

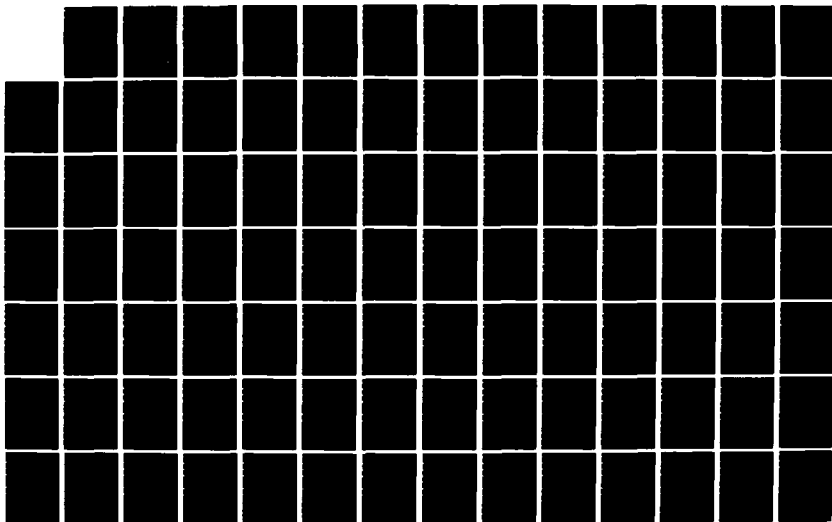
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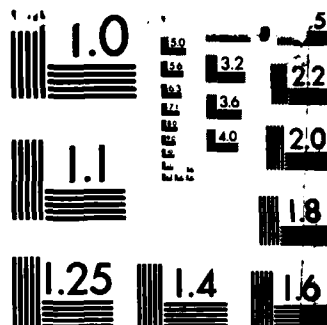
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ABSTRACT

Quality assurance functions at some major industrial manufacturers are confronted with test data on a massive scale and are not capable through manual methods of the in-depth analyses that are necessary for effective quality control. This report details the development of a quality control system for use at the Garrett Turbine Engine Company, Phoenix, Arizona, in analyzing the results of testing of vendor-supplied castings and forgings.

Traditional quality control chart theory and more elaborate statistical testing, such as analysis of variance, were integrated into computer programs to produce detailed quality control charts and summaries of data analysis and testing. These programs were integrated into a quality control system to allow management to make more timely and better founded decisions on accepting castings/forgings from vendors, modifying testing plans, and modification of material specifications, thereby reducing costs.

The testing results of two selected parts were used to verify operation of the programs. Three example situations were developed to demonstrate the system decision making; primarily comparisons of vendor and Garret testing of the same casting/forging and/or comparing different vendors. Further improvements were discussed and recommendations made.

Although the system was designed specifically for use by Garrett, it could be used by statistically experienced or inexperienced quality assurance personnel in other firms and/or manufacturing disciplines for effective data analysis.

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AN APPLICATION OF QUALITY CONTROL THEORY
TO VENDOR-SUPPLIED PARTS
AT AN AEROSPACE MANUFACTURING COMPANY

by

Daniel E. Gellenbeck

An Engineering Report Presented in Partial Fulfillment
of the Requirements for the Degree
Master of Science

ARIZONA STATE UNIVERSITY

August 1985

AN APPLICATION OF QUALITY CONTROL THEORY
TO VENDOR-SUPPLIED PARTS
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CHAPTER 1

INTRODUCTION

Background

Controlling the quality of procured hardware is a serious quality problem that companies must face (31:611). Because of increasing product specialization, most industrial and business concerns have found it necessary to purchase various parts and/or subassemblies from a number of suppliers (31:611). Logically, then, when a company does purchase from a number of vendors, some means of evaluating the individual vendor should be available. The basis for this evaluation should be the quality of product being supplied by the vendor. This report details an application of quality control theory to the evaluation of individual vendors at the AiResearch Manufacturing Company, Phoenix, Arizona.¹

This report is divided into five chapters. The remainder of this chapter describes the problem to be

¹AiResearch Manufacturing Company is now known as Garrett Turbine Engine Company. As the change occurred subsequent to research for this paper, references to AiResearch have been retained throughout. Any reference to AiResearch means Garrett Turbine Engine Company.

approached, a method for analysis, and goals that the project will attempt to fulfill. Chapter 2 discusses the basis for control charts, some approaches to situations that are peculiar to the problem, and previous examples of computerized quality control. Chapter 3 presents the computer program developed as a problem solution, while Chapter 4 presents two test cases utilized to verify the program. Recommendations for further study and a conclusion are included in Chapter 5.

Problem Statement

AiResearch Manufacturing Company, Phoenix, Arizona (hereafter referred to as AiResearch), receives, on a somewhat regular basis, shipments of various castings and forgings from a variety of manufacturers (vendors) for use in aviation and/or industrial gas turbine engines. Accompanying these shipments are the results of destructive testing of a sample of the castings or forgings as performed by the vendor. These results, in the form of Certifications of Compliance (CERTs) are routed to the Procurement Quality Engineering department for processing.

In order to check on vendor results and assure that the parts are acceptable, additional tests are conducted by the AiResearch testing lab ("in-house" testing). The frequency of this testing is included in the design specifications for each casting/forging. A sample specification is included in Appendix B. The results of these

tests, summarized in Chemical and Metallurgical Reports (CMRs), are then sent to the Procurement Quality Engineering department.

The results of vendor and in-house testing, summarized in, respectively, CERTs and CMRs, are compared to the specification minimum values and to the vendors' past performances on an intuitive basis. There presently exists, at AiResearch, no quick, efficient, economical method of comparing a particular vendor's current product with his past (historical) performance. A number of people in the Procurement Quality Engineering department who are familiar with a specific vendor's product, compare the present test results and make intuitive judgments on the reliability of the test results, and, hence, the reliability of the vendor's manufacturing processes.

Currently, the Quality Assurance and various Engineering departments at AiResearch are attempting to develop a system that will allow them to compare incoming vendor data with the past historical data of the particular vendor. By analyzing and comparing this data over time, changes in the process that would be detrimental to the quality of the casting/forging and, likewise, to the overall engine might be detected with greater accuracy than at present.

An AiResearch Office Memo, dated October 17, 1978 (Appendix A), summarizes the method to be used to develop the comparison system.

After several meetings, the subject of which was the analysis of vendor generated and CMR data, it was the consensus of Materials Engineering, Quality Assurance, and Manufacturing Engineering personnel that the use of control charts would be the best method . . .

Additionally, this method of analysis is to be computerized in such a way so as to allow people with varying degrees of skill to update and compare data from many vendors. This will also allow Quality Assurance personnel at AiResearch to query the individual vendor to determine if the manufacturing process has been changed in a manner that would account for a variation in test data from past vendor performance or if another cause might account for a noted variation.

Goals

In order to solve the problem developed in the above problem statement, two main goals have been established that this project will attempt to fulfill:

- 1) A quality control statistical analysis of vendor and AiResearch data is to be automated in order to more efficiently track a vendor's performance and to allow storage of data to be both more flexible and less space-consuming.

- 2) After comparing the performance of a specific vendor's product over time, the need for the current testing level is to be evaluated with respect to predetermined

criteria for testing frequency, which will be determined as part of this project. If testing frequency can be reduced, the product specifications for this vendor can be changed to reflect the reduction.

If these goals can be accomplished, considerable cost savings may be realized in both the volume of testing and the amount of required handling and analyzing of test results.

Now that the problem has been defined and a method of analysis proposed, namely statistical quality control, it seems appropriate that some background of statistical quality control, particularly control chart theory, be discussed. Chapter 2 describes control chart theory in sufficient detail to justify the rationale of AiResearch personnel in specifying control charts as a solution to the problem.

CHAPTER 2

QUALITY CONTROL CHARTS

. . . The object of control is to enable us to do what we want to do within economic limits.--W. A. Shewhart (27:356)

Quality Control

Before delving into the intricacies of quality control charts, an understanding of what is meant by quality and control of quality is necessary.

Quality may be defined simply as the level of performance of a product in fulfilling the expectations of the customer (17:27). In order to effectively measure this "level of performance," many of the engineering and manufacturing characteristics of a product may be considered. Product quality emphasis has in fact become a leading force in economic growth (10:22).

Quality control had its beginnings in 1924 when Dr. W. A. Shewhart of Bell Telephone Laboratories first applied a statistical quality control chart to manufacturing operations. During and following World War II and the Korean War, the Department of Defense widely used quality-control techniques in procurement of goods and services. This influenced the quality-control practices used in industry.

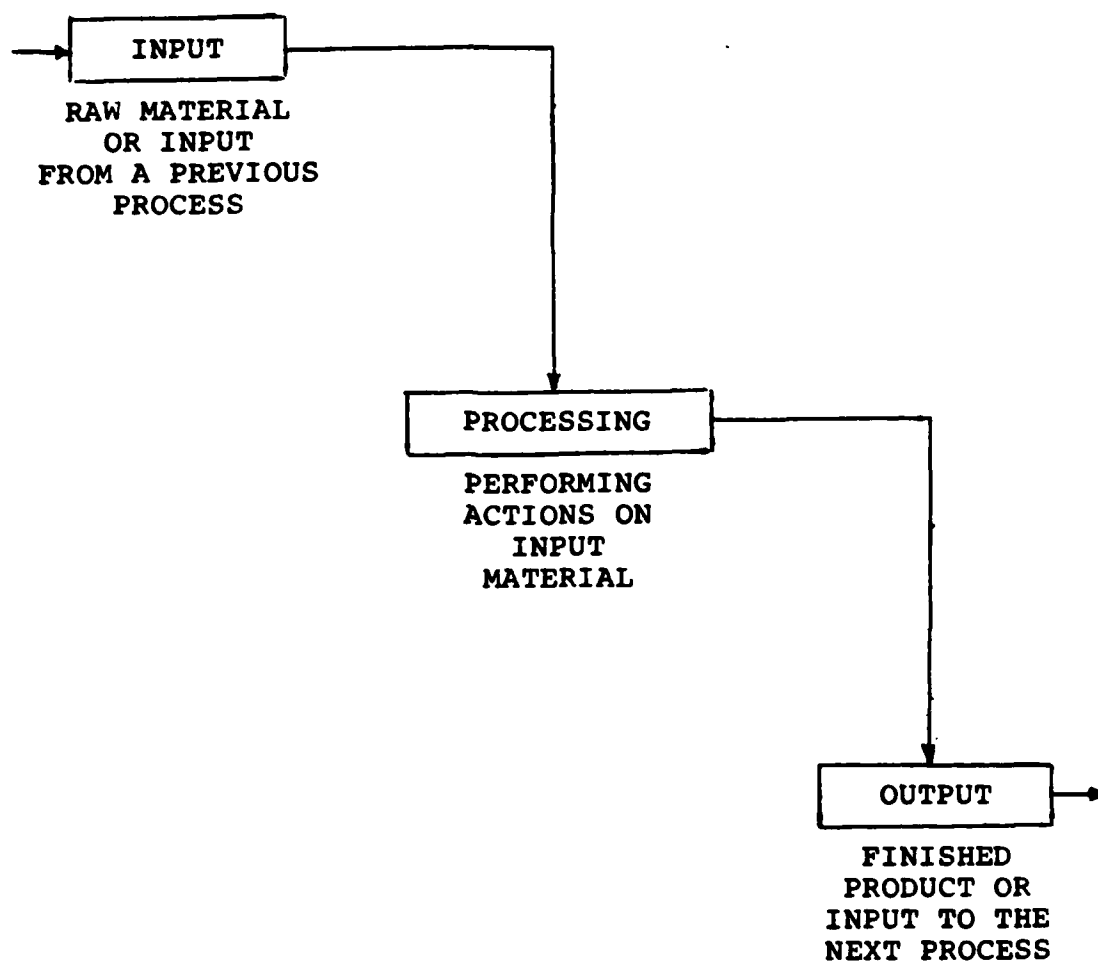
Control of quality involves two major aspects. The first is measuring the product characteristics that are significant in indicating product performance and analyzing this data to determine negative trends that may be affecting performance. The second aspect involves providing corrective action to offset the negative trends found above. Corrective action may be applied to any of the three general stages of the production process (Figure 2-1): incoming materials, components production or final assembly (35:4, 17:29).

Quality control, then, is accomplished by first asking the process whether its average or central tendency has changed and/or whether its spread (dispersion) has changed (25:35). If an out-of-tolerance condition is detected (where tolerance is the specified spread in a measurement), then a correction is applied to an appropriate area of the process and its effect in bringing the condition back into tolerance is measured.

A moment's reflection will indicate that quality control is only as good as the data it generates and is useful only to the extent that management can understand and use the information provided as a basis for decisions. Problems arise, however, in providing the data in terms that management can understand and/or use effectively.

Fiiegenbaum (11:67) and Kirkpatrick (15:11) both view quality control as a feedback function where measuring,

FIGURE 2-1
Stages of a Process



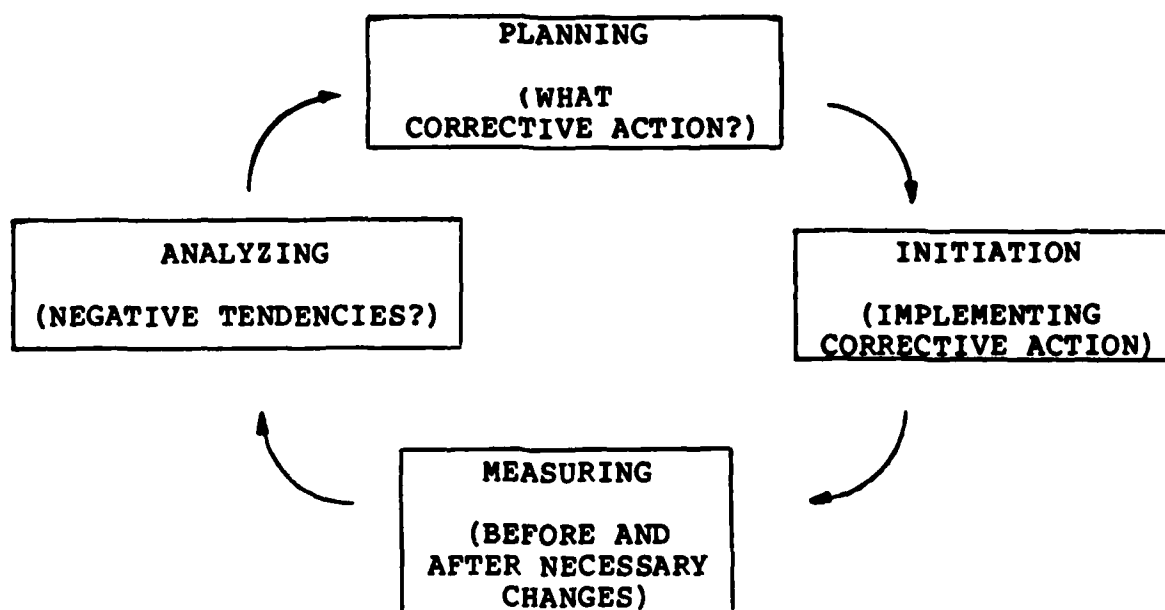
analyzing, and planning are a continuous cycle. Figure 2-2 illustrates and summarizes quality control as a feedback function. Initiation has been added to more fully represent how a quality control system actually operates. While most quality control efforts begin measuring a certain characteristic of a product, it should be remembered that any of the four areas may serve as the initial action.

