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INVESTIGATION OF THE REQUIREMENTS FOR COMBINED ENVIRONMENT TESTING OF AIR FORCE MATERIEL

VOLUME II
(APPENDIXES)

E. R. WILSON
W. P. RADER
H. N. McGREGOR
J. D. DONAHUE

MARTIN-MARIETTA CORP.
(DENVER DIVISION)

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FOREWORD

This report was prepared by the Martin-Marietta Corporation, Denver, Colorado, on Air Force Contract AF 33(615)-1313, of Project 1309, "Investigation of the Requirements for Combined Environment Testing of Air Force Materiel". The work was administered under the direction of the Air Force Flight Dynamics Laboratory, Research and Technology Division. Mr. Carl W. Gerhardt was task engineer for the Laboratory.

The investigation began in March 1964 and was completed in June 1965 with Mr. H. N. McGregor acting as project engineer for the Martin Company. The manuscript was released by the authors in August 1965 for publication as an RTD technical report.

Although the investigation was a group effort, the chief contributors and their fields of interest were: E. R. Wilson, test conductor; W. P. Rader, data reduction; and J. D. Donahue, statistical data analyst.

This report concludes the work on Contract AF 33(615)-1313.

Publication of this report does not constitute Air Force approval of the report's findings or conclusions. It is published only for the exchange of ideas.

William C. Savage
WILLIAM C. SAVAGE
Chief, Environmental Control Branch
Vehicle Equipment Division
Air Force Flight Dynamics Laboratory

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ABSTRACT

A series of experiments was statistically designed and conducted to determine the effect of environments singularly and in combination upon the performance of a specimen representative of typical aircraft or missile equipment.

The test specimen consisted of electronic, mechanical, and hydraulic components assembled in a manner which would produce a measurable deviation from a reproducible norm when subjected to combinations of the following eight environments:

1. High Temperature
2. Low Temperature
3. Thermal Shock
4. Altitude
5. Humidity
6. Vibration
7. Mechanical Shock
8. Sustained Acceleration

The experiments consisted of 8 single-environment tests, 21 combinations of 2 environments, 25 combinations of 3 environments, and 4 combinations of 4 environments. In general, the results of the experiments indicated that the response or deviation from the norm of the test specimen when subjected to multiple environments was greater than the sum of the environments when taken independently. The combinations involving altitude, vibration, high and low temperature, relative humidity and thermal shock produced the greatest interaction while the combinations involving mechanical shock and sustained acceleration produced much smaller interactions.

This section (Volume II) contains Appendixes A through D which are a detailed treatment of the statistical analysis employed in designing the multi-environment experiments and the analysis of the test results.

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APPENDIX A

INVESTIGATION THROUGH EXPERIMENTAL DESIGN

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A. Introduction

Many experimental situations require the examination of the effects on a response variable of deliberate variations in two or more variables which are hypothesized to be important in a physical process. It may be shown that in a complete exploration of such a process, it is not sufficient to vary one variable at a time. Indeed, several combinations of different variable settings (each combination representing a "treatment") must be examined in order to elucidate the effect of variations in each variable and the possible ways in which each variable reacts to variations in other pertinent variables in the process.

In the investigation of the experimental results, by the methods of Analysis of Variance, the effect of each variable can be determined with the same accuracy as if only one factor had been varied at a time; and, in addition, the interaction effects between the factors can also be evaluated.

Experimental designs are generally intended to determine the effects of one or more variables on some measure of "response" such as the yield of a product, the resistance of a material to a chemical process, etc.

A considerable advantage is gained if the experiments are designed so as to assess the effect of changing one variable independently of other changes. One method of achieving this objective is to decide upon a set of values, or levels, for each of the factors to be studied, and to carry out one or more trials of the process with each of the possible combinations. A set of levels, one for each factor, is termed a treatment. Experimentation with an adequate number of treatments will provide sufficient information with which to explore the entire response surface. Such experiments are called Factorial Designs. This term is also extended to modified designs in which the number of trials, due to economic or time limitations, is restricted in certain well-defined ways.

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A generally useful technique then is provided by the factorial design with which to study variations in the response variable produced by deliberate changes in the experimental conditions. The following terms are defined in order to further discuss the analysis of variance procedures.

Factor - This term generally denotes any experimental variable. In this case, such environmental variables as altitude, high temperature, and vibration are denoted as factors.

Level of Factor - The various values of a factor or variable at which the response variable is measured in the experiment are known as levels. A variable such as altitude will be examined within a certain range or factor spece. Discrete points, within the factor space, will be chosen at which to run the experiment. These points, say A_1, A_2, and A_3, will be chosen at will by the investigator. The points 620 mm, 310 mm, and 5 mm, for example, could be chosen arbitrarily as levels at which to investigate the factor altitude.

Effect of a Factor - The effect of a factor is a numerical estimate of the change in the response resulting from a change in the level of the factor. When the factor is examined at two levels only, the effect is simply the average difference between the mean responses of all trials carried out at the first level of the factor and that of all trials at the second level.

Main Effects and Interaction - Each average used in deriving the effects of a factor is an average taken over all levels of the other factors. For example, the averages of the two levels of altitude are taken over all levels of high temperature and over all levels of vibration. The difference between the levels of altitude may

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not be the same at all levels of vibration. The average effect is called the main effect of the factor and, if the effect of one factor is different at different levels of another, the two factors are said to interact. In some experiments we might expect interactions to play an important role. Consider figure 1, which presents hypothetical but feasible curves relating the response variable to altitude at two levels of high temperature; the trials being made at four altitudes, A_1, A_2, A_3, and A_4, and two levels of high temperature, HT_1 and HT_2. The effects of changing the high temperature from HT_1 to HT_2 at the four altitudes are seen to be:

at A_1 - a moderate effect;

at A_2 - a large reduction in output;

at A_3 - a large increase in output;

at A_4 - very little effect.

The effect of one factor thus depends on the level of the other factor, and the two variables interact. When A is also at two levels, the interaction is numerically defined as the effect of HT at A_1 minus the effect of HT at A_2. The interaction is symmetrical in the two factors, and its value is the same whether expressed as the variation in the effect of HT at different levels of A, or as the variation in the effect of A at different levels of HT. In Figure 1, the interaction between HT and A is large and complex; if the experiment had been run at only two levels of altitude the interaction could have been either negligible (A_1 and A_4), large and positive (A_1 and A_2), or large and negative (A_2 and A_3).

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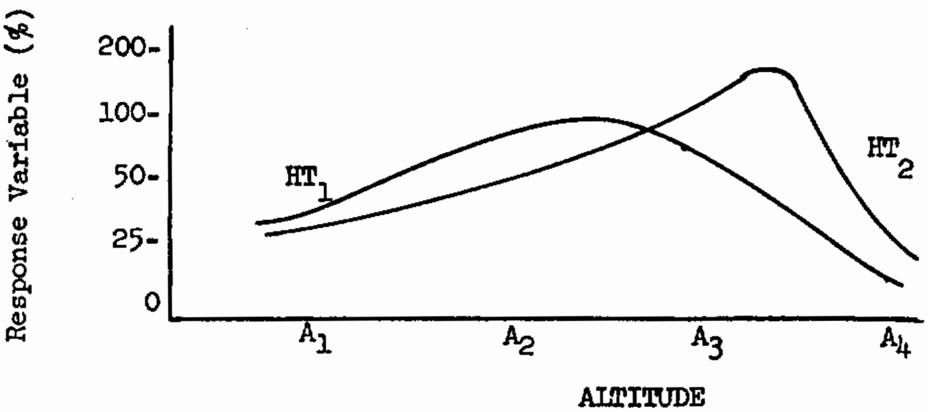

Figure 1 - Effect of High Temperature and Altitude on Yield, Illustrating Interacting Factors

The example is exaggerated, since the altitude levels are obviously too widely spaced, but it illustrates the strong interactions that may occur in these experiments when insufficient attention is paid to factor level spacing.

The advantages of a factorial design can easily be illustrated by means of a simple two-factor experiment. Let the factors in this general discussion be denoted as A and B, and denote their low and high levels as A_1, A_2 and B_1, B_2 respectively.

The one-factor-at-a-time approach requires a minimum of three trials to give information on both factors. Let these three trials be denoted as A_1 B_1, A_2 B_1, and A_1 B_2. These experimental results may be tabularized as follows:

TABLE I

FACTOR A	FACTOR B	
	B_1	B_2
A_1	(1)	(2)
A_2	(3)	

Experiments Taken in the One-Factor-At-A-Time Approach

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The effect of changing factor B is given by (2)-(1) and that of changing factor A by (3)-(1). Because of experimental error some confirmation is desirable; and one way of obtaining this is to duplicate or replicate each of the trials, the effects being deduced from the averages of the duplicated responses.

Consider now the addition of experiment A_2B_2 as(4) which completes the factorial design. The effect of Factor B is estimated by (2)-(1) at A_1 and by (4)-(3) at A_2. If there is no interaction between the factors these estimates will differ only because of experimental error, and the average of the two estimates gives the effects of factor B just as precisely as the duplicated observations of (1) and (2). Similarly, the effect of factor A is estimated by (3)-(1) and (4)-(2); if there is no interaction this estimate is as precise as one based on duplicate trials of (3) and (1). Thus, in the absence of an interaction, the four trials of the factorial design estimate the effects of the two factors with the same precision as the six trials of the duplicated One-Factor-at-a-time approach. All four observations are used in estimating each effect and the estimate is as precise as though only one factor were involved; whereas, in One-Factor-at-a-time design only two-thirds of the observations are used.

Now compare the two designs when the factors interact. If from Table I it were found that both A_1B_2 and A_2B_1 gave a better result than A_1B_1, a natural conclusion would be that A_2B_2 would be <u>even better</u>. This involves the assumption that A and B do no interact; but as shown in Figure 1, such an inference may be seriously in error. Alternatively, it might be found that B_2A_1 and A_2B_1 are little if any better than A_1B_1, but it is possible that A_2B_2 may be much better. The One-Factor-at-a-Time design would miss the most favorable treatment. If the factors interact, therefore, the One-Factor approach may lead to the wrong conclusion.

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In summary:

a) When there are no interactions the factorial design gives the maximum efficiency in the estimation of the effects.

b) When interactions exist, their nature being unknown, a factorial design is necessary to avoid misleading conclusions.

c) In the factorial design the effect of a factor is estimated at several levels of the other factors, and the conclusions hold over a wide range of conditions.

These conclusions are based on a 2^n design and hold with even greater emphasis when more than two factors are involved.

B. The 2^n Factorial Design

The simplest class of factorial design is that involving factors at two levels, that is a 2^n class, n being the number of factors. The results of changing two or more factors can be studied by the most efficient method with this class of design. By an efficient method is meant one which obtains the required information with the required degree of precision and with the minimum expenditure of testing. In the case where some prior knowledge of the effects of the factors and their interactions is available it is possible to reduce the amount of testing required by using a modified or fractional factorial design. A modified design for use in the environmental testing program is discussed in Appendix C.

A detailed summary of the 2^n design is given in order to provide a firm foundation for the discussion of the analysis used in the combined environments testing program.

The postulated setup in the simple 2^n factorial design is as follows: The response variable in a treatment with one factor, say A, at its i^{th} level, and the other factor, say B, at its j^{th} level, for the k^{th} trial is written as:

$$Y_{ijk} = \mu + A_i + B_j + (AB)_{ij} + \epsilon_{ijk}$$

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where:

μ = the mean response of all trials in the experiment,

A_i = the mean of all trials in which A is at its i^{th} level, measured from the true mean μ,

B_j = the mean of all trials in which B is at its j^{th} level, measured from the true mean, μ,

$(AB)_{ij}$ = the measurement of the extent by which the true response in the trials with the treatment A_iB_j differs from the value $(A_i + B_j + \mu)$, i.e. it measures the lack of independence in the effects of A and B,

ϵ_{ijk} = the experimental measurement error associated with the k^{th} trial.

In effect, estimates of expected values of A_i, B_j, $(AB)_{ij}$, and ϵ_{ijk} are obtained from the data by the Analysis of Variance procedures. These expected values A, B, (AB), and σ_o^2 are called main effects, (A and B); interaction, (AB); and experimental error, σ_o^2. In the analysis of variance procedures, the estimates of A, B, AB and σ_o^2 are in the form of sums of squares calculated from the experimental results. The sums of squares terms are divided by their respective degrees of freedom to form mean squares. The mean squares are estimates of the main effects and interactions of the experimental variables and are tested against the mean square estimate of σ_o^2 in order to assess their statistical importance. The standard statistical F test is used for this purpose. If the F test shows that a mean square (say that of factor A) is significantly greater than the error mean squares, it is inferred that the terms A_i for all levels of factor A are not all zero, thus changing the level of factor A affects the response variable. A detailed discussion of the F test is given in Appendix D.

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The expectations (mean values) of the mean square estimates in a factorial experiment with, say two factors, A and B at p and m levels, where each treatment is tested v times, are shown in Table II.

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TABLE II

EXPECTATIONS OF MEAN SQUARES IN A TWO FACTOR DESIGN

Source of Variation	Sums of Squares	Degrees of Freedom	Mean Squares	Expectation of Mean Squares
Main Effects:				
Factor A	SS_A	(p-1)	$SS_A^* = \frac{SS_A}{(p-1)}$	$\sigma_o^2 + mv \sum A_i^2/(p-1)$
Factor B	SS_B	(m-1)	$SS_B^* = \frac{SS_B}{(m-1)}$	$\sigma_o^2 + pv \sum B_j^2/(m-1)$
Interaction:				
(AB)	SS_{AB}	(p-1)(m-1)	$SS_{AB}^* = \frac{SS_{AB}}{(p-1)(m-1)}$	$\sigma_o^2 + v \sum (AB)_{ij}^2/(p-1)(m-1)$
Residual:	SS_R	pm(v-1)	$SS_R^* = \frac{SS_R}{pm(v-1)}$	σ_o^2

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If the variations from level to level of factor A and/or B do not affect the response variable, then the additive effects, $mv\sum A_i^2/(p-1)$, etc., in the average mean squares are approximately zero and all the numerical values in the analysis of variance table are simply independent estimates of the experimental error, σ_o^2.

If A and/or B affect the response, the respective mean squares have expectation greater than the value σ_o^2. The main effect and interaction estimates are tested against the residual, SS_R^*, by means of the F test.

C. Methods of Calculation

The 2^n design has undergone extensive research and as a result several known methods of calculation may be used to calculate the main effects and interaction directly. It will simplify later discussion if, at this point, symbolic expressions are introduced. Consider a $2^{n = 3}$ factorial design. Refer to the high levels of factors A, B, and C as a, b, and c; the low levels of A, B, and C as blanks, and the treatment in which all three factors are at their low level as (1). The $2^3 = 8$ treatments in this design are then: (1), a, b, c, ab, ac, bc, and abc. In accordance with the definition of main effects (section A), the main effect A is

A = Average response at the high level of A minus the average response at the low level of A.

By the prescribed notation, this becomes,

$$\text{main effect } A = 1/4[a + ab + ac + abc] - 1/4[(1) + b + c + bc]$$

By treating (1), a, b, c as algebraic symbols, the expression for main effect A can be written as

$$A = 1/4[(a-1) + (ab - b) + (ac - c) + (abc - bc]$$
$$= 1/4[(a-1)(b+1)(c+1)].$$

Similar expressions for main effects B and C may be derived:

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$$B = 1/4[(a + 1)(b - 1)(c + 1)],$$

$$C = 1/4[(a + 1)(b + 1)(c - 1)].$$

The interaction between A and B denoted as (AB) is defined as one-half the difference between the effect of A when B is at its high level, and the effect of A when B is at its low level. The effect of A with B at level B_2 is

$$A_2 = 1/2\,(abc + ab) - 1/2\,(bc + b)$$
$$= 1/2\,b\,(a - 1)(c + 1).$$

The effect of A with B at its low level is

$$A_1 = 1/2\,(ac + a) - 1/2\,(c + (1))$$
$$= 1/2\,(a - 1)(c + 1).$$

Thus,

$$A_2 - A_1 = 1/2\,(a-1)(b-1)(c+1)$$

and the interaction AB is $1/2\,(A_2 - A_1)$ or

$$AB = 1/4\,(a-1)(b-1)(c+1).$$

Similar expression may be derived for AC and BC so that

$$AC = 1/4\,(a - 1)(b + 1)(c - 1),$$

$$BC = 1/4\,(a + 1)(b - 1)(c - 1).$$

The three-factor interaction is defined on one-half the difference between the interaction AB with factor C at its high level and when factor C is at its low level. The effect of A with B at its high level is

$$A_{22} = (abc - bc),$$

and with B at its low level is

$$A_{12} = (ac - c).$$

Thus, interaction AB with C at the high level is

$$(AB)_2 = 1/2\,(abc - bc - ac + c)$$
$$= 1/2\,c\,(a - 1)(b - 1).$$

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The interaction term with C at its low level, by the same analysis is

$(AB)_1 = 1/2 \ (a - 1) \ (b - 1).$

The interaction ABC by definition, is $1/2 \ [(AB)_2 - (AB)_1]$ or

$$ABC = 1/4 \ (a - 1) \ (b - 1) \ (c - 1).$$

These seven symbolic expressions are

$$A = 1/4 \ (a - 1) \ (b + 1) \ (c + 1),$$
$$B = 1/4 \ (a + 1) \ (b - 1)(c + 1),$$
$$C = 1/4 \ (a + 1) \ (b + 1) \ (c - 1),$$
$$AB = 1/4 \ (a - 1) \ (b - 1) \ (c + 1),$$
$$AC = 1/4 \ (a - 1) \ (b + 1) \ (c - 1),$$
$$BC = 1/4 \ (a + 1) \ (b - 1) \ (c - 1),$$
$$ABC = 1/4 \ (a - 1) \ (b - 1) \ (c - 1).$$

It must be emphasized that these expressions are symbolic, and must be expanded prior to substituting numerical values into the expression for the treatments a, b, ---, etc.

