	173	346	520	693	0	866	1039	0
PRESSURE										

TANK STATION	VERTICAL DEFLECTION READING IN INCHES								+ = UP − = DN.
40.0	0	0	.02	.04	.05	0	.07	.07	0
90.0	0	0	−.04	−.07	−.12	0	−.15	−.20	−.01
140.0	0	−.06	−.17	−.28	−.39	−.02	−.52	−.65	−.05

TANK STATION	HORIZONTAL DEFLECTION READING IN INCHES								+ = TO L. − = TO R.
45.0	0	.01	.05	.05	.06	.02	.09	.11	.03
85.0	0	0	.01	.05	.05	.01	.09	.13	.01
142.0	0	.02	.04	.05	.06	.01	.08	.10	.02

ENGINEERING: Wayne Callahan

QUALITY CONTROL: W. H. Hillard

CUSTOMER: A. F. Bauman

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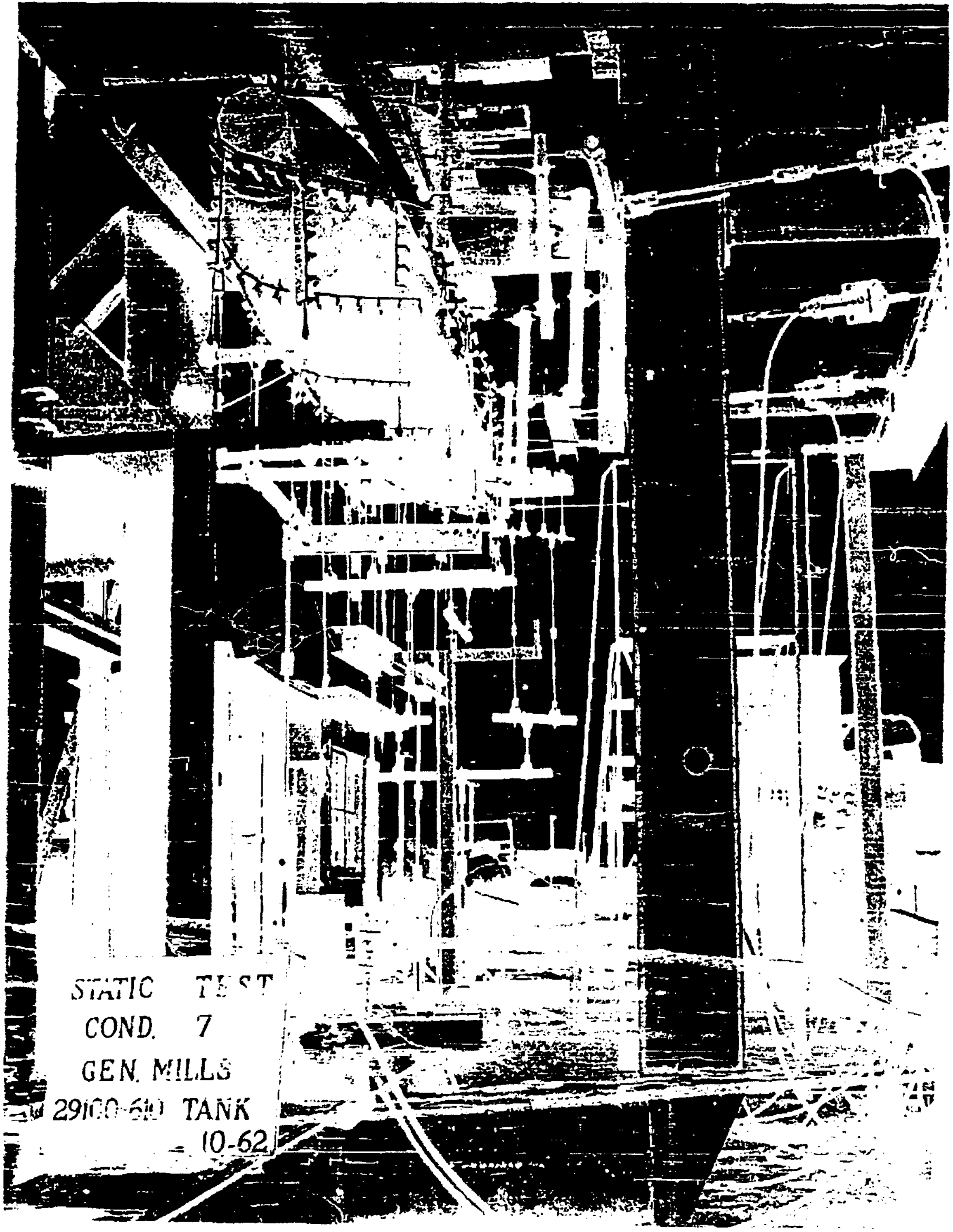
	NAME	DATE	FLETCHER AVIATION CORP.	PAGE	TEMP.	PERM.
PREPARED	G. FORD	0-31-62				513.3
CHECKED	[illegible]	[illegible]	TITLE STATIC TEST	MODEL 21-150		
APPROVED	[illegible]	[illegible]		REPORT No. 43 394		



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	NAME	DATE	FLETCHER AVIATION CORPORATION	PAGE	TEMP. 5	PERM. 14
PREPARED	R.W. Hill	9-6-62	TITLE	MODEL	21-150	
CHECKED	G.J. Callahan	10-31-62	STATIC TESTS	REPORT No.	43.304	
APPROVED	H.W. Hill	9-28-64				

Test Loads ~ Cond. #11 Arrested Landing

$n_z = -4.50$　　$P_x = -15768$
$n_y = 2.25$　　$M_x = 0$
$M_{y_{CG}} = 89640$
$M_{z_{CG}} = 44820$

} Basic Loads pg. 12, Rep. #43.300

Vertical Loads

1	2	3	4	5
T.S.	$\frac{P}{n}$	$\frac{P}{10^{3} M_{y_{CG}}}$	$P_{z_{AIR}}$	P_z
	Rep. 43.300 pg. 11	Rep. 43.300 pg. 11		-4.50 ② +89.64 ③
10	61.8	3.237	0	+ 12
33	78.8	2.809		- 103
56	210.7	3.985		- 592
79	403.9	+ .894		- 1737
102	225.6	- 3.282		- 1309
125	94.4	- 2.953		- 689
148	78.8	- 3.784	↓	- 694
171	14.0	- .906	0	- 144
				- 5256

Lateral Loads

1	2	3	4	5
T.S.	$\frac{P}{n}$	$\frac{P}{10^{3} M_{z_{CG}}}$	$P_{y_{AIR}}$	P_y
	Ref. above	Ref above		2.25 ② +44.82 ③
8	53.8	- 2.926	0	- 10
31	66.3	- 2.486		+ 38
54	208.7	- 4.296		277
77	4011.7	- 1.495		843
100	229.1	+ 3.030		652
123	104.0	3.134		374
146	85.5	4.022	↓	373
169	15.9	1.017	0	81
				2628

	NAME	DATE	FLETCHER AVIATION CORPORATION	PAGE 5.15
PREPARED	R. W. Hill	9-6-62	TITLE	MODEL 21-150
CHECKED	H. Callahan	10-3-62		43,304
APPROVED		9-28-62	STATIC TESTS	REPORT No.

WHIFFLE-TREE LOADING

Load Condition No. 11 ~ Arrested Landing
Reference Diagram Pages

$\boxed{N}$ = Gauge no.

VERTICAL LOADS + = UP, − = DN.

Sta.	Ult. Ld.	Dead Wt.	Tare	Net Ld.	Comb.	Sta.	Comb.	Sta.
10	+ 12	62	15	+ 89	+ 72	4.57	$\boxed{1}$	
33	− 103	71		− 17				
56	− 592	103		− 474	− 1888	73.22	$\boxed{2}$	
79	− 1737	308		− 1414				
102	− 1309	118		− 1176	− 1787	109.86	$\boxed{3}$	
125	− 689	63		− 611				
148	− 694	79		− 600	− 715	151.70	$\boxed{4}$	
171	− 144	14	15	− 115				
	−5256	818	120	−4318 −4318	✓			

HORIZONTAL LOADS + = TO L, − = TO R.

	Sta.	Ult. Ld.	Comb.	Sta.	Comb.	Sta.
Lateral Loads	8	−10	28	39.21	$\boxed{6}$	
	31	+38				
	54	277	1120	71.31	$\boxed{7}$	
	77	843				
	100	652	1026	108.38	$\boxed{8}$	
	123	374				
	146	373	454	150.10	$\boxed{9}$	
	169	81				
		2628	−			
Nose Pull	Tank ℄	15768	Acting	Fwd	$\boxed{10}$	