Before discussing sampling inspection and methods of accomplishing it, the involvement of statistics in quality control should be addressed. According to Fiegenbaum (11:39-40), there are four basic statistical tools that have had a profound effect on quality control. These tools are:

1. The frequency distribution of particular quality characteristics, which provides a graphic² portrayal of the quality of a given product. It can provide, at a glance, information about the average quality level, the distribution (spread) of the quality, and how the quality compares with established standards.
2. The control chart of quality characteristics, which provides a chronological history of a product's performance. It can indicate, graphically, negative performance trends that would detrimentally affect the process if not corrected. In other words, it can be used to maintain control of a process.
3. Sampling Tables, which yield the probable quality of a given number of product units (a lot) when the proper number of samples are selected from the lot. Quality of material

²Product, when used in this paper, refers to any process or device that is the result of a manufacturing procedure.

FIGURE 2-2:
Quality Control as a Feedback Function



either received or produced can be assured through use of these tables.

4. Specialized methods, such as analysis of variance and other techniques, have been adopted from the general body of statistics for use. These techniques can be used to investigate problems in a process or for specialized analyses of designs.

Statistics, along with other tools such as simulation and information systems, form a powerful means of solving quality control problems that exist in industry.

Standards

Standards are based on the scale of measurements used (such as inches, millimeters, pounds, etc.) and on the limits of acceptable products (25:112). For example, a particular shaft in a mechanical assembly can have a diameter of 0.245 in. to 0.255 in. without having a detrimental effect on the operation of the assembly. The limits, 0.245 in. and 0.255 in. in the example, are frequently referred to as specifications. They are (or should be) based on engineering considerations that must be met in order that the product will perform as intended (29:163).

In other words, standards and specifications define limits, stating how far (.005 in. in the example) from perfect the product can be before it fails to be

acceptable. They are used to protect against all objectionable variations and are set up for any or all of the following purposes (25:112):

- a) Ensure interchangeability of parts.
- b) Determine the difference between good and bad product based on the ability to function.
- c) Determine the difference between good and bad product based on the expected effects of aging and/or usage (reliability).
- d) Determine the difference between good and bad product based on the aesthetic appearance.

Specifications and standards also serve to assure continuity and uniformity in the evaluations of many inspectors and to allow the management group to make the necessary major quality decisions. Setting such specifications compels management to investigate the required design needs and capabilities and to make a decision, from a financial and economic standpoint, between the high cost of quality and customer satisfaction (27:113-4).

In other words, if management sets specifications/-standards too rigidly (tightly), the product will probably perform properly but may cost an excessive amount to produce. On the other hand, if the set specifications are not rigid enough (loose) the production costs will probably not be excessive, but the product may not perform adequately. Such important decisions, according to Samson, Hart, and Rubin (25:113), should not be based on the recommendation of an engineer who is asking twice his needs because he knows he'll get half of what he asks; nor should

they be based on the request of a production manager who is asking for specs³ twice as loose because he knows the engineering department will tighten them anyway. To achieve the desired optimum profit, management must be certain to set precise standards that are neither too tight nor too loose to ensure the product will perform adequately and can be produced economically.

Inspection

For some industries, it is necessary to inspect each item produced and/or received from a vendor to identify and reject all defective items. Such 100 percent inspection accompanied by rejection of all defective items is termed "screening" (30:10). Inspection of this type is the only way to guarantee the rejection of all defective items and only defective items. Effective screening inspection, however, requires automatic machinery to eliminate the human error of misidentifying good items as defective or an inspector's work load must not be so excessive as to impair accuracy.⁴ Suitable machinery is costly if it is available, and even utilizing a human inspection system makes screening quite expensive in personnel and time.

³Specs is short for specifications.

⁴A statistical study conducted at Franford Arsenal, Philadelphia, indicates very clearly that the percentage of items classified erroneously increases sharply with the volume of inspection (30:10).

Additionally, screening rarely is able to eliminate all defective items. Of course, if the quality test for an item is destructive (as it is in the case of metallic castings and forgings), screening cannot be used.

Screening contributes very little to the improvement of the quality of product delivered in the future; there is very little, if any, feedback of information to the supplier (vendor) since only rejected items are returned. One can, thus, tell very little about the manufacturing process from a screening inspection.

Inspection, in respect to control of product quality, may basically be defined as comparing the quality characteristics of a product to the standards/specifications applying to the selected quality characteristics. This is done to fulfill one or both of the objectives of inspection: 1) whether material produced should be accepted or rejected; 2) whether corrective action should be taken on the production process (25:55). Inspection cannot improve the quality of a process of and by itself. Rather, the corrective action indicated by the sampling information improves quality which can reduce costs.

To obtain the necessary information for quality control decisions, an acceptance sampling plan is usually employed that utilizes an inspection by attributes (pass/fail plan) or an inspection by variables (measurement plan).

Acceptance Sampling

Incoming materials should conform to the specifications and tolerances submitted to the supplier as part of the purchase order. To ensure this conformance, acceptance sampling of each shipment (lot) of material is necessary. There are two means of sampling, according to Lester, Enrick, and Motley (17:141):

1. Sampling prior to receipt of the purchased materials; also known as advanced sampling.
2. Sampling upon receipt; also termed on-arrival sampling or sampling for receiving inspection.

Advance sampling involves the vendor sending samples to the consumer (or the manufacturer in the case of AiResearch) or the vendor conducting tests in accordance with the manufacture-approved procedures prior to shipping the lot of material (both apply to this report). The advantage of re-routing or refusing a lot prior to delivery to the consumer is significantly outweighed by a number of possible events.

1. Contamination or other damage occurs during transit.

2. An overzealous person(s) at the vendor ships pretested samples that are not representative of the actual lot quality.

3. Unethical practices such as "salting" (defective items are added to material of high quality level, while keeping the percentage of defectives within the limits

specified by the consumer) are not detected.

On-arrival sampling allows random selection of units under the user's (consumer's) quality control system, but delays using the items immediately while samples are being tested and until acceptance decisions are made. Another drawback is that the consumer must have the necessary test equipment or must contract out that function.

Whenever possible, samples from actual regular production should be checked for their conformance to specifications. The data obtained from these samples can be used to develop a history of the vendor's (supplier's) performance, according to Lester, Enrick, and Motley (17:146). This is quite important in the case of a new supplier, since it gives the consumer an appraisal of the supplier's ability to meet quality, cost and delivery requirements. Vendor quality histories and ratings can be quite effective in the long-term monitoring of vendor performance and can be used to keep acquisition personnel (i.e., purchasing) current on vendor quality.

In some cases, it may be beneficial to certify a vendor as supplying consistently high quality product, thus protecting the purchaser from unacceptable product sources and reducing the need for inspection. Swaton and Weaver (31:611-616) advocate a program for acquisition of castings and forgings such as those acquired by AiResearch.

Acceptance sampling plans are characterized as lot-by-lot sampling inspections. In this type of inspection, the product is divided into appropriate inspection lots (for example, the number of items poured from one "melt" of metal, as in this study; the number of items produced in a day's production, etc.) and a sample or samples are drawn from this lot and tested. The inspection lot is then accepted/rejected (sentenced) on the test performance of the selected item.

There are, of course, advantages and disadvantages to acceptance sampling. There is a possibility that good items are rejected and, since not all items are inspected, bad items accepted. In other words, because the test items will follow the laws of chance, the result of their testing occasionally will not indicate the true quality of the lot. However, if the acceptance sampling plan is well-designed, in a statistical sense, the chance of this happening is greatly reduced. When these risks are balanced against the great cost savings, sampling inspection will generally be preferred to screening or 100% inspection (30:11). In the case of products that can only be tested destructively, acceptance sampling is necessary and will provide protection against accepting more than a very small number of low quality lots. That acceptance sampling is the only economical means of evaluating products requiring destructive

testing is the opinion of authorities in the field of quality control.⁵

This author found it interesting that AiResearch had attempted to perform a screening operation on all vendor-supplied castings and forgings by including a prolongation ring in the specs for all castings and forgings. This ring, cast or forged into the incoming products, was then machined off the item and portions of it subjected to destructive testing. While theoretically sound, this screening plan did not operate effectively because the properties of the prolongation ring could not be correlated with those of the casting/forging from which the ring was cut. Management then decided it needed an economical acceptance sampling plan to ensure that quality castings/forgings were being placed in their engines.

Inspection by Attributes

Inspection by attributes involves subjecting the selected test item to a specified level of the chosen testing characteristic. As a rather simplified example, let's say management wishes to test vendor-supplied steel rods on their ability to hold two-hundred pounds of weight. The acceptance sampling plan might be to divide the steel rods

⁵See, for instance, Weatherill (35:3), The Statistical Research Group of Columbia University (30:11), and Duncan (9:156), among others.

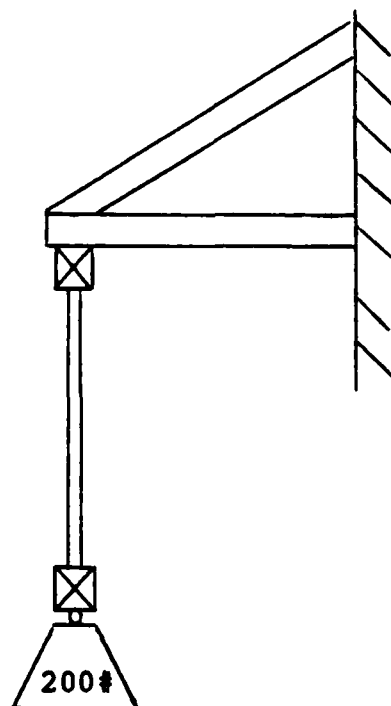
into lots of one-hundred and randomly select 5 for testing (5%).⁶ The inspection by attributes for this plan would be to secure one end of the test rod and hang two hundred pounds of weight from it (Figure 2-3).

If three or more of the five rods can successfully hold the weight without breaking (i.e., pass the test), we accept that lot of one hundred. If only one or two of five pass the test, we reject the lot. If the lot is rejected, it is sent back to the vendor.

This type of inspection provides more information to the vendor than screening each rod does (he has the whole rejected lot instead of only the rejected ones), but the results do not indicate what can be done in the manufacturing process to improve the rods. While testing costs are substantially reduced (only 5% of all rods submitted are tested, versus 100% in a screening), there is still no feedback information available to correct the deficiencies in the manufacturing process.

⁶The number of test items selected and the size of the inspection lot has a great impact on the economy of the test. According to the Statistical Research Group of Columbia University (30:42), the operating characteristic (OC) curve of a sampling plan (to be discussed later in this report) depends on the number of items selected per inspection lot; the higher the number the better the protection plan gives against rejecting high-quality and accepting low-quality lots. However, the total cost of inspection depends on the percentage of submitted products that are inspected since both a large number of items is desired in each sample (for good protection) and a small percentage of items is desired (for low cost), it follows that large inspection lots are required. The lot size chosen for this example was done so arbitrarily and may be assumed to be the most economical.

FIGURE 2-3:
Testing Apparatus
For Test of Steel Rods



Inspection by Variables⁷

If a characteristic (variable) can be measured upon which the quality (or acceptance) of an item depends, it may be possible to operate an inspection by variables (35:32-3). The advantages of this type of inspection system over an inspection by attributes include the following, as discussed by Fetter (12:19), Samson et al. (25:73) and Duncan (9:156), among others:

a) Fewer items must be inspected to give the same degree of assurance regarding acceptance/rejection. This method, hence, is less costly than 100% inspection.

b) It provides quick feedback of information for diagnosis and correction of process quality control deficiencies.

c) Since the decision to accept or reject a "lot" of material (the batch or group of product of size "n" that is submitted for testing [30:4]⁸) is based on a measurement of a chosen quantity rather than on a discrete (pass/fail) test, the proper weight is given to each item being tested, in order to make a decision on (sentence) the lot. Rather

⁷This type of inspection plan is also referred to as acceptance sampling by measurements and variables sampling, among others, in the literature (12:8, :102, 3:64, et al.).

⁸In the case of castings/forgings the lot size is that number of items made from one "pour" of molten material.

than base the decision on a set number of test items passing/failing a minimum (or maximum) level as in attribute sampling, variables sampling bases the sentence on the probable behavior of the remainder of the lot as determined by measurement of the chosen property of the test items (castings/forgings).

There are disadvantages, too, such as the higher cost of inspection (especially instrumentation), the greater time usually required, and the more complex computations involved. These are outweighed, however, when the inspection is destructive as is the case in this situation.

This type of inspection is accomplished by measuring quality along a scale (17:120). Such measurements might be in inches, centimeters, degrees of temperature, kilograms per square inch of yield point, etc. The procedure would be to take a sample of size "n" of a particular property, and compute a statistic of the sample, for instance the mean (average), and then compare it to an accepted standard usually expressed in terms of limits. If the mean falls within the limits, that particular lot of material from which the sample of size "n" was drawn is accepted. If not, it is rejected.

One of the basic assumptions of a variables inspection plan is that the distribution of measurements of the chosen characteristic is approximately normal. Burr (5:563-568), Owen (21:454), and Rossow (24:135) conducted research that

indicates variables sampling plans (in particular $\bar{X}$ and R control charts) remain useful unless the normality assumption is severely violated. Berthoex, Hunter and Pallesen go on to add:

It is fortunate, however, that even when the standard assumptions are seriously violated and the simple (quality control) charts can no longer be used quantitatively, they may nevertheless still provide useful qualitative information(4:139)

Operating Characteristic (OC) Curve

According to Duncan (9:147), the power of a sampling plan to discriminate between good and bad product is revealed by its operating characteristic, or OC, curve as it is termed. This curve shows how the probability of accepting a lot varies with the quality of the material offered. Another way of saying this, stated by Kirkpatrick (15:184) is that an OC curve describes the probability of accepting H_0 (the null hypothesis) for various H_1 -values (alternate hypothesis) for a fixed risk factor α .⁸

An assertion about H_0 carries the risk α of making a wrong decision; the null hypothesis being incorrectly rejected when nothing has been introduced into the process to change the value of the statistic (for example, μ_0).

⁸ α = probability of rejecting a lot of material even though it has an acceptable quality level; a selected risk factor. β = probability of accepting a lot of material even though it has an unacceptable quality level; a selected risk factor. Burr (6:402).