This method can be generalized so as to be applicable to any 2^n design. These expressions become:

$$A = (1/2)^{n-1} \ (a - 1) \ (b + 1) \ . \ . \ . \ . \ . \ . \ . \ . \ (q + 1),$$
$$B = (1/2)^{n-1} \ (a + 1) \ (b - 1) \ . \ . \ . \ . \ . \ . \ . \ . \ (q + 1),$$
$$Q = (1/2)^{n-1} \ (a + 1) \ (b + 1) \ . \ . \ . \ . \ . \ . \ . \ . \ (q - 1),$$
$$AB = (1/2)^{n-1} \ (a - 1) \ (b - 1) \ . \ . \ . \ . \ . \ . \ . \ . \ (q + 1),$$
$$AC = (1/2)^{n-1} \ (a - 1) \ (b + 1) \ (c - 1) \ . \ . \ . \ . \ . \ (q + 1),$$
$$AQ = (1/2)^{n-1} \ (a - 1) \ (b + 1) \ (c + 1) \ . \ . \ . \ . \ . \ (q - 1),$$
$$ABC = (1/2)^{n-1} \ (a - 1) \ (b - 1) \ (c - 1) \ . \ . \ . \ . \ . \ (q + 1).$$

This algebraic property is used to develop the modified design in appendix C.

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D. Experimental Error

As seen in Table II the experiment must be replicated at least twice in order for it to contain an estimate of experimental error. The term SS_R^* is undefined unless v>1, v is the number of replicates. An experiment containing an estimate of experimental error is said to be self-contained. Obviously, a great deal more experimentation is required if all designs are to be self-contained and thus provide an estimate of experimental error.

Two alternate procedures are generally used when the experimentation is not done on a replicated basis. The first method is simply to test the main effects and interactions against an "outside" or "independent" estimate of error. This, of course, assumes some a prior knowledge about the process. Frequently in industrial experimentation some knowledge of the relative error is available from results of past experience. For example, it is reasonably safe to assume that, say, a new additive may not affect the experimental error associated with the yield in a chemical process. The mean response, of course, may change radically.

The second approach involves making assumptions to the physical improbability of certain interaction effects. For example, if from consideration of the physical characteristics of factors A and B, it can be concluded that an interaction effect is quite unlikely; we could assume this to be the case and use the numerical estimate of interaction AB as an estimate of experimental error. The additional step of combining several unlikely interaction estimates is taken on occasion. This process is referred to as pooling variances.

In an effort to reduce the number of individual tests required for this study only a few experiments have been replicated.

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An "independent estimate" of experimental error has been obtained based on 60 degrees of freedom (see Vol. I - Section F). In a statistical sense, this sample size is considered to be large enough so that the estimate may be treated as an adequate approximation to the actual experimental error involved in this experimentation. We have denoted the estimate of experimental error as σ^2_{exp}.

In the absense of replication, only the mean squares for factor A and B and their interaction estimate are calculated (Table II). The usual procedure is to first test for a significant difference between the interaction estimate, SS^*_{AB}, and σ^2_{exp}. This is accomplished by the "F" test where the test statistic is

$$F_1 = \frac{SS^*_B}{\sigma^2_{exp}}.$$

The acceptance of the null hypothesis of no significant difference implies that there is no interaction between factors A and B and that either SS^*_{AB} or σ^2_{exp} may be used in the test of significance for factors A and B. It is usual to use the estimate which is associated with the largest degrees of freedom for this purpose.

E. Factorial Designs with Factors at More than Two Levels

When a factor is examined at two levels its main effect is uniquely defined as the difference between the mean of all results involving that factor at its high level and the mean of the results with the factor at its low level. This definition implies a linear relationship. When treating a factor at three or more levels, the effect of that factor now must be considered as a function of the particular levels of the factor. In most instances, the effect of changing the factor over its various levels will not be a linear function of those levels.

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For quantitative factors, the levels denote points selected from a continuous numerical scale representing the factor space, e.g. the temperature scale. There is an implied functional relationship between the response variable and the level of the factor. Usually the relationship is not known, but for practical purposes is approximated by means of the polynomial,

$$y = a + bx + cx^2 + \text{---},$$

where x represents the level of the factor. The number of levels chosen for a factor dictates the degree of the polynomial. For example, a quadratic is used to approximate the relationship of a factor over 3 levels. In general, the levels of a factor are chosen at equal intervals over its respective factor space.

The first step in analyzing, say, a two-factor experiment where each factor is investigated at more than two levels is to develop the analysis of variance tables as shown by Table II (Here the number of levels for A and B are not necessarily equal).

The mean square estimates corresponding to main effects of factors A and B do not account for the levels of these factors. It is then conceivable that the analysis can be more sensitive by taking into account the levels of the various factors. The usual next step is to partition the main effect estimates of the factors involved into their respective linear, quadratic, cubic, etc. components. With the levels of a factor at equal intervals, the effect of a variable can be partitioned into a linear, quadratic, cubic, etc. components by means of orthogonal polynomials. The method is outlined in several texts, [1] and [2].

The use of orthogonal polynomials implies that only one experimental result is obtained at each level of a factor and also assumes that the levels of a factor are equally spaced. In this study, some replicated trials were conducted within each experiment so as to assure that the experimental error remained stable during experimentation. As a result, within all of the experiments, there

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are some replicated trials. In order to make use of this data and to compensate for the fact that some of the factors were not investigated at equally-spaced intervals, an alternate approach for estimation was used.

Regression surfaces were fit to all data collected from each experiment. The levels chosen for each factor are assumed to adequately represent the complete response surface. These surfaces are given in Table IX, Vol. I.

In general, in the three and four factor environmental tests, each factor has been investigated at three levels each. These particular levels for each factor were chosen after analysis of the single and double-environment tests. The class of design applicable to these higher order experiments is the 3^n factorial design, where n represents the number of factors treated at 3 levels each. The postulated set-up for a 3^n design involving 3 factors treated at $r = s = t = 3$ levels each, where each trial is replicated v times as follows: The response variable Y_{ijkl} may be written as,

$$Y_{ijkl} = \mu + A_i + B_j + C_k + \eta_{ij} + \psi_{ik} + \gamma_{jk} + \rho_{ijk} + \epsilon_{ijkl}$$

where: ijkl refers to the l^{th} of trials using the i^{th} of r levels of factor A, the j^{th} of s levels of factor B, and the k^{th} of t levels of factor C;

μ = mean response of all trials;

A_i = the effect of the i^{th} level of factor A;

B_j = the effect of the j^{th} level of factor B;

C_k = the effect of the k^{th} level of factor C;

η_{ij} = the interaction of the i^{th} level of factor A with the j^{th} level of factor B;

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ψ_{ik} = the interaction of the i^{th} treatment A with the k^{th} level of factor C;

ρ_{ijk} = the three factor interaction of the factors at their respective levels;

γ_{jk} = the interaction of the j^{th} level of factor B with the k^{th} level of factor C;

ϵ_{ijkl} = the experimental error associated with the $ijkl^{th}$ trial.

The analysis of variance table for this 3^n experiment appears as Table III. Again, each effect is tested against SS_R^*, for a measure of significance. If the experiment has not been replicated, the value SS_R^*, may not be calculated, as seen from Table III, and the outside estimate of error σ^2_{exp} is used. Very few of the three factor tests have been completely replicated (a few trials within each have been replicated as a check on our experimental error estimate); thus the value σ^2_{exp} is used to test for three-factor interaction. With the acceptance of the null hypothesis of no significant difference between SS_2^{ABC*} and σ^2_{exp}, either of these estimates is used to test the remaining effects in Table III.

A number of easily followed methods for calculating the sums of squares in Table III are outlined in such references as [1] and [2].

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TABLE III

EXPECTATIONS OF MEAN SQUARES IN A THREE FACTOR DESIGN

Source of Variation	Sums of Squares	Degrees of Freedom	Mean Squares	Expectation of Mean Squares
Main Effects:				
Factor A	SS_3	$(r-1)$	$SS_3^* = \frac{SS_3}{(r-1)}$	$\sigma_o^2 + \frac{stv}{(r-1)} \sum^{r} A_i^2$
Factor B	SS_4	$(s-1)$	$SS_R^* = \frac{SS_4}{(s-1)}$	$\sigma_o^2 + \frac{rtv}{(s-1)} \sum^{s} B_j^2$
Factor C	SS_5	$(t-1)$	$SS_5^* = \frac{SS_5}{(t-1)}$	$\sigma_o^2 + \frac{rsv}{(t-1)} \sum^{t} C_k^2$
Interactions				
(AB)	SS_2^{AB}	$(r-1)(s-1)$	$SS_2^{AB*} = \frac{SS_2^{AB}}{(r-1)(s-1)}$	$\sigma_o^2 + \frac{vt}{(r-1)(s-1)} \sum^{r} \sum^{s} \eta_{ij}^2$
(AC)	SS_2^{AC}	$(r-1)(t-1)$	$SS_2^{AC*} = \frac{SS_2^{AC}}{(r-1)(t-1)}$	$\sigma_o^2 + \frac{vs}{(r-1)(t-1)} \sum^{r} \sum^{t} \psi_{ik}^2$
(BC)	SS_2^{BC}	$(s-1)(t-1)$	$SS_2^{BC*} = \frac{SS_2^{BC}}{(s-1)(t-1)}$	$\sigma_o^2 + \frac{vr}{(s-1)(t-1)} \sum^{s} \sum^{t} \Upsilon_{jk}^2$
ABC	SS_2^{ABC}	$(r-1)(s-1)(t-1)$	$SS_2^{ABC*} = \frac{SS_2^{ABC}}{(r-1)(s-1)(t-1)}$	$\sigma_o^2 + \frac{v}{(r-1)(s-1)(t-1)} \sum^{r} \sum^{s} \sum^{t} \rho_{ijk}^2$
Residual	SS_R	$rst(v-1)$	$SS_R^* = \frac{SS_R}{rst(v-1)}$	σ_o^2
Total	SS	$rstv-1$	SS^*	

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APPENDIX B

EXPERIMENTAL RESULTS AND

ANALYSIS OF VARIANCE TABLES

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TWO FACTOR EXPERIMENTAL DESIGN #1

ALTITUDE VS. VIBRATION (REPLICATED TWICE)

ALTITUDE (A)	VIBRATION (B)				
	0 g's	2 g's	4 g's	6 g's	8 g's
620mm	8.64 8.64	8.79 8.84	17.84 14.82	29.96 34.22	70.81 75.22
465mm	90.80 90.75	88.36 114.08	146.35 125.76	191.71 188.71	260.68 244.10
310mm	117.72 117.52	117.47 120.05	186.10 165.41	218.38 201.90	272.11 271.02
155mm	137.77 137.78	163.05 135.95	199.99 178.19	225.60 225.75	313.92 296.97
5 mm	141.04 141.00	139.84 144.43	188.60 194.63	250.62 291.53	354.12 349.76

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ANALYSIS OF VARIANCE TABLE

ALTITUDE VS. VIBRATION

SOURCE	SUMS OF SQUARES	DEGREES OF FREEDOM	MEAN SQUARES	F TESTS
Main Effects:				
Altitude (A)	$SS_3 = 230,667.24$	$(r-1) = 4$	$SS_3^* = 57,666.81^+$	$F_3 = \frac{SS_3^*}{\sigma^2_{EXP}} = 349.35$ $F_3 = \frac{SS_3^*}{SS_1^*} = 528.23$
Vibration (B)	$SS_4 = 160,111.48$	$(s-1) = 4$	$SS_4^* = 40,027.87^+$	$F_4 = \frac{SS_4^*}{\sigma^2_{EXP}} = 242.49$ $F_4 = \frac{SS_4^*}{SS_1^*} = 366.66$
Interaction: (AB)	$SS_2 = 18,613.53$	$(r-1)(s-1) = 16$	$SS_2^* = 1,163.35^+$	$F_2 = \frac{SS_2^*}{\sigma^2_{EXP}} = 7.05$ $F_2 = \frac{SS_2^*}{SS_1^*} = 10.66$
Between Replicates	$SS_1 = 2,729.37$	$rs(v-1)=25$	$SS_1^* = 109.17$	$F_1 = \frac{SS_1^*}{\sigma^2_{EXP}} = .66$

+Significant factor at α = .01 level of significance

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ANALYSIS OF VARIANCE TABLE

(Con't)

			$\sigma^2_{EXP} = 165.07$ $F_{.01;4,60} = 3.65$ $F_{.01;16,60} = 2.31$ $F_{.01;25,60} = 2.10$	$F_{.01;4,25} = 4.18$ $F_{.01;16,25} = 2.81$

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TWO FACTOR EXPERIMENTAL DESIGN #2

LOW TEMPERATURE VS. ALTITUDE

LOW TEMPERATURE (A)	ALTITUDE (B)				
	20 mm	90 mm	205 mm	310 mm	495 mm
10°	16.00	16.94	36.05	48.25	79.10
30°	120.25	47.87	10.37	4.40	43.84
50°	172.13	151.35	105.18	97.74	65.73

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ANALYS OF VARIANCE TABLE

LOW TEMPERATURE VS. ALTITUDE

SOURCE	SUMS OF SQUARES	DEGREES OF FREEDOM	MEAN SQUARES	F TESTS
Main Effects:				
Low Temperature (A)	$SS_3 = 27{,}124.98$	$(r-1) = 2$	$SS_3^* = 13{,}562.49^+$	$F_3 = 82.16$
Altitude (B)	$SS_4 = 5{,}631.09$	$(s-1) = 4$	$SS_4^* = 1{,}407.77^+$	$F_4 = 8.53$
Interaction: (AB)	$SS_2 = 5{,}235.01$	$(r-1)(s-1)=8$	$SS_2^* = 654.37^+$	$F_2 = \frac{SS_2^*}{\sigma^2_{EXP}} = 3.24$
Total	$SS = 27.991.08$			
			$\sigma^2_{EXP} = 165.07$	$F_{.01;2,60} = 4.98$
			$F_{.01;8,60} = 2.82$	$F_{.01;4,60} = 3.65$
			$F_{.01;2,8} = 8.65$	$F_{.01,4,8} = 7.01$

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TWO FACTOR EXPERIMENTAL DESIGN #3

HIGH TEMPERATURE VS. ALTITUDE

HIGH TEMPERATURE (A)	ALTITUDE (B)				
	20 mm	90 mm	205 mm	310 mm	495 mm
100°	211.94	192.42	171.69	135.45	49.88
140°	281.59	240.00	258.84	293.94	213.72
180°	330.34	327.06	303.24	281.30	293.03

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ANALYSIS OF VARIANCE TABLE

HIGH TEMPERATURE VS. ALTITUDE

SOURCE	SUMS OF SQURES	DEGREES OF FREEDOM	MEAN SQUARES	F TESTS
Main Effects:				
High Temperature (A)	$SS_3 = 60,866.47$	$(r-1) = 2$	$SS_8^* = 30,433.24$	$F_3 = 184.37$
Altitude (B)	$SS_4 = 14,089.22$	$(s-1) = 4$	$SS_4^* = 3,522.30^+$	$F_4 = 21.34$
Interaction:				
(AB)	$SS_2 = 6,584.15$	$(r-1)(s-1) = 8$	$SS_2^* = 823.02$	$F_2 = \frac{SS_2^*}{\sigma^2_{EXP}} = 4.99$
Total	$SS = 81,539.84$		$\sigma^2_{EXP} = 165.07$	$F_{01;2,60} = 4.98$
			$F_{.01;\ 8,60} = 2.82$	$F_{.01;\ 4,60} = 3.65$
			$F_{.01;\ 2,8} = 8.65$	$F_{.01;\ 4,8} = 7.01$

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TWO FACTOR EXPERIMENTAL DESIGN #4

SUSTAINED ACCELERATION VS. ALTITUDE

SUSTAINED ACCELERATION (A)	ALTITUDE (B)					
	620 mm	480 mm	380 mm	250 mm	120 mm	10 mm
0 g's	24.76	102.13	120.84	154.82	183.89	180.90
3 g's	17.21	95.63	113.36	158.13	175.40	193.36
6 g's	29.87	116.57	117.18	150.98	178.47	191.55
9 g's	36.67	84.36	115.65	150.37	181.44	189.32

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ANALYSIS OF VARIANCE TABLE

SUSTAINED ACCELERATION VS. ALTITUDE

SOURCE	SUMS OF SQUARES	DEGREES OF FREEDOM	MEAN SQUARES	F TESTS
Main Effects:				
Sustained Acceleration (A)	$SS_3 = 97.25$	$(r-1) = 3$	$SS_3^* = 32.42$	$F_3 = .20$
Altitude (B)	$SS_4 = 72,545.85$	$(s-1) = 5$	$SS_4^* = 14,509.17^+$	$F_4 = 87.90$
Interactions:				
(AB)	$SS_2 = 851.24$	$(r-1)(s-1) = 15$	$SS_2^* = 56.75^{‡}$	$F_2 = \frac{SS_2^*}{\sigma^2_{EXP}} = .34$
TOTAL	$SS_2 = 73,494.34$			
			$\sigma^2_{EXP} = 165.07$	$F_{.01;\ 15,60} = 2.35$
			$F_{.01;\ 3,60} = 4.13$	$F_{.01;\ 3,15} = 5.42$
			$F_{.01;\ 5,60} = 3.34$	$F_{.01;\ 5,15} = 4.56$

‡ SS_2^* significantly smaller than σ^2_{EXP} at $\alpha = 2\%$ level of significance

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TWO FACTOR EXPERIMENTAL DESIGN #5

THERMAL SHOCK VS. ALTITUDE

THERMAL SHOCK (A)	ALTITUDE (B)		
	620 mm	310 mm	5 mm
80%	205.22	236.38	222.32
90%	176.82	224.60	266.04
100%	170.71	225.30	349.29

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ANALYSIS OF VARIANCE TABLE

THERMAL SHOCK VS. ALTITUDE

SOURCE	SUMS OF SQUARES	DEGREES OF FREEDOM	MEAN SQUARES	F TESTS
Main Effects:				
Thermal Shock (A)	$SS_3 = 1,410.51$	$(r-1) = 2$	$SS^*_3 = 705.26^+$	$F_3 = 4.27$
Altitude (B)	$SS_4 = 13,545.68$	$(s-1) = 2$	$SS^*_4 = 6,772.84^+$	$F_4 = 41.03$
Interaction:				
(AB)	$SS_2 = 7,676.24$	$(r-1)(s-1) = 4$	$SS^*_2 = 1,919.06^+$	$F_2 = \frac{SS^*{}_2}{\sigma^2_{EXP}} = 11.63$
Total	$SS = 22,632.43$			
			$\sigma^2_{EXP} = 165.07$	$F_{.01;2,4} = 18.0$
			$F_{.01;4,60} = 3.65$	
			$F_{.01;2,60} = 4.98$	