FAC Form 7168

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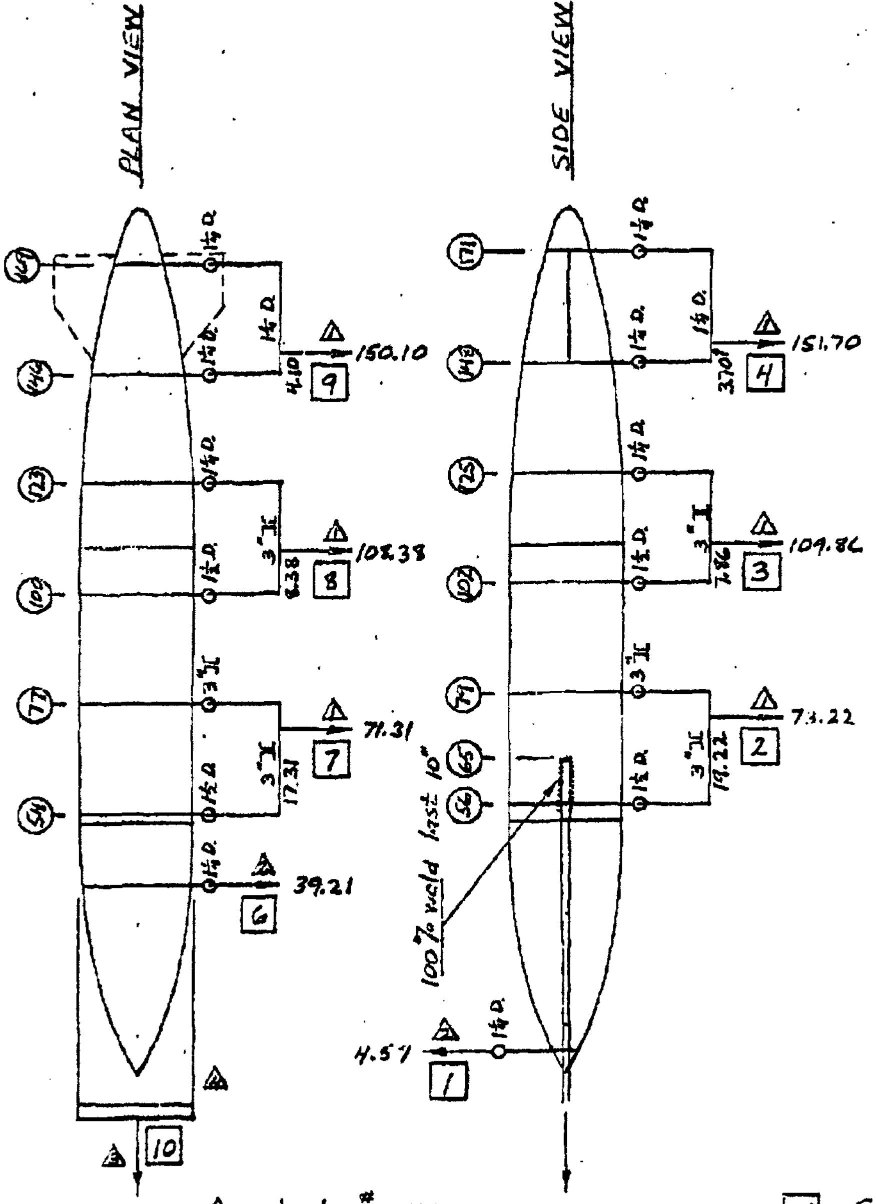
	NAME	DATE	FLETCHER AVIATION CORPORATION		TEMP.	PERM.
PREPARED	R.W. Hill	10-2-62		PAGE	5	16
CHECKED	D.J. Callahan	10-31-62	TITLE STATIC TESTS	MODEL 21-150		
APPROVED	[illegible]	9-28-62		43.304 REPORT No.		



TEST LOADING DIAGRAM
CONDITION #11

△1 Jack #42710
△2 Jack #H-5A 50
△3 Jack #5126043
△4 See details on separate sheet.

N Gauge no.

FAC Form 1508-1

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Date: JUL 19 2013

	NAME	DATE			
PREPARED	W. Callahan	10-5-62	FLETCHER AVIATION CORPORATION	PAGE	5.17
CHECKED	R. Hill	10/6/62	TITLE STATIC TESTS	MODEL	21-150
APPROVED		10-6-62		REPORT NO.	43.304

LOAD CONDITION NO. (11) TEST DATE 10-26-62 ②

REFERENCE DIAGRAM PAGES 5.16

GAGE NO.	JACK AREA	PRESSURE GAGE READINGS IN PERCENT OF LIMIT LOAD								
		0	25	50	75	100	0	125	150	0
1	.798	20	32	43	55	67	20	78	90	20
2	2.795	0	0	120	258	397	0	536	675	0
3	2.795	0	43	162	281	401	0	520	639	0
4	2.795	0	6	56	106	156	0	206	256	0
5	-									
6	.798	0	6	12	18	24	0	30	35	0
7	2.795	0	67	134	200	267	0	334	401	0
8	2.795	0	61	122	184	245	0	306	367	0
9	2.795	0	27	54	81	108	0	135	162	0
10	10.308	0	255	510	765	1020	0	1275	1530	0
PRESSURE										

+ = UP
- = DN.

TANK STATION	VERTICAL DEFLECTION READING IN INCHES								
45.0	0	0	0	.01	.03	.01	.07	.11	.02
95.0	0	-.01	-.03	-.05	-.06	0	-.06	-.07	0
142.0	0	0	-.06	-.12	-.17	0	-.21	.28	-.01

+ = TO L.
- = TO R.

TANK STATION	HORIZONTAL DEFLECTION READING IN INCHES								
42.0	0	.01	.02	.02	.03	.01	.04	.06	.02
90.0	0	0	0	.01	.02	0	.06	.07	0
145.0	0	.03	.04	.08	.12	.02	.19	.24	.04

ENGINEERING: Wayne Callahan

QUALITY CONTROL: W. H. Hillard

CUSTOMER: A. T. Bauman

FAC Form 7108

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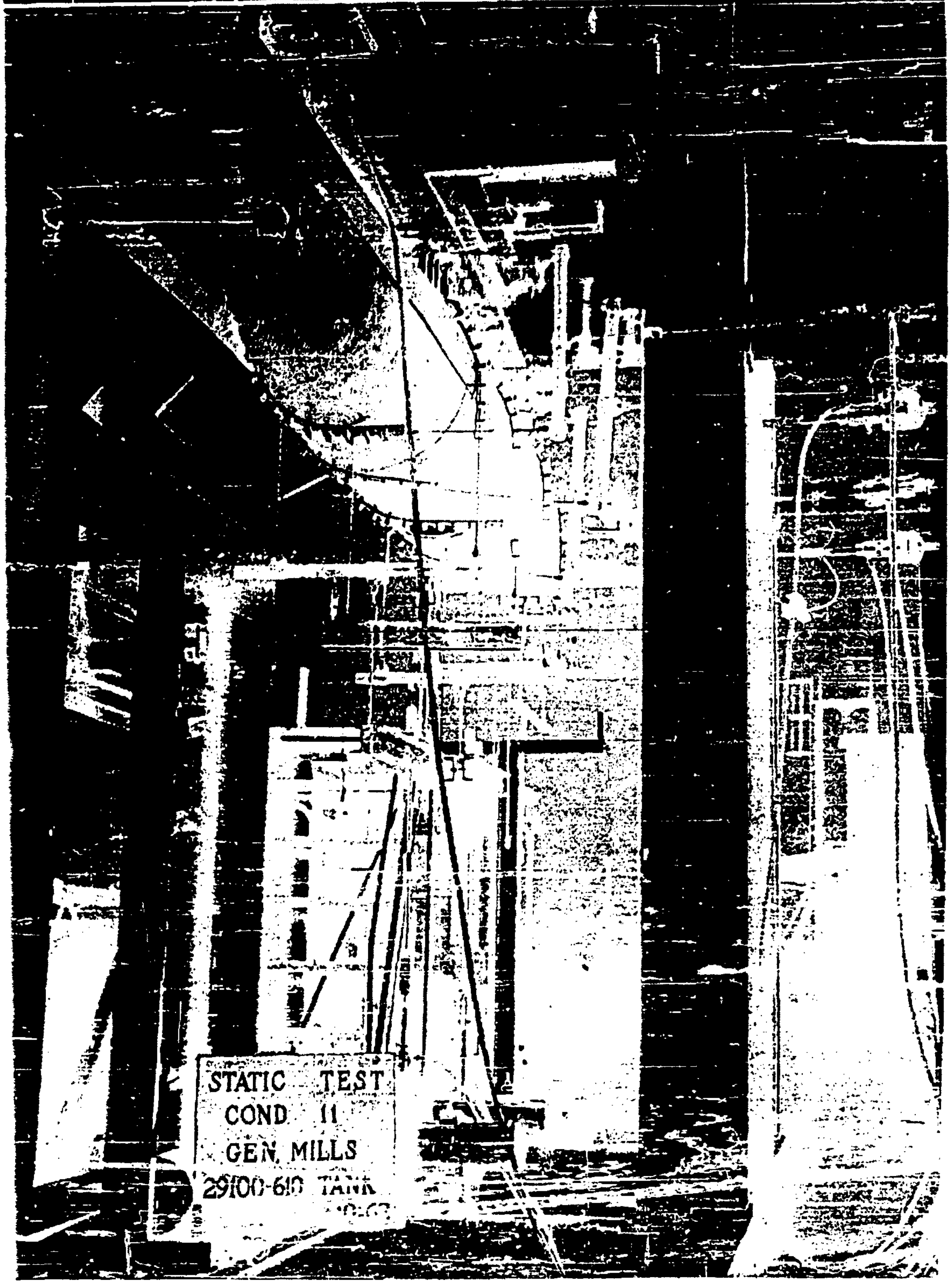
IAW EO 13526, Section 3.5
Date: JUL 19 2013

	NAME	DATE	FLETCHER AVIATION CORP.	PAGE	TEMP.	PERM. 537.1
PREPARED	G. FORD	[illegible]	TITLE STATIC TEST	21-150 MODEL		
CHECKED	[illegible]	[illegible]		43.304 REPORT No.		
APPROVED	[illegible]	[illegible]				



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IAW EO 13526, Section 3.5
Date: JUL 19 2013

	NAME	DATE			TEMP.	PERM.
PREPARED	W.Callahan	10-7-62	**FLETCHER AVIATION COMPANY**	PAGE		6.0
CHECKED	R Hill	10-8-62	TITLE LEAKAGE TEST	MODEL	21-150	
APPROVED		10-8-62	GENERAL MILLS TANK ASSY	REPORT No.	43.304	

②

ADMINISTRATIVE DATA

PURPOSE OF TEST:

To demonstrate that the tank is sealed prior to the tests.

MANUFACTURER:

Fletcher Aviation Company

MANUFACTURER'S MODEL NO.:

21-150

ASSEMBLY DRAWING:

21-150-48032

QUANTITY OF ITEMS:

One (1)

SECURITY CLASSIFICATION:

None

DATE TEST COMPLETED:

10-23-62

TEST CONDUCTED BY:

Wayne Callahan

DISPOSITION OF SPECIMEN:

Use for Structural Test

ABSTRACT:

There was no leakage as a result of the Pitch/Vibration, Vibration, or Vibration Survey Tests.

	NAME	DATE			TEMP.	PERM.
PREPARED	W. Callahan	10-5-62	FLETCHER AVIATION COMPANY	PAGE		6.1
CHECKED			TITLE LEAKAGE TEST GENERAL MILLS TANK ASSY	MODEL 21-150		
APPROVED				43.304 REPORT NO.		

③

FACTUAL DATA

REQUIREMENTS:

1. The inner stainless steel tank with all openings sealed is subjected to an internal pressure of 20 P.S.I.G. using Freon 12. The tank is then checked for leakage using a General Electric H-2 tester.