This according to Belz (3:169-170), Walpole and Myers (33:228-230), and others, is a Type I error, or an error of the first kind, it's probability being α . A mathematical function which indicates the probability α of rejecting H_0 for various values of the parameter under consideration is called a power function, and a graph of the function is called a power curve (15:92). An error of the second kind, or Type II error, arises when nothing is said about H_0 although the value of the statistic (μ_0 in the example above) has changed. In other words, accepting the lot even though it is not good. This error has a probability β (3:170, 33:230-231). An operating characteristic (OC) function is a mathematical expression stating the probability of accepting a process (or lot) as a function of the population (or lot) parameter. If the parameter is the mean (or average) and H_0 (null hypothesis) is $\mu = \mu_0$ (see Figure 2-4) and the process is to be accepted when the sample mean falls between:

$$\bar{x}_L = \text{Lower limit for means}$$

and

$$\bar{x}_U = \text{Upper limit for means}$$

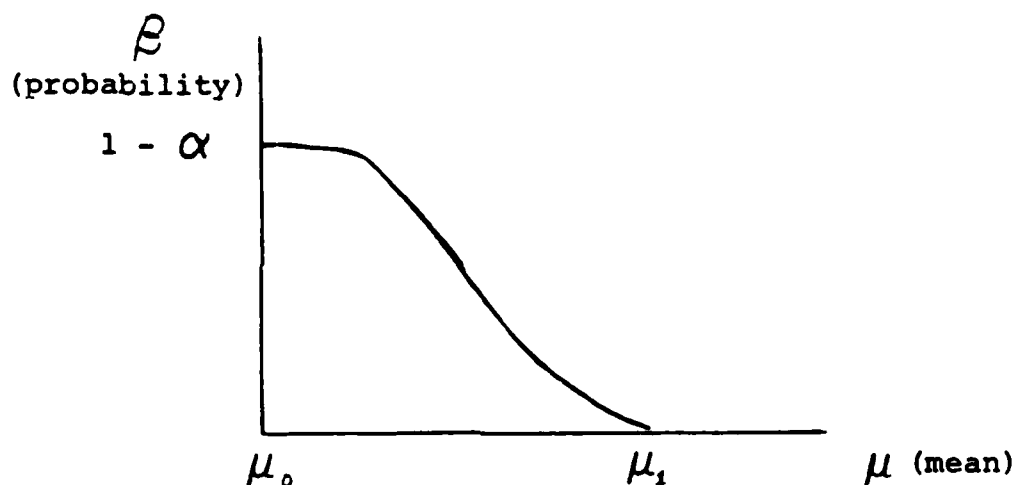
then the OC function is

$$\beta(\mu) = \Pr (\bar{x}_L \leq \bar{x} \leq \bar{x}_U | \mu) = \int_{\bar{x}_L}^{\bar{x}_U} f(\bar{x}) d\bar{x}$$

An operating characteristic curve graphs the OC function and is thus one way of summarizing a process (or lot) acceptance

FIGURE 2-4:

Operating Characteristic (OC) Curve
In Definitional Form



Operating Characteristic (OC) Curve
In Definitional Form

H_0 : (null hypothesis) $\mu = \mu_0$ (σ_x known)

H_1 : (alternate hypothesis) $\mu = \mu_1 > \mu_0$

μ = mean of population

$\alpha = P(\text{reject } H_0 | \mu = \mu_0)$

μ_0 = null hypothesis value

$\beta = P(\text{accept } H_0 | \mu \neq \mu_0)$

μ_1 = alternative hypothesis value

σ_x = standard deviation

This curve describes the probability of accepting H_0 for various H_1 - values, for fixed α and n (15:184).

sampling plan. In quality control work the OC curve is customarily used versus the power curve. The two curves are related through selection of the null hypothesis (H_0), however. If H_0 is that the lot is good, one rejects the lot when rejecting the hypothesis, and the operating characteristic curve is the power curve inverted. On the other hand, if the hypothesis is that the lot is bad, one accepts the lot when rejecting the hypothesis, hence the two curves (power and OC) are identical (8:92). This is presented graphically in Figure 2-4.

While the operating characteristic (OC) and the OC curve are used to design sampling plans, they are also the best-known devices for judging the efficacy of a control chart (8:257). The use of OC curves to describe quality control charts will be developed later in this report.

Quality Control Charts

As stated previously, quality control information is useful only if management can understand and use the information as a basis for making decisions. The most comprehensive display of quality information is attained through use of quality control charts.

A control chart is a statistical device principally used for the study and control of repetitive processes. . . . Shewhart suggests that the control chart may serve, first, to define the goal or standard for a process that . . . management might strive to obtain; second, it may be used as an instrument for attaining that goal; and third, it may serve as a means of judging whether the goal has been reached (9:337).

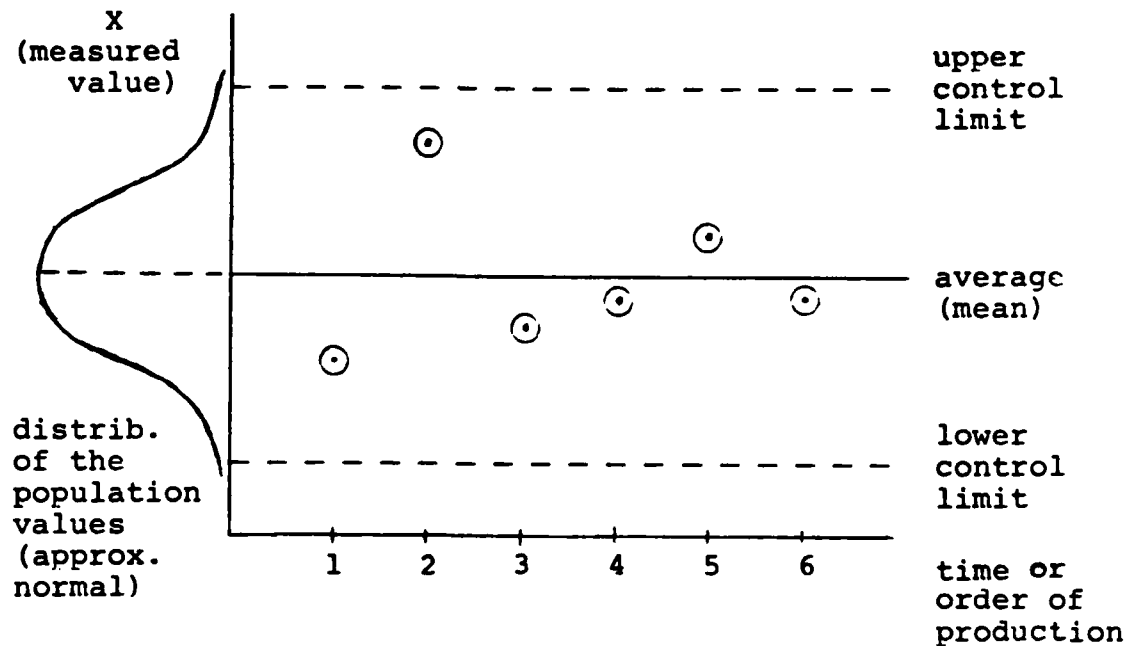
Thus, the control chart can be used in all phases of the industrial process (see Figure 2-1) to improve quality. In any product or process some variation in quality is unavoidable. The theory behind the quality control chart originated by Dr. W. A. Shewhart is that this variation can be divided into two categories, random variation and variation due to assignable causes (35:42). Assignable causes are those over which we have some degree of control. Random variation is the result of many complex causes over which we have little or no control.

The basic idea of a Shewhart control chart¹⁰ is simple. Groups of size "n" are drawn from a process (or from incoming lots of material) at regular intervals and measurements of some statistic(s) of quality are made. These measurements are plotted as ordinates on a chart provided with a center line (the average) and a pair of parallel control lines (the upper and lower control limits), as in Figure 2-5. This provides a chronological graphical comparison of actual product-quality characteristics with control limits.¹¹

¹⁰Throughout the literature the term control chart is used to describe the Shewhart control chart. The author, throughout the remainder of the report, will do likewise. See Burr (6:92) and (7:29).

¹¹Control charts can be developed for both measurement sampling plans and attribute (go/no go, pass/fail, etc.) plans. This report will deal primarily with the measurement control chart although in most cases, the same procedures apply for either.

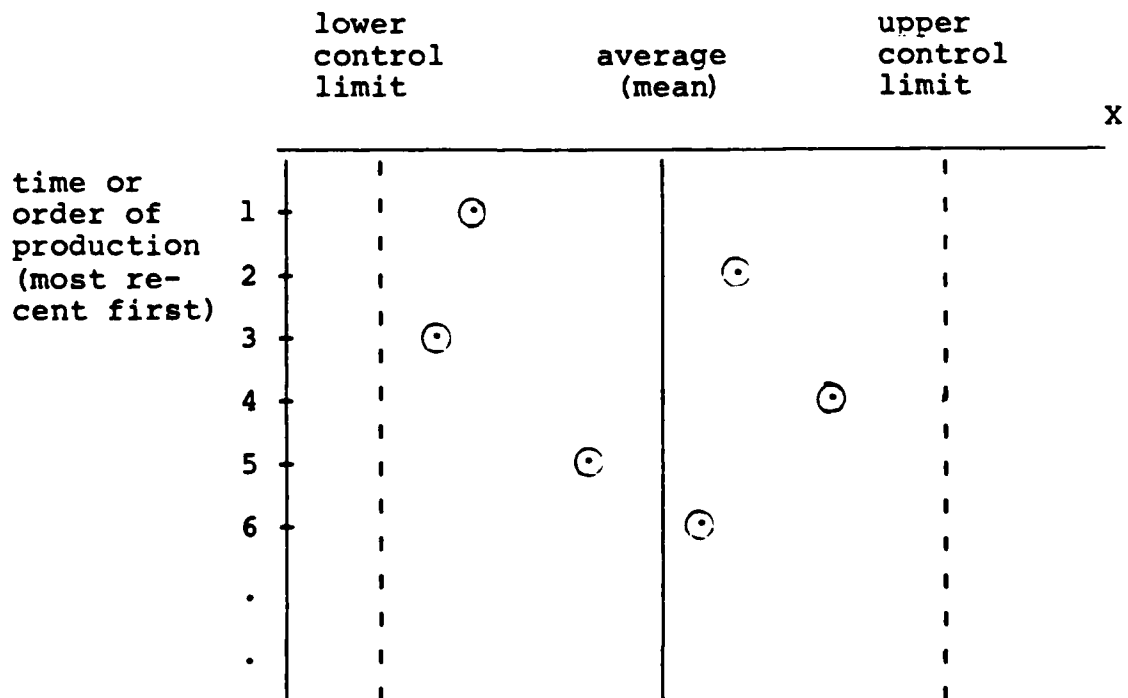
Theoretical Basis of Control Charts



X = Value of measured statistic

⊙ = Plotted Value

Computer-produced control charts to be developed in this report are of the following theoretical basis:



Suppose, for example, that one statistic (variable) is measured by testing an item. Assume that this variable is normally distributed under a state of statistical control. The presence of assignable causes of variation would then show up on the data as variation outside the usual range (usually $\pm 3\sigma$ of the average--this will be discussed later) for a normal variable. This can usually be attributed to a change in either μ or σ of the normal distribution for the measured variable. Thus, plotting estimates of the population mean ($\bar{x}$) and standard deviation (s) from the sample group n can be used to determine if the process (or lot of incoming material) is "in" or "out of control" (35:43). If all points fall within limits, the process is probably "in control." If not, the reverse is probably true.

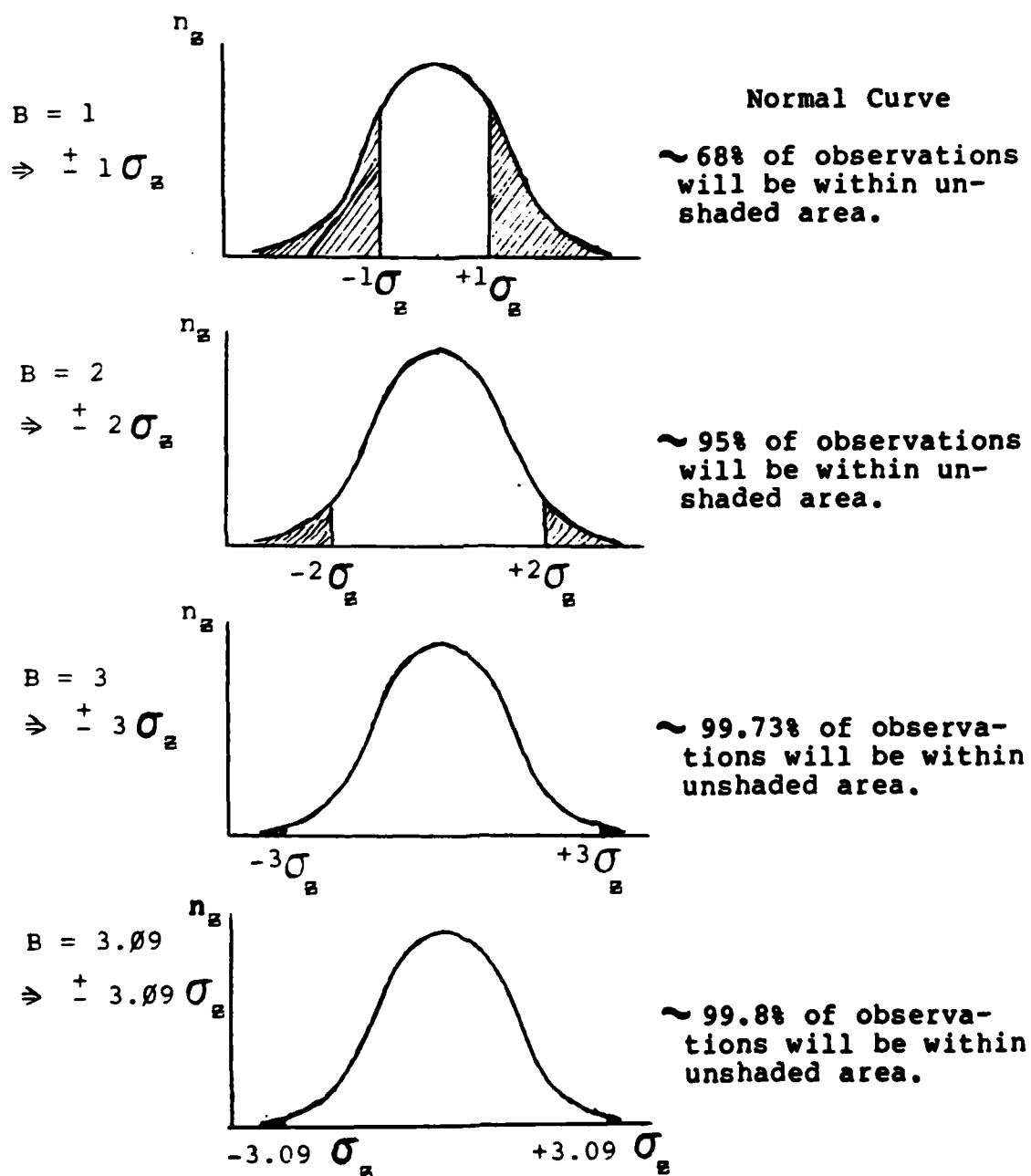
The question of normally distributed data was addressed earlier in this report, and must be mentioned again. Control chart theory assumes that the distribution of observations (measurements) is approximately normal. Even if the population of observations is somewhat non-normal, the distribution of means of observations of sufficient sample size drawn from the population, will exhibit nearly normal behavior according to the central limit theorem (12:47). The normal curve drawn on the left of the ordinate axis of Figure 2-5 represents the distribution of all samples taken.