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TWO FACTOR EXPERIMENTAL DESIGN #6

MECHANICAL SHOCK VS. ALTITUDE

MECHANICAL SHOCK (A)	ALTITUDE (B)			
	620 mm	460 mm	180 mm	5 mm
9 g's	8.16	75.30	301.97 114.34[A]	127.10
12 g's	17.49	74.98	112.34	128.06
16 g's	18.00	91.68	113.78	128.48
18 g's	17.24	74.77	130.43	127.75

[A] Results of second trial at these levels used in calculations

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ANALYSIS OF VARIANCE TABLE

MECHANICAL SHOCK VS. ALTITUDE

SOURCE	SUMS OF SQUARES	DEGREES OF FREEDOM	MEAN SQUARES	F TESTS
Main Effects:				
Mechanical Shock (A)	$SS_3 = 132.07$	$(r-1) = 3$	$SS_3^* = 44.02$	$F_3 = .26$
Altitude (B)	$SS_4 = 31{,}231.41$	$(s-1) = 3$	$SS_4^* = 10{,}410.37^{+}$	$F_4 = 63.06$
Interaction:				
(AB)	$SS_2 = 362.26$	$(r-1)(s-1) = 9$	$SS_2^* = 40.25^{\ddagger}$	$F_2 = \frac{SS_2^*}{\sigma^2_{EXP}} = .24$
Total	$SS = 31{,}725.44$		$\sigma^2_{EXP} = 165.07$	$F_{.01;\,3,9} = 6.99$
			$F_{.01;3,60} = 4.13$	$F_{.01;9,60} = 2.72$

‡ SS_2^* significantly smaller than σ^2_{EXP}

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TWO FACTOR EXPERIMENTAL DESIGN #7

LOW TEMPERATURE VS. VIBRATION

Low Temperature (A)	VIBRATION (B)				
	0 g's	2 g's	4 g's	6 g's	8 g's
5°	81.44 74.74	72.55 71.66	102.78 93.66	176.30 132.65	279.50 283.66
30°	60.23 56.16	53.53 53.53	70.87 75.03	105.20 113.92	195.84 195.92
55°	36.43 36.23	33.75 36.03	46.53 46.18	68.03 72.19	124.36 124.26
75°	8.15 14.17	5.72 5.76	14.69 14.04	36.09 35.99	83.05 83.30

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ANALYSIS OF VARIANCE TABLE

LOW TEMPERATURE VS. VIBRATION (REPLICATED TWICE)

SOURCE	SUMS OF SQUARES	DEGREES OF FREEDOM	MEAN SQUARES	F TESTS
Main Effects:				
Low Temperature (A)	$SS_3 = 63,482.26$	$(r-1) = 3$	$SS^*_3 = 21,160.75^+$	$F_3 = 128.19$
Vibration (B)	$SS_4 = 92,691.88$	$(s-1) = 4$	$SS^*_4 = 23,175.47^+$	$F_4 = 140.39$
Interaction:				
(AB)	$SS_2 = 15,180.37$	$(r-1)(s-1) = 12$	$SS^*_2 = 1,265.03^+$	$F_2 = 7.66$
Between Replicates	$SS_1 = 1,110.40$	$rs(v-1) = 20$	$SS^*_1 = 55.52^{\ddagger}$	$F_1 = \frac{SS^*_1}{\sigma^2_{EXP}} = .34$
Total	$SS = 172,464.91$			
			$\sigma^2_{EXP} = 165.07$	$F_{.01,12,60} = 2.50$
			$F_{.01;3,60} = 4.13$	$F_{.01;20,60} = 2.20$
			$F_{.01;4,60} = 3.65$	$F_{.01;3,20} = 4.94$
			$F_{.01;12,20} = 3.23$	$F_{.01;4,70} = 4.43$

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TWO FACTOR EXPERIMENTAL DESIGN #8

HIGH TEMPERATURE VS. VIBRATION

HIGH TEMPERATURE (A)	VIBRATION (B)				
	0 g's	2 g's	4 g's	6 g's	8 g's
75°	11.36	8.93	14.76	36.06	83.73
100°	13.39	8.57	21.65	52.02	120.89
120°	40.25	40.17	50.36	89.00	175.66
145°	86.56	88.40	127.09	178.62	299.71
175°	201.77	215.76	293.14	383.61	508.51

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ANALYSIS OF VARIANCE TABLE

HIGH TEMPERATURE VS. VIBRATION

SOURCE	SUMS OF SQUARES	DEGREES OF FREEDOM	MEAN SQUARES	F TESTS
Main Effects:				
High Temperature (A)	$SS_3 = 284{,}139.13$	$(r-1) = 4$	$SS^*_3 = 71{,}034.78^+$	$F_3 = 430.33$
Vibration (B)	$SS_4 = 97{,}490.24$	$(s-1) = 4$	$SS^*_4 = 24{,}372.55^+$	$F_4 = 147.65$
Interaction:				
(AB)	$SS_2 = 24{,}756.32$	$(r-1)(s-1) = 16$	$SS^*_2 = 1{,}547.27^+$	$F_2 = \frac{SS^*_2}{\sigma^2_{EXP}} = 9.37$
Total	$SS = 362{,}088.99$			
			$\sigma^2_{EXP} = 165.07$	$F_{.01;16,60} = 2.31$
			$F_{.01;4,60} = 3.65$	$F_{.01;4,16} = 4.77$

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TWO FACTOR EXPERIMENTAL DESIGN #9

SUSTAINED ACCELERATION VS. VIBRATION

SUSTAINED ACCELERATION (A)	VIBRATION (B)				
	0 g's	2 g's	4 g's	6 g's	8 g's
0 g's	8.68	6.33	15.52	26.45	47.68
3 g's	9.97	8.19	12.75	28.22	47.31
6 g's	10.09	7.48	12.90	27.74	51.67
9 g's	7.91	10.69	20.36	27.64	44.98

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ANALYSIS OF VARIANCE TABLE

SUSTAINED ACCELERATION VS. VIBRATION

SOURCE	SUMS OF SQUARES	DEGREES OF FREEDOM	MEAN SQUARES	F TESTS
Main Effects:				
Sustained Acceleration (A)	$SS_3 = 5.95$	$(r-1) = 3$	$SS_3^* = 1.98$	$F_3 = .012$
Vibration (B)	$SS_4 = 4,403.52$	$(s-1) = 4$	$SS_4^* = 1100.88^+$	$F_4 = 6.66$
Interaction: (AB)	$SS_2 = 70.05$	$(r-1)(s-1) = 12$	$SS_2^* = 5.84^{\ddagger}$	$F_2 = .035$
Total	$SS = 4429.52$			
			$\sigma^2_{EXP} = 165.07$	$F_{.01;4,60} = 3.65$
			$F_{.01;3,60} = 4.13$	$F_{.01;4,12} = 5.41$
			$F_{.01;3,12} = 5.95$	$F_{.01;12,60} = 2.50$

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TWO FACTOR EXPERIMENTAL DESIGN #10
THERMAL SHOCK VS. VIBRATION

THERMAL SHOCK (A)	VIBRATION (B)			
	0 g's	2 g's	4 g's	6 g's
80%	189.90	207.67	232.00	260.55
90%	263.67	295.81	327.89	353.78
100%	268.59	343.12	374.72	436.56

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ANALYSIS OF VARIANCE TABLE

THERMAL SHOCK VS. VIBRATION

SOURCE	SUMS OF SQUARES	DEGREES OF FREEDOM	MEAN SQUARES	F TESTS
Main Effects:				
Thermal Shock (A)	$SS_3 = 38,013.72$	$(r-1) = 2$	$SS^*_3 = 19,006.86^+$	$F_3 = 41.14$
Vibration (B)	$SS_4 = 20,373.13$	$(s-1) = 3$	$SS^*_2 = 6,791.04^+$	$F_4 = 115.14$
Interaction: (AB)	$SS_2 = 2,364.79$	$(r-1)(s-1) = 6$	$SS^*_2 = 394.13^+$	$F_2 = \frac{SS^*_2}{\sigma^2_{EXP}} = 2.39$
Total	$SS = 60,751.64$			
			$\sigma^2_{EXP} = 165.07$	$F_{.01;6,60} = 3.12$
			$F_{.01;2,60} = 4.98$	$F_{.01;2,6} = 10.9$
			$F_{.01;3,60} = 4.13$	$F_{.01;3,6} = 9.78$

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TWO FACTOR EXPERIMENTAL DESIGN #11
VIBRATION VS. RELATIVE HUMIDITY

VIBRATION (A)	RELATIVE HUMIDITY (B)					
	0%	24%	36%	40%	65%	75%
0 g's	8.69	101.84	101.10	159.58	159.73	159.73
2 g's	8.54	102.64	107.57	180.49	217.13	191.50
4 g's	10.35	173.13	156.60	250.88	256.81	261.42
6 g's	23.24	197.49	216.51	323.06	338.96	334.22
8 g's	70.61	198.77	408.35	501.71	540.40	497.63

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ANALYSIS OF VARIANCE TABLE

VIBRATION VS. RELATIVE HUMIDITY

SOURCE	SUMS OF SQUARES	DEGREES OF FREEDOM	MEAN SQUARES	F TESTS
Main Effects:				
Vibration (A)	$SS_3 = 251,531.98$	$(r-1) = 4$	$SS_3^* = 62,882.99^+$	$F_3 = 380.94$
Relative Humidity (B)	$SS_4 = 293,248.19$	$(s-1) = 5$	$SS_4^* = 58,649.64^+$	$F_4 = 355.30$
Interaction: (AB)	$SS_2 = 60,948.42$	$(r-1)(s-1) = 20$	$SS_2^* = 3,047.42^+$	$F_2 = \frac{SS_2^*}{\sigma^2_{EXP}} = 18.46$
Total	$SS = 605,728.59$			
			$\sigma^2_{EXP} = 165.07$	$F_{.01;20,60} = 2.20$
			$F_{.01;4,60} = 3.65$	$F_{.01;4,20} = 4.43$
			$F_{.01;5,60} = 3.34$	$F_{.01;5,20} = 4.10$

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TWO FACTOR EXPERIMENTAL DESIGN # 12

MECHANICAL SHOCK VS. VIBRATION

MECHANICAL SHOCK (A)	VIBRATION (B)			
	0 g's	2 g's	4 g's	6 g's
0 g's	7.76	6.32	23.99	64.92
12 g's	6.04	24.19	26.18	130.23 82.14 [A]
21 g's	4.75	26.27	23.88	65.27
27 g's	4.93	91.92 24.47 [A]	23.38	64.94

[A] Results of Second Observation Used in Analysis of Variance Calculations

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ANALYSIS OF VARIANCE TABLE

MECHANICAL SHOCK VS. VIBRATION

SOURCE	SUMS OF SQUARES	DEGREES OF FREEDOM	MEAN SQUARES	F TESTS
Main Effects:				
Mechanical Shock (A)	$SS_3 = 84.94$	$(r-1) = 3$	$SS_3^* = 28.31$	$F_3 = .78$
Vibration (B)	$SS_4 = 8,246.90$	$(s-1) = 3$	$SS_4^* = 2748.97+$	$F_4 = 16.65$
Interaction (AB)	$SS_2^{AB} = 225.59$	$(r-1)(s-1)=9$	$SS_2^{AB*} = 25.06^{\ddagger}$	$F_{AB} = .15$
Total	$SS = 8557.43$		$\sigma_{EXP}^2 = 165.07$	$F_{.01;9,60} = 2.72$
			$F_{.01;3,60} = 4.13$	$F_{.01;3,9} = 6.99$

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TWO FACTOR EXPERIMENTAL DESIGN #13

LOW TEMPERATURE VS. SUSTAINED ACCELERATION

LOW TEMPERATURE (A)	SUSTAINED ACCELERATION (B)			
	0 g's	3 g's	6 g's	9 g's
5°	113.26	117.72	113.71	148.01
40°	79.91	86.53	84.42	84.95
60°	46.72	54.71	47.55	47.50

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ANALYSIS OF VARIANCE TABLE

LOW TEMPERATURE VS. SUSTAINED ACCELERATION

SOURCE	SUMS OF SQUARES	DEGREES OF FREEDOM	MEAN SQUARES	F TESTS
Main Effects:				
Low Temperature (A)	$SS_3 = 10,981.14$	$(r-1) = 2$	$SS_3^* = 5,490.57^+$	$F_3 = 33.26$
Sustained Acceleration (B)	$SS_4 = 324.29$	$(s-1) = 3$	$SS_4^* = 108.10$	$F_4 = .65$
Interaction:				
(AB)	$SS_2 = 576.43$	$(r-1)(s-1) = 6$	$SS_2^* = 96.07$	$F_2 = \frac{SS_2^*}{\sigma^2_{EXP}} = .58$
Total	$SS = 11,881.86$			
			$\sigma^2_{EXP} = 165.07$	$F_{.01;6,60} = 3.12$
			$F_{.01;2,60} = 4.98$	$F_{.01;2,6} = 10.9$
			$F_{.01;3,60} = 4.13$	$F_{.01;3,6} = 9.78$

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TWO FACTOR EXPERIMENTAL DESIGN #14

LOW TEMPERATURE VS. MECHANICAL SHOCK

LOW TEMPERATURE (A)	MECHANICAL SHOCK (B)				
	0 g's	5 g's	11 g's	14 g's	16 g's
4°	109.75	108.37	108.37	108.06	110.16
36°	78.53	132.84 80.01[A]	147.74 80.00[A]	80.16	80.04
57°	52.69	52.16	52.54	50.84	51.10
83°	13.89	17.57	14.13	14.00	14.27

(A) Results of second experiment used in calculations

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ANALYSIS OF VARIANCE TABLE

LOW TEMPERATURE VS. MECHANICAL SHOCK

SOURCE	SUMS OF SQUARES	DEGREES OF FREEDOM	MEAN SQUARES	F TESTS
Main Effects:				
Low Temperature (A)	$SS_3 = 24{,}191.18$	$(r-1) = 3$	$SS_3^* = 8.063.72^{+}$	$F_3 = 48.85$
Mechanical Shock (B)	$SS_4 = 3.29$	$(s-1) = 4$	$SS_4^* = 0.82$	$F_4 = .005$
Interaction:				
(AB)	$SS_2 = 14.87$	$(r-1)(s-1) = 12$	$SS_2^* = 1.24^{\ddagger}$	$F_2 = \frac{SS_2^*}{\sigma^2_{EXP}} = .008$
Total	$SS = 24{,}209.34$			
			$\sigma^2_{EXP} = 165.07$	$F_{.01;12,60} = 2.50$
			$F_{.01;3,60} = 4.13$	$F_{.01;3,12} = 5.95$
			$F_{.01;4.60} = 3.65$	$F_{.01;4.12} = 5.41$

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TWO FACTOR EXPERIMENTAL DESIGN #15

SUSTAINED ACCELERATION VS. HIGH TEMPERATURE

SUSTAINED ACCELERATION (A)	HIGH TEMPERATURE (B)				
	80°	105°	125°	160°	180°
0 g's	23.16	36.52	97.15	236.34	272.40
3 g's	26.17	37.97	94.84	236.26	272.55
6 g's	29.19	40.53	101.36	228.24	263.86
9 g's	30.13	40.64	90.23	228.45	253.67

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ANALYSIS OF VARIANCE TABLE

SUSTAINED ACCELERATION VS. HIGH TEMPERATURE

SOURCE	SUMS OF SQUARES	DEGREES OF FREEDOM	MEAN SQUARES	F TESTS
Main Effects:				
Sustained Acceleration (A)	$SS_3 = 77.34$	$(r-1) = 3$	$SS_3^* = 25.78$	$F_3 = .16$
High Temperature (B)	$SS_4 = 195{,}512.78$	$(s-1) = 4$	$SS_4^* = 48{,}878.20^{+}$	$F_4 = 296.11$
Interaction: (AB)	$SS_2 = 332.64$	$(r-1)(s-1) = 12$	$SS_2^* = 27.72^{\ddagger}$	$F_2 = \frac{SS_2^*}{\sigma^2_{EXP}} = .17$
Total	$SS = 195{,}922.76$			
			$\sigma^2_{EXP} = 165.07$	$F_{.01;12,60} = 2.50$
			$F_{.01;3,60} = 4.13$	$F_{.01;3,12} = 5.95$
			$F_{.01;4,60} = 3.65$	$F_{.01;4,12} = 5.41$

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TWO FACTOR EXPERIMENTAL DESIGN #16

MECHANICAL SHOCK VS. HIGH TEMPERATURE

MECHANICAL SHOCK (A)	HIGH TEMPERATURE (B)			
	80°	125°	150°	170°
9 g's	7.55	55.98	93.94	194.67
13 g's	6.70	58.93	102.02	222.37
17 g's	6.21	95.60	82.93	174.45
20 g's	10.30	66.54	86.18	170.50

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ANALYSIS OF VARIANCE TABLE
MECHANICAL SHOCK VS. HIGH TEMPERATURE

SOURCE	SUMS OF SQUARES	DEGREES OF FREEDOM	MEAN SQUARES	F TESTS
Main Effects:				
Mechanical Shock (A)	$SS_3 = 447.37$	$(r-1) = 3$	$SS_3^* = 149.12$	$F_3 = .903$
High Temperature (B)	$SS_4 = 74,354.53$	$(s-1) = 3$	$SS_4^* = 24,784.84^+$	$F_4 = 150.14$
Interaction:				
(AB)	$SS_2 = 3,128.33$	$(r-1)(s-1) = 9$	$SS_2^* = 347.59$	$F_2 = \frac{SS_2^*}{\sigma^2_{EXP}} = 2.10$
Total	$SS = 77,930.23$			
			$\sigma^2_{EXP} = 165.07$	$F_{.01;3,9} = 6.99$
			$F_{.01;3,60} = 4.13$	$F_{.01;9,60} = 2.72$

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TWO FACTOR EXPERIMENTAL DESIGN #17

THERMAL SHOCK VS. SUSTAINED ACCELERATION

THERMAL SHOCK (A)	SUSTAINED ACCELERATION (B)		
	3 g's	6 g's	9 g's
80%	229.53	416.92	168.95
90%	250.00	217.63	212.76
100%	373.25	284.17	228.94