TEST EQUIPMENT:

1. Tank Support
2. Pressure Gage
3. Freon 12 container with regulator.
4. General Electric H-2 tester.

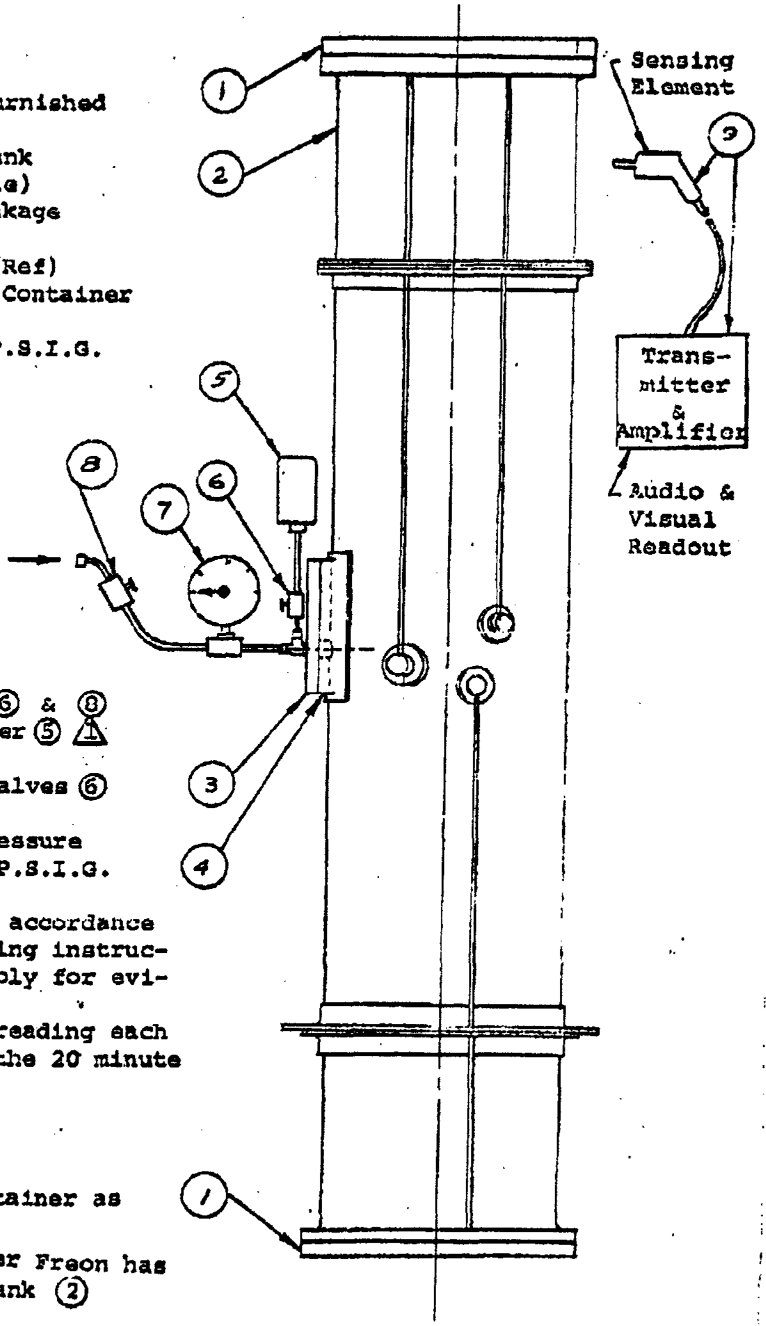
PROCEDURE:

1. With the tank supported, connect equipment as shown on page 6.2 of this report.

2. Conduct test as specified in procedure on page 6.2 of this report. Sniffing rate shall be 1/2 inch per second.

3. Inspect the tank visually for evidence of failure such as damage to the bulkheads or other structural damage to the inner or outer tank.

PRESSURE & LEAKAGE TEST
21-150-20180 TANK ASSEMBLY



EQUIPMENT

①—End Cover & Seals (furnished by General Mills)
②—21-150-20180 Inner Tank Assembly (Test Article)
③—Cover, Pressure & Leakage Test
④—21-150-20180-17 Pad (Ref)
⑤—Freon 12 Pressurized Container
⑥—Shut-off Valve
⑦—Pressure Gage, 0-50 P.S.I.G.
⑧—Shut-off Valve
⑨—General Electric H-2 Halogen Gas Detector

PROCEDURE

1. Close Shutoff Valves ⑥ & ⑧
2. Connect Freon Container ⑤ △1
3. Open Valve ⑥ △2
4. Connect Air Supply (Valves ⑥ & ⑧ closed)
5. Open Valve ⑧ until pressure gage ⑨ reads 20 ± 1 P.S.I.G. Close Valve ⑧
6. Using Detector ⑨ in accordance with specified operating instructions test tank assembly for evidence of leakage.
7. Record pressure gage reading each 5 (five) minutes of the 20 minute test period.

Note:

1 One or more Freon Container as required.

2 Shutoff Valve ⑥ after Freon has transferred to test tank ②

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	NAME	DATE	FLETCHER AVIATION COMPANY	PAGE	TEMP.	PERM.
PREPARED	W. Callahan	10-5-62				6.3
CHECKED	R. Hill	10/8/62	TITLE LEAKAGE TEST	MODEL 21-150		
APPROVED		10-8-62	GENERAL MILLS TANK ASSY	REPORT NO. 43.304		

②

TEST RESULTS

There was no leakage as a result of the vibration tests.

F.A.C. TEST ENGR. Wayne Callahan

F.A.C. QUALITY CONTROL:

CUSTOMER REPRESENTATIVE:

FAC form F808

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Reviewed Chief, RDD, WHS
IAW EO 13526, Section 3.5
Date: JUL 19 2013

	NAME	DATE	**FLETCHER AVIATION COMPANY**		TEMP.	PERM.
PREPARED	W.Callahan	10-5-62		PAGE		7.0
CHECKED	R. Hill	10/9/62	TITLE GROUND EJECTION TEST GENERAL MILLS TANK ASSY	MODEL	21-150	
APPROVED		10-8-62		REPORT NO.	43.304	

②

ADMINISTRATIVE DATA

PURPOSE OF TEST

To determine ejection characteristics.

MANUFACTURER

Fletcher Aviation Company

MANUFACTURER'S MODEL NO.

21-150

ASSEMBLY DRAWING

21-150-48032

QUANTITY OF ITEMS

SECURITY CLASSIFICATION

None

DATE TEST COMPLETED

10-30-62

TEST CONDUCTED BY

Wayne Callahan

DISPOSITION OF SPECIMEN

Hold at Fletcher Aviation Company for sixty (60) days for G.M.I. disposition.

ABSTRACT

The assembly satisfactorily met all the requirements of the test.

	NAME	DATE	FLETCHER AVIATION COMPANY	PAGE	TEMP.	PERM. 7.1
PREPARED	W.Callahan	10-5-62	TITLE GROUND EJECTION TEST GENERAL MILLS TANK ASSY	MODEL 21-150		
CHECKED	R. A. H	10/8/62		43.304 REPORT NO.		
APPROVED		10-8-62				

FACTUAL DATA

REQUIREMENTS

That one (1) or more ejection be made with a lightweight tank and one (1) or more ejection be made with heavy weight tank so as to accurately determine the peak force, velocity, acceleration, and tank attitude at end of stroke. The peak ejection force shall not exceed 30,000 lbs.

TEST EQUIPMENT

1. Ejection frame
2. Suspension fixture
3. Pylon
4. Lightweight Store
5. Heavyweight Store
6. 28V DC power supply
7. 20,000 Ohm/Volt Multimeter
8. Midwestern Oscillograph
9. F.A.C. Force Transducer
10. Extensometer (Century Eng.)
11. Accelerometer
12. Amplifier (Miller)
13. High Speed Camera (Wollensak)
14. Goose Control

TEST PROCEDURE

1. Install suspension fixture on ejection frame.
2. Install pylon on suspension fixture.
3. Install lightweight store on pylon.
4. Apply 28V DC to the mechanism.
5. Measure voltage at firing pins.
6. Remove safety pin.
7. Measure voltage at firing pins.
8. Disconnect power supply and install safety pin.

	NAME	DATE	FLETCHER AVIATION COMPANY	PAGE	TEMP.	PERM.
PREPARED	W.Callahan	10-5-62	TITLE GROUND EJECTION TEST GENERAL MILLS TANK ASSY			7.2
CHECKED	R. Hill	10/8/62		MODEL	21-150	
APPROVED		10-8-62		REPORT NO.	43.304	

FACTUAL DATA

TEST PROCEDURE (contd)

9. Install extensometer.
10. Install camera.
11. Check instrument and camera circuit.
12. Install cartridges.
13. Remove safety pin.
14. Activate instrument and camera circuits.
15. Activate firing mechanism.
16. Clean pylon assembly and inspect.
17. Install heavyweight store on pylon.
18. Repeat steps 4 through 17.

PREPARED	NAME W.Callahan	DATE 10-5-62	FLETCHER AVIATION COMPANY	PAGE	TEMP.	PERM. 7.3
CHECKED	R Hill	10/8/62	TITLE GROUND EJECTION TEST GENERAL MILLS TANK ASSY	MODEL 21-150		
APPROVED		10-8-62		43.304 REPORT NO.		