Figure 2-5 is representative of the distribution of all samples taken.

The center line of a control chart for a statistic corresponds either to a given value or, more commonly, to an estimate (perhaps an average) obtained from observed data. The control lines (or limits) are placed symmetrically relative to the center line at distances based on the estimated standard deviation of "z," where "z" is the value of a random variable having the standard normal distribution; $z = (x - \mu) / \sigma$ (18:105-6, 487). Shewhart, based on his experience, chose 3 times ($B=3$) the standard deviation of z for his charts, yielding the term "three-sigma limits" (3:293-4). The choice of a factor to use for setting up control limits depends on the amount of risk (or cost) in looking for an assignable cause when none is present and the cost of not looking for an assignable cause when one is present. The use of "three-sigma limits" is predominant practice. Under many situations, other values may apply.

Figure 2-6 indicates the effect varying the value of B has on risk. The tighter control limits presented by $B = 2$ represents a 5% risk of rejecting a lot (and/or declaring a process out of control) when only variation due to chance exists. This may be acceptable if cost of rework/replacement/adjustment is low, but may not if costs are high. Two-sigma limits may, however, be used as warning limits to indicate an approach to the control limits. The question of how many points must be outside the control limits for the

FIGURE 2-6:
Effect of Change of Proportionality Factor (B)
on Control Limits



process (or lot) to be "out of control" is of interest. Cowden (8:155) indicates that according to research conducted by the American Standards Association there is strong evidence that a process is out of control if at least 2 of 35, or at least 3 of 100, points of the control chart fall outside the 3-sigma control limits.

Because of lack of knowledge of the exact distribution of the population from which samples are taken, significant reliance cannot be placed on precise probability calculations for determining if a process is in control and the control chart should be considered only a diagnostic device with final judgments (sentencing) relying on other statistical techniques. Cowden (8:155) suggests the following indicators of lack of control.

1. One point far outside a control limit.
2. Several points close to a control limit.
3. A peculiar pattern or arrangement of points, even though none is close to a control limit.

The type of control chart to be used is based on a number of factors. These include the sizes of the sample and overall populations, whether standard deviation is known, and whether or not there is a natural grouping of product, such as shift change, crew change, a certain number of items in each shipment, as in the case being studied in this report, a certain number of items produced from a "melt" of materials, or tests being taken out of multiple positions of a single test object.

Recalling basic probability and statistics indicates that the arithmetic mean, $\bar{X}$, is the most significant single statistic that can be used to describe a distribution (25:8). This indicates that a control chart tracking the average of measurement over time would be of great value. Such a chart, however, gives us no indication as to how such measurements vary about the mean or average. There must be relative uniformity of variation and an absence of variation beyond the limits allowable. Of the numerous available measurements of variability, the most commonly used in quality control according to all references are the standard deviation (or variance) and the range, the difference between the highest and lowest values. Which of these to use is an item of contention among sources. Lester (17:53) advocates the use of range for n (number of observations in the average) < 10 . Cowden (8:249) recommends use of standard deviation for $n > 12$, as does Duncan (9:401), while Samson, Hart and Rubin (25:9) state the range is a suitable statistic. This is due to the significant effect sample size has on the range since there are more chances for extremely high or low values. The standard deviation is only negligibly affected by sample size. The range can be used as a relatively stable measure of variability when one can average a series of ranges (17:301). The simplicity of the R-chart, a plot of the range of each data set used to determine $\bar{X}$, however, is recognized by all sources and all

advocate use of it to make less complicated explanation to managers and other control chart users.

While charts for individual measurements can be constructed, they are not normally used in industry (8:226). Such charts can provide "something" from such meager data as measurements taken once a day, a week, a year, etc., that would require an extensive period of time to assemble a data base for means ($\bar{X}$) (6:263). They can also be used as aids in interpreting control charts for means and ranges by indicating a cause for a mean to go out of control limits and if items have exceeded specification limits while the mean (average) has stayed within the limits. Such charts must be carefully interpreted if the process (or lot) shows evidence of marked departure from normality as they are quite insensitive to shifts in the process mean according to Nelson (20:172-3) and Duncan (9:400).

All control charts are based on tests of hypotheses and the probability of accepting/rejecting these hypotheses. The $\bar{X}$ -control chart provides a good example of this as presented by Kirkpatrick (15:188-189):

H_0 (null hypothesis): $\mu = \mu_0$

H_1 (alternative hypothesis): $\mu = \mu_1 \neq \mu_0$

The following relationships apply:

1. If H_0 is true, the X_i -population of measurements is distributed with mean μ_0 and variance σ_x^2

2. All possible samples of size n from the X_i -population generate an $\bar{X}_j$ -population of mean values where

$$\sigma_{\bar{X}}^2 = \frac{\sigma_X^2}{n}$$

3. Thus, if H_0 is true, the $\bar{X}_j$ -population is distributed with mean μ_0 and variance $\sigma_{\bar{X}}^2$.
4. If the X_i -population is normal, the $\bar{X}_j$ -population is normal. If the X_i -population is not normal and the sample size n is sufficiently large, the $\bar{X}_j$ -population is approximately normal.

If X_i is a random variable normally distributed with mean μ_0 and variance σ_X^2 , then

$$P(\mu_0 - 3\sigma_X \leq X_i \leq \mu_0 + 3\sigma_X) = 0.9973 \quad (1)$$

and

$$P(\mu_0 - 3\sigma_{\bar{X}} \leq \bar{X}_j \leq \mu_0 + 3\sigma_{\bar{X}}) = 0.9973 \quad (2)$$

Probability (2) is the basis for the $\bar{X}$ -control chart shown in Figure 2-7. The ordinate axis indicates $\bar{X}_j$ -values. The abscissa axis indicates sample numbers 1, 2, ..., j , ..., k . The lower control limit (LCL) corresponds to $\mu_0 - 3\sigma_{\bar{X}}$ and the upper control limit (UCL) to $\mu_0 + 3\sigma_{\bar{X}}$.

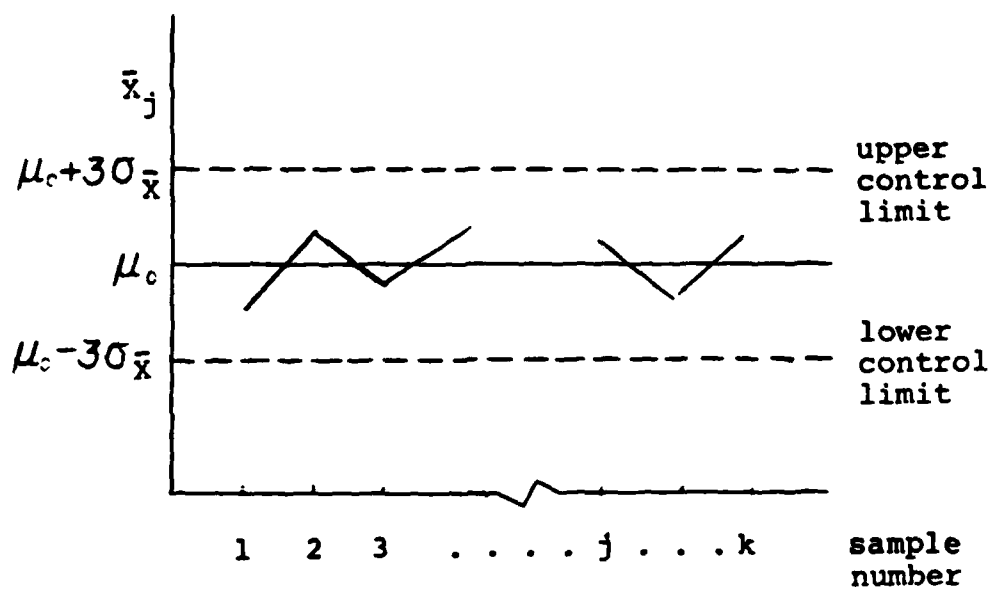
Thus the $\bar{X}$ chart is a hypothesis test where

H_0 : process in control at quality level μ_0

$$\alpha = P(\text{reject } H_0, H_0 \text{ true}) = 0.003.$$

In some cases, fixed values for the mean (or center) line and control limits of a control chart are provided or at least the standard deviation and mean are known and used to construct the control chart. This method is usually applied to data from a process that has a long history of

FIGURE 2-7:
 $\bar{X}$ CONTROL CHART



Tests the Hypothesis H_0 : Process in control
 at quality level μ_0

$$\alpha = P(\text{reject } H_0; H_0 \text{ is True}) = 0.003$$

being in control. In the case of this research, these population parameters are not available and the recent past data will be used to estimate these values. As Burr states (6:112), "We let the process do the talking." The control limits and center line can then be determined using these estimates.¹²

For the $\bar{X}$ -chart, consider a variable (measurement) "X" that is assumed to be normally distributed (discussed previously in this chapter) with mean " μ " and variance " σ^2 ." Samples of uniform size "n" are taken at regular intervals and the sample mean

$$\bar{X} = \frac{\sum_{i=1}^n X}{n}$$

is taken to be used as the charted statistic. Since by assumption

$$\bar{X} \text{ is } N(\mu, \sigma^2/n)$$

the control chart is specified by a center line at ordinate value

$$\bar{\bar{X}} = \frac{1}{k} \sum_{j=1}^k \bar{X}_j$$

k usually ≈ 25

¹²Burr (6:112-3), Kirkpatrick (15:190-1), Belz (3:299-300), Fiegenbaum (11:257-8), ASTM Manual STP 15D (1:81-2), et al. present similar developments and elements of all used here.

and two control limits at

$$\bar{\bar{X}} \pm \frac{3\hat{\sigma}}{\sqrt{n}}$$

As discussed earlier, the sample range can be used as an estimate of the variance of the sample. An adjustment can be made to bring the sample range closer to sample variance by application of coefficient d_2 that is dependent on sample size. The average range is multiplied by $1/d_2$ to yield an estimated standard deviation

$$\hat{\sigma} = \bar{R}/d_2$$

and the control limits may be written

$$\bar{\bar{X}} \pm 3 \frac{\bar{R}/d_2}{\sqrt{n}} = \bar{\bar{X}} \pm A_2 \bar{R}$$

where

$$A_2 = \frac{3}{d_2\sqrt{n}}$$

Tables of the values A_2 and other values to be used are found throughout the literature.¹³

Range charts were used due to the lack of historical data. Sample standard deviations could be used to estimate variance in place of range if more data was available.

The limits for the range control chart also utilize coefficients to make their calculation simpler with R_o and σ_R unknown:

¹³Two comprehensive tables for values up to $n=25$ can be found in ASTM STP 15D (1:135-5) and Burr (7:486).

$R_o = E(R) = \text{expected value of } R = \bar{R}$

$\sigma_R = \text{deviation of ranges} = d_3 \hat{\sigma} = d_3 \sigma.$

The control limits are

$$\begin{aligned} E(R) \pm 3\sigma_R &= \bar{R} \pm 3 d_3 \hat{\sigma} \\ &= \bar{R} \pm 3 \frac{d_3 \bar{R}}{d_2} \\ &= D_4 \bar{R} \text{ and } D_3 \bar{R} \end{aligned}$$

where $D_4 = 1 + 3 \frac{d_3}{d_2}$ and $D_3 = 1 - 3 \frac{d_3}{d_2}.$

Just as the range was used to estimate the estimated process standard deviation for developing control chart limits, it can be used to develop operating characteristic (OC) curves for each control chart. When the process is normally distributed, as we have assumed, we can derive an OC curve for an R-chart that is independent of the mean of the process. The OC function for the $\bar{X}$ -chart, however, is dependent on both the mean and the standard deviation of the process. The OC curve for the R-chart will, then, be developed first.

For example, consider an R-chart with $3\sigma_R$ limits as previously defined. Let's assume $N=4$ and values were determined for the $UCL(R)$ and $LCL(R)$. For any given value of Q the probability that a sample value of R is between $LCL(R)$ and $UCL(R)$ is to be determined. Thus, the probability of detecting a shift in σ is yielded by the difference between the probabilities that R will be less than the $LCL(R)$ and greater than the $UCL(R)$, and this difference can be plotted to construct the OC curve. The central line of the

R-chart is R , and the control limits are, as previously determined, $D_4\bar{R}$ and $D_3\bar{R}$ or

$$\bar{R} \pm 3 \frac{d_3 \bar{R}}{d_2} = \bar{R} \pm 3d_3 \hat{\sigma}$$

The process standard deviation can also be used to develop R-chart control limits, if known.

$$UCL = D_4 \bar{R} \quad LCL = D_3 \bar{R} \Rightarrow E(R) \pm 3\sigma_R = E(R) \pm 3d_3\sigma$$

$$E\left(\frac{R}{\sigma}\right) = d_2 \Rightarrow E(R) = d_2\sigma$$

These lead to

$$\begin{aligned} \text{control limits} &= d_2\sigma \pm 3d_3\sigma = \sigma(d_2 \pm 3d_3) \\ &= D_2\sigma \text{ and } D_1\sigma \end{aligned}$$

since $D_1 = (d_2 - 3d_3)$ and $D_2 = (d_2 + 3d_3)$.

Since $P_r(R \text{ is between } LCL \text{ and } UCL) = P_r\left(\frac{R}{\sigma} \text{ is between } LCL/\sigma \text{ and } UCL/\sigma\right)$ and since a determination if the new $\hat{\sigma}$ is indicating a shift in σ is being sought, the relation between $\hat{\sigma}$ and σ ($\sigma/\hat{\sigma}$) is of interest.

$$\text{Set the 3-sigma } LCL = D_1\hat{\sigma}$$

and

$$\begin{aligned} \text{3-sigma } UCL &= D_2\hat{\sigma} \\ \Rightarrow LCL/\sigma &= D_1\left(\frac{\hat{\sigma}}{\sigma}\right) = \frac{D_1}{\left(\frac{\sigma}{\hat{\sigma}}\right)} \end{aligned}$$

and

$$UCL/\sigma = D_2\left(\frac{\hat{\sigma}}{\sigma}\right) = \left(\frac{D_2}{\frac{\sigma}{\hat{\sigma}}}\right)$$

Now let $W = R/\sigma$ and the probability statement becomes $P_r(R \text{ is between } LCL \text{ and } UCL) = P_r(W \text{ is between } \frac{D_1}{\frac{\sigma}{\hat{\sigma}}} \text{ and } \frac{D_2}{\frac{\sigma}{\hat{\sigma}}})$.