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ANALYSIS OF VARIANCE TABLE
THERMAL SHOCK VS. SUSTAINED ACCELERATION

SOURCE		SUMS OF SQUARES	DEGREES OF FREEDOM	MEAN SQUARES	F TESTS
Main Effects:					
Thermal Shock	(A)	$SS_3 = 7,298.52$	$(r-1) = 2$	$SS_3^* = 3,649.26^+$	$F_3 = 22.11$
Sustained Acceleration	(B)	$SS_4 = 17,542.46$	$(s-1) = 2$	$SS_4^* = 8,771.23^+$	$F_4 = 53.13$
Interaction	(AB)	$SS_2 = 27,305.34$	$(r-1)(s-1) = 4$	$SS_2^* = 6,826.36^+$	$F_2 = \frac{SS_2^*}{\sigma^2_{EXP}} = 41.35$
Total		$SS = 52,146.32$			
				$\sigma^2_{EXP} = 165.07$	$F_{.01;2,4} = 18.00$
				$F_{.01;2,60} = 4.98$	$F_{.01;4,60} = 3.65$

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TWO FACTOR EXPERIMENTAL DESIGN #18

SUSTAINED ACCELERATION VS. HUMIDITY

SUSTAINED ACCELERATION (A)	HUMIDITY (B)			
	25%	50%	75%	95%
3 g's	120.43	128.56	139.66	153.98
6 g's	134.84	115.17	180.87	188.22
9 g's	156.86	221.63	180.87	205.10

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ANALYSIS OF VARIANCE TABLE
SUSTAINED ACCELERATION VS. HUMIDITY

SOURCE	SUMS OF SQUARES	DEGREES OF FREEDOM	MEAN SQUARES	F TESTS
Main Effects:				
Sustained Acceleration (A)	$SS_3 = 6,348.82$	$(r-1) = 2$	$SS_3^* = 3,266.11^+$	$F_3 = 19.79$
Humidity (B)	$SS_4 = 3,266.11$	$(s-1) = 3$	$SS_4^* = 1,088.70^+$	$F_4 = 6.60$
Interaction: (AB)	$SS_2^{AB} = 3,538.46$	$(r-1)(s-1) = 6$	$SS_2^{AB*} = 589.74^+$	$F_{AB} = 3.57$
Total	$SS = 13,153.39$			
			$\sigma^2_{EXP} = 165.07$	$F_{.01;3,60} = 4.13$
			$F_{.01;2,60} = 4.98$	$F_{.01;2,6} = 10.9$
			$F_{.01;6,60} = 3.12$	$F_{.01;8,6} = 9.78$

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TWO FACTOR EXPERIMENTAL DESIGN #19

MECHANICAL SHOCK VS. SUSTAINED ACCELERATION

THERMAL SHOCK (A)	SUSTAINED ACCELERATION (B)			
	0 g's	3 g's	6 g's	9 g's
10 g's	5.75	7.13	6.73	7.74
14 g's	6.82	7.21	9.03	7.89
18 g's	6.21	6.57	5.20	7.20

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ANALYSIS OF VARIANCE TABLE
MECHANICAL SHOCK VS. SUSTAINED ACCELERATION

SOURCE	SUMS OF SQUARES	DEGREES OF FREEDOM	MEAN SQUARES	F TESTS
Main Effects:				
Mechanical Shock (A)	$SS_3 = 4.28$	$(r-1) = 2$	$SS_3^* = 2.14$	$F_3 = .013$
Sustained Acceleration (B)	$SS_4 = 4.27$	$(s-1) = 3$	$SS_4^* = 1.42$	$F_4 = .009$
Interaction: (AB)	$SS_2 = 4.24$	$(r-1)(s-1) = 6$	$SS_2^* = .71^{\ddagger}$	$F_2 = \frac{SS_2^*}{\sigma^2_{EXP}} = .004$
Total	$SS = 12.79$			
			$\sigma^2_{EXP} = 165.07$	$F_{.01;6,60} = 3.12$
			$F_{.01;2,60} = 4.98$	$F_{.01;2,6} = 10.9$
			$F_{.01;3,60} = 4.13$	$F_{.01;3,6} = 9.78$

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TWO FACTOR EXPERIMENTAL DESIGN #20
THERMAL SHOCK VS. MECHANICAL SHOCK

THERMAL SHOCK (A)	MECHANICAL SHOCK (B)		
	10 g's	16 g's	21 g's
80%	175.93	172.47	167.27
90%	177.03	176.76	177.96
100%	193.05	190.30	189.27

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ANALYSIS OF VARIANCE TABLE
THERMAL SHOCK VS. MECHANICAL SHOCK

SOURCE	SUMS OF SQUARES	DEGREES OF FREEDOM	MEAN SQUARES	F TESTS
Main Effects:				
Thermal Shock (A)	$SS_3 = 574.69$	$(r-1) = 2$	$SS_3^* = 287.85$	$F_3 = 1.74$
Mechanical Shock (B)	$SS_4 = 22.19$	$(s-1) = 2$	$SS_4^* = 11.10$	$F_4 = .07$
Interaction (AB)	$SS_2 = 24.24$	$(r-1)(s-1) = 4$	$SS_2^* = 6.06^{\ddagger}$	$F_2 = .04$
Total	$SS = 621.12$			
			$\sigma^2_{EXP} = 165.07$	$F_{.01;4,60} = 3.65$
			$F_{.01;2,60} = 4.98$	$F_{.01;2,4} = 18.00$

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TWO FACTOR EXPERIMENTAL DESIGN #21

MECHANICAL SHOCK VS. HUMIDITY

MECHANICAL SHOCK (A)	HUMIDITY (B)			
	25%	45%	70%	90%
10 g's	149.70	151.79	160.86	154.17
16 g's	149.72	151.74	148.39	152.90
21 g's	150.73	154.69	148.09	154.90

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ANALYSIS OF VARIANCE TABLE

MECHANICAL SHOCK VS. HUMIDITY

SOURCE	SUMS OF SQUARES	DEGREES OF FREEDOM	MEAN SQUARES	F TESTS
Main Effects: Mechanical Shock (A)	$SS_3 = 24.02$	$(r-1) = 2$	$SS_3^* = 12.01$	$F_3 = .07$
Humidity (B)	$SS_4 = 24.48$	$(s-1) = 3$	$SS_4^* = 8.16$	$F_4 = .05$
Interaction: (AB)	$SS_2 = 61.71$	$(r-1)(s-1) = 6$	$SS_2^* = 10.28^{\ddagger}$	$F_2 = .06$
Total	$SS = 110.21$			
			$\sigma^2_{EXP} = 165.07$	$F_{01;\ 2,6} = 10.9$
			$F_{01;\ 2,60} = 4.98$	$F_{01;\ 3,6} = 9.78$
			$F_{01;\ 3,60} = 4.13$	$F_{01;\ 6,60} = 3.12$

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LOW TEMPERATURE (A)	THREE FACTOR EXPERIMENTAL DESIGN #22 LOW TEMPERATURE VS. ALTITUDE VS. VIBRATION								
	ALTITUDE (B)								
	5 mm			310 mm			620 mm		
	VIBRATION (C)								
LEVEL	2 g's	4 g's	6 g's	2 g's	4 g's	6 g's	2 g's	4 g's	6 g's
10°	7.26	28.65	57.76	92.54	117.93	160.52	148.70	165.38	200.58
40°	38.56	59.12	84.45	7.76	20.36	41.73	105.99	114.18	131.52
70°	159.04	194.37	245.78	97.14	115.04	145.68	20.03	25.36	40.24

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ANALYSIS OF VARIANCE TABLE

LOW TEMPERATURE VS. ALTITUDE VS. VIBRATION

SOURCE	SUMS OF SQUARES	DEGREES OF FREEDOM	MEAN SQUARES	F TESTS
Main Effects:				
Low Temperature (A)	SS_3 = 12,513.23	(r-1) = 2	SS^*_3 = 6,256.61$^+$	F_3 = 37.90
Altitude (B)	SS_4 = 1,302.30	(s-1) = 2	SS^*_4 = 651.15	F_4 = 3.94
Vibration (C)	SS_5 = 10,533.79	(t-1) = 2	SS^*_5 = 5,266.89$^+$	F_5 = 31.91
Interactions:				
(AB)	SS_2^{AB} = 85,960.41	(r-1)(s-1)=4	SS_2^{AB*} = 21,490.10$^+$	F_{AB} = 130.19
(AC)	SS_2^{AC} = 399.22	(r-1)(t-1)=4	SS_2^{AC*} = 99.81	F_{AC} = .60
(BC)	SS_2^{BC} = 626.99	(s-1)(t-1)=4	SS_2^{BC*} = 156.75	F_{AC} = .95

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ANALYSIS OF VARIANCE TABLE

LOW TEMPERATURE VS. ALTITUDE VS. VIBRATION - Continued

(ABC)	$SS_2^{ABC} = 1159.38$	$(r-1)(s-1)(t-1) = 8$	$SS_2^{ABC*} = 144.93$	$F_{ABC} = 0.87$
			$\sigma^2_{EXP} = 165.07$	$F_{.01;8,60} = 2.82$
			$F_{.01;2,60} = 4.98$	$F_{.01;2,8} = 8.65$
			$F_{.01;4,60} = 3.65$	$F_{.01;4,8} = 7.01$

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HIGH TEMPERATURE (A)	THREE FACTOR EXPERIMENTAL DESIGN #23 HIGH TEMPERATURE VS. ALTITUDE VS. VIBRATION								
	ALTITUDE (B)								
	5 mm			310 mm			620 mm		
	VIBRATION (C)								
LEVEL	2 g's	4 g's	6 g's	2 g's	4 g's	6 g's	2 g's	4 g's	6 g's
70°	171.75	206.94	228.31	117.15	123.05	144.37	4.24	1.90	10.36
120°	244.58	288.87	353.89	228.60	279.13	326.93	87.88	113.28	143.63
170°	245.37	286.37	357.06	262.87	331.53	366.58	232.86	293.10	367.52

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ANALYSIS OF VARIANCE TABLE

HIGH TEMPERATURE VS. ALTITUDE VS. VIBRATION

SOURCE	SUMS OF SQUARES	DEGREES OF FREEDOM	MEAN SQUARES	F TESTS
Main Effects:				
High Temperature (A)	$SS_3 = 169{,}980.02$	$(r-1) = 2$	$SS^*_3 = 84{,}990.01^+$	$F_3 = 514.87$
Altitude (B)	$SS_4 = 80{,}386.16$	$(s-1) = 2$	$SS^*_4 = 40{,}193.08^+$	$F_4 = 243.49$
Vibration (C)	$SS_5 = 28{,}032.51$	$(t-1) = 2$	$SS^*_5 = 14{,}016.26^+$	$F_5 = 84.91$
Interactions:				
(AB)	$SS^{AB}_2 = 39{,}650.60$	$(r-1)(s-1)=4$	$SS^{AB*}_2 = 9{,}912.62^+$	$F_{AB} = 60.05$
(AC)	$SS^{AC}_2 = 5{,}599.38$	$(r-1)(t-1)=4$	$SS^{AC*}_2 = 1{,}399.84^+$	$F_{AC} = 8.48$
(BC)	$SS^{BC}_2 = 1{,}152.68$	$(s-1)(t-1)=4$	$SS^{BC*}_2 = 288.17$	$F_{BC} = 1.75$

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ANALYSIS OF VARIANCE TABLE

HIGH TEMPERATURE VS. ALTITUDE VS. VIBRATION - Continued

(ABC)	$SS_2^{ABC} = 138.16$	$(r-1)(s-1)(t-1) = 8$	$SS_2^{ABC*} = 17.27^{‡}$	$F_{ABC} = .10$
			$\sigma^2_{EXP} = 165.07$	$F_{.01;8,60} = 2.82$
			$F_{.01;2,60} = 4.98$	$F_{.01;2,8} = 8.65$
			$F_{.01;4,60} = 3.65$	$F_{.01;4,8} = 7.01$

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ALTITUDE (A)	THREE FACTOR EXPERIMENTAL DESIGN #24 ALTITUDE VS. VIBRATION VS. SUSTAINED ACCELERATION								
	VIBRATION (B)								
	2 g's			4 g's			6 g's		
	SUSTAINED ACCELERATION (C)								
LEVEL	3 g's	6 g's	9 g's	3 g's	6 g's	9 g's	3 g's	6 g's	9 g's
620 mm	14.16	15.31	19.75	19.82	20.00	19.13	22.54	25.38	21.61
310 mm	87.38	89.42	93.47	112.10	120.45	118.16	138.52	143.60	142.60
5 mm	185.45	182.49	191.87	200.43	211.16	207.58	230.14	226.92	214.58

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ANALYSIS OF VARIANCE TABLE
ALTITUDE VS. VIBRATION VS. SUSTAINED ACCELERATION

SOURCE	SUMS OF SQUARES	DEGREES OF FREEDOM	MEAN SQUARES	F TESTS
Main Effects:				
Altitude (A)	$SS_3 = 155,475.82$	$(r-1) = 2$	$SS_3^* = 77,737.91^+$	$F_3 = 470.94$
Vibration (B)	$SS_4 = 4,560.22$	$(s-1) = 2$	$SS_4^* = 2,280.11^+$	$F_4 = 13.81$
Sustained Acceleration (C)	$SS_5 = 41.79$	$(t-1) = 2$	$SS_5^* = 20.89$	$F_5 = .13$
Interactions:				
(AB)	$SS_2^{AB} = 1,560.28$	$(r-1)(s-1)=4$	$SS_2^{AB*} = 390.06$	$F_{AB} = 2.36$
(AC)	$SS_2^{AC} = 39.14$	$(r-1)(t-1)=4$	$SS_2^{AC*} = 9.79$	$F_{AC} = .06$
(BC)	$SS_2^{BC} = 244.62$	$(s-1)(t-1)=4.$	$SS_2^{BC*} = 61.15$	$F_{BC} = .37$

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ANALYSIS OF VARIANCE TABLE
ALTITUDE VS. VIBRATION VS. SUSTAINED ACCELERATION - Continued

(ABC)	$SS_2^{ABC} = 841.16$	$(r-1)(s-1)(t-1)=8$	$SS_2^{ABC*} = 105.14$	$F_{ABC} = .64$
			$\sigma^2_{EXP} = 165.07$ $F_{.01;2,60} = 4.98$ $F_{.01;4,60} = 3.65$	$F_{.01;8,60} = 2.82$ $F_{.01;2,8} = 8.65$ $F_{.01;4,8} = 7.01$

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THREE FACTOR EXPERIMENTAL DESIGN #25

THERMAL SHOCK VS ALTITUDE VS. VIBRATION

THERMAL SHOCK (A)	ALTITUDE (B)								
	5 mm			310 mm			620 mm		
	VIBRATION (C)								
LEVEL	2 g's	4 g's	6 g's	2 g's	4 g's	6 g's	2 g's	4 g's	6 g's
80%	937.51			627.42			418.43		
		931.65			623.51			428.72	
			940.52			652.20			439.79
90%	1212.26			673.80			507.36		
		1231.29			676.97			508.39	
			1233.75			700.14			541.27
100%	1583.40			811.62			640.23		
		1564.66			823.92			647.33	
			1609.49			850.52			671.25

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ANALYSIS OF VARIANCE TABLE

THERMAL SHOCK VS. ALTITUDE VS. VIBRATION

SOURCE	SUMS OF SQUARES	DEGREES OF FREEDOM	MEAN SQUARES	F TESTS
Main Effects:				
Thermal Shock (A)	$SS_3 = 577,190.66$	$(r-1) = 2$	$SS_3^* = 288,595.33^+$	$F_3 = 1,748.32$
Altitude (B)	$SS_4 = 2,491,158.71$	$(s-1) = 2$	$SS_4^* = 1,245,579.36^+$	$F_4 = 7,545.76$
Vibration (C)	$SS_5 = 3,614.04$	$(t-1) = 2$	$SS_5^* = 1,807.02^+$	$F_5 = 10.94$
Interactions:				
(AB)	$SS_2^{AB} = 195,086.54$	$(r-1)(s-1)=4$	$SS_2^{AB*} = 48,771.63^+$	$F_{AB} = 295.46$
(AC)	$SS_2^{AC} = 338.82$	$(r-1)(t-1)=4$	$SS_2^{AC*} = 84.75$	$F_{AC} = 0.51$
(BC)	$SS_2^{BC} = 107.03$	$(s-1)(t-1)=4$	$SS_2^{BC} = 26.76$	$F_{BC} = 0.16$

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ANALYSIS OF VARIANCE TABLE

THERMAL SHOCK VS. ALTITUDE VS. VIBRATION

(Con't)

SOURCE	SUMS OF SQUARES	DEGREES OF FREEDOM	MEAN SQUARES	F TESTS
ABC	$SS_2^{ABC} = 889.28$	$(r-1)(s-1)(t-1)=8$	$SS_2^{ABC*} = 111.16$	$F_{ABC} = .67$
			$\sigma^2_{EXP} = 165.07$	$F_{.01;8,60} = 2.82$
			$F_{.01;2,60} = 4.98$	$F_{.01;2,8} = 8.65$
			$F_{.01;4,60} = 3.65$	$F_{.01;4,8} = 7.01$

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THREE FACTOR EXPERIMENTAL DESIGN #26

ALTITUDE VS. VIBRATION VS. MECHANICAL SHOCK

ALTITUDE (A)	VIBRATION (B)								
	2 g's			4 g's			6 g's		
	MECHANICAL SHOCK (C)								
LEVEL	10 g's	16 g's	21 g's	10 g's	16 g's	21 g's	10 g's	16 g's	21 g's
620 mm	4.32	5.31	4.75	116.87	100.49	88.58	22.55	21.46	21.61
310 mm	92.13	91.32	130.83	112.03	108.71	<u>216.99</u>	136.05	134.48	<u>305.33</u>
10 mm	187.43	206.78	150.69	181.43	<u>258.55</u>	214.99	228.94	228.33	228.28

Underlined values reflect random fluctuations in the experiment

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THREE FACTOR EXPERIMENTAL DESIGN #27

LOW TEMPERATURE VS. ALTITUDE VS. SUSTAINED ACCELERATION

LOW TEMPERATURE (A)	ALTITUDE (B) 5 mm			310 mm			620 mm		
	SUSTAINED ACCELERATION (C)								
LEVEL	3 g's	6 g's	9 g's	3 g's	6 g's	9 g's	3 g's	6 g's	9 g's
10°	7.49	7.94	8.26	74.16	77.82	72.93	136.42	139.87	127.16
40°	38.28	34.16	42.19	15.14	19.28	17.77	98.16	95.54	97.47
70°	134.28	146.15	139.28	72.71	86.42	82.16	16.42	16.22	21.38