②

TEST RESULTS

	Lightweight Tank	Heavyweight Tank
Peak Ejection Force	18,060	23,480 lbs.
Peak Acceleration	25.8 G's	22.4 G's
Peak Velocity	36.2 ft/sec	42.0 ft/sec
Attitude at end of stroke	level	level

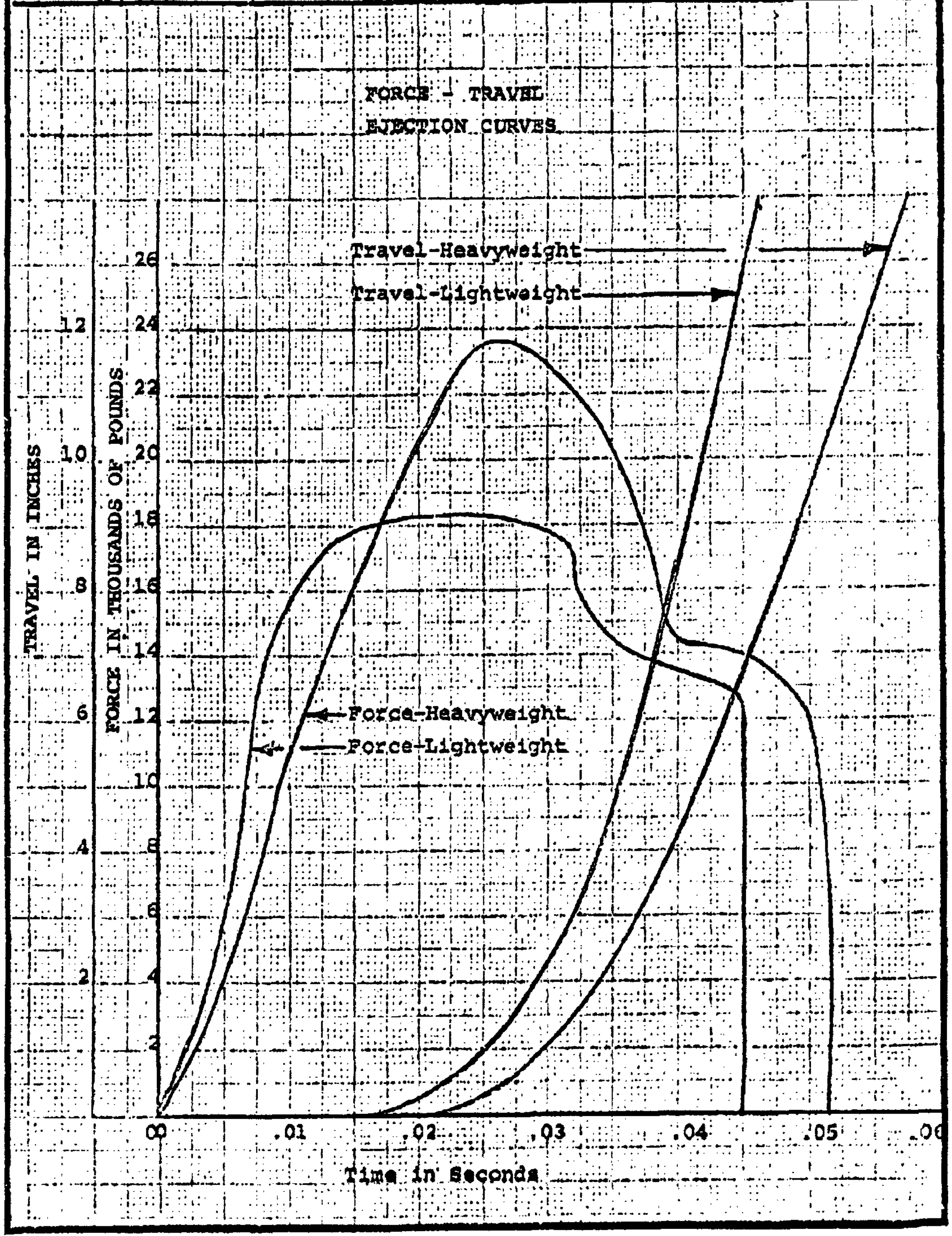
RECOMMENDATIONS: ____________________

F.A.C. ENG'R: Wayne Callahan

F.A.C. QUALITY CONTROL: W. H. [illegible]

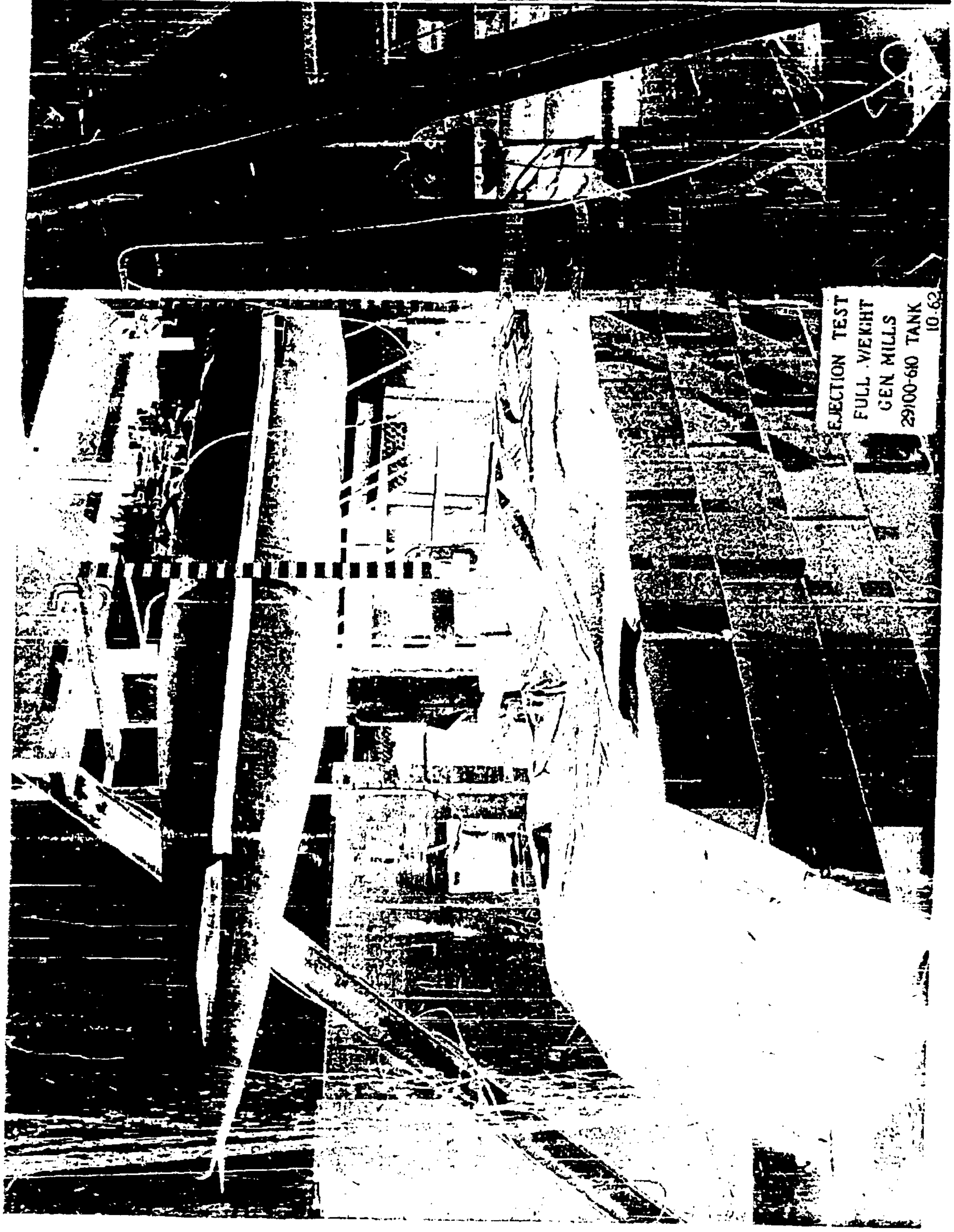
CUSTOMER REPRESENTATIVE: A. F. Bauman

	Name	Date	FLETCHER AVIATION CORP.	Page	Temp.	Perm.
Prepared	W.Callahan	10-31-62	Title			7.4
Checked	R. Hall	10-31-62	GROUND EJECTION TEST GENERAL MILLS TANK ASSY	Model	21-150	
Approved	A Malin	10-31-62		Report No.	43.304	



FAC Form F108-1

	NAME	DATE	FLETCHER AVIATION CORP.	PAGE	TEMP. 7.5	PERM.
PREPARED	G. FORD	10-31-62	TITLE EJECT. TEST	MODEL	21-150	
CHECKED	D. Callahan	10-31-62		REPORT NO.	43.304	
APPROVED	H W MALM	10-31-62				



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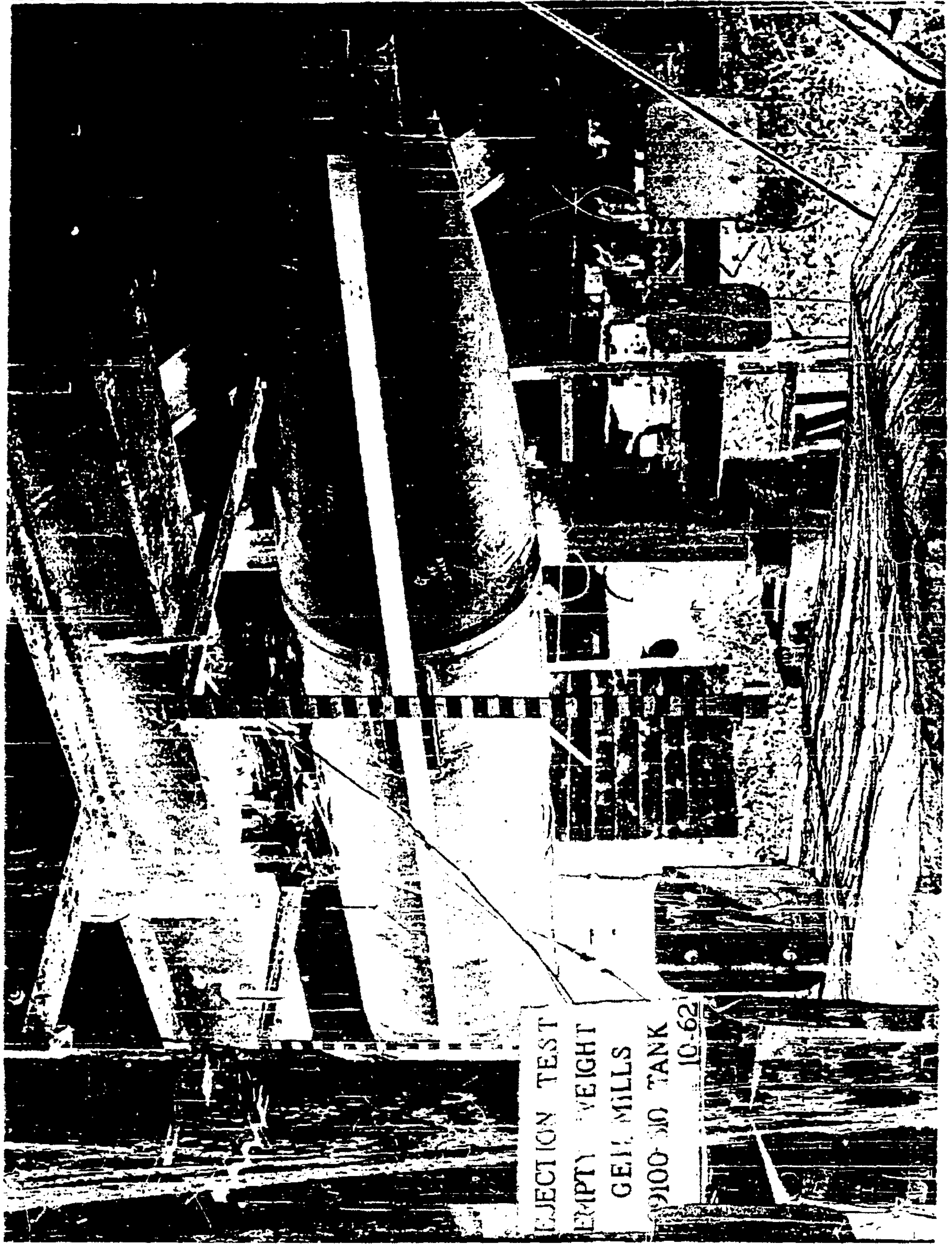
	NAME	DATE	FLETCHER AVIATION CORP.	PAGE 7.6
PREPARED	G. FORD	10-31-62	TITLE EJECT. TEST	21-150 MODEL
CHECKED	H. Callahan	10-31-62		43.304 REPORT NO.
APPROVED	H. D. Mirm	10-31-62		