A different OC function must be determined for each sample size and, since for n (sample size) < 7 , $D_1 = 0$, only the

probability, for different values of σ , that R is below the UCL is of interest. Selecting various ratios of $\frac{\sigma}{\bar{\sigma}}$ and referring to a chart of values of $W(\frac{R}{\bar{\sigma}})$ at selected probability points¹⁴ yields Table 2-1. Plotting these yields Figure 2-8.

The OC curve for the $\bar{X}$ chart is derived in a similar manner. We assume that $\hat{\sigma}$ remains constant,¹⁵ and compute the probability that a sample $\bar{X}$ will fall within the control limits as a function of the process average μ or $\bar{X}'$. Assume also that $\sigma = \hat{\sigma}$ the value used when constructing the chart. Then, when $\bar{X}'$ equals the standard for the chart ($\bar{\bar{X}}$ or $\bar{X}''$, when given or determined from past history)

$$P_r (\bar{\bar{X}} - 3\hat{\sigma} \leq \bar{X}_i \leq \bar{\bar{X}} + 3\hat{\sigma}) = 0.9973$$

when $\bar{X}'$ shifts to either $\bar{\bar{X}} - 3\hat{\sigma}$ or $\bar{\bar{X}} + 3\hat{\sigma}$, the

$$P_r (\bar{\bar{X}} - 3\hat{\sigma} \leq \bar{X}_i \leq \bar{\bar{X}} + 3\hat{\sigma}) = 0.50$$

In general, if $\bar{X}'$ shifts to $\bar{\bar{X}} + k\hat{\sigma}$, the probability of a point's ($\bar{X}_i$) falling within the control limits will be the probability of a normal-distributed variable's falling above $\bar{\bar{X}} + k\hat{\sigma} - \bar{\bar{X}} - 3\hat{\sigma} = (k-3)\hat{\sigma}$. So, if $k=2$, we have $P = \text{Prob}(Z > -1) = 1 - \text{Prob}(Z > 1) = 0.84$ and if $k=4$, $\text{Prob}(Z > 1) = 0.16$. This leads

¹⁴See for instance Duncan (9:614).

¹⁵If $\hat{\sigma}$ is variable then the OC function is dependent on both μ and σ and the function must be represented by a surface versus a curve. Research indicated that variation hence, μ and σ remain constant. This topic is treated by Duncan (9:309-315), Cowden (8:270-275) et al.

TABLE 2-1:

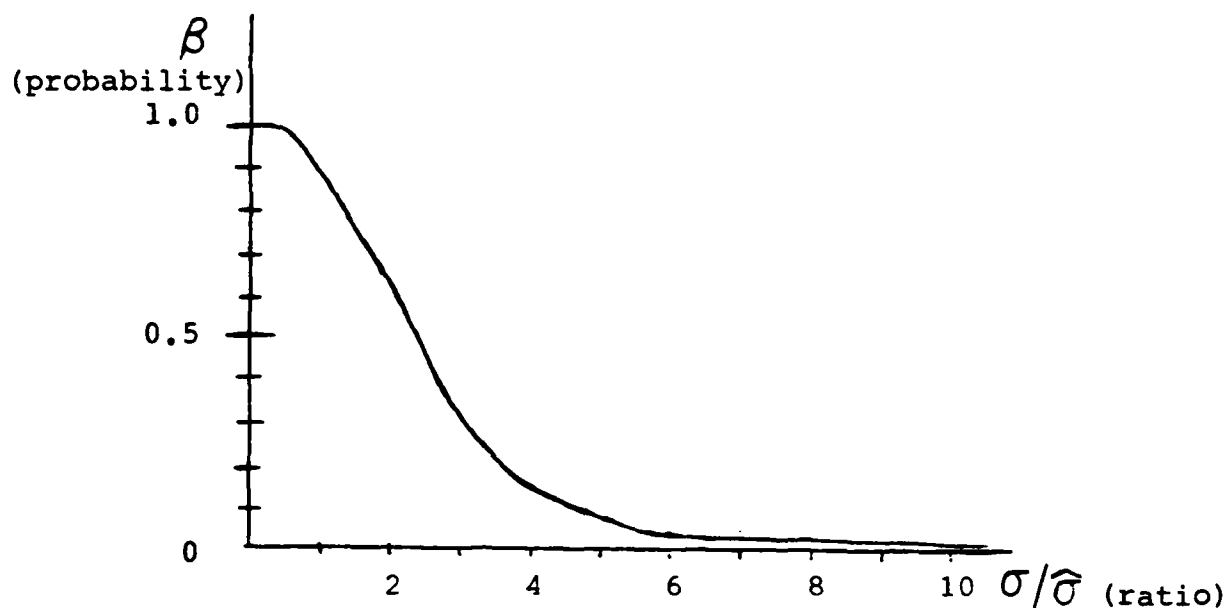
OC of Control Chart for R
 Given: 3 sigma control limits

$$n=4, D_{2(n=4)} = 4.698$$

$\frac{\sigma}{\hat{\sigma}}$	$D_2 \div \frac{\sigma}{\hat{\sigma}}$	β
0.5	9.396	*
1.0	4.698	0.995
1.5	3.132	0.881
2.0	2.349	0.656
3.0	1.566	0.312
4.0	1.174	0.160
5.0	0.940	0.085
6.0	0.783	0.055
8.0	0.587	0.024
10.0	0.470	0.013

FIGURE 2-8:

OC Curve for R-chart ($n = 4$)
 (3-sigma control limits, $\alpha = .003$)



H_0 : (null hypothesis) $\sigma = \hat{\sigma}$

H_1 : (alternate hypothesis) $\sigma \neq \hat{\sigma}$

σ = standard deviation of population

$\hat{\sigma}$ = estimated standard deviation of population

β = P (accept H_0 | $\sigma \neq \hat{\sigma}$)

This curve charts the probability of accepting H_0 for various H_1 -values, in terms of the ratio of σ to $\hat{\sigma}$ for $\alpha = 0.003$ and $n=4$ (8:268-9).

to Table 2-2 and Figure 2-9¹⁶ (9:308-9).

A control chart, then is essentially an analytical picture of the distribution of the mean and of the variation over time. Numerous researchers and authors have developed or refined computer-generated quality control charts and, no doubt, many others have developed control chart programs for personal computers. Berthoux, Hunter and Pallesen (4:139-149) developed and are utilizing computer-generated charts to monitor Wisconsin Sewage Treatment plants. Sawyer (25:391-395) used computer-generated control charts in a systems approach towards raw product analysis (RPA). This approach utilizes the computer to analyze data to determine out-of-limit conditions and to produce $\bar{X}$ and σ plots for those out-of-limit situations. Reliability engineers analyze the output to determine causes. The aim of this analysis is the achievement of process stability. These two examples indicate that more accurate, up-to-date quality control information can be made available for management decisions through the use of the computer to meet the goal of any quality control program: quality assurance (12:6).¹⁷

¹⁶See Cowden (8:258-9) for another method of plotting the OC function for means.

¹⁷This term, quality assurance, has come to mean the total set of operations and procedures included within the production system whose goals are conformance of product output to design specifications.

TABLE 2-2:

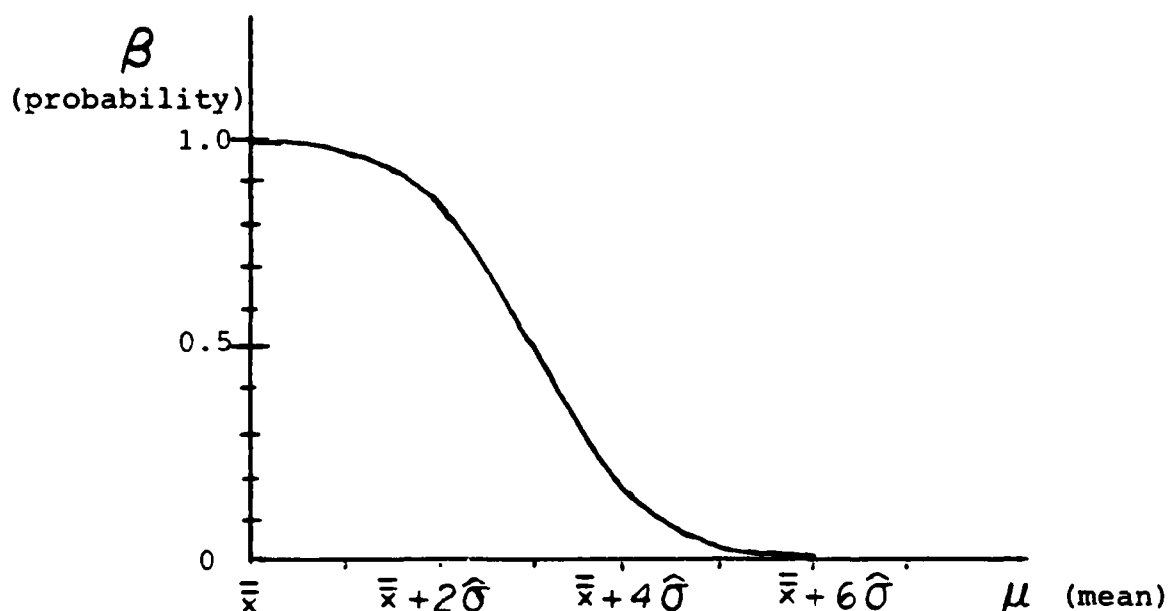
OC of Control Chart for $\bar{X}$
Given: 3 sigma control limits
 σ is constant

k^*	β
0	0.9973
1	0.9772
2	0.84
3	0.50
4	0.16
5	0.0228
6	0.0027

*k = number of sigmas (σ)

FIGURE 2-9:

OC Curve for $\bar{X}$ -chart ($n = 4$)
 (3-sigma control limits, $\alpha = .003$)



H_0 : (null hypothesis) $\mu = \mu_0 = \bar{\bar{x}}$

H_1 : (alternate hypothesis) $\mu \neq \mu_0$

σ = population standard deviation

$\hat{\sigma}$ = estimated population standard deviation

$\hat{\sigma}$ is assumed known and fixed = σ

$\bar{\bar{x}}$ = process average

$\beta = P(\text{accept } H_0 | \mu \neq \mu_0)$

This curve describes the probability of accepting H_0 for various H_1 - values for $\alpha = .003$, $n = 4$, and $\sigma = \hat{\sigma} = \text{constant}$ (9:309-15).

One of the most interesting, to this author, of available quality control chart programs is one developed in 1969 by Thayer and Storer at the Western Electric Company Engineering Research Center (16:149-152). It provides for reading individual sample values, computing the averages and control limits, and printing of these values on vertical (versus the horizontal presentation of Figure 2.7). This program will be explained further in Chapter 3 of this report and applied to the solution of the problem as stated in Chapter 1.

CHAPTER 3

PROBLEM SOLUTION

What you see is what you've got.--ANONYMOUS

Data Identification and Selection

Data was available from AiResearch for both their testing (CMR data) and for each of the vendors (CERT data). This data was screened and sorted with respect to extent of past history, correlation between vendor and AiResearch data, number of samples taken from each test item, and type of item (casting/forging). The screening indicated that in some cases only one sample was taken from a test item, while in others there were multiple samples taken. This, after reviewing the literature, indicated two separate approaches were required to satisfy the research goals, as stated in Chapter 1; one approach for the multiple-samples case, and another for the single-sample case. Two parts with data histories of minimally adequate length were selected for study; part No. 3072112 (multiple samples) and 3072316 (single samples). Data on these two parts was assembled from manual files to be used as test cases.¹⁸

¹⁸See Table 3-1 for typical data.

TABLE 3-1

Typical Data from Vendor Testing, AiResearch Testing, and Specification Values
(for Part No. 3072112, a turbine disk of forged Astroloy)

IDENTIFICATION				ROOM TEMP TENSILE TEST						
CMR#	DATE	VENDOR CODE ¹	HEAT NO.	SAMPLE ID#	PQS ID ^{2,4}	YIELD PSI	ULT PSI	%E	% RED AREA	CERT ⁵
64081	4/77	12112	8-4935 LFZ	8800	1	140.7	189.8	12.0	15.9	
					3	136.4	193.6	19.0	17.5	
					4	134.0	195.2	21.0	19.5	
					5	135.9	196.4	20.0	18.8	
					7	135.9	193.6	19.0	18.2	
64081	4/77	12112	8-4935	8800	3	139.1	206.1	25.0	26.7	CMR ⁵
					4	138.7	203.3	22.5	26.0	
					5	135.7	202.7	33.9	24.4	
					ALL	130.0	170.0	6.0	6.0	
					SPEC. 3,4 MIN VALUES					

¹A Vendor code is assigned to each vendor.

²Pos ID indicates the location of the test sample from the test forging; see spec. EMS55389, Pg. 6 (Appendix B).

³Taken from spec. EMS 55389 (Appendix B).

⁴The other test item 3072316 is also a forged turbine disk but of Waspaloy under AiResearch spec. No. EMS 55388, Condition B (Appendix B).

⁵CERT results are those from the vendor tests, CMR from AiResearch tests.

Specification Review

In order to determine the performance of the items, a knowledge of the specifications, as established by AiResearch was required. This was accomplished by ordering the applicable specifications from the AiResearch specification library. These are summarized in Table 3-2.¹⁹

Program Development

Screening and sorting of the extensive amount of manual testing data available indicated the need for a computerized (digital) file system that could rapidly retrieve individual data and be compatible with the quality control charting program that the author envisioned. Review of process approval requests from numerous vendors and the interoffice memos²⁰ approving these requests indicated that numerous vendors could supply any one part and would be required to submit test results in accordance with the specifications. Thus files for test results of a part would have to include two separate files for each part for each type of test for both the vendor and AiResearch. This was accomplished by assembling the data for each test into two files, one for the vendor CERT data and one for the AiResearch CMR data. They were labeled respectively:

¹⁹ See Appendix B for copies of specifications.

²⁰ See Appendix B for copies of these.

TABLE 3-2

**Specification Minimum Mechanical Properties
for Selected Part Numbers¹**

TEST	Part No. TYPE Cond.	3072112 Astroloy A	3072316 Waspaloy B
	Property		
	Ultimate (psi)	170.000	175.000
ROOM	Yield (0.2%) (psi)	130.000	120.000
TEMP	Elongation (% in 4D)	6	12.0
TENSILE	Reduction of Area	6	15.0

1 SOURCES

AiResearch Spec. No. EMS 55388
AiResearch Spec. No. EMS 55389

3072112*VENDOR.