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ANALYSIS OF VARIANCE TABLE

LOW TEMPERATURE VS. ALTITUDE VS. SUSTAINED ACCELERATION

SOURCE	SUMS OF SQUARES	DEGREES OF FREEDOM	MEAN SQUARES	F TESTS
Main Effects:				
Low Temperature (A)	$SS_A = 3,975.70$	$(r-1) = 2$	$SS^*_A = 1,987.85^+$	$F_3 = 12.04$
Altitude (B)	$SS_B = 3,440.35$	$(s-1) = 2$	$SS^*_B = 1,720.17^+$	$F_4 = 10.42$
Sustained Acceleration (C)	$SS_C = 124.14$	$(t-1) = 2$	$SS^*_C = 62.07$	$F_5 = 0.37$
Interactions:				
(AB)	$SS_2^{AB} = 53,244.66$	$(r-1)(s-1)=4$	$SS_2^{AB*} = 13,311.16^+$	$F_{AB} = 80.63$
(AC)	$SS_2^{AC} = 141.54$	$(r-1)(t-1)=4$	$SS_2^{AC*} = 35.38$	$F_{AC} = 0.21$
(BC)	$SS_2^{BC} = 180.16$	$(s-1)(t-1)=4$	$SS_2^{BC*} = 45.04$	$F_{BC} = 0.27$

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ANALYSIS OF VARIANCE TABLE

SOURCE	SUMS OF SQUARES	DEGREES OF FREEDOM	MEAN SQUARES	F TESTS
(ABC)	$SS_2^{ABC} = 761.29$	$(r-1)(s-1)(t-1)=8$	$SS_2^{ABC*} = 95.16$	$F_{ABC} = 0.57$
			$\sigma^2_{EXP} = 165.07$	$F_{.01;8,60} = 2.82$
			$F_{.01;2,60} = 4.98$	$F_{.01;2,8} = 8.65$
			$F_{.01;4,60} = 3.65$	$F_{.01;4,8} = 7.01$

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THREE FACTOR EXPERIMENTAL DESIGN #28

LOW TEMPERATURE VS. ALTITUDE VS. MECHANICAL SHOCK

LOW TEMPERATURE (A)	ALTITUDE (B)								
	5 mm			310 mm			620 mm		
	MECHANICAL SHOCK (C)								
LEVEL	10 g's	16 g's	21 g's	10 g's	16 g's	21 g's	10 g's	16 g's	21 g's
10°	4.54	5.42	2.15	91.12	90.44	89.78	151.29	150.77	151.34
40°	41.20	40.45	39.62	10.39	20.46	9.63	108.58	149.47	109.87
70°	148.70	178.11	150.95	99.52	100.38	100.90	22.67	19.22	21.38

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ANALYSIS OF VARIANCE TABLE
LOW TEMPERATURE VS. ALTITUDE VS. MECHANICAL SHOCK

SOURCE	SUMS OF SQUARES	DEGREES OF FREEDOM	MEAN SQUARES	F TESTS
Main Effects: Low Temperature (A)	$SS_3 = 6,629.34$	$(r-1) = 2$	$SS_3^* = 3,314.67^+$	$F_3 = 20.08$
Altitude (B)	$SS_4 = 5,509.07$	$(s-1) = 2$	$SS_4^* = 2,754.53^+$	$F_4 = 16.69$
Mechanical Shock (C)	$SS_5 = 449.89$	$(t-1) = 2$	$SS_5^* = 224.95$	$F_5 = 1.36$
Interactions: (AB)	$SS_2^{AB} = 75,490.83$	$(r-1)(s-1) = 4$	$SS_2^{AB*} = 18,897.71^+$	$F_{AB} = 114.48$
(AC)	$SS_2^{AC} = 249.83$	$(r-1)(t-1) = 4$	$SS_2^{AC*} = 62.46$	$F_{AC} = .38$
(BC)	$SS_2^{BC} = 83.57$	$(s-1)(t-1) = 4$	$SS_2^{BC*} = 20.89$	$F_{BC} = .13$

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Contrails

ANALYSIS OF VARIANCE TABLE
LOW TEMPERATURE VS. ALTITUDE VS. MECHANICAL SHOCK - Continued

(ABC)	$SS_2^{ABC} = 110.42$	$(r-1)(s-1)(t-1)=8$	$SS_2^{ABC*} = 13.80^{‡}$	$F_{ABC} = .08$
			$\sigma^2_{EXP} = 165.07$ $F_{.01;2,60} = 4.98$ $F_{.01;4,60} = 3.65$	$F_{.01;8,60} = 2.82$ $F_{.01;2,8} = 8.65$ $F_{.01;4,8} = 7.01$

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Contrails

HIGH TEMPERATURE	THREE FACTOR EXPERIMENTAL DESIGN #29 HIGH TEMPERATURE VS. ALTITUDE VS. SUSTAINED ACCELERATION								
	ALTITUDE (B)								
	5 mm			310 mm			620 mm		
	SUSTAINED ACCELERATION (C)								
LEVEL	3 g's	6 g's	9 g's	3 g's	6 g's	9 g's	3 g's	6 g's	9 g's
70°	188.97	178.63	186.45	90.98	111.16	105.09	15.96	18.28	18.61
120°	234.96	222.38	233.41	182.98	181.32	185.77	73.08	78.60	77.66
170°	235.03	226.42	236.46	224.61	231.73	233.99	195.38	200.96	194.28

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Contrails

ANALYSIS OF VARIANCE TABLE

HIGH TEMPERATURE VS. ALTITUDE VS. SUSTAINED ACCELERATION

SOURCE	SUMS OF SQUARES	DEGREES OF FREEDOM	MEAN SQUARES	F TESTS
Main Effects:				
High Temperature (A)	$SS_3 = 63,022.03$	$(r-1) = 2$	$SS_3^* = 31,511.02^+$	$F_3 = 190.89$
Altitude (B)	$SS_4 = 65,042.82$	$(s-1) = 2$	$SS_4^* = 32,521.41^+$	$F_4 = 197.01$
Sustained Acceleration (C)	$SS_5 = 53.24$	$(t-1) = 2$	$SS_5^* = 26.62$	$F_5 = 0.16$
Interactions:				
(AB)	$SS_2^{AB} = 16,501.54$	$(r-1)(s-1)=4$	$SS_2^{AB*} = 4,125.38^+$	$F_{AB} = 24.99$
(AC)	$SS_2^{AC} = 37.75$	$(r-1)(t-1)=4$	$SS_2^{AC*} = 9.44$	$F_{AC} = 0.05$
(BC)	$SS_2^{BC} = 235.14$	$(s-1)(t-1)=4$	$SS_2^{BC*} = 58.79$	$F_{BC} = 0.35$

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ANALYSIS OF VARIANCE TABLE

SOURCE	SUMS OF SQUARES	DEGREES OF FREEDOM	MEAN SQUARES	F TESTS
(ABC)	$SS_2^{ABC} = 514.19$	$(r-1)(s-1)(t-1)=8$	$SS_2^{ABC*} = 64.28$	$F_{ABC} = 0.39$
			$\sigma^2_{EXP} = 165.07$	$F_{.01;8,60} = 2.82$
			$F_{.01;2,60} = 4.98$	$F_{.01;2,8} = 8.65$
			$F_{.01;4,60} = 3.65$	$F_{.01;4,8} = 7.01$

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HIGH TEMPERATURE (A)	THREE FACTOR EXPERIMENTAL DESIGN #30 HIGH TEMPERATURE VS. ALTITUDE VS. MECHANICAL SHOCK								
	ALTITUDE (B)								
	5 mm			310 mm			620 mm		
	MECHANICAL SHOCK (C)								
LEVEL	10 g's	16 g's	21 g's	10 g's	16 g's	21 g's	10 g's	16 g's	21 g's
70°	209.46	208.38	206.66	124.29	141.42	135.09	35.69	33.47	33.47
120°	264.08	262.32	263.99	212.73	211.61	205.30	103.86	108.60	107.95
170°	245.03	246.77	256.98	244.41	251.84	263.07	205.30	209.93	206.61

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Contrails

ANALYSIS OF VARIANCE TABLE
HIGH TEMPERATURE VS. ALTITUDE VS. MECHANICAL SHOCK

SOURCE	SUMS OF SQUARES	DEGREES OF FREEDOM	MEAN SQUARES	F TESTS
Main Effects:				
High Temperature (A)	$SS_3 = 56,700.10$	$(r-1) = 2$	$SS_3^* = 28,350.05^+$	$F_3 = 171.75$
Altitude (B)	$SS_4 = 75,086.87$	$(s-1) = 2$	$SS_4^* = 32,543.44^+$	$F_4 = 197.14$
Mechanical Shock (C)	$SS_5 = 76.55$	$(t-1) = 2$	$SS_5^* = 38.27$	$F_5 = .23$
Interaction:				
(AB)	$SS_2^{AB} = 15,553.78$	$(r-1)(s-1) = 4$	$SS_2^{AB*} = 3,888.46^+$	$F_{AB} = 23.56$
(AC)	$SS_2^{AC} = 131.27$	$(r-1)(t-1) = 4$	$SS_2^{AC*} = 32.82$	$F_{AC} = .20$
(BC)	$SS_2^{BC} = 67.93$	$(s-1)(t-1) = 4$	$SS_2^{BC*} = 16.98$	$F_{BC} = .10$

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Contrails

ANALYSIS OF VARIANCE TABLE
HIGH TEMPERATURE VS. ALTITUDE VS. MECHANICAL SHOCK - Continued

(ABC)	SS_2^{ABC}	$(r-1)(s-1)(t-1) = 8$	$SS_2^{ABC^*} = 145.02$	$F_{ABC} = .88$
			$\sigma^2_{EXP} = 165.07$ $F_{.01;2,60} = 4.98$ $F_{.01;4,60} = 3.65$	$F_{.01;8,60} = 2.82$ $F_{.01;2,8} = 8.65$ $F_{.01;4,8} = 7.01$

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THREE FACTOR EXPERIMENTAL DESIGN #31

.LTITUDE VS. THERMAL SHOCK VS. SUSTAINED ACCELERATION

ALTITUDE (A)	THERMAL SHOCK (B)								
	80%			90%			100%		
	SUSTAINED ACCELERATION (C)								
LEVEL	3 g's	6 g's	9 g's	3 g's	6 g's	9 g's	3 g's	6 g's	9 g's
5 mm	952.68	903.51	926.54	1221.05	1183.97	1142.92	1315.32	1422.42	1590.49
310 mm	665.67	599.87	574.96	757.11	779.74	719.52	968.38	973.06	915.46
620 mm	447.38	356.30	292.41	602.60	521.15	447.59	765.96	662.61	626.27

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ANALYSIS OF VARIANCE TABLE

ALTITUDE VS. THERMAL SHOCK VS. SUSTAINED ACCELERATION

SOURCE	SUMS OF SQUARES	DEGREES OF FREEDOM	MEAN SQUARES	F TESTS
Main Effects:				
Altitude (A)	$SS_3 = 1,998,190.98$	$(r-1) = 2$	$SS_3^* = 999,095.49^+$	$F_3 = 6,052.55$
Thermal Shock (B)	$SS_4 = 689,413.14$	$(s-1) = 2$	$SS_4^* = 344,706.57^+$	$F_4 = 2088.24$
Sustained Acceleration (C)	$SS_5 = 12,037.52$	$(t-1) = 2$	$SS_5^* = 6,018.76^+$	$F_5 = 36.46$
Interactions:				
(AB)	$SS_2^{AB} = 36,037.80$	$(r-1)(s-1)=4$	$SS_2^{AB*} = 9,009.45^+$	$F_{AB} = 54.57$
(AC)	$SS_2^{AC} = 29,412.36$	$(r-1)(t-1)=4$	$SS_2^{AC*} = 7,353.09^+$	$F_{AC} = 44.54$
(BC)	$SS_2^{BC} = 294,140.23$	$(s-1)(t-1)=4$	$SS_2^{BC*} = 73,535.05^+$	$F_{BC} = 445.47$

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ANALYSIS OF VARIANCE TABLE

SOURCE	SUMS OF SQUARES	DEGREES OF FREEDOM	MEAN SQUARES	F TESTS
(ABC)	$SS_2^{ABC} = 2821.20$	$(r-1)(s-1)(t-1) = 8$	$SS_2^{ABC*} = 351.40$	$F_{ABC} = 2.12$
			$\sigma^2_{EXP} = 165.07$	$F_{.01;8,60} = 2.82$
			$F_{.01;2,60} = 4.98$	$F_{.01;2,8} = 8.65$
			$F_{.01;4,60} = 3.65$	$F_{.01;4,8} = 7.01$

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ALTITUDE (A)	THREE FACTOR EXPERIMENTAL DESIGN #32 ALTITUDE VS. SUSTAINED ACCELERATION VS. MECHANICAL SHOCK								
	SUSTAINED ACCELERATION (B)								
	3 g's			6 g's			9 g's		
	MECHANICAL SHOCK (C)								
LEVEL	10 g's	16 g's	21 g's	10 g's	16 g's	21 g's	10 g's	16 g's	21 g's
620 mm	34.10	38.97	42.16	38.15	45.40	41.16	42.80	39.79	38.77
310 mm	69.87	72.43	73.60	71.16	73.48	77.15	77.68	82.14	79.47
5 mm	131.40	142.44.	139.17	139.87	148.88	142.34	149.16	154.18	155.42

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ANALYSIS OF VARIANCE TABLE
ALTITUDE VS. SUSTAINED ACCELERATION VS. MECHANICAL SHOCK

SOURCE	SUMS OF SQUARES	DEGREES OF FREEDOM	MEAN SQUARES	F TESTS
Main Effects:				
Altitude (A)	$SS_3 = 51,034.25$	$(r-1) = 2$	$SS_3^* = 25,517.17^+$	$F_3 = 154.58$
Sustained Acceleration (B)	$SS_4 = 316.42$	$(s-1) = 2$	$SS_4^* = 158.21$	$F_4 = .96$
Mechanical Shock (C)	$SS_5 = 118.67$	$(t-1) = 2$	$SS_5^* = 59.34$	$F_5 = .36$
Interactions: (AB)	$SS_2^{AB} = 151.62$	$(r-1)(s-1) = 4$	$SS_2^{AB*} = 37.91$	$F_{AB} = .23$
(AC)	$SS_2^{AC} = 813.75$	$(r-1)(t-1) = 4$	$SS_2^{AC*} = 203.44$	$F_{AC} = 1.23$
(BC)	$SS_2^{BC} = 27.58$	$(s-1)(t-1) = 4$	$SS_2^{BC*} = 6.89$	$F_{BC} = .04$

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ANALYSIS OF VARIANCE TABLE
ALTITUDE VS. SUSTAINED ACCELERATION VS. MECHANICAL SHOCK - Continued

(ABC)	$SS_2^{ABC} = 749.28$	$(r-1)(s-1)(t-1) = 8$	$SS_2^{ABC*} = 93.66$	$F_{ABC} = .57$
			$\sigma^2_{EXP} = 165.07$ $F_{.01;2,60} = 4.98$ $F_{.01;4,60} = 3.65$	$F_{.01;8,60} = 2.82$ $F_{.01;2,8} = 8.65$ $F_{.01;4,8} = 7.01$

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ALTITUDE (A)	THREE FACTOR EXPERIMENTAL DESIGN #33 ALTITUDE VS. THERMAL SHOCK VS. MECHANICAL SHOCK								
	THERMAL SHOCK (A)								
	80%			90%			100%		
	MECHANICAL SHOCK (C)								
LEVEL	10 g's	16 g's	21 g's	10 g's	16 g's	21 g's	10 g's	16 g's	21 g's
5 mm	933.73	925.55	925.05	1217.95	1264.27	1214.99	1590.24	1558.53	1583.45
310 mm	629.06	621.79	1749.69*	673.80	668.40	666.72	817.83	811.42	814.11
620 mm	422.83	420.86	421.02	571.30	510.97	507.26	704.74	634.75	636.99

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LOW TEMPERATURE (A)	THREE FACTOR EXPERIMENTAL DESIGN #34 LOW TEMPERATURE VS. SUSTAINED ACCELERATION VS. VIBRATION								
	SUSTAINED ACCELERATION (B)								
	3 g's			6 g's			9 g's		
	VIBRATION (C)								
LEVEL	2 g's	4 g's	6 g's	2 g's	4 g's	6 g's	2 g's	4 g's	6 g's
70°	6.38	1.54	25.25	2.50	20.51	33.01	9.81	9.91	27.23
40°	26.02	35.50	52.49	25.10	35.33	55.84	26.15	35.15	55.03
10°	110.11	126.87	183.48	109.49	133.94	199.68	109.83	127.19	182.77

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ANALYSIS OF VARIANCE TABLE
LOW TEMPERATURE VS. SUSTAINED ACCELERATION VS. VIBRATION

SOURCE	SUMS OF SQUARES	DEGREES OF FREEDOM	MEAN SQUARES	F TESTS
Main Effects:				
Low Temperature (A)	SS_3 = 82,284.88	(r-1) = 2	SS_3^* = 41,142.44$^+$	F_3 = 249.24
Sustained Acceleration (B)	SS_4 = 106.60	(s-1) = 2	SS_4^* = 53.30	F_4 = 0.32
Vibration (C)	SS_5 = 8,999.11	(t-1) = 2	SS_5^* = 4,499.55$^+$	F_5 = 27.26
Interactions:				
(AB)	SS_2^{AB} = 66.45	(r-1)(s-1) = 4	SS_2^{AB*} = 16.61	F_{AB} = 0.10
(AC)	SS_2^{AB} = 3,183.40	(r-1)(t-1) = 4	SS_2^{AC*} = 795.85$^+$	F_{AC} = 4.82
(BC)	SS_2^{BC} = 130.73	(s-1)(t-1) = 4	SS_2^{BC*} = 32.68	F_{BC} = C.19

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ANALYSIS OF VARIANCE TABLE
LOW TEMPERATURE VS. SUSTAINED ACCELERATION VS. VIBRATION - Continued