	NAME	DATE	FLETCHER AVIATION CORP.		
PREPARED	G. FORD	10-31-62	TITLE EJECTION TEST - LIGHTWEIGHT TANK	PAGE	7.7
CHECKED	W. Callahan	10-31-62		MODEL	27-150
APPROVED	F. J. MAIM	10-31-62		REPORT NO.	43.304



	NAME	DATE	FLETCHER AVIATION CORP.	PAGE	TEMP.	PERM. 7.8
PREPARED	G. FORD	10-31-62	TITLE EJECTION TEST –	MODEL 21-150		
CHECKED		10-31-62	LIGHTWEIGHT TANK	REPORT NO. 43.304		
APPROVED		10-31-62				

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General Mills

SHEET ____ OF ____

RELEASE DATE 5/14/62

ENGINEERING DEPARTMENT

SPECIFICATION GMB 29100-375

LTR. A

MOTOR, 2HP, 400 CYCLE

	A	1. Item 3 - 7.5 amp to 8.8 amp 2. Item 7 - SK29100-372 to 372A	6/7/62	J.A.W
ECO NO.	REV.	REMARKS	DATE	INIT.

APPROVED BY	J. Walter ENGINEER	PROJECT ENGINEER	CHIEF PROJECT ENGINEER	

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SHEET 1 OF 2

RELEASE DATE 5/14/62

ENGINEERING DEPARTMENT

SPECIFICATION: GMS 29100-375

LET. A

MOTOR, 2HP, 400 CYCLE

Westinghous Electric Corporation shall supply a motor meeting the following minimum specifications:

ITEM: 400 Cps, 3 Phase, 400 Frame A.C. Motor

1. Input Power - 400 ± 20 Cps.
   200 ± 10 volts A.C. - Line to Line
   3 Phase
2. Minimum Rated Capacity - 22 in-# at 5600 RPM
   Starting Torque - (Min) - 125% operating torque
3. (A-1) Power Required - Current Drain 8.8 Amp. per Phase (Max) at 22 in/# Torque
   Power Factor - .60 (min) at 22 in/# Torque
   Efficiency - 75% (Min.) at 22 in/# Torque
4. Wire Connection - Color Coded - Pigtail type
   Minimum Length - 36"
5. Duty Cycle - Continuous
6. Life - Minimum <u>200 Hour</u> - Under conditions described below:

   NOTE:

   Entire motor will be encased in a sealed container with a volume of approximately 1/3 ft.^{3}. The maximum continuous operating time while so encased is 30 minutes. It will also be exposed to ON-OFF cycling where by the on time in any given 60 minute period shall be less than 30 minutes.
7. (A-2) Package - See Drawing SK 29100-372 A for:
   Outline of maximum space envelope and mounting pad detail.

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SHEET 2 OF 2

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SPECIFICATION GMS 29100-375

LET. A.

8. Weight - 10.5 lbs. maximum

9. Environment - (See 5.)

Temperature -65°F + 160°F

Acceleration- 10 g's in any direction

Vibration - 5 to 500 cps at 0.036 inch double amplitude or ± 10 g's whichever is lower value.

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SHEET i OF iv

RELEASE DATE April 2, 1962

ENGINEERING DEPARTMENT

SPECIFICATION GMS - 29100 - 610

LET.

STATEMENT OF WORK

EXTERNAL REMOVABLE AIRCRAFT TANK ASSEMBLY

FOR GENERAL MILLS ELECTRONICS GROUP

ECO NO.	REV.	REMARKS	DATE	INIT.
	A	ADDED SHEETS iii and iv	6/22/62	[illegible]

APPROVED BY

ENGINEER

J. L. McGillicuddy
PROJECT ENGINEER

CHIEF PROJECT ENGINEER

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SHEET ii OF iv
RELEASE DATE April 2, 1962

ENGINEERING DEPARTMENT
SPECIFICATION GMS - 29100 - 610
LTR.

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SHEET iii OF iv

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ENGINEERING DEPARTMENT

SPECIFICATION GMS - 29100 - 610

LET.

The following paragraphs of General Mills Specification No. 29100-610 shall be changed as indicated below:

Paragraph	Change
2.4	Change "SK29100-608" to "SK29100-698" Change "SK29100-609" to "SK29100-699"
3.4	Change "SK29100-612" to SK29100-698"
3.5	Delete "Aft Gas Tank"
3.6	Delete "Aft Gas Tank","And Cover" change"supplied" to"installed"
3.7	Add Statement" The contractor shall not be responsible for adverse flight characteristics or buffeting arising from pylon or aircraft characteristics. to paragraphs 3.5.7 and 3.5.7.1 of MIL-T-7378A.
3.8	Add "Provision shall be made for alternate use of 14" lug spacing.
4.1.3	Delete the Entire Paragraph
4.1.5	Delete the Entire Paragraph
4.1.6	Delete the Entire Paragraph
4.1.8	Change "Station 46" to "Station 52.1"
4.1.9	Delete the Entire Paragraph
4.1.10	Change "Station 46 to Station 52.1"
4.2.1	Change "Station 46" to Station 52.1"
4.2.3	Change Entire Paragraph to Read as Follows: Orifice well, frame and ejection tube shroud as shown on SK29100-698 and SK29100-699.
4.2.4	Change "Three to Four"; "One from station 40"to "two from station 40"
4.2.6	Change Entire Paragraph to Read As Follows: Gas lines from station 40 to center of inner tank and from center of inner tank to station 124.25.

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General Mills

SHEET iv OF iv

RELEASE DATE April 2, 1962

ENGINEERING DEPARTMENT

SPECIFICATION 29100-610

LET.

Paragraph	Change
4.2.8	Change Entire Paragraph to Read As follows: Insulation in space between inner tank and outer shell station 52.1 to station 109.5. Insulation in space between inner tank and sleeve stations 40.5 to 52.1 and stations 109.5 to 125.75
4.2.9	Change "Station 118.25 to Station 109.5
4.2.10	Change "Station 46.0 to Station 52.1";Station 118.25 to station 109.5
4.3.1	Change "Station 118.25 to Station 109.5
4.3.3	Change "Stations 133.5 and 147 to Stations 131.90 and 141.38.
4.3.4	Change Entire Paragraph to Read as follows: Fin support bulkhead and section Joint Station 159.50
4.3.5	Change Entire Paragraph to Read as Follows: Electrical compartment Stations 136.75 to 139.75
4.3.6	Change Entire Paragraph to Read as follows: Electrical compartment stations 156 to 159.50
4.3.7	Change Entire Paragraph to Read as Follows: Support ring station164 add Bulkhead section Joint station 170.
4.3.9	Change "Station 118.25 to Station 109.5"
4.4	Change "Sections to Section"
4.4.1	Change Entire Paragraph to Read as Follows: Fabrication of inner tank shell per GMI Drawing SK29100-698
5.0	Add "General Mills, Inc. Will supply air loading data.
9.0	Change "90 days to 120 days"

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SHEET 1 OF 6
RELEASE DATE April 2, 1962

ENGINEERING DEPARTMENT
SPECIFICATION GMS - 29100 - 610
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 Corporation attended by R. Lindquist and J. McGillicuddy on April 4th and 5th, 1962.

2.2 Quotation from Fletcher Corporation (T. Derlachter) to General Mills dated January 22, 1962.

2.3 Specifications MIL-A-8591B and MIL-T-7378A.

2.4 General Mills, Inc. drawings No. SK 29100-612, SK 29100-608, SK 29100-609.

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 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 SK 29100-612 shall be suitable for flight on the F-100, F-105, B-66, A-4D, A3J and the USD-5 drone 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 SK 29100-612.

3.4 The inner tank is to be supported in place and insulated from the outer skin or shell by the foamed-in-place insulation designated on GMI drawing No. SK 29100-612 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 Forward Gas Tank, Aft Gas Tank, and Center Structure of the Inner Tank, shall not exceed 325 pounds.

3.6 The contractor shall provide all materials exclusive of the Forward Gas Tank, Aft Gas Tank, Orifice Mechanism and Cover, and Center Structure of the Inner Tank, which will be supplied by General Mills, Inc.