3072316*VENDOR.

and

3072112*CMRARESRCH.

3072316*CMRARESRCH.

and were formatted to include identification of test type and particular data, the vendor (for the CERT files) dates the data covered, the part No., and particular assembly (engine) it belonged to, the number of test items (forgings) and the number of samples taken from each item, the format the data is presented in, and the specification minimum value. The data for each tested property is listed by test item (forging) number and position from the test item (forging). Data from

3072112*CMRARESRCH.

is presented in Figure 3-1.

Reference to AiResearch specification EMS 52476 para 1.4.1 defines a forging lot in terms of two classes (I and II). These are dependent on item size as only so much of the alloy can be processed in a "heat" from which billets are poured prior to forging. In the case of both selected test items, about one hundred (100) items can be made out of a "heat" of material²¹ and, as the forging dies have a

²¹This information was gathered from personal interviews with AiResearch personnel during the period Feb-Sept 1979.

FIGURE 3-1

Data from 3072112*CMRARESRCH
For Room Temperature Tensile Tests-Yield

("s" indicates "space")

LINE

```
1 ROOM*TEMP. TENSILEsTESTS-YIELDssLADISHsPACIFIC(1/77TO10/78)CMRsDATA
2 s13s3
3 FORMAT(I5.3f10.2)
4 130
5 s2164ss133.9ssssss134.7ssss135.4
6 ss395ss134.4ssssss135.0ssss129.4
7 s2382ss138.9ssssss138.3ssss138.9
8 s2361ss135.6ssssss140.6ssss134.1
9 s3004ss130.43ssss134.8ssss132.4
10 s3443ss133.0ssssss135.3ssss132.7
11 s1011ss133.6ssssss134.4ssss134.6
12 s1048ss133.3ssssss136.6ssss132.4
13 ss800ss139.1ssssss138.7ssss135.7
14 s3337ss133.4ssssss135.4ssss132.4
15 s3368ss134.4ssssss134.4ssss130.3
16 s3040ss132.6ssssss135.8ssss131.2
17 s3046ss132.2ssssss132.2ssss132.6
```

limited life, only about 33 can be made consecutively, yielding 3 lots of approximately 33 items from one heat of material. The number of lots are used to analyze individual (single) tests of an item to be discussed later.

ASTM STP 15D (1:97) indicates that the data in the situation being investigated might be approached in two ways:

- 1) If there are more than one observation per batch (for instance three samples tested from each test forging, as in the case of part No. 3072112) and the variation within the forging (i.e., between the three tests) is considered small in relation to the variation between the batches (the forgings in this case), then the average of the observations can be treated as an individual observation ($\bar{x}$). Such an approach requires caution because of the within-batch and between-batch effects that may exist. This situation readily fits into the normal control chart situation ($\bar{x}$ and R) described in Chapter 2. Grouping the measurements for a single test item is a rational approach since it is logical to assume that any variations within such a group (or subgroup as it might be termed) would be due on engineering grounds to non-assignable chance causes, but that between the groups (subgroups) the differences (variations) may be due to assignable causes whose presence is suspected or considered possible (1:76).

This assumption, since there is little knowledge of the population, is subject to testing.

- 2) In the instance of individual measurements (where only one test sample is taken from each test item (forging)), the use of control charts for individual measurements is of benefit. Of particular interest is grouping the individual measurements into subgroups of a rational size and utilizing these subgroups to determine range values for calculation of control limits, i.e. giving some indication of population variation (1:76). Predicating the selection on previous discussion in this chapter leads to $n = 3$ as the rational subgroup size.²²

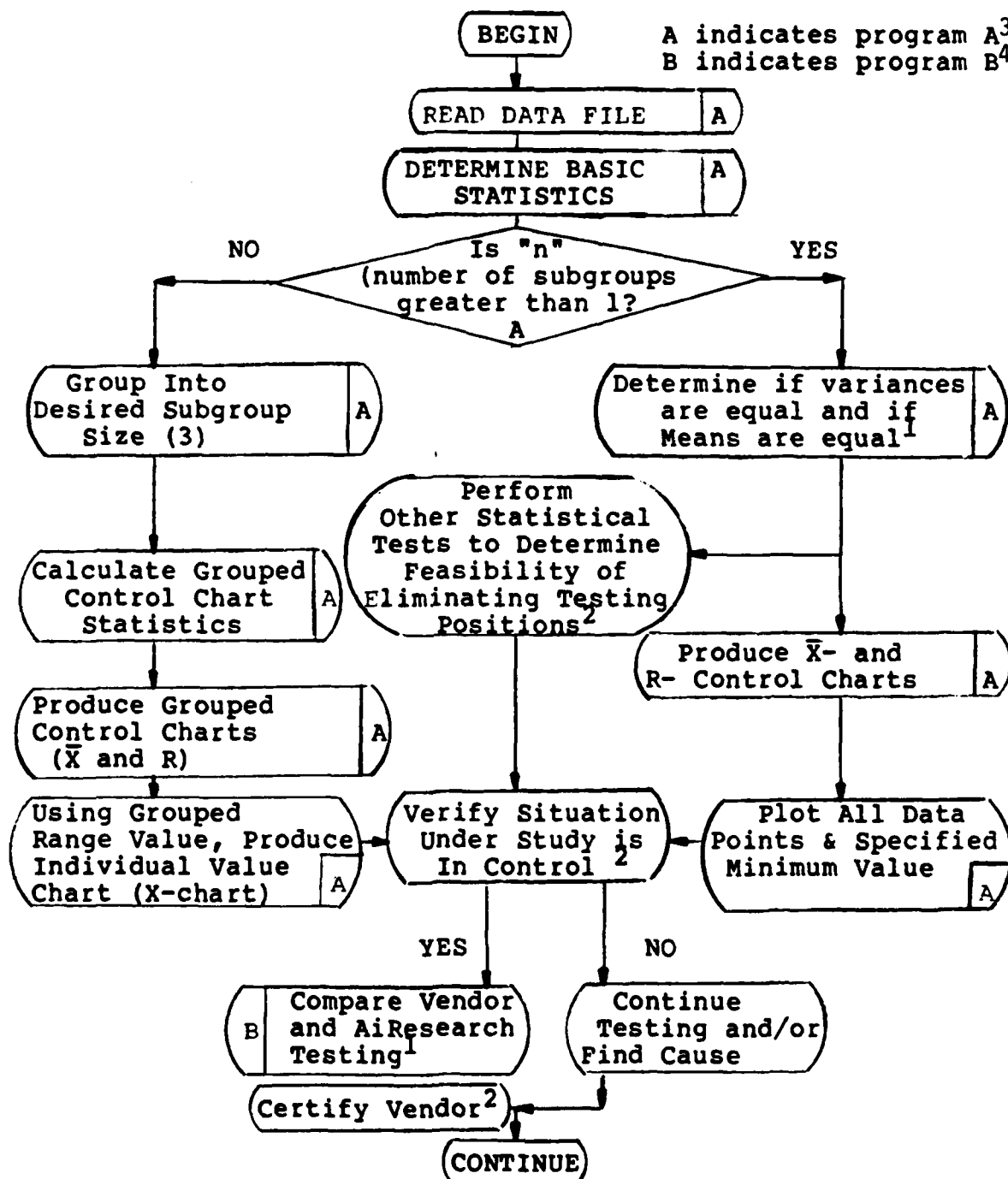
Thus, the use of quality control charts are of value in analyzing the data, thereby verifying the decision reached by AiResearch personnel (Chapter 1) and indicating a quality control system that is outlined in Figure 3-2. Analysis of this QC system indicated the need to fulfill the following program requirements.

Two basic programs were required, the first (Program A) being a program to transform the historical data (test results), either individual measurements or group data into required statistical values such as mean ($\bar{\bar{X}}$, $\bar{X}$ or $\bar{R}$), control limits, squares of differences, averages, etc., test the

²²This could be termed a type of "Grand Lot" scheme of sampling with the sublots (of approximate size 33) regarded as part of the larger lot of 100 (6:347).

FIGURE 3-2

Casting/Forging QC System Flow Chart



¹Computer program to calculate statistics for quality assurance (QA) personnel.

²This manual operation performed by QA personnel.

³Program A is the QC-chart program in this report.

⁴Program B is the T-star program in this report.

data for correctness in assumptions such as equality of means, variances, etc., and present it in traditional quality control chart form for rapid management assimilation and decision making. The type of charts to be presented include $\bar{X}$ -,²³ $\bar{\bar{X}}$ -, and R-charts.

The second program (Program B, Figure 3-2) was to test the hypothesis:

H_0 : Vendors Testing Results $\equiv$ Company Testing Results
Through use of an appropriate test, such as

$$T^* = \frac{\bar{D} - d_0}{\frac{s_d}{\sqrt{n}}} ; \nu = n - 1$$

where $T^* = T$ - distribution statistic

n = number of paired observations (Test items)

$$s_d^2 = \text{variance of the differences} = \frac{n(\sum_{i=1}^n d_i^2) - (\sum_{i=1}^n d_i)^2}{n(n-1)}$$

d_i = individual pair differences

$$\bar{D} = \frac{\sum_{i=1}^n d_i}{n} = \text{mean difference}$$

ν = degrees of freedom

d_0 = tested difference = 0

μ_D = mean of the population of differences

$H_0: \mu_D = D_0 = 0$ in this case

²³For the individual and multi-measurement situations alike.

Assume samples are dependent and paired as they are in our case, since they come from the same casting.

These programs would also have to produce statistical data to enable rapid, accurate calculation of the manual testing necessary.

Other requirements, requested during interviews with AiResearch personnel (27:1, 36:1), included making the system comprehensive and effective, but not overly complicated, so that personnel at any corporate level could load data, execute the program, and make simple changes as the situation warranted. In this way, meaningful data could be presented to the head of the Quality Assurance Section for decision making and further analysis to include calling for further testing, vendor certification, elimination of testing. etc.

The selection of a computer language for writing the programs was explored. Three factors, a thorough understanding of the language by AiResearch personnel and the author, adequate computer facilities, and previous programs for plotting control charts, led to the selection of FORTRAN IV.

Initially, the program for plotting $\bar{X}$ - and R- charts developed by Thayer and Storer (16:149-152) was evaluated for use. While it performed well at figuring the required statistics ($\bar{\bar{X}}$, $\bar{R}$, control limits) and plotting the values, it had little flexibility and could not perform any more detailed statistical tests. To alleviate this shortcoming, attempts were made to utilize this program along with

statistical programs that were available on the AiResearch computer. The data transformation between the two programs was a monumental task and, after repeated attempts, this approach was abandoned in favor of devising a program or programs that would fit logically and efficiently into the QC system that was outlined in Figure 3-2.

The main program (Figure 3-3) was written as a "command" program to read the data, identify and classify it, and direct, according to its classification, that certain operations be performed on it by means of various subroutines. The subroutines were titled according to function and are listed below with a brief descriptive statement of that function:

CHARTS: Produces X-, $\bar{X}$ -, and R- charts

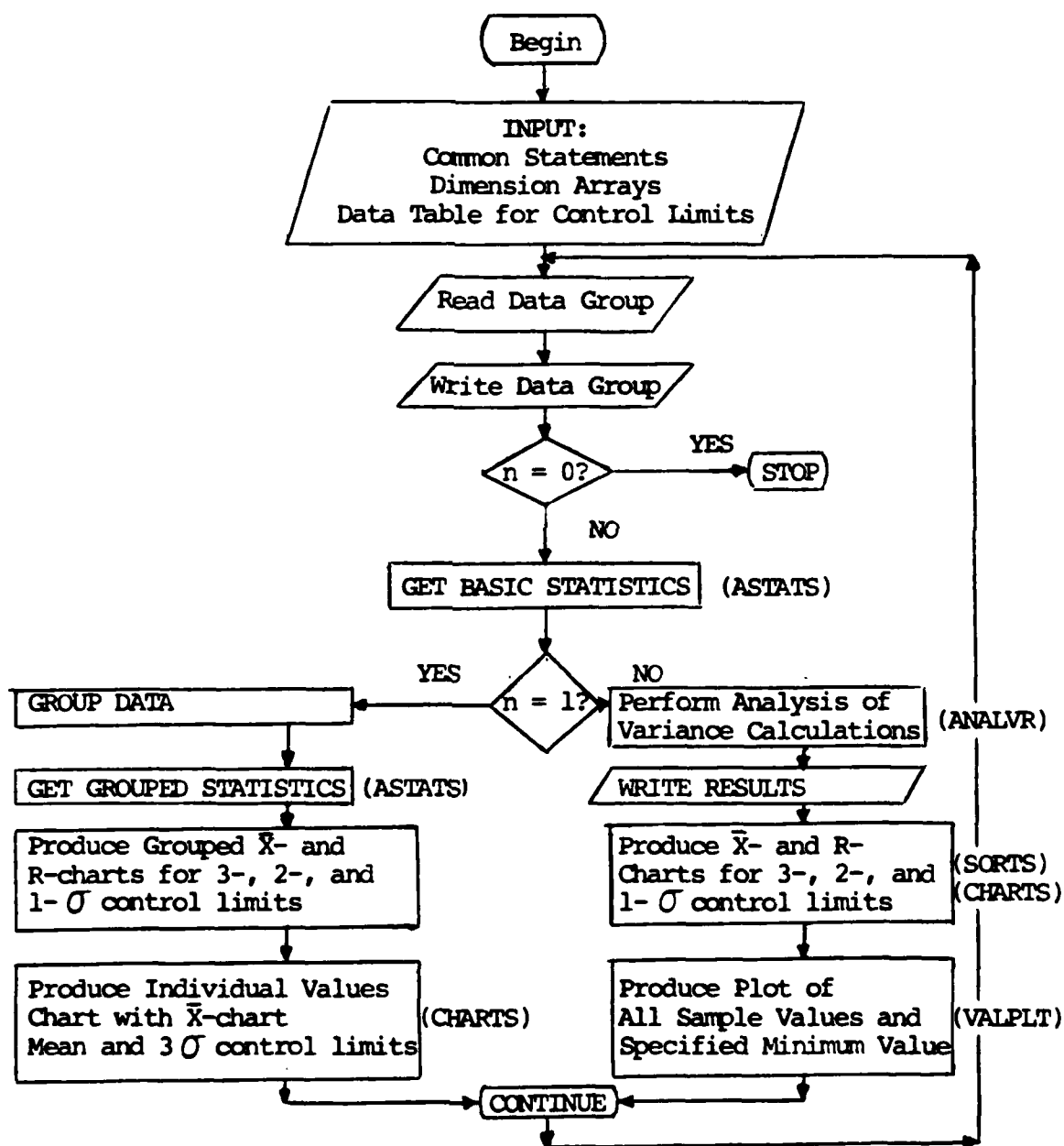
SCALE: Provides scaling values for CHARTS

SORTS: Sorts values to find highest and lowest of each subgroup

ASTATS: Determines the sample average, subgroup averages and sample standard deviation of the input data

VALPLT: Plots test results from multiple positions on each casting/forging, if this situation exists. It labels each point with the position in the casting/forging from which the test sample was taken.