(ABC)	$SS_2^{ABC} = 72.76$	$(r-1)(s-1)(t-1)=8$	$SS_2^{ABC*} = 9.09$‡	$F_{ABC} = \frac{SS_2^{ABC*}}{\sigma^2_{EXP}} = .06$
			$\sigma^2_{EXP} = 165.07$ $F_{.01;2,60} = 4.98$ $F_{.01;4,60} = 3.65$	$F_{.01;2,8} = 8.65$ $F_{.01;4,8} = 7.01$ $F_{.01;8,60} = 2.82$

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THREE FACTOR EXPERIMENTAL DESIGN #35
LOW TEMPERATURE VS. VIBRATION VS. MECHANICAL SHOCK

LOW TEMPERATURE (A)	VIBRATION (B)								
	2 g's			4 g's			6 g's		
	MECHANICAL SHOCK (C)								
LEVEL	10 g's	15 g's	20 g's	10 g's	15 g's	20 g's	10 g's	15 g's	20 g's
70°	5.19	4.71	40.30	126.89	1.28	2.90	20.95	20.95	42.34
40°	28.72	86.59	172.42	25.17	26.12	26.12	28.87	39.25	38.90
10°	111.58	170.30	110.16	118.35	118.13	119.67	148.67	149.35	149.33

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HIGH TEMPERATURE (A)	THREE FACTOR EXPERIMENTAL DESIGN #36 HIGH TEMPERATURE VS. VIBRATION VS. SUSTAINED ACCELERATION								
	VIBRATION (B)								
	2 g's			4 g's			6 g's		
	SUSTAINED ACCELERATION (C)								
LEVEL	3 g's	6 g's	9 g's	3 g's	6 g's	9 g's	3 g's	6 g's	9 g's
100°	37.71	40.20	40.74	51.09	42.47	38.03	59.58	55.27	62.43
140°	179.11	160.21	163.88	180.69	185.05	190.25	264.62	220.43	224.92
180°	251.09	255.40	246.78	283.72	282.40	275.10	348.10	348.38	358.04

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ANALYSIS OF VARIANCE TABLE
HIGH TEMPERATURE VS. VIBRATION VS. SUSTAINED ACCELERATION

SOURCE		SUMS OF SQUARES	DEGREES OF FREEDOM	MEAN SQUARES	F TESTS
Main Effects:					
High Temperature	(A)	SS_3 = 278,005.18	(r-1) = 2	SS_3^* = 139,002.59+	F_3 = 842.08
Vibration	(B)	SS_4 = 19,083.48	(s-1) = 2	SS_4^* = 9,541.74+	F_4 = 57.80
Sustained Acceleration	(C)	SS_5 = 167.96	(t-1) = 2	SS_5^* = 83.98	F_5 = .51
Interactions:					
	(AB)	SS_2^{AB} = 5,352.95	(r-1)(s-1) = 4	SS_2^{AB*} = 1,338.24+	F_{AB} = 8.11
	(AC)	SS_2^{AC} = 597.61	(r-1)(t-1) = 4	SS_2^{AC*} = 149.40	F_{AC} = .91
	(BC)	SS_2^{BC} = 294.56	(s-1)(t-1) = 4	SS_2^{BC*} = 73.64	F_{BC} = .45

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ANALYSIS OF VARIANCE TABLE
HIGH TEMPERATURE VS. VIBRATION VS. SUSTAINED ACCELERATION - Continued

(ABC)	$SS_{2}^{ABC} = 633.60$	$(r-1)(s-1)(t-1)=8$	$SS_{2}^{ABC^*} = 79.20$	$F_{ABC} = .48$
			$\sigma^{2}_{EXP} = 165.07$	$F_{.01;8,60} = 2.82$
			$F_{.01;2,60} = 4.98$	$F_{.01;2,8} = 8.65$
			$F_{.01;4,60} = 3.65$	$F_{.01;4,8} = 7.01$

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THREE FACTOR EXPERIMENTAL DESIGN #36A
HIGH TEMPERATURE VS. SUSTAINED ACCELERATION VS. VIBRATION

HIGH TEMPERATURE (A)	SUSTAINED ACCELERATION (B)																			
	0 g's					3 g's					6 g's					9 g's				
	VIBRATION (C) (g's)																			
LEVEL	0	2	4	6	8	0	2	4	6	8	0	2	4	6	8	0	2	4	6	8
75°	8.67	7.89	8.96	26.83	48.79	7.25	7.33	8.47	21.65	43.77	7.16	7.43	7.96	20.92	43.11	6.68	7.41	12.78	25.92	43.92
115°	77.71	79.84	98.47	123.89	163.03	76.80	80.40	97.79	122.50	158.00	77.29	80.40	97.92	122.94	162.88	82.96	79.61	102.05	131.99	176.14
150°	148.56	161.33	205.94	253.46	314.28	150.29	163.80	206.96	269.32	334.44	149.19	162.43	209.59	275.82	339.66	147.41	158.65	200.97	257.97	310.17
180°	228.78	239.50	285.79	345.64	420.39	228.49	243.86	290.41	351.19	429.87	230.08	235.39	282.65	347.97	428.93	229.72	234.15	277.58	330.02	404.01

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ANALYSIS OF VARIANCE TABLE
HIGH TEMPERATURE VS. SUSTAINED ACCELERATION VS. VIBRATION

SOURCE		SUMS OF SQUARES	DEGREES OF FREEDOM	MEAN SQUARES	F TESTS
Main Effects:					
High Temperature	(A)	SS_3 = 934,278.42	(r-1) = 3	SS_3^* = 311,426.14$^+$	F_3 = 1886.63
Sustained Acceleration	(B)	SS_4 = 216.84	(s-1) = 3	SS_4^* = 72.28	F_4 = .44
Vibration	(C)	SS_5 = 154,237.08	(t-1) = 4	SS_5^* = 38,559.27$^+$	F_5 = 233.59
Interaction:					
	(AB)	SS_2^{AB} = 1,038.90	(r-1)(s-1) = 9	SS_2^{AB*} = 115.43	F_{AB} = .70
	(AC)	SS_2^{AC} = 58,949.26	(r-1)(t-1) = 12	SS_2^{AC*} = 4,912.44$^+$	F_{AC} = 29.76
	(BC)	SS_2^{BC} = 599.93	(s-1)(t-1) = 12	SS_2^{BC*} = 49.99	F_{BC} = .22

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ANALYSIS OF VARIANCE TABLE
HIGH TEMPERATURE VS. SUSTAINED ACCELERATION VS. VIBRATION - Continued

(ABC)	$SS_2^{ABC} = 1,283.43$	$(r-1)(s-1)(t-1)=36$	$SS_2^{ABC*} = 35.65^{‡}$	$F_{ABC} = \frac{SS_2^{ABC*}}{\sigma^2_{EXP}} = .22$
			$\sigma^2_{EXP} = 165.07$ $F_{.01;3,60} = 4.13$ $F_{.01;4,60} = 3.65$ $F_{.01;9,60} = 2.72$ $F_{.01;12,60} = 2.50$	$F_{.01;3.36} = 4.38$ $F_{.01;4,36} = 3.89$ $F_{.01;9,36} = 2.95$ $F_{.01;12,36} = 2.72$ $F_{.01;36,60} = 1.96$

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HIGH TEMPERATURE (A)	THREE FACTOR EXPERIMENTAL DESIGN #37 HIGH TEMPERATURE VS. VIBRATION VS. MECHANICAL SHOCK								
	VIBRATION (B)								
	2 g's			4 g's			6 g's		
	MECHANICAL SHOCK (C)								
LEVEL	10 g's	15 g's	20 g's	10 g's	15 g's	20 g's	10 g's	15 g's	20 g's
100°	76.82	131.72	119.61	58.45	42.34	46.78	59.26	59.71	137.16
140°	221.57	250.70	251.72	246.38	234.50	222.34	277.58	274.17	273.19
180°	348.10	322.51	364.16	344.07	292.07	378.65	350.23	348.38	391.21

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ANALYSIS OF VARIANCE TABLE
HIGH TEMPERATURE VS. VIBRATION VS. MECHANICAL SHOCK

SOURCE		SUMS OF SQUARES	DEGREES OF FREEDOM	MEAN SQUARES	F TESTS
Main Effects:					
High Temperature	(A)	$SS_3 = 329,432.96$	$(r-1) = 2$	$SS_3^* = 164,716.48^+$	$F_3 = 997.86$
Vibration	(B)	$SS_4 = 5,527.92$	$(s-1) = 2$	$SS_4^* = 2,763.96^+$	$F_4 = 16.74$
Mechanical Shock	(C)	$SS_5 = 3,479.90$	$(t-1) = 2$	$SS_5^* = 1,739.95^+$	$F_5 = 10.54$
Interactions:					
	(AB)	$SS_2^{AB} = 3,814.14$	$(r-1)(s-1) = 4$	$SS_2^{AB*} = 953.53^+$	$F_{AB} = 5.78$
	(AC)	$SS_2^{AC} = 3,475.90$	$(r-1)(t-1) = 4$	$SS_2^{AC*} = 868.95^+$	$F_{AC} = 5.26$
	(BC)	$SS_2^{BC} = 2,325.91$	$(s-1)(t-1) = 4$	$SS_2^{BC*} = 581.48$	$F_{BC} = 3.52$

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ANALYSIS OF VARIANCE TABLE
HIGH TEMPERATURE VS. VIBRATION VS. MECHANICAL SHOCK - Continued

(ABC)	$SS_2^{ABC} = 3,282.34$	$(r-1)(s-1)(t-1)=8$	$SS_2^{ABC*} = 410.29$	$F_{ABC} = 2.49$
			$\sigma^2_{EXP} = 165.07$ $F_{.01,2,60} = 4.98$ $F_{.01;4,60} = 3.65$	$F_{.01,8,60} = 2.82$ $F_{.01;2,8} = 8.65$ $F_{.01;4,8} = 7.01$

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…E FACTOR EXPERIMENTAL DESIGN #38

THERMAL SHOCK VS. VIBRATION VS. SUSTAINED ACCELERATION

THERMAL SHOCK (A)	VIBRATION (B) 2 g's			4 g's			6 g's		
	SUSTAINED ACCELERATION (C)								
LEVEL	3 g's	6 g's	9 g's	3 g's	6 g's	9 g's	3 g's	6 g's	9 g's
80%	452.37	362.46	299.78	465.20	375.34	312.81	469.66	396.79	334.41
90%	595.09	524.39	423.50	603.86	525.86	420.82	608.07	538.79	433.95
100%	695.19	588.62	601.11	696.97	696.73	599.14	709.80	696.78	611.41

Contrails

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Contrails

ANALYSIS OF VARIANCE TABLE

THERMAL SHOCK VS. VIBRATION VS. SUSTAINED ACCELERATION

SOURCE	SUMS OF SQUARES	DEGREES OF FREEDOM	MEAN SQUARES	F TESTS
Main Effects:				
Thermal Shock (A)	$SS_3 = 327{,}226.32$	$(r-1) = 2$	$SS_3^* = 163{,}613.16^+$	$F_3 = 991.17$
Vibration (B)	$SS_4 = 3{,}722.39$	$(s-1) = 2$	$SS_4^* = 1861.19^+$	$F_4 = 11.27$
Sustained Acceleration (C)	$SS_5 = 88{,}203.00$	$(t-1) = 2$	$SS_5^* = 44{,}101.50^+$	$F_5 = 267.16$
Interactions:				
(AB)	$SS_2^{AB} = 1120.77$	$(r-1)(s-1)=4$	$SS_2^{AB*} = 280.19$	$F_{AB} = 1.69$
(AC)	$SS_2^{AC} = 5595.06$	$(r-1)(t-1)=4$	$SS_2^{AC*} = 1398.76^+$	$F_{AC} = 8.47$
(BC)	$SS_2^{BC} = 842.16$	$(s-1)(t-1)=4$	$SS_2^{BC*} = 210.54$	$F_{BC} = 1.27$

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ANALYSIS OF VARIANCE TABLE

SOURCE	SUMS OF SQUARES	DEGREES OF FREEDOM	MEAN SQUARES	F TESTS
(ABC)	$SS_2^{ABC} = 1149.53$	$(r-1)(s-1)(t-1) = 8$	$SS_2^{ABC*} = 143.69$	$F_{ABC} = 0.87$
			$\sigma^2_{EXP} = 165.07$	$F_{.01;8,60} = 2.82$
			$F_{.01;2,60} = 4.98$	$F_{.01;2,8} = 8.65$
			$F_{.01;4,60} = 3.65$	$F_{.01;4,8} = 7.01$

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VIBRATION (A)	THREE FACTOR EXPERIMENTAL DESIGN #39 VIBRATION VS. HUMIDITY VS. SUSTAINED ACCELERATION								
	HUMIDITY (B)								
	4%			40%			80%		
	SUSTAINED ACCELERATION (C)								
LEVEL	3 g's	6 g's	9 g's	3 g's	6 g's	9 g's	3 g's	6 g's	9 g's
2 g's	192.18	178.82	188.31	223.92	209.96	223.28	200.61	163.22	171.89
4 g's	239.55	222.82	236.95	270.90	252.97	270.60	242.82	206.27	218.67
6 g's	300.27	277.12	274.57	331.53	310.23	309.59	308.32	262.21	258.22

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ANALYSIS OF VARIANCE TABLE
VIBRATION VS. HUMIDITY VS. SUSTAINED ACCELERATION

SOURCE		SUMS OF SQUARES	DEGREES OF FREEDOM	MEAN SQUARES	F TESTS
Main Effects:					
Vibration	(A)	$SS_3 = 43{,}078.76$	$(r-1) = 2$	$SS_3^* = 21{,}539.38^+$	$F_3 = 130.49$
Humidity	(B)	$SS_4 = 8{,}484.73$	$(s-1) = 2$	$SS_4^* = 4{,}242.37^+$	$F_4 = 25.70$
Sustained Acceleration	(C)	$SS_5 = 2{,}998.16$	$(t-1) = 2$	$SS_5^* = 1{,}499.08^+$	$F_5 = 9.08$
Interaction:					
	(AB)	$SS_2^{AB} = 7.67$	$(r-1)(s-1) = 4$	$SS_2^{AB*} = 1.92$	$F_{AB} = .01$
	(AC)	$SS_2^{AC} = 539.73$	$(r-1)(t-1) = 4$	$SS_2^{AC*} = 134.93$	$F_{AC} = .82$
	(BC)	$SS_2^{BC} = 767.53$	$(s-1)(t-1) = 4$	$SS_2^{BC*} = 191.88$	$F_{BC} = 1.16$

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ANALYSIS OF VARIANCE TABLE
VIBRATION VS. HUMIDITY VS. SUSTAINED ACCELERATION - Continued

(ABC)	$SS_2^{ABC} = 1,169.42$	$(r-1)(s-1)(t-1)=8$	$SS_2^{ABC*} = 146.18$	$F_{ABC} = .89$
			$\sigma^2_{EXP} = 165.07$	$F_{.01;8,60} = 2.82$
			$F_{.01;2,60} = 4.98$	$F_{.01;2,8} = 8.65$
			$F_{.01,4,60} = 3.65$	$F_{.01;4,8} = 7.01$

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MECHANICAL SHOCK (A)	THREE FACTOR EXPERIMENTAL DESIGN #40 MECHANICAL SHOC VS. SUSTAINED ACCELERATION VS. VIBRATION								
	SUSTAINED ACCELERATION (A)								
	3 g's			6 g's			9 g's		
	VIBRATION (C)								
LEVEL	2 g's	4 g's	6 g's	2 g's	4 g's	6 g's	2 g's	4 g's	6 g's
10 g's	24.10	46.05	59.13	32.18	37.87	49.98	36.42	39.19	51.19
16 g's	151.14	54.05	57.63	37.99	197.16	49.90	38.87	47.10	53.47
21 g's	47.16	53.09	61.01	43.17	48.82	58.73	44.92	51.27	57.23

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THERMAL SHOCK (A)	THREE FACTOR EXPERIMENTAL DESIGN #41 THERMAL SHOCK VS. VIBRATION VS. MECHANICAL SHOCK								
	VIBRATION (B)								
	2 g's			4 g's			6 g's		
	MECHANICAL SHOCK (C)								
LEVEL	10 g's	16 g's	21 g's	10 g's	16 g's	21 g's	10 g's	16 g's	21 g's
80%	512.45	484.21	510.61	523.35	523.05	523.00	548.08	544.30	543.74
90%	574.78	606.43	575.54	584.02	583.36	582.05	609.99	609.02	610.04
100%	677.95	677.74	678.96	687.26	689.36	687.78	712.16	712.82	713.38

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ANALYSIS OF VARIANCE TABLE

THERMAL SHOCK VS. VIBRATION VS. MECHANICAL SHOCK

SOURCE	SUMS OF SQUARES	DEGREES OF FREEDOM	MEAN SQUARES	F TESTS
Main Effects:				
Thermal Shock (A)	$SS_3 = 119,697.28$	$(r-1) = 2$	$SS_3^* = 59,848.64^+$	$F_3 = 362.56$
Vibration (B)	$SS_4 = 5,504.53$	$(s-1) = 2$	$SS_4^* = 2752.26^+$	$F_4 = 16.67$
Mechanical Shock (C)	$SS_5 = 1.91$	$(t-1) = 2$	$SS_5^* = 0.95$	$F_5 = 0.00$
Interactions:				
(AB)	$SS_2^{AB} = 11,344.93$	$(r-1)(s-1) = 4$	$SS_2^{AB*} = 2,836.23^+$	$F_{AB} = 17.18$
(AC)	$SS_2^{AC} = 548.16$	$(r-1)(t-1) = 4$	$SS_2^{AC*} = 137.04$	$F_{AC} = 0.83$
(BC)	$SS_2^{BC} = 642.13$	$(s-1)(t-1) = 4$	$SS_2^{BC*} = 160.54$	$F_{BC} = .94$

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ANALYSIS OF VARIANCE TABLE

SOURCE	SUMS OF SQUARES	DEGREES OF FREEDOM	MEAN SQUARES	F TESTS
(ABC)	$SS_2^{ABC} = 1298.43$	$(r-1)(s-1)(t-1) = 8$	$SS_2^{ABC*} = 162.30$	$F_{ABC} = 0.98$
			$\sigma^2_{EXP} = 165.07$ $F_{.01;2,60} = 4.98$ $F_{.01;4,60} = 3.65$	$F_{.01;8,60} = 2.82$ $F_{.01;2,8} = 8.65$ $F_{.01;4,8} = 7.01$