3.7 The tank assembly is to meet the requirements of the following paragraphs of MIL-T-7378A. Where reference in those paragraphs is made to "fuel tanks" it shall be construed to refer to the tank assembly that is the subject of work statement. Also, requirements of referenced portions of applicable paragraphs are limited only to those that exist if powdered solid material is carried instead of fuel and with no requirements made for handling the powder but only for storing it in varying quantities in the inner tank. This excludes all requirements that result from the peculiar characteristics of aviation fuel in contrast to the characteristics of the powder, that arise from direct contact of a load with any part of the skin and structure and that arise from the provisions that must be made for handling fuel.

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 C and 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 range 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. The Contractor shall not be responsible for flutter problems arising from pylon or aircraft characteristics.

3.5.7.3, 3.6, 3.6.1 (Modified) - Delete "riveting through the tank wall shall not be permitted".

3.6.2 (Modified) - Delete second sentence.

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

3.7.3 (Modified) - Delete "or evidence of leakage".

3.7.7, 3.7.8, 3.8, 3.8.1, 3.8.1.1, 3.10 (Modified) - Delete "and used" from first line.

3.10.1 (Modified) - Delete "plus" from line 7 and delete completely lines 8 thru 12.

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

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

3.9 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 13

4.1.2 Two Access Doors and Frames

4.1.3 Bulkheads in Front and Aft of Forward Gas Tank Stations 22.5 and Station 30.5

4.1.4 Gas Tank Attachment Ring Station 28.5

4.1.5 Installation of Forward Gas Tank

4,1.6 Insulation between Forward Gas Tank and Outer Shell in Volume Enclosed by Bulkheads.

4.1.7 Brackets to support Valves, Pressure Regulators, etc.

4.1.8 Section Joint Ring Station 46

4.1.9 Electrical Conduit and Gas Line from Forward of Gas Tank to Aft of Gas Tank

4.1.10 Outer Shell Assembly Station 13 to Station 46

4.2 Center Section

4.2.1 Section Joint and Inner Tank Support Ring Station 46

4.2.2 Main Support Structure Including Lug Attachments, Sway Brace and Ejection Areas, and Support Rings

4.2.3 Orifice Wall and Frame

4.2.4 Three 1/2" Diameter Conduits - One from Station 40 to Station 124.5, a Second from Station 124.5 to a Station Suitable for Umbilical Connection Provisions, and a Third from Station 124.25 to the Orifice Wall.

4.2.5 Connector Well, Connectors, and Well Cover for Umbilical Connection Provisions

4.2.6 Gas Lines from Station 40 to Center of Inner Tank and from Station 124.5 to Ends of Inner Tank

4.2.7 Installation of Inner Tank

4.2.8 Insulation in Space between Inner Tank and Outer Shell Station 46 to Station 118.25

4.2.9 Section Joint and Inner Tank Attachment Ring Station 118.25

4.2.10 Outer Shell Assembly Station 46 to Station 118.25

4.3 Tail Section

4.3.1 Section Joint Ring Station 118.25

4.3.2 Two Access Doors and Frames

4.3.3 Support Rings for Actuator Stations 133.5 and 147

4.3.4 Bulkhead Forward of Aft Gas Tank Station 159

4.3.5 Aft Gas Tank Support Ring Station 162.5

4.3.6 Installation of Aft Gas Tank

4.3.7 Insulation in Space between Aft Gas Tank and Outer Shell Station 159 to Station 180

4.3.8 Brackets to Support Valves, Pressure Regulators, and Electrical Components in Aft Compartment

4.3.9 Outer Shell Assembly Station 118.25 to Station 180

4.4 Inner Tank Shell Sections

4.4.1 Fabrication of Two Sections of Inner Tank Shell per GMI Drawings SK 29100-608 and SK 29100-609

4.5 Additional Structural Members

4.5.1 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

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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) Formulas and equations used with source references
(d) Actual calculations
(e) Tabulation of results

Loading conditions considered in the structural analysis are to include, in addition to inertia loads, aerodynamic drag, side loads, vertical loads, pitching moment and yawing moment.

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
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General Mills

SHEET i OF iii

RELEASE DATE April 3, 1962

ENGINEERING DEPARTMENT

SPECIFICATION GMS-29100-611

LET.

GENERATOR, RAM AIR DRIVEN

ECO NO.	REV.	REMARKS	DATE	INIT.

APPROVED BY

ENGINEER

J. L. McGillicuddy PROJECT ENGINEER

CHIEF PROJECT ENGINEER

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General Mills

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RELEASE DATE April 3, 1962

ENGINEERING DEPARTMENT

SPECIFICATION GMS-29100-611

LET.

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 a unit similar to the Allison Division of General Motors Corporation, Model GA1240H-92.

1.2 Classification - The 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-6099A	Generators and Regulators, Aircooled A-C, Aircraft General Specification for, dated 25 March 1957.
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 2 September 1958.
MIL-STD-210A,Chg.1	Climatic Extremes for Military Equipment dated 30 November 1958.

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Drawings:

GMI SK29100-603 Generator-Ram Air Driven dated 2/21/62.

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 GA124GH-92 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 - five and one-fourth 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, being driven 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 (356-450 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 SK29100-603).

3.4.5 Structure

3.4.5.1 Mounting Provisions - Generator mounting provisions shall be as shown on the outline drawing, (GMI SK29100-603).

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 similar 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-R-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 ± 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 High Temperature Start - 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 Generator Performance

3.5.5.1 Wave Form - 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-6099A.

3.5.5.2 Short Circuit Capacity - 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 Unbalanced Load - 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.

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 High Temperature Start - 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 Generator Performance

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3.5.5.3 Unbalanced Load - 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 percent.

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
4.5 KVA, p. f. = .75-1.0	108-122

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, 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 wind tunnel testing.

Load I - No load
Load II - Balanced 3 phase, 1700 VA at 1.0 PF
Load III - Balanced 3 phase, 3400 VA at 1.0 PF

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 within the specified governing rpm range, at 300 KEAS, 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 III 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 III 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 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.

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. 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.

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.

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ELECTRONIC DIVISION
1620 CENTRAL AVENUE, MINNEAPOLIS 13, MINNESOTA

General Mills

SHEET 1 OF 1

RELEASE DATE 5/22/62

ENGINEERING DEPARTMENT

SPECIFICATION GIS - 29100 - 669

LTR.

SPECIFICATION FOR A NITROGEN STORAGE
AND CONTROL SYSTEM
BUILT BY
TAVCO INCORPORATED

ECO NO.	REV.	REMARKS	DATE	INIT.
	A	Changes shown on sheet 10	12/7/62	GL

APPROVED BY

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ELECTRONIC DIVISION
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1620 CENTRAL AVENUE, MINNEAPOLIS 13, MINNESOTA

General Mills

SHEET 1 OF 10
RELEASE DATE 5/22/62

ENGINEERING DEPARTMENT
SPECIFICATION GMS - 29100 - 669

SPECIFICATION FOR A NITROGEN STORAGE AND CONTROL SYSTEM BUILT BY TAVCO INCORPORATED

1.0 SCOPE

This specification pertains to a pneumatic system which stores nitrogen gas under 3000psi pressure over an extended period of time, and provides a constant pressure for a predetermined rate of flow upon electrical excitation of the solenoid shut off valve.

2.0 APPLICABLE DRAWINGS AND SPECIFICATIONS

Drawings	Description
SK29100-668	Dry Nitrogen Handling System Schematic
SK29100-677	Installation Layout
SK29100-606	Reservior - Dry Nitrogen, Showing outline dimensions
23111126	Tavco System Assembly Drawing - Also Part Number Of the System

Specifications	Description
MIL-R-8573A(ASG)	Reservoir, Air (Limited Portions Only)
MIL-C-490	Phosphate Coating
MIL-R-3043	Resin coating
MIL-C-5055	Coating Application
MIL-T-5021	Welding
MIL-W-8611	Welding
MIL-I-6865	X-Ray
MIL-H-6875	Heat Treatment
MIL-I-6868	Magnetic Particle Inspection
MIL-S-5002	Passivation
MIL-A-8625	Anodizing - Grey
MIL-STD-130	Nameplates
MIL-STD-129	Marking for Shipment

Specifications	Description
AN or MS Standards	Bosses and Fittings
MIL-E-5272	Environmental Testing
MIL-P-8564 (ASG)	Pneumatic System Components, General
MS-24478	Gage
MIL-S-4040	Solenoid
MIL-Q-9858	Quality Control System

3.0 GENERAL REQUIREMENTS OF THE SYSTEM

3.1 Purpose

The basic purpose of the system is to store dry nitrogen under 3000 psi pressure and provide the necessary valves and regulators for safe and efficient control of the flow of nitrogen. The pressure in the storage vessel is regulated to give a constant discharge pressure as the nitrogen is used. Valves are provided for charging the vessel, manually and electrically shutting off the flow, flowing nitrogen through the regulator for adjustment purposes, and relieving excess pressure to the atmosphere. Pressure gauges are provided upstream and downstream of the regulator for charging and flow regulation purposes.

3.2 Design

The nitrogen storage and control system shall conform to the applicable portions of the drawings and specifications listed herein and the detail requirements of this specification so as to fulfill the purpose for which it is intended to be used.

3.3 Components

The system consists of two major subassemblies; the pressure vessel assembly and the control valve assembly, which are composed of the following:

3.3.1 Pressure Vessel Assembly;
- Pressure Vessel
- Mounting Brackets
- Pressure Connections

3.3.2 Control Valve Assembly
Solenoid Valve
Pressure Regulator
High Pressure Relief Valve No. 1
Low Pressure Relief Valve No. 2
Manual Shut Off Valve
Gage - 5000 psi
Gage - 200 psi
Charge and Drain Valve
Ground Checkout and Control Valve
Suitable Pressure Connections

3.4 Envelope

The pressure vessel and control valve assemblies shall be designed to fit in the space provided as shown on SK29100-677. The arrangement of the components and outline of the system assembly shall be as shown on 23111126 as approved by General Mills. The components shall be arranged so that the ground crew can see the gages, make and break the electrical and pressure connections, and adjust the manual shutoff valve and pressure regulator, all from the access door. The exit port of the system shall be a MS 33656-8 Style E fitting pointed in the direction of downstream connector.

3.5 Environmental Conditions

The system as assembled shall perform satisfactorily when submitted to the following conditions:

3.5.1 Temperature
The ambient temperature range is -65 F to +250 F.

3.5.2 Acceleration
The maximum inertial loadings are 10 "g" which may be applied in any direction relative to the system.