FIGURE 3-3

Flow Chart of QCC-MAIN (Main Program)¹

¹Subroutine names are indicated in parenthesis to the right of block requiring them.

ANALVR: Analyzes the test data for equality of means and/or variances so that a determination concerning continued testing frequency can be made. Note: This is a general analysis of variance that can be used for other applications.

Main Program

The main program is charted in Figure 3-3. As stated previously, it functions as a "command" program to handle the data. Initially it identifies the data as being individual measurements or grouped measurements. For individual measurements it directs that these be grouped in three's ($n = 3$, as determined above), necessary statistics and control limits be calculated, and the grouped $\bar{X}$ - and R- charts be produced. A final treatment of the individual measurement data is to plot the individual data on an $\bar{X}$ -chart using the grouped $\bar{X}$ and control limits.

In the case of the grouped data, the main program directs that the basic statistics be calculated, an analysis of variance (ANOVA) be calculated (to include a One-Way ANOVA, a Two-Way ANOVA, the Cochran's test of variance homogeneity statistic ("G"), (8:159-160) and sufficient statistical data to perform the Duncan multiple range test (18:352-3) , production of $\bar{X}$ - and R- charts and a plot of all the data points for each test casting/forging along with the minimum specification value.

This program also allows for input of control limit values if these are known from past history and for suppression of printing of means and ranges if the user wishes to exercise either of these options.

ASTATS

Subroutine ASTATS, charted in Figure 3-4, provides statistics necessary for calculation of the control limits, mean lines, and preliminary values for analysis of variance. As depicted in the flow chart of the main program (Figure 3-3) it has been designed with some inherent flexibility as shown by its being used twice for producing the individual measurement charts.

Important values used in ASTATS and their definitions are:

SUM = Total number of items for the population = $n \cdot k$

SUMX = $\sum_{i=1}^n x_i$ for each subgroup J

SUMSQ = $\sum_{i=1}^n x_i^2$ for each subgroup J

SUBAR(J) = $\frac{\text{SUMX}}{n}$ for each subgroup J = $\bar{X}_j$

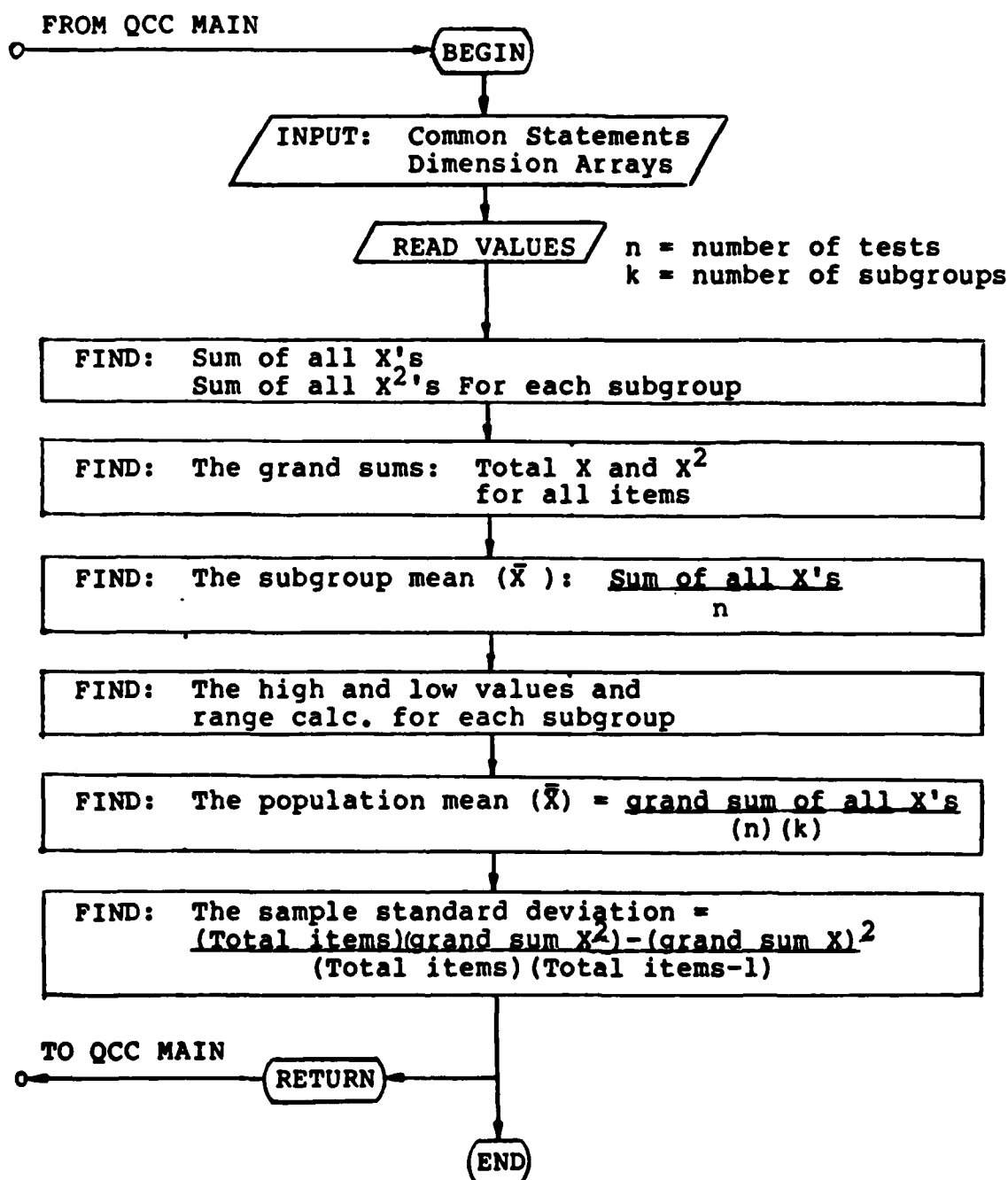
RANGE(J) = $\text{HIX}_i - \text{LOWX}_i$ for each subgroup J = R_j

STOT = $\sum_{j=1}^n \sum_{i=1}^k x_{ij}$ for the population = $n \cdot k$

XBAR = STOT/SUM = population mean

FIGURE 3-4

FlowChart of QCC-ASTATS (Preliminary Statistics)



$$SQRTOT = \sum_{i=1}^n \sum_{j=1}^k x_{ij}^2 \text{ for the population}$$

$$SSDEV = \left[\frac{(\text{SUM})(SQRTOT) - (\text{STOT})^2}{(\text{SUM})(\text{SUM} - 1)} \right]^{1/2}$$

= sample standard deviation for the test population.

CHARTS

This subroutine, flowcharted in Figure 3-5, plots the data values desired, either $\bar{x}$, $\bar{\bar{x}}$, or R , in vertical quality control charts to include control limits, average value, minimum spec. value, test item number, statistic value being plotted and scale values used. It also has inherent flexibility as it is employed to produce 3-, 2-, and 1-sigma control charts and can handle user-specified limits when applied.

Important values used in CHARTS and their definitions include

NNDEV = Desired control limit σ (sigma)

RBAR = $\bar{R}$

UCL = Range Chart Upper Control Limit = $D_4 \bar{R}$

BCL = Range Chart Lower Control Limit = $D_3 \bar{R}$

XBAR = $\bar{\bar{x}}$

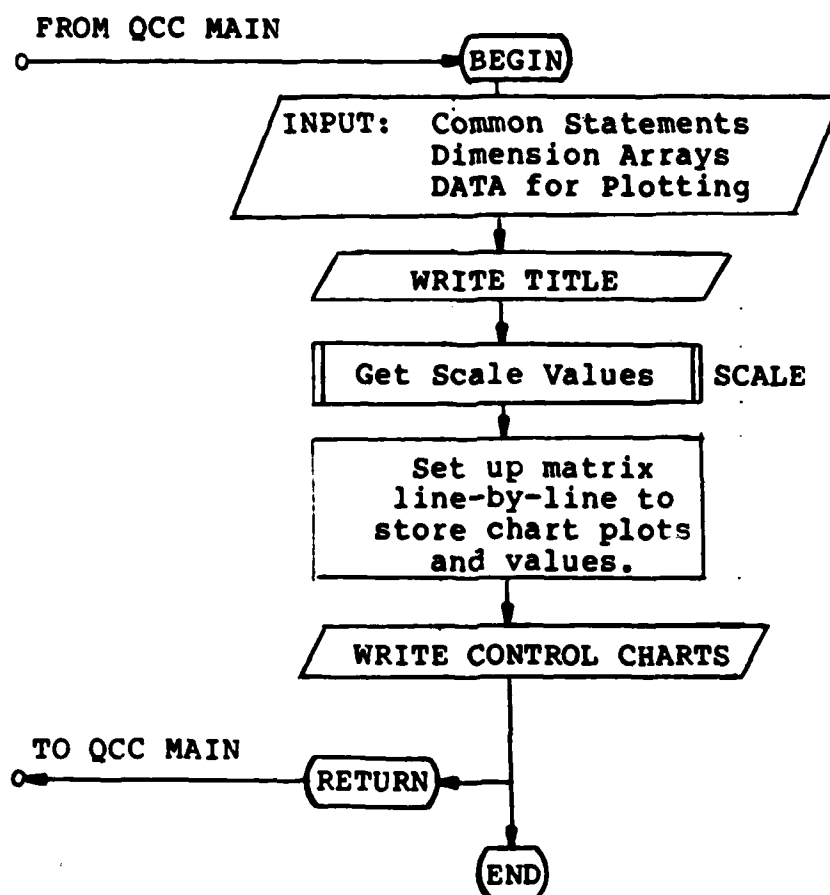
UCLL = $\bar{\bar{x}}$ - Chart Upper Control Limit = $\bar{\bar{x}} + A_2 \bar{R}$

BCLL = $\bar{\bar{x}}$ - Chart Lower Control Limit = $\bar{\bar{x}} - A_2 \bar{R}$

SP2, DIV, SB = Scaling factors for R chart

SP1, DIV1, RA1, = Scaling factors for $\bar{\bar{x}}$ - or $\bar{x}$ - chart

FIGURE 3-5
Flow Chart of QCC-Charts
(Plotting of X-, $\bar{X}$ -, and R-Charts)



SORTS

This subroutine is used to find the largest and smallest values of the subgroup mean and range to use in the CHARTS subroutine. It merely sorts through the subgroup ranges and means, comparing them initially to the intentionally high and low values and continues to reset the values as it finds larger and smaller values. This short subroutine has good flexibility as it can sort through either range or mean data, and is vital to the program as a whole. No flow chart is presented here, but detailed flow charts of the main program and all subroutines are available in Appendix C.

SCALE

This subroutine determines the scale to be used for the 36-space width, respectively, of the $\bar{X}$ - and R-charts. It does so by utilizing the high and low values from the SORTS subroutine to determine the scale and the values that divide the scale into thirds. For example, say

L = Low Value

H = High Value

then the scale would have to cover

$H - L = \text{scale}$

The values to divide the scale in thirds would be

$L + ((H-L)/3)$ and $H - ((H-L)/3)$

This subroutine also has the flexibility to be used with either means or ranges and, with slight modification, to

divide the scale into whatever increments the user desires. Again, no flowchart is presented here; for a detailed one, see Appendix C.

VALPLT

Subroutine VALPLT is a specialized derivative of the CHARTS subroutine that produces a plot of the test value of each tested position in a sample casting/forging and labels each value with the position from which it came. As in CHARTS, it sets up a line-by-line array to print out a chart of the values within the 101 available spaces. Because it is intended to supplement the $\bar{X}$ - and R-charts, it does not utilize the control limits but only the minimum specified value so that the user can detect "below specifications" individual measurements that may (or may not) have contributed to a mean or range value being "out-of-limits." While designed for the specialized case of tests being taken from four locations in the test forgings of part number 3072112, it is easily modifiable to meet user demands. As it resembles CHARTS closely, with the exception of utilizing the scale values determined by SCALE through CHARTS, no flowchart is presented here, although the detailed flowchart is available in Appendix C.

ANALVR

To provide statistical calculations that were not conveniently obtained through available statistical programs, subroutine ANALVR (ANALysis of VaRiance) was designed

to provide the following:

- a) Compute statistical values for One-Way Analysis of Variance (ANOVA)
- b) Compute "F" value for One-Way ANOVA
- c) Compute "G" value for Cochran's test for homogeneity of variances
- d) Compute statistical values for Two-Way ANOVA
- e) Compute "F" values for Two-Way ANOVA

The one-way ANOVA was selected to test the hypothesis

$$H_0: \mu_{\text{pos}_1} = \mu_{\text{pos}_2} = \dots = \mu_{\text{pos}_i} \\ \text{for } i = 1, 2, \dots, n$$

where n = number of test positions in a test casting/forging. The statistical model for a case where there are different treatments (positions) for any number of observations (test casting/forging) (See figure 3-6) can be described as (18:337, 19:34, et al.):

X_{ij} = i th, j th observation

$$X_{ij} = \mu + \tau_i + \epsilon_{ij}, \text{ for } i=1, 2, \dots, n \text{ and } j=1, 2, \dots, k$$

where

k = number of groups (test pieces)

μ = overall mean

τ_i = effect due to treatment

ϵ_{ij} = random error component

Since the treatment (position) observations are not random, we wish to determine the effect, if any, of position of the test sample in the casting/forging or

$$H_0: \tau_1 = \tau_2 = \dots = \tau_n = 0 \quad (\text{null hypothesis})$$

FIGURE 3-6
One-Way Analysis of
Variance Data and Table

DATA:

	Treatment (i = 1, 2, . . . , n)					
Observations replications (j = 1, 2, . . . , k)	X ₁₁	X ₂₁	X ₃₁		X _{i1}	
	X ₁₂	X ₂₂				
	X ₁₃					
						
	X _{1j}	X _{2j}			X _{ij}	

TABLE:

SOURCE OF VARIATION	SUM OF SQUARES	DEGREES OF FREEDOM	MEAN SQUARE	F
Between trtments (positions)	SS _{Tr}	n-1	$\frac{SS_{Tr}}{n-1} = MS_{Tr}$	$\frac{MS_{Tr}}{MS_E}$
Error (with- in trtments)	SS _E	N-n	$\frac{SS_E}{N-n} = MS_E$	
Total	SS _T	N-1		

with $H_1 : T_1 \neq 0$ for at least one "1" (alternate hypothesis)

By partitioning the total variability into its component parts, the total corrected sum of squares

$$SS_{TOTAL} = SS_T = \sum_{i=1}^n \sum_{j=1}^k x_{ij}^2 - \frac{(X_{TOT})^2}{N}$$

where $N = (n) \cdot (k)$

$$X_{TOT} = \sum_{i=1}^n \sum_{j=1}^k x_{ij}, \quad x_i = \sum_{j=1}^k x_{ij},$$

can be expressed as

SS_T = Sum of squares due to treatment + sum of squares due to error

$$= \sum_{i=1}^n \frac{(X_{ij})^2}{n} - \frac{(X_{TOT})^2}{N} + SS_{ERROR}$$

$$SS_T = SS_{TREATMENTS} + SS_{ERROR}$$

$$= SS_{position} + SS_{error} \quad (\text{in this case})$$

$$= SS_{Tr} + SS_E \quad (\text{see 19:36 for derivation})$$

and, thus $SS_E = SS_T - SS_{Tr}$

There are: a) N observations (sample values)

b) n levels of treatment $\Rightarrow n-1$ degrees of freedom

c) k levels of replication (test castings or forgings) in any treatment (position) $\Rightarrow k-1$ degrees of freedom

d) $n(k-1) = N - n =$ Total degrees of freedom for error

A theorem proposed by Cochran (19:37) leads to the conclusion that under H_0

$$F_0 = \frac{SS_{Tr} / (n-1)}{SS_E / N-n} = \frac{MS_{Tr}}{MS_E}$$

where $MS_{Tr} =$ Mean square of treatments

$MS_E =$ Mean square of error

follows the $F_{(n-1)(N-n)}$ distribution tables which can be found in many statistics and quality control texts (18:490-491, 19:397-401, and others). This allows us to see if, for various confidence levels (various levels of α), the treatments (positions) are the same. The one-way analysis of variance can be summarized in an ANOVA table such as that in Figure 3-6.