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VIBRATION (A)	THREE FACTOR EXPERIMENTAL DESIGN #42 VIBRATION VS. HUMIDITY VS. MECHANICAL SHOCK								
	HUMIDITY (B)								
	4%			40%			80%		
	MECHANICAL SHOCK (C)								
LEVEL	10 g's	16 g's	21 g's	10 g's	16 g's	21 g's	10 g's	16 g's	21 g's
2 g's	172.65	171.23	170.56	198.44	198.91	193.39	189.61	188.44	328.54
4 g's	216.42	215.94	213.15	232.98	233.77	232.78	210.89	211.53	209.84
6 g's	264.68	267.41	267.42	315.19	314.92	312.50	270.75	272.60	272.59

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LOW TEMPERATURE (A)	THREE FACTOR EXPERIMENTAL DESIGN #43 LOW TEMPERATURE VS. SUSTAINED ACCELER ION VS. MECHANICAL SHOCK								
	SUSTAINED ACCELERATION (B)								
	3 g's			6 g's			9 g's		
	MECHANICAL SHOCK (C)								
LEVEL	10 g's	15 g's	20 g's	10 g's	15 g's	20 g's	10 g's	15 g's	20 g's
70°	5.24	70.96	7.58	5.57	24.54	63.33	8.18	6.37	25.29
40°	28.09	28.22	28.55	28.55	29.22	138.75	28.65	28.25	27.94
10°	114.02	269.62	127.75	112.56	248.24	169.56	111.18	216.90	131.53

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MECHANICAL SHOCK (A)	THREE FACTOR EXPERIMENTAL DESIGN #44 MECHANICAL SHOCK VS. SUSTAINED ACCELERATION VS. HIGH TEMPERATURE								
	SUSTAINED ACCELERATION								
	3 g's			6 g's			9 g's		
	HIGH TEMPERATURE (C)								
LEVEL	95°	135°	180°	95°	135°	180°	95°	135°	180°
6 g's	51.89	136.02	251.68	46.83	155.42	248.48	59.05	158.24	244.41
12 g's	115.06	142.58	251.58	44.16	153.14	248.93	100.77	155.67	245.27
14 g's	91.73	149.17	255.15	43.13	163.57	245.11	47.64	157.33	243.33

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ANALYSIS OF VARIANCE TABLE

MECHANICAL SHOCK VS. SUSTAINED ACCELERATION VS. HIGH TEMPERATURE

SOURCE	SUMS OF SQUARES	DEGREES OF FREEDOM	MEAN SQUARES	F TESTS
Main Effects:				
Mechanical Shock (A)	$SS_3 = 619.40$	$(r-1) = 2$	$SS_3^* = 309.70$	$F_3 = 1.87$
Sustained Acceleration (B)	$SS_4 = 529.40$	$(s-1) = 2$	$SS_4^* = 264.70$	$F_4 = 1.60$
High Temperature (C)	$SS_5 = 148,429.27$	$(t-1) = 2$	$SS_5^* = 74,214.63^+$	$F_5 = 449.59$
Interactions:				
(AB)	$SS_2^{AB} = 813.38$	$(r-1)(s-1)=4$	$SS_2^{AB*} = 203.34$	$F_{AB} = 1.23$
(AC)	$SS_2^{AB} = 748.16$	$(r-1)(t-1)=4$	$SS_2^{AC*} = 187.04$	$F_{AC} = 1.13$
(BC)	$SS_2^{BC} = 912.19$	$(s-1)(t-1)=4$	$SS_2^{BC*} = 228.05$	$F_{BC} = 1.38$

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ANALYSIS OF VARIANCE TABLE

SOURCE	SUMS OF SQUARES	DEGREES OF FREEDOM	MEAN SQUARES	F TESTS
(ABC)	$SS_2^{ABC} = 1286.19$	$(r-1)(s-1)(t-1) = 8$	$SS_2^{ABC*} = 160.77$	$F_{ABC} = 0.97$
			$\sigma^2_{EXP} = 165.07$	$F_{.01;8,60} = 2.82$
			$F_{.01;2,60} = 4.98$	$F_{.01;2,8} = 8$
			$F_{.01;4,60} = 3.65$	$F_{.01;4,8} = 7.01$

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THREE FACTOR ANALYSIS OF VARIANCE #45

THERMAL SHOCK VS. SUSTAINED ACCELERATION VS. MECHANICAL SHOCK

THERMAL SHOCK (A)	SUSTAINED ACCELERATION (B)								
	3 g's			6 g's			9 g's		
	MECHANICAL SHOCK (C)								
LEVEL	10 g's	16 g's	21 g's	10 g's	16 g's	21 g's	10 g's	16 g's	21 g's
80%	221.82	221.95	222.77	213.92	203.23	215.07	158.44	167.89	157.92
90%	274.78	275.49	274.91	179.71	177.30	179.79	207.06	202.57	225.21
100%	306.49	306.92	306.03	302.49	298.68	301.10	274.10	276.07	276.50

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ANALYSIS OF VARIANCE TABLE
THERMAL SHOCK VS. SUSTAINED ACCELERATION VS. MECHANICAL SHOCK

SOURCE		SUMS OF SQUARES	DEGREES OF FREEDOM	MEAN SQUARES	F TESTS
Main Effects:					
Thermal Shock	(A)	$SS_3 = 45,152.24$	$(r-1) = 2$	$SS_3^* = 22,576.12^+$	$F_3 = 136.77$
Sustained Acceleration	(B)	$SS_4 = 12,883.95$	$(s-1) = 2$	$SS_4^* = 6,441.97^+$	$F_4 = 39.03$
Mechanical Shock	(C)	$SS_5 = 49.94$	$(t-1) = 2$	$SS_5^* = 24.97$	$F_5 = .15$
Interactions:					
	(AB)	$SS_2^{AB} = 9,329.74$	$(r-1)(s-1) = 4$	$SS_2^{AB*} = 2,332.44^+$	$F_{AB} = 14.13$
	(AC)	$SS_2^{AC} = 60.64$	$(r-1)(t-1) = 4$	$SS_2^{AC*} = 15.16$	$F_{AC} = .09$
	(BC)	$SS_2^{BC} = 68.92$	$(s-1)(t-1) = 4$	$SS_2^{BC*} = 17.23$	$F_{BC} = .10$

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ANALYSIS OF VARIANCE TABLE

THERMAL SHOCK VS. SUSTAINED ACCELERATION VS. MECHANICAL SHOCK - Continued

(ABC)	SS_2^{ABC} =1019.04	(r-1)(s-1)(t-1)=8	SS_2^{ABC*} = 127.38	F_{ABC} = .77
			σ^2_{EXP} = 165.07 $F_{.01;2,60}$ = 4.98 $F_{.01;4,60}$ = 3.65	$F_{.01;8,60}$ = 2.82 $F_{.01;2,8}$ = 8.65 $F_{.01;4,8}$ = 7.01

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SUSTAINED CCELERATION (A)	THREE FACTOR EXPERIMENTAL DESIGN #46 SUSTAINED ACCELERATION VS. HUMIDITY VS. MECHANICAL SHOCK								
	HUMIDITY (B)								
	4%			40%			80%		
	MECHANICAL SHOCK (C)								
LEVEL	10 g's	16 g's	21 g's	10 g's	16 g's	21 g's	10 g's	16 g's	21 g's
3 g's	173.22	173.81	174.11	246.93	241.57	204.86	309.45	181.75	181.31
6 g's	173.50	230.60	213.82	203.98	301.33	390.62	158.26	166.80	157.08
9 g's	178.78	177.92	178.02	213.60	300.82	278.97	161.49	170.56	172.65

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FOUR FACTOR EXPERIMENTAL DESIGN #47

LOW TEMPERATURE VS. SUSTAINED ACCELERATION VS. VIBRATION VS. MECHANICAL SHOCK

LOW TEMPERATURE (A)		SUSTAINED ACCELERATION (B)								
		3 g's			6 g's			9 g's		
		VIBRATION (C)								
LEVEL		2 g's	4 g's	6 g's	2 g's	4 g's	6 g's	2 g's	4 g's	6 g's
70°	D(10)	5.57	6.68	24.59	3.28	19.66	32.26	6.71	8.25	25.27
	D(15)	6.51	7.34	24.87	3.28	19.43	31.98	7.04	72.83	25.48
	D(20)	5.52	7.39	50.36	96.92	19.23	31.70	90.51	68.12	25.62
40°	D(10)	25.82	34.52	51.48	25.93	34.49	57.13	149.77	33.72	55.53
	D(15)	86.77	34.82	50.82	26.25	34.67	55.94	149.01	86.01	55.56
	D(20)	64.86	34.82	52.77	25.62	33.34	55.84	73.18	142.30	55.43
10°	D(10)	109.76	127.50	182.22	109.98	135.19	201.39	108.34	127.40	183.86
	D(15)	109.93	127.48	183.20	109.93	134.92	200.09	162.24	127.32	182.62
	D(20)	110.44	127.65	181.91	108.98	135.51	200.31	126.00	127.32	182.75

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ANALYSIS OF VARIANCE TABLE

Low Temperature Vs. Sustained Acceleration Vs. Vibration Vs. Mechanical Shock

Source		Sums of Squares	Degrees of Freedom	Mean Squares	F Tests
Main Effects:					
Low Temperature	(A)	$SS_3 = 48{,}611.97$	$(r-1) = 2$	$SS_3^* = 24{,}305.98^+$	$F_3 = 147.24$
Sustained Accel.	(B)	$SS_4 = 1{,}634.20$	$(s-1) = 2$	$SS_4^* = 817.10$	$F_4 = 4.95$
Vibration	(C)	$SS_5 = 5{,}397.48$	$(t-1) = 2$	$SS_5^* = 2{,}698.74^+$	$F_5 = 16.34$
Mechanical Shock	(D)	$SS_6 = 1{,}624.28$	$(w-1) = 2$	$SS_6^* = 812.14$	$F_6 = 4.92$
Two-Factor Interactions:	(AB)	$SS_2^{AB} = 2{,}377.00$	$(r-1)(s-1)=4$	$SS_2^{AB*} = 594.25$	$F_{AB} = 3.60$
	(AC)	$SS_2^{AC} = 5{,}407.68$	$(r-1)(t-1)=4$	$SS_2^{AC*} = 1{,}351.92^+$	$F_{AC} = 8.19$
	(AD)	$SS_2^{AD} = 2{,}363.80$	$(r-1)(w-1)=4$	$SS_2^{AD*} = 590.95$	$F_{AD} = 3.58$
	(BC)	$SS_2^{BC} = 1{,}413.00$	$(s-1)(t-1)=4$	$SS_2^{BC*} = 353.25$	$F_{BC} = 2.14$

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ANALYSIS OF VARIANCE TABLE

Continued

(BD)	$SS_2^{BD} = 59.40$	$(s-1)(w-1)=4$	$SS_2^{BD*} = 14.85$	$F_{BD} = .09$
(CD)	$SS_2^{CD} = 2,291.16$	$(t-1)(w-1)=4$	$SS_2^{CD*} = 572.79$	$F_{CD} = 3.47$
Three Factor Interaction:				
(ABC)	$SS_2^{ABC} = 3,578.72$	$(r-1)(s-1)(t-1)=8$	$SS_2^{ABC*} = 447.34$	$F_{ABC} = 2.71$
(ABD)	$SS_2^{ABD} = 2,231.76$	$=8$	$SS_2^{ABD*} = 278.97$	$F_{ABD} = 1.69$
(ACD)	$SS_2^{ACD} = 2,680.72$	$=8$	$SS_2^{ACD*} = 335.09$	$F_{ACD} = 2.03$
(BCD	$SS_2^{BCD} = 2,973.92$	$=8$	$SS_2^{BCD*} = 374.71$	$F_{BCD} = 2.27$
Four Factor Interaction:				
(ABCD)	$SS_2^{ABCD} = 4,463.52$	$(r-1)(s-1)(t-1)\cdot(w-1) = 16$	$SS_2^{ABCD*} = 278.97$	$F_{ABCD} = 1.69$

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HIGH TEMPERATURE (A)		FOUR FACTOR EXPERIMENTAL DESIGN #48 HIGH TEMPERATURE VS. VIBRATION VS. SUSTAINED ACCELERATION VS. MECHANICAL SHOCK								
		VIBRATION (B)								
		2			4			6		
		SUSTAINED ACCELERATION (C)								
LEVEL		3	6	9	3	6	9	3	6	9
100°	D(10)	33.71	39.15	39.48	49.83	42.02	42.02	63.47	59.71	64.02
	D(15)	36.90	63.57	54.95	46.65	41.21	41.21	64.02	55.27	98.37
	D(20)	67.78	158.85	141.61	51.09	38.03	116.94	59.58	58.45	140.34
140°	D(10)	174.16	327.85	162.67	216.21	185.95	190.20	271.61	220.43	224.35
	D(15)	186.04	321.27	163.35	212.95	305.95	190.07	265.55	221.47	224.74
	D(20)	195.69	198.87	186.56	222.45	319.46	370.68	264.67	220.33	224.97
180°	D(10)	248.97	253.28	244.93	279.41	280.07	270.79	350.23	350.23	341.61
	D(15)	451.82	249.24	240.62	283.45	283.45	275.10	348.23	348.38	339.76
	D(20)	251.09	255.44	246.78	348.38	283.72	275.10	382.59	348.10	339.76

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ANALYSIS OF VARIANCE TABLE

High Temperature Vs. Vibration Vs. Sustained Acceleration Vs. Mechanical Shock

Source		Sums of Squares	Degrees of Freedom	Mean Squares	F Tests
Main Effects:					
High Temperature	(A)	SS_3 = 178,312.96	(r-1) = 2	SS_3^* = 89,156.48$^+$	F_3 = 540.11
Vibration	(B)	SS_4 = 98,467.12	(s-1) = 2	SS_4^* = 49,233.56$^+$	F_4 = 298.25
Sustained Accel.	(C)	SS_5 = 1,412.82	(t-1) = 2	SS_5^* = 706.41	F_5 = 4.27
Mechanical Shock	(D)	SS_6 = 1,630.82	(w-1) = 2	SS_6^* = 815.41	F_6 = 4.93
Two-Factor Interaction:					
	(AB)	SS_2^{AB} = 12,186.91	(r-1)(s-1) = 4	SS_2^{AB*} = 3,046.73$^+$	F_{AB} = 18.45
	(AC)	SS_2^{AC} = 1,938.40	(r-1)(t-1) = 4	SS_2^{AC*} = 484.60	F_{AC} = 2.93
	(AD)	SS_2^{AD} = 2,137.97	(r-1)(w-1) = 4	SS_2^{AB*} = 534.49	F_{AD} = 3.23
	(BC)	SS_2^{BC} = 2,766.80	(s-1)(t-1) = 4	SS_2^{BC*} = 691.92	F_{BC} = 4.19

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ANALYSIS OF VARIANCE TABLE

Continued

(BD)	$SS_2^{BD} = 768.37$	$(s-1)(w-1) = 4$	$SS_2^{BD*} = 192.09$	$F_{BD} = 1.16$
(CD)	$SS_2^{CD} = 1,666.27$	$(t-1)(w-1) = 4$	$SS_2^{CD*} = 416.58$	$F_{CD} = 2.52$
Three Factor Interaction:				
(ABC)	$SS_2^{ABC} = 3,657.92$	$(r-1)(s-1)(t-1) = 8$	$SS_2^{ABC*} = 457.24$	$F_{ABC} = 2.77$
(ABD)	$SS_2^{ABD} = 1,294.16$	$= 8$	$SS_2^{ABD*} = 161.77$	$F_{ABD} = 0.98$
(ACD)	$SS_2^{ACD} = 2,931.68$	$= 8$	$SS_2^{ACD*} = 366.46$	$F_{ACD} = 2.22$
(BCD)	$SS_2^{BCD} = 2,469.44$	$= 8$	$SS_2^{BCD*} = 308.68$	$F_{BCD} = 1.87$
Four Factor Interaction:				
(ABCD)	$SS_2^{ABCD} = 3,538.38$	$(r-1)(s-1)(t-1)\cdot(w-1) = 16$	$SS_2^{ABCD*} = 221.14$	$F_{ABCD} = 1.33$

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FOUR FACTOR EXPERIMENTAL DESIGN #49

HIGH TEMPERATURE VS. VIBRATION VS. ALTITUDE VS. SUSTAINED ACCELERATION

HIGH TEMPERATURE (A)		VIBRATION (B) 2			4			6		
		ALTITUDE (C)								
LEVEL		5mm	310mm	620mm	5mm	310mm	620mm	5mm	310mm	620mm
70°	SA(3)	143.05	-	-	-	-	58.77	-	42.04	-
	SA(6)	-	-	363.73	-	19.64	-	228.53	-	-
	SA(9)	-	11.38	-	174.53	-	-	-	-	73.79
120°	SA(3)	-	243.65	-	310.77	-	-	-	-	200.16
	SA(6)	285.19	-	-	-	-	145.79	-	319.49	-
	SA(9)	-	-	124.80	-	274.90	-	366.66	-	-
170°	SA(3)	-	-	287.80	-	380.53	-	475.81	-	-
	SA(6)	-	375.21	-	434.10	-	-	-	-	375.90
	SA(9)	425.05	-	-	-	-	303.21	-	452.10	-

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ANALYSIS OF VARIANCE TABLE

High Temperature Vs. Vibration Vs. Altitude Vs. Sustained Acceleration

Source		Degrees of Freedom	Mean Squares	F Tests
Main Effects:				
High Temperature (A)	$SS_3 = 53{,}611.10$	$(r-1) = 2$	$SS_3^* = 26{,}805.05^+$	$F_3 = 162.38$
Vibration (B)	$SS_4 = 37{,}437.82$	$(s-1) = 2$	$SS_4^* = 18{,}718.91^+$	$F_4 = 113.39$
Altitude (C)	$SS_5 = 17{,}012.88$	$(t-1) = 2$	$SS_5^* = 8{,}506.44$	$F_5 = 51.53$
Sustained Accel. (D)	$SS_6 = 1{,}508.74$	$(w-1) = 2$	$SS_6^* = 754.37$	$F_6 = 4.57$
Two Factor Interaction:				
(AB)	$SS_2^{AB} = 10{,}416.34$	$(r-1)(s-1) = 4$	$SS_2^{AB*} = 2{,}604.08^+$	$F_{AB} = 15.77$
(AC)	$SS_2^{AC} = 3{,}216.17$	$(r-1)(t-1) = 4$	$SS_2^{AC*} = 804.04$	$F_{AC} = 4.87$
(BC)	$SS_2^{BC} = 2{,}297.76$	$(s-1)(t-1) = 4$	$SS_2^{BC*} = 574.44$	$F_{BC} = 3.48$
Remainder (Confounded Effects)	$SS_R = 3{,}070.32$	6	$SS_R^* = 511.72$	$F_R = 3.10$