3.5.3 Vibration
The maximum vibration frequency is 2000 cycles/minute with a double amplitude of .020 inch.

3.5.4 Atmospheric

Conditions of 0 to 70000 feet altitude and all conditions of relative humidity from 0 to 100%.

3.6 Pressure Rating

The system shall operate at a nominal pressure of 3000 psi. All components shall be rated to operate at their respective pressures and meet a proof pressure test of 1.67 times the operating pressure and 2.25 times the operating pressure for burst.

3.7 Leakage

External leakage shall be zero at ambient to +250 F, and not more than 1.0 cc standard air per minute at -65 F. The internal leakage is specified for the individual components.

3.8 Rated Flow

The system shall be capable of supplying a flow of 25 SCFM with the inlet pressures varying from 3000 to 300 psig and with an outlet pressure range of 100 to 30 psig plus or minus 5%.

4.0 REQUIREMENTS FOR DESIGN OF THE CONTROL VALVE ASSEMBLY

The individual components making up the control valve assembly must meet the following specifications:

~~4.1~~
4.1 Solenoid Shut Off Valve

It shall be a normally closed, maintained contact valve, rated for continuous duty at maximum operating conditions. It shall open at 3000 psi with a maximum current consumption of 2 amps with 25 to 31 volts d.c. applied. The v valve shall meet applicable portions of MIL-S-4040. It must permit a flow of 25 SCFM with 3000 psi to 300 psi at the inlet and pressure drop compatable with the system performance of this specification. The allowab le internal leakage is 3 cc/hr from 300to 3000 upstream pressure with the valve in the normally closed position. The design shall be fail safe in the closed position

The electrical connector shall be a MS3106E - 10SL-4P. The valve shall be designed to withstand a minimum of 20,000 cycles of close-open-close with a 3000 psi supstream pressure.

4.2 Pressure Regulator

The regulator shall control the outlet pressure at a set value with an accuracy of ±5% of the set value, for an inlet pressure range of 300 to 3000 psi and with a flow rate of from3 to 25 SCFM. Provisions shall be made for outlet pressure adjustment within the range of 30 to 100 psig. Adjustment must be accomplished with the system installed and shall be secured to hold adjurtment under the maximum inertial loadings and vibration conditions. No lockup provisions are required and the fail safe condition is open.

4.3 High Pressure Relief Valve No. 1

Shall be rated to crack at 3400 psig maximum, reseat at 3100 psig minimum, and flow a minimum of 5 SCFM at 3500 psig. There shall be no zero leakage below crack on increasing pressure and reseat or decreasing pressure.

4.4 Low Pressure Relief Valve No. 2

Shall be rated to crack 150 psig maximum, reseat at 110 psig minimum, and flow a minimum of 10 SCFM at 175 psig. There shall be zero leakage below crack on increasing pressure and reseat on decreasing pressure.

4.5 Manual Shut Off Valve

Operating pressure is rated at 3000 psi. It shall handle system flow rates with a minimm equivalent orifice diameter of .15 inches in the fully open position. The value Stem can terminate in a hex socket for speed wrench operation. The internal leakage shallnot exceed 1 cc/hour with the valve in the closed position and 3000 psi upstream pressure. The valve must have provisions to securely hold in the wide open and fully closed positions under inertial loadings and vibration conditions.

4.6 Gage - 0 to 5000 psi

It shall be calibrated in 100 psi increments and be accurate to plus or minus 50 psi over the full scale. No leakage from the internal to the atmosphere is permitted, and the case shall be constructed so that external fluids shall not enter.

4.7 Gage - 0 to 200 psi

It shall be calibrated in 5 psi increments and be accurate to plus or minus 2.5 psi over the full scale. No leakage is permitted to the atmosphere, and the case shall be constructed so that external fluids shall not enter.

4.8 Charge and Drain Valve

This valve must provide means of pressurizing the storage vessel to 3000 psi at a maximum rate of 15 SCFM. The valve is shut off using a wrench and shall have zero leakage from 0 to 3000 psi. Provisions shall be made so that the valve can be used to bleed fluid from the storage vessel at pressures of 3000 to 0 psi. The valve must mate with an AN818 nut and AN819 sleeve for charging purposes.

4.9 Ground Checkout and Control Valve

This valve shall permit the system to be pressurized from a ground source in order that the regulator outlet pressure may be adjusted. This valve is to be ported so that the ground source nitrogen will enter the system immediately upstream of the regulator, will flow through the regulator and past the low pressure gauge and out into the atmosphere. The valve must shut off flow to any components downstream of the system during its operation. The valve shall be manually shut-off with a speed wrench and not leak or otherwise affect the function of the airborne automatic control system. The valve shall permit a flow of 15 SCFM through the regulator when 2000 psi is supplied from the ground source.

5.0 REQUIREMENTS FOR THE DESIGN OF THE PRESSURE VESSEL ASSEMBLY

The pressure vessel assembly shall provide a means of storing dry nitrogen gas at system operating pressures. The vessel shall incorporate installation mounting provisions for the control valve assembly and the [illegible] system attachment points. The four brackets spaced at 90 degree intervals around the circumference of the pressure vessel on a 15.000 inch diameter bolt circle shall be sloted for 1/4 - 28 UNF bolts to allow for expansion during filling of the vessel. The number of brackets shall be kept at a minimum. The weld beads shall be held to a minimum height above the surface of the vessel and shall be free of any sharp edges which would tend to cut the heating element which will be laced to the exterior of the vessel.

The volume of the pressure vessel shall be at least 1480 cubic inches and its shape shall conform to the outline drawing SK29100-606 and TAVCO drawing 23111126. The vessel shall meet the applicable portions of MIL-R-8573A except gunfire. The vessel is type 30-40 Class B. The sections of MIL-R-8573A (ASG) which are <u>not</u> applicable for this application are the following:

Section	Description
1.2.3	Sizes
2.0 NAVSHIPS NO. 250-692-2	Substitute weld per MIL-W-8611
3.1	Preproduction sample
3.4.1.1	Formula
3.4.1.2	Formula
3.4.4	Draining
4.2	Preproduction Tests
4.3.2	Sampling Tests
4.3.3	Rejection and retest
4.4.3	Cycling
4.4.5.2	Extreme Temperature Leakage
4.4.6	Physical
4.4.7	Internal Finish

Section	Description
4.4.8	Macrostructure
4.4.10	Hydrostatic burst
4.4.11	Gunfire
5.0	Preparation for delivery

6.0 BURST PRESSURE VESSEL

One pressure vessel shall be built to the same design as the system vessel and then subjected to cycling and burst tests. The cycling shall be a minimum of 500 cycles of 200 to 3000 to 200 psi. The burst test shall consist of pressurizing the vessel to the point of burst and recording the burst pressure and type of failure. If the test vessel fails to meet the required minimum burst pressure of 6667 psi, then TAVCO shall redesign the vessel and run another burst test.

7.0 TOTAL SYSTEM WEIGHT

The weight of one complete assembled system shall not exceed 39.0 pounds.

8.0 CLEANING OF THE SYSTEM

While assembled the system will be cleaned periodically and must be able to withstand exposure to external flooding with the following agents, without reducing the functional reliability of the system. The period of exposure is estimated to be five minutes at any one time.

8.1 Cleaning Agents

8.1.1 Saturated steam at 250 F.

8.1.2 Formaldehyde (HCHO) at 70 F

8.1.3 Lysol solution (Creslyic acid plus ortho-hydroxydiphenyl and soap) at 70 F.

8.1.4 Roccal (Alkyd dimenthylbenzyl-ammonium chloride), a quaternary amine or "quaternary ammonia". It is a product of Winthrop-Stearns Lab., 1450 Broadway, New York 18, New York

9.0 MATERIALS

All metals exposed to the ambient must be either stainless steel passivated per MIL-S-5002 or aluminum alloy anodized per MIL-A-8625. All elastomers exposed to the ambient must be compatible with the agents specified in paragraph 8.1. A recommended elastomer is Minnesota Rubber's compound 366Y Buna - N, or an equivalent.

10.0 IDENTIFICATION

All components must be identified per MIL-STD-130. The nameplates must be legible and adhere to the surface on which they are applied, under all conditions of this specification.

11.0 QUALITY CONTROL

TAVCO shall provide an approved quality control system in accordance with MIL-Q-9858.

12.0 QUALITY ASSURANCE PROVISIONS

Each component and the system as a whole shall be subjected to the following tests during the course of their manufacture:

Functional Check
Proof Pressure
Leakage at operating pressure
Interim and final inspection
Radiograph of all welds
Magnaflux of all Ferrous alloys
Verification of all heat treatments of metals
Burst Pressure (One vessel only)

TAVCO shall furnish a certification that all conditions of this specification have been met. TAVCO shall keep records of all tests, to be available for inspection upon request.

The Following changes [illegible] [illegible] as of 12/7/62

Section	Changes
[illegible] Par. 2	[illegible] connector shall be a MS 3106E - 10SL - 3P.
[illegible]	Remove this sentence. No lock is necessary.
4.0 Drawings	Substitute SK29100-678 for SK29100-677.
3.4 1st Sentence	..... shown on SK29100-678.

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

APPENDIX B

FLIGHT TESTS OF PROTOTYPE AIRBORNE BW SPRAY TANKS ON THE A-4C (A4D-2N) AIRCRAFT

INTERIM REPORT NO. 1

NAVAL AIR TEST CENTER
WEAPONS SYSTEMS TEST DIVISION
PATUXENT RIVER, MARYLAND

airplane, to determine if disseminated powder (talc) had come in contact with the airplane. Prior to the test flight, a satisfactory functional test was performed with the spray tank mounted on the test airplane. This included both armament and dissemination tests.