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FOUR FACTOR EXPERIMENTAL DESIGN #50

LOW TEMPERATURE VS. VIBRATION VS. ATTITUDE VS. SUSTAINED ACCELERATION

LOW TEMPERATURE (A)		VIBRATION (B)								
		2 g's			4 g's			6 g's		
		ALTITUDE (C)								
LEVEL		5mm	310mm	620mm	5mm	310mm	620mm	5mm	310mm	620mm
10°	SA(3)	17.85	-	-	-	-	240.01	-	230.03	-
	SA(6)	-	-	211.64	-	161.13	-	86.27	-	
	SA(9)	-	125.41	-	42.31	-	-	-	-	322.62
40°	SA(3)	-	19.04	-	92.50	-	-	-	-	159.23
	SA(6)	76.94	-	-	-	-	146.40	-	91.81	-
	SA(9)	-	-	136.20	-	47.00	-	158.83	-	-
70°	SA(3)	-	-	29.63	-	75.41	-	285.67	-	-
	SA(6)	-	46.99	-	262.18	-	-	-	-	64.81
	SA(9)	195.45	-	-	-	-	41.16	-	96.28	-

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ANALYSIS OF VARIANCE TABLE

Low Temperature Vs. Vibration Vs. Altitude Vs. Sustained Acceleration

Source		Sums of Squares	Degrees of Freedom	Mean Squares	F Tests
Main Effects:					
Low Temperature	(A)	$SS_3 = 44,112.96$	$(r-1) = 2$	$SS_3^* = 22,056.48^+$	$F_3 = 133.61$
Vibration	(B)	$SS_4 = 32,612.17$	$(s-1) = 2$	$SS_4^* = 16,306.08^+$	$F_4 = 98.78$
Altitude	(C)	$SS_5 = 27,397.18$	$(t-1) = 2$	$SS_5^* = 13.698.59$	$F_5 = 82.98$
Sustained Accel.	(D)	$SS_6 = 1,634.20$	$(w-1) = 2$	$SS_6^* = 817.10$	$F_6 = 4.95$
Two Factor Interactions:					
	(AB)	$SS_2^{AB} = 18,894.16$	$(r-1)(s-1) = 4$	$SS_2^{AB*} = 4,723.54^+$	$F_{AB} = 28.61$
	(AC)	$SS_2^{AC} = 13,033.39$	$(r-1)(t-1) = 4$	$SS_2^{AC*} = 3,508.35^+$	$F_{AC} = 21.25$
	(BC)	$SS_2^{BC} = 2,183.34$	$(s-1)(t-1) = 4$	$SS_2^{BC*} = 545.84$	$F_{BC} = 3.30$
Remainder (Confounded Effects)		$SS_R = 2,976.38$	6	$SS_R^* = 496.06$	$F_R = 3.00$

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APPENDIX C

MODIFIED DESIGNS

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F[illegible]onal-Factorial Designs: The basic method of constructing a fractional-factorial design involves the principle of "confounding." This statistical method can best be illustrated by considering a 2^3 full factorial design in some detail.

Confounding is a statistical method of deliberately confusing certain unimportant variations for the purpose of assessing more important effects with greater precision. Frequently, when three or more factors are investigated simultaneously, the appropriate factorial design requires a larger number of experiments than can be carried out due to time limitations, economic consideration, insufficient supplies of homogeneous testing materials, etc. Consider, for illustrative purposes, that the latter situation exists. The most efficient method of dealing with this situation is to divide the testing materials into relatively homogeneous blocks, or lots, in a particular manner such that estimates of the main effects of all experimental factors and their interaction effects are free from the differences between blocks of materials. This difference between blocks of materials is in reality an additional factor and in some cases would constitute a significant effect. The process of confounding utilizes the assumption that a high-order interaction effect, say ABC, will be negligible. The mathematical estimate corresponding to what would normally be the interaction ABC is treated as an estimate of a fourth factor, the difference between blocks of materials. This fourth factor thus is "equated" to the difference between blocks of material.

Consider a simple 2^3 factorial experiment in which factors A, B, and C, are considered at two levels. Denote the levels as follows: a, b, or c, refers to the respective high levels of A, B, or C; (1) denotes the treatment combination at which all factors are at their low levels; and any factor at its low level is denoted by a blank. The possible 8 treatment combinations are then: (1), a, b, c, ab, ac, bc, and abc.

In the 2^3 design, we could consider two blocks or lots of materials in which the 8 treatments are allocated as shown in Table C-I.

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TABLE C-I

PARTITION OF THE 2^3 FACTORIAL DESIGN CONFOUNDING ABC

Made from Lot 1 of Base Material		Made from Lot 2 of Base Material	
(1)	ac	c	a
bc	ab	b	abc

This partition will confuse or confound the analysis of variance estimate of the high-order interaction ABC with the block differences in the materials. By a suitable rearrangement, any other effect, which because of physical considerations can be considered to be negligible, may be confounded or equated to a fourth factor.

In order to demonstrate the effects of confounding, consider the experiment of the 2^3 full factorial design as arranged in Table C-II.

TABLE C-II

EXPERIMENTS FROM A 2^3 FACTORIAL DESIGN

	Level of factor C (1)*		(c)	
Level of Factor A	Level of Factor B (1)*	(b)	Level of Factor B (1)*	(b)
(1)*	(1)	b	c	bc
a	a	ab	ac	abc

* These symbols denote the low level of the respective factor.

Assume that there is an insufficient supply of homogeneous material on which to conduct the eight experiments but that we may divide the material into two relatively homogeneous blocks. If the partition as shown in Table C-1 is made between these two blocks, the results of each experiment will not only contain the effect of each experimental factor but also an effect due to the difference between blocks of material. Denote the contribution due to the difference in

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blocks as " so that the results of the experiment could be written as:

Lot 1	Lot 2
(1)	b + X
bc	a + X
ac	c + X
ab	abc + X

From appendix A, the algebraic expressions for all main effects and interactions in a 2^n factorial experiment are renumerated:

$$A = (1/2)^{n-1} \ (a-1)\ (b+1)\ (c+1)\ \text{---}\ (q+1),$$

$$B = (1/2)^{n-1} \ (a+1)\ (b-1)\ (c+1)\ \text{---}\ (q+1),$$

$$\vdots$$

$$Q = (1/2)^{n-1} \ (a+1)\ (b+1)\ (c+1)\ \text{---}\ (q-1),$$

$$AB = (1/2)^{n-1} \ (a-1)\ (b-1)\ (c+1)\ \text{---}\ (q+1),$$

$$AC = (1/2)^{n-1} \ (a-1)\ (b+1)\ (c-1)\ \text{---}\ (q+1),$$

$$\vdots$$

$$AQ = (1/2)^{n-1} \ (a-1)\ (b+1)\ (c+1)\ \text{---}\ (q-1),$$

$$ABC = (1/2)^{n-1} \ (a-1)\ (b-1)\ (c-1)\ \text{---}\ (q+1),$$

$$\vdots$$

$$ABQ = (1/2)^{n-1} \ (a-1)\ (b-1)\ (c+1)\ \text{---}\ (q-1).$$

In the 2^3 factorial design, these algebraic expressions become:

$$A = 1/4\ (a-1)\ (b\ 1)\ (c+1),$$

$$B = 1/4\ (a+1)\ (b-1)\ (c+1),$$

$$C = 1/4\ (a+1)\ (b+1)\ (c-1),$$

$$AB = 1/4\ (a-1)\ (b-1)\ (c+1),$$

$$AC = 1/4\ (a-1)\ (b+1)\ (c-1),$$

$$BC = 1/4\ (a+1)\ (b-1)\ (c-1),$$

$$ABC = 1/4\ (a-1)\ (b-1)\ (c-1).$$

If the design of Table C-I is to confound the three-factor interaction ABC with the difference between lots of material, then all effects other than ABC must be free of the effect X. This may be verified by expanding any of the algebraic functions for the remaining factors. For example, we may demonstrate that the interaction AB is free of block differences by expanding the expression for AB,

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$$\text{Interaction } AB = 1/4 \left[(1) + ab + (c+X) + (abc + X)\right] - 1/4 \left[(a+X) + (b+X) + ac + bc\right].$$

In this expression all X's cancel, thus the interaction AB is free from the effects of block differences. A similar method of analysis will demonstrate that all effects except that of interaction ABC are free from block differences. Thus, by making the assumption that this high-order interaction is physically impossible, we may now "equate" the numerical estimate of ABC to the difference between blocks, a fourth factor. One may verify that the design of C-II confounds effect B.

By confounding the interaction ABC with the difference between blocks of materials, it is possible to reduce the error in the assessment of the other and more important effects. When the three-factor interaction effect is assumed negligible, the difference recorded between blocks measures the effect of the difference in quality of the two lots of material, and this information may well be important.

The number of statistical estimates confounded depends upon the number of blocks into which the total number of tests are to be partitioned. In general, partitioning a 2^n factorial experiment into k blocks requires that K-1 high-order interaction terms be confused with block differences. The basic principles of confounding in 3^n factorial design are similar to those for the 2^n designs, subject to differences in procedure due to larger number of levels per factor. Since each factor has three levels, the number of blocks must be 3, 9, 27, or in general, 3^p where p = the number of factors.

From Table C-I, it is seen that the experiments performed on Block 1 of test material constitute a 1/2 replicate of the full 2^3 factorial design. If this <u>one block</u> is treated from an analysis of variance viewpoint, it becomes a fractional factorial design. Indeed it may be shown that any fractional factorial design corresponds to one block of a confounded full-factorial design where the principles

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of confounding dictate which treatment combinations will be considered in the fractional design.

In the 3^4 factorial designs, a total of 81 experiments are required. The fractional factorial design may be used to reduce the number of experiments required in a full factorial design at the sacrifice of some of the advantages gained by the full design. The object of the fractional design then is to obtain information on the main effects and as many of the interactions as seem necessary with a smaller n[illegible]f observations than required by the complete design. In the following table, some of the fractional replicates in the 3^n factorial designs with the confounded effects listed are given.

TABLE C-III

FRACTIONAL REPLICATES IN 3^n DESIGNS

No. of Observations	No. of Factors	Confounded Effects
9	2	All effects clear, this being a complete 3^2 factorial design
	3	Two factor interactions are confounded with one another and main effect. May be used only when all interactions are negligible.
27	3	All effects clear, this being a complete 3^3 factorial design.
	4	All main effects clear. May be used to estimate main effects and two-factor interactions provided three of the factors do not interact with the fourth.
	5	Only two main effects are clear of two-factor interaction. May be used only when all interactions are negligible.
	6	All main effects are clear. May be used to estimate main effects and two factor interaction provided 2 of the 6 factors do not interact with other effects.

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From Table C-III, it is seen that a one-third replicate (27 observations) of a full 3^4 factorial design will allow for the estimation of all main effects and two factor interactions provided three of the factors do not interact with the fourth.

In Vol. I, we have concluded that the factors sustained acceleration and mechanical shock do not interact with the other factors in most cases. Furthermore, all the proposed four factor experimental tests include one or both of these factors. Thus, we may conclude that every four-factor test may be reduced from the 3^4 full factorial design to the one-third replicate fractional design. A design which requires only 27 experiments.

The twenty-seven treatment combinations are presented in Table C-IV. This list of experiments must be followed very closely. In this table, the fourth factor is either mechanical shock or sustained acceleration (when thermal shock or relative humidity is not involved).

TABLE C-IV

THE TWENTY-SEVEN TREATMENT COMBINATIONS REQUIRED IN A ONE-THIRD FRACTIONAL FACTORIAL DESIGN

0000*	0021	0012
1010	1001	1022
2020	2011	2002
0120	0111	0102
1100	1121	1112
2110	2101	2122
0210	0201	0222
1220	1211	1202
2200	2221	2212

*This notation indicates the level of each of the four factors for each experiment. Consider the four factor test involving High Temperature, Vibration, Mechanical Shock, and Sustained Acceleration. The number 0 indicates the low level of a factor, 1 represents the intermediate level and 2 denotes the high

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l el. Thus, 0000 indicates an experiment in which high temperature, etc., are tested at their low levels. The experiment 2001 indicates the high temperature is at its high level, vibration and mechanical shock are at their low levels and sustained acceleration is at its intermediate level.

This design confounds all 3 factor and higher-order interactions.

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APPENDIX D

THE F TEST

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The random variable ratio,

$$F = \frac{\chi^2_1/v_1}{\chi^2_2/v_2}, \qquad \text{(D-1)}$$

where χ^2_1 and χ^2_2 are chi-square random variables with v_1 and v_2 degrees of freedom, respectively, may be shown to obey the F probability density function (p.d.f.) with v_1 and v_2 degrees of freedom. The ratio of two sample variances,

$$F = s_A^2/s_B^2 \qquad \text{(D-2)}$$

is of the form (D-1) and obeys the F p.d.f.

The F p.d.f. may be written as

$$f(F) = \frac{\Gamma\left(\frac{v_1+v_2}{2}\right) v_1^{\frac{v_1}{2}} v_2^{\frac{v_2}{2}}}{\Gamma\left(\frac{v_1}{2}\right) \Gamma\left(\frac{v_2}{2}\right)} \quad \frac{F^{\left(\frac{v_1}{2}-1\right)}}{(v_2+v_1 F)^{(v_1+v_2)/2}}, \text{ for } F > 0.$$

The function f (F) is tabulated in many texts, [1] and [2]. The probability that F is greater than a constant is represented as

$$P\left\{F > F_{\alpha;v_1,v_2}\right\} = \int_{F_{\alpha;v_1v_2}}^{\infty} f(F)\, dF = \alpha.$$

We see that

$$P\left\{\frac{\chi^2_1/v_1}{\chi^2_2/v_2} \geq F_{\alpha;v_1,v_2}\right\} = P\left\{\frac{\chi^2_2/v_2}{\chi^2_1/v_1} < \frac{1}{F_{\alpha;v_1,v_2}}\right\} = \alpha,$$

or that

$$P\left\{\frac{\chi^2_1/v_1}{\chi^2_2/v_2} = F \geqq \frac{1}{F_{\alpha;v_1,v_2}}\right\} = 1-\alpha.$$

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Hence,

$$F_{1-\alpha;\ v_1,\ v_2} = \frac{1}{F_{\alpha;\ v_1,\ v_2}}$$

Since most tables of F include only values of F for $\alpha \leq .5$, the other values must be obtained from (D-3).

In the analysis of variance procedures we wish to test the hypothesis that a main effect or a particular interaction effect is negligible. It is seen by referring to the analysis of variance table II that the expected value of the mean square for both a factor, say A, and the residual equals σ_o^2 if the hypothesis is true. The $E(SS_R^*) = \sigma_o^2$ even if the hypothesis is false. When the hypothesis is false $E(SS_R^*)$ exceeds σ_o^2 by the amount $mv \sum A_i^2/(p-1)$. Hence, if the ratio SS_A^*/SS_R^* is computed, a value far from unity would indicate that the hypothesis is false.

It is shown that the terms in the ratios, $\frac{SS_A^*}{SS_R^*}$, $\frac{SS_B^*}{SS_R^*}$ etc. are analogous to sample variances, thus the ratios are of the form (D-1), when the hypothesis is true. For example, the ration $\frac{SS_A^*}{SS_R^*}$ is distributed as an F p.d.f. with (p-1) and (pm(k-1)) degrees of freedom when the hypothesis is true.

The hypothesis of an insignificant effect of factor A is rejected if

$$F = \frac{SS_A^*}{SS_R^*} > F_{\alpha;\ v_1,\ v_2},$$

where $F_{\alpha;\ p-1,\ pm(k-1)}$ is the upper α percentage point of the F p.d.f. Note that the one-sided test is used in this case since the ratio can only be too large if the hypothesis is false.

In the case where an "outside or independent" estimate of experimental error σ_{exp}^2 is used in the F ratio, say $F = \frac{SS_{AB}^*}{\sigma_{exp}^2}$, the two-sided testing procedure is used. Here $E(SS_{AB}^*)$ is a function of σ_o^2, the error associated with the one experiment in question. The value σ_{exp}^2 is a value calculated from all experiments.

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In this case, the test of hypothesis is that of testing if SS^{*}_{AB} is significantly different from σ^2_{exp}. The acceptance region for this test is

$$\left[F_{1-\frac{\alpha}{2};\, v_1,\, v_2}, \quad F_{\frac{\alpha}{2};\, v_1,\, v_2} \right]$$

Through the relation (D-3), the hypothesis of no significant difference is rejected if F lies outside the interval

$$\left[\frac{1}{F_{\alpha/2;\, v_1,\, v_2}}, \quad F_{/2,\, v_1,\, v_2} \right]$$

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13. ABSTRACT

A series of experiments was statistically designed and conducted to determine the effect of environments singularly and in combination upon the performance of a specimen representative of typical aircraft or missile equipment. The test specimen consisted of electronic, mechanical, and hydraulic components assembled in a manner which would produce a measurable deviation from a reproducible norm when subjected to combinations of the following eight environments: (1) high temperature, (2) low temperature, (3) thermal shock, (4) altitude, (5) humidity, (6) vibration, (7) mechanical shock, and (8) sustained acceleration. The experiments consisted of 8 single-environment tests, 21 combinations of 2 environments, 25 combinations of 3 environments, and 4 combinations of 4 environments. In general, the results of the experiments indicated that the response or deviation from the norm of the test specimen when subjected to multiple environments was greater than the sum of the environments when taken independently. The combinations involving altitude, vibration, high and low temperature, relative humidity and thermal shock produced the greatest interaction while the combinations involving mechanical shock and sustained acceleration produced much smaller interactions. This section (Volume II) contains appendixes A through D which are a detailed treatment of the statistical analysis employed in designing the multi-environment experiments and the analysis of the test results.

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

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