6. The spray tank functioned without a mechanical discrepancy during a 56-minute air flight. The only electrical discrepancy noted during the flight was the GEN OFF light which illuminated momentarily each time the dissemination process was initiated. This discrepancy has no apparent effect on the dissemination and was not objectionable to the pilot. Twelve disseminations runs were made at altitudes from 300 to 2,000 feet and 350 to 520 knots indicated airspeed (KIAS). The dissemination period was approximately 45 seconds for each of nine runs and on three runs the dissemination period was approximately one minute per run. Dissemination occurred while the pickle button, located on the left side of the control stick, was depressed. The pilot noted a slight hand discomfort while keeping the pickle button depressed for periods of time in excess of approximately 45 seconds. The correction of this discrepancy should be considered in future design for improved service use. The spray tank and the test airplane maintained their structural integrity during the captive flight portion of the test to 570 KIAS and 0.895 Indicated Mach Number (IMN) in 1 g flight and during normal accelerations from 0 to 6 g at 380 to 450 KIAS.

7. No unusual ground handling or flight characteristics were encountered during the taxi and flight test. At 570 KIAS and at 0.895 IMN, a slight nose down pitch and light airframe buffet was encountered. However, these characteristics were not considered to be deficiencies. Results of the test conducted with the spray tank on the A-4B airplane are considered applicable to the A-4B, A-4C and A-4E airplanes.

8. During postflight inspection, no evidence of powder deposits on the airplane were discovered. However, the three strips of lightly greased ordnance tape were not on the airplane after the test flight. The underside of the spray tank aft of the dissemination nozzle had evidence of the talc, and the inside of the dissemination nozzle fairing was heavily contaminated.

9. After a limited test with the GMI dry agent dissemination tank system, it is concluded that:

a. The GMI BW spray tank is completely compatible with the Aero 7A centerline rack of the A-4B airplane (paragraph 3).

b. The GMI BW spray tank does fit satisfactorily on the Aero 20A wing racks of the A-4B airplane (paragraph 3).

c. The contractor's control panel for the GMI BW spray tank does satisfactorily fit the A-4B cockpit, was easily readable and conveniently located for pilot use (paragraph 4).

d. Ground function tests were satisfactory (paragraph 5).

e. The system functioned satisfactorily at altitudes from 300 to 2,000 feet and airspeeds of 350 and 570 KIAS for dissemination periods of approximately [illegible]5 and 60 seconds (paragraph 6).

f. The GMI BW spray tank can be safely carried at airspeeds up to 570 KIAS and 0.895 IMN, and during normal accelerations from 0 to 6 g at 380 to 4[illegible]0 KIAS (paragraph 6).

g. The GMI BW spray tank does not cause any unusual taxi or flight characteristics (paragraph 7).

h. The GMI BW spray tank does not deposit spray powder on the A-4B airplane during in-flight dissemination but does leave deposits on the spray tank itself (paragraph 8).

i. The results of tests conducted with the A-4B airplane are applicable to the A-4B, A-4C and A-4E airplanes (paragraph 7).

10. It is recommended that:

a. Elimination of the requirement to keep the pickle button depressed during dissemination should be considered in future design for improved service use.

b. The GMI BW spray tank be cleared to the flight limitation described in this report.

c. Further testing be conducted on the wing stations of a suitably configured A-4 type airplane.

JAMES E. VOSE, JR.
Acting

S/ G. H. SULT
By direction

DEPARTMENT OF DEFENSE
WASHINGTON HEADQUARTERS SERVICES
1155 DEFENSE PENTAGON
WASHINGTON, DC 20301-1155

MEMORANDUM FOR DEFENSE TECHNICAL INFORMATION CENTER
(ATTN: WILLIAM B. BUSH)
8725 JOHN J. KINGMAN ROAD, STE 0944
FT. BELVIOR, VA 22060-6218

AUG 1 2013

SUBJECT: OSD MDR Cases 12-M-3144 through 12-M-3156

At the request of [redacted], we have conducted a Mandatory Declassification Review of the documents in the above referenced cases on the attached Compact Disc (CD) under the provisions of Executive Order 13526, section 3.5, for public release. We have declassified the documents in full. We have attached a copy of our response to the requester. If you have any questions, please contact Ms. Luz Ortiz by phone at 571-372-0478 or by e-mail at luz.ortiz@whs.mil, luz.ortiz@osd.smil.mil, or luz.ortiz@osdj.ic.gov.

Robert Storer

Robert Storer
Chief, Records and Declassification Division

Attachments:
1. MDR request w/ document list
2. OSD response letter
3. CD (U)

April 26, 2012

[redacted]

Department of Defense
Directorate for Freedom of Information and Security Review
Room 2C757
1155 Defense Pentagon
Washington, D.C. 20301-1155

Sir:

I am requesting under the Mandatory Declassification Review provisions of Executive Order 13291, copies of the following documents. I have tried several times to acquire them through DTIC, but the sites stated they are not available.

I am conducting research into the previous methods used to disseminate biological agents. Many source I use to have access to have been deleted from the internet. On numerous occasions I have been informed that formerly classified information that was declassified, have now become classified again (since 911). My attempts to locate such Executive Orders, regulations, laws, or other changes to this question have not successful nor revealed a specific source. As such I would appreciate any information you can shed on this question.

Documents requested.

AD 348405, Dissemination of Solid and Liquid BW (Biological Warfare)Agents Quarterly 12-M-3144 Progress Report Number 14, 4 Sept - 4 Dec 1963, G. R. Whitnah, February 1964, General Mills Report number 2512, General Mills, Inc., Minneapolis, MN, Contract number DA 18064 CML 2745, 102 pages. Prepared for U.S. Army Biological Laboratories, Fort Detrick, Maryland. Approved by S.P. Jones, Director of Aerospace Research at General Mills. Project No. 82408. General Mills Aerospace Research Division, 2295 Walnut Street, St. Paul 13, Minnesota.

AD 346751, Dissemination of Solid and Liquid BW (Biological Warfare) Agents, Quarterly 12-M-3145 Progress Report Number 12, March 4 - June 4, 1963, G. R. Whitnah, July 1963, General Mills Report number 2411, General Mills, Inc., Minneapolis, MN, Contract number DA 18064 CML 2745. 184 pages. Approved by S.P. Jones, Director of Aerospace Research at General Mills. Project No. 82408. General Mills Aerospace Research Division, 2295 Walnut Street, St. Paul 13, Minnesota.

AD 346750, Dissemination of Solid and Liquid BW (Biological Warfare) Agents, Quarterly 12-M-3146 Progress Report Number 13, 4 June - 4 Sept 1962, G.R. Whitnah, October 1963, General Mills

12-M-3144

Report number 2451, General Mills, Inc., Minneapolis, MN, Contract Number DA 18064 CML 2745. 19 pages (?)

AD 332404, Dissemination of Solid and Liquid BW (Biological Warfare) Agents, Quarterly Progress Report Number 7, Dec. 4, 1961 - March 4, 1962, by G.R.Whitnah, February 1963, General Mills Report Number 2373, General Mills, Inc., Minneapolis, MN, Contract Number DA 18064 CML 2745. 123 pages. 12-M-3147

AD 333298, Dissemination of Solid and Liquid BW (Biological Warfare)Agents, Quarterly Progress Report Number 9, June 4, 1962 - Sept. 4, 1962. by G.R. Whitnah, October 1962, General Mills Report Number 2344, General Mills, Inc., Minneapolis, MN, Contract Number DA 18064 CML 2745. 130 (or 150) pages. 12-M-3148

AD 332405, Dissemination of Solid and Liquid BW (Biological Warfare) Agents, Quarterly Progress Report Number 8, Period March 4, 1962 - June 4, 1962. G.R. Whitnah, August 1962, General Mills Report Number 2322, General Mills, Inc., Minneapolis, MN, Contract Number DA 18064 CML 2745. 198 pages. 12-M-3149

AD 329067, Dissemination of Solid and Liquid BW (Biological Warfare) Agents, Quarterly Progress Report Number Six, G.R. Whitnah, February 1962, General Mills Report Number 2264, General Mills, Inc., Minneapolis, MN, Contract Number DA 18064 CML 2745. 103 pages. Approved by S.P. Jones, Manager, Materials and Mechanics Research, General Mills Research and Development Office, 2003 East Hennepin Avenue, Minneapolis 13, Minnesota. 12-M-3150

AD 327072, Dissemination of Solid and Liquid BW (Biological Warfare) Agents, Quarterly Progress Report Number Five, 4 June - 4 Sept 1961. by G.R.Whitnah, November 1961, General Mills Report Number 2249, General Mills, Inc., Minneapolis, MN, Contract Number DA 18064 CML 2745. 12-M-3151

AD 325247, Dissemination of Solid and Liquid BW (Biological Warfare) Agents, Quarterly Progress Report Number 4, 4 March - 4 June 1961, by J.E. Upton for G.R. Whitnah, Project Manager. February 1963, General Mills Report Number 2216, General Mills, Inc., Minneapolis, MN, Contract Number DA 18064 CML 2745. General Mills Electronics Group, Research Dept., 2003 East Hennepin Avenue, Minneapolis 13, Minnesota. 225 pages. 12-M-3152

AD 324746, Dissemination of Solid and Liquid BW (Biological Warfare) Agents, Progress Report 3 Juen - 3 Sept. 1960. by G.R. Whitnah, October 1960, General Mills Report Number 2125, General Mills, Inc., Minneapolis, MN, Contract Number DA 18064 CML 2745. 78 pages 12-M-3153

AD 323599, Dissemination of Solid and Liquid BW (Biological Warfare) Agents, Quarterly Progress Report Number 2, for period 4 Sept - 4 Dec 1960, by G.R. Whitnah, February 1961, General Mills Report Number 2161, General Mills, Inc., Minneapolis, MN, Contract Number DA 18064 CML 2745. 90 pages? Mechanical Division of General Mills, Inc., Research Department, 2003 East Hennepin Avenue, Minneapolis 13, Minnesota. 12-M-3154

AD 323598, Dissemination of Solid and Liquid BW (Biological Warfare) Agents, Quarterly Progress Report, for period 4 Dec. 1960 - 4 March 1961, by G.R. Whitnah, May 1961, General Mills Report Number 2200, General Mills, Inc., Minneapolis, MN, Contract Number DA 18064 CML 2745. 95 pages. 12-M-3155

AD 337635, Dissemination of Solid and Liquid BW (Biological Warfare) Agents, Quarterly Progress Report No. 10, period Sept. 4, 1962 - Dec. 4, 1962. G.R. Whitnah, Project Manager, Approved by S.P. Jones, Aerospace Research, February 1963. 247 pages. 12-M-3156

Sincerely

[redacted]