There are occasions when a single point falls far outside of a control limit and the user wishes to determine if such a point is too extreme to be attributed to chance. Cochran's test for homogeneity of variances (8:159-160) compares the variances as estimated by the standard deviation. The statistic g ,

$$\text{where } g = \frac{\text{largest } x^2}{\text{sum } x^2} = \frac{\text{largest sample standard deviation}}{\text{sum of all sample std. deviations}}$$

is used to address

$$H_0: \sigma_1^2 = \sigma_2^2 = \dots = \sigma_j^2, \\ \text{for } j = 1, 2, \dots, k$$

using the sample standard deviation as an estimation of variance. Tables of g for $\alpha = .05$ and $\alpha = .01$ are available (8:688). This statistical tool can be used to identify bad samples, "back-up" the range chart, and eliminate testing positions.

The two-way analysis of variance (ANOVA) was chosen to test both the treatment and block effect of the model.

X_{ij} = any i th, j th observation

$$X_{ij} = \mu + \tau_i + \beta_j + \epsilon_{ij} \quad \text{for } i=1,2,\dots,n \text{ and } j=1,2,\dots,k$$

where k = number of blocks (test pieces)

μ = overall mean

n = number of treatments (testing positions)

τ_i = effect due to treatment

β_j = effect due to blocks

ϵ_{ij} = random error component

Theoretical data is presented in figure 3-7. The two-way ANOVA tests

$$H_0: \tau_1 = \tau_2 = \dots = \tau_n = 0$$

and

$$H_0: \beta_1 = \beta_2 = \dots = \beta_k = 0$$

against

$$H_1: \text{One of the effects} \neq 0.$$

By partitioning the total variability into its component parts as was done in the one-way analysis of variance,

$$\begin{aligned}
 SS_{TOTAL} &= SS_T = SS_{Treatment} + SS_{Blocks} + SS_{error} \\
 &= SS_{Tr} + SS_{BL} + SS_E \\
 &= \left[\sum_{i=1}^n \frac{(X_i)^2}{n} + \frac{(X_{TOT})^2}{n} \right] + \left[\sum_{j=1}^k \frac{(X_{\cdot j})^2}{n} + \frac{(X_{TOT})^2}{N} \right] + SS_E
 \end{aligned}$$

and, thus

$$SS_E = SS_T - (SS_{Tr} + SS_{BL})$$

$$X_{\cdot j} = \sum_{i=1}^n X_{ij}$$

While the degrees of freedom are similar to the one-way ANOVA, there are differences:

1) Since there are k levels of blocking $\Rightarrow k-1$ degrees of freedom

2) This leads to the error degrees of freedom of those for treatment times those for blocks $\Rightarrow$

$$(n-1)(k-1)$$

3) Treatment degrees of freedom = $n-1$

$$\text{Total degrees of freedom} = N-1$$

In the same way, the "F" statistic for the one-way ANOVA was determined

$$F_o = F_{Tr}$$

and

$$F_{Bl} = \frac{SS_{BL}/(K-1)}{SS_E/(n-1)(k-1)} = \frac{MS_{BL}}{MS_E}$$

where MS_{B1} = Mean square of treatments
 MS_E = Mean square error

The distribution to be used for $F_{Tr} = F_{(n-1), (n-1)(k-1)}$ and for $F_{BL} = F_{(k-1), (n-1)(k-1)}$ at various levels of confidence.

Use of this method of statistical analysis allows not only testing for treatments, but for blocks as well.

The two-way analysis of variance is summarized in tabular form in Figure 3-7. Subroutine ANALVR, based on the aforementioned equations and testing statistics, was written to provide the desired values in a usable format. This subroutine, flowcharted in Figure 3-8, has the capability of being used in numerous situations requiring only minor modification. A detailed flowchart of this subroutine can be found in Appendix C.

Some important variables used in subroutine ANALVR include:

SQRTOT = Sum of all values squared

STOT = Sum of all values

TRT(I) = Total of values for each treatment (position)

TRM(I) = TRT(I)/n

BLK(J) = Total of values for each block (test piece)

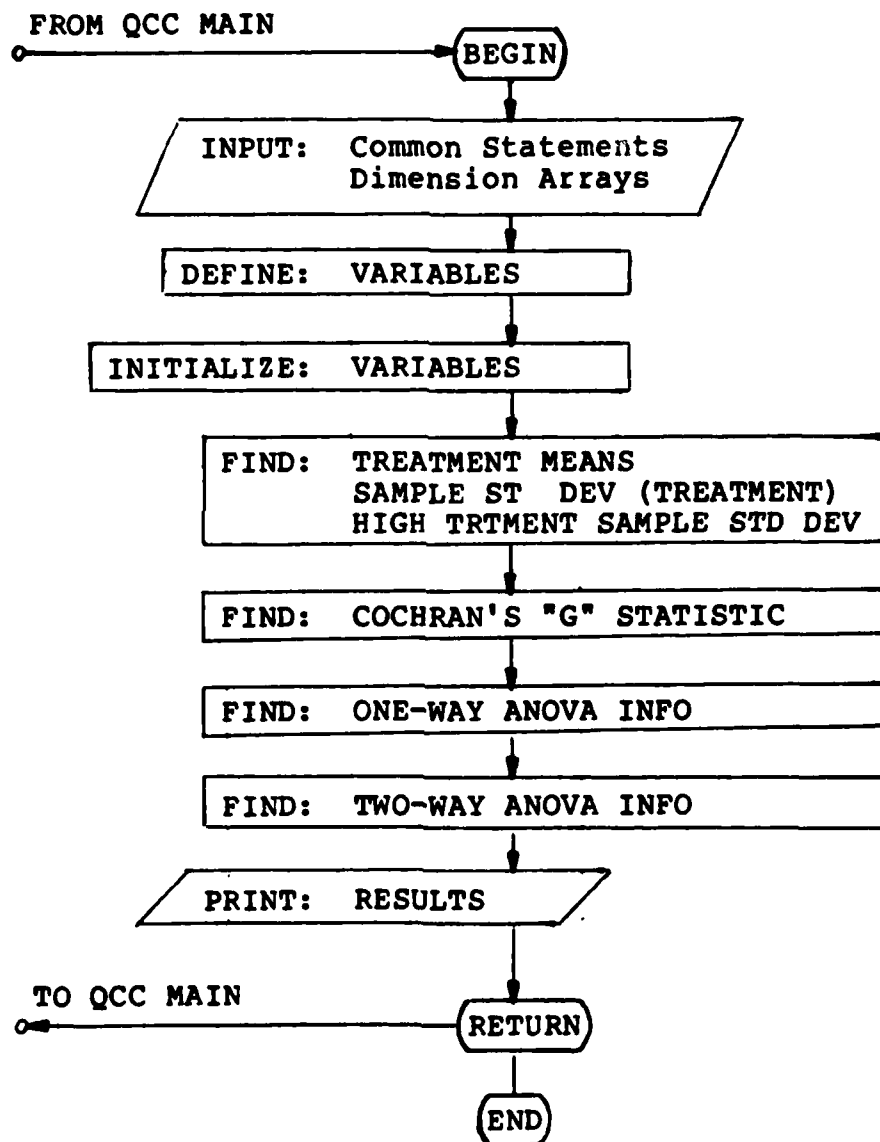
SSPOS(I) = Sum of squared differences for each treatment

TSDEV(I) = Treatment sample standard deviation

SUMDEV = Sum of all TSDEV(I)

FIGURE 3-8

FlowChart of QCC-ANALVR
(Statistical Testing, ANOVA)



DIFSQR(I) = Squared difference between test value and
average value for each position

COCRNG = Cochran's "G"

$$= \frac{\text{Highest TSDEV(I)}}{\text{SUMDEV}}$$

SSTR^m = SS_{Tr}

SSBLK = SS_{bl}

SSE = SS_E for one-way ANOVA

SSE2 = SS_E for two-way ANOVA

DFTRT = Treatment degrees of freedom

DFBLK = Block degrees of freedom

DFTOT = Total degrees of freedom

DFERR = Error degrees of freedom for one-way

DFE2 = Error degrees of freedom for two-way

AMSE = MS_E for one-way

AMSE2 = MS_E for two-way

AMSTRT = MS_{Tr}

AMSBLK = MS_{Bl}

F = F_O for one-way

F2TRT = F_{Tr} for two-way

F2BLK = F_{Bl}

TSTAR

In order to test the hypothesis

H₀: Vendors Test Results = Company Test Results ,

a program was written to take manually-paired data from both
AiResearch and vendor tests of their respective halves of

the test forging/castings and perform the "paired-T" (or T^*) test on the data. This program is flowcharted in Figure 3-9. A more detailed flowchart can be found in Appendix C. Like subroutine ANALVR this program, TSTAR has considerable flexibility as it is not dependent on the main program for data (although it could be used as a subroutine). In this way, any paired, dependent data could be tested against the null hypothesis discussed previously.

Some important variables used in TSTAR include:

NG = ANG

= Number of data pairs

DMU = Value to be investigated by testing H_0

VALCRT = Average value from vendor test

VALCMR = Average value from AiResearch test

DIFF(I) = VALCRT - VALCMR

DIF2(I) = DIFF(I)²

TSTAR = T used to test H_0

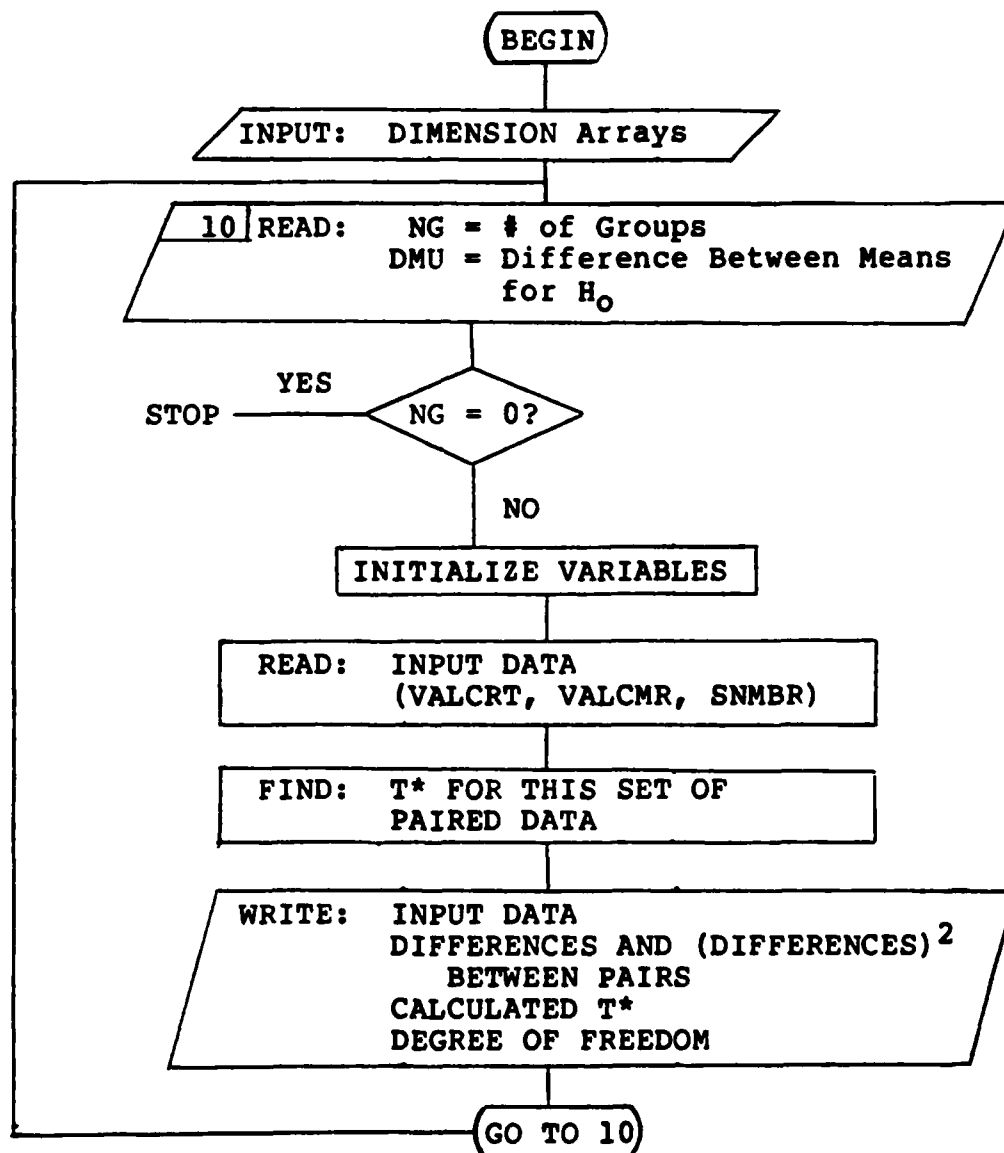
NDOF = Number of degrees of freedom

SNMBR = Serial number of casting/forging

Program Testing

The two programs were written and tested using selected data from testing of the two selected forgings. Chapter 4 presents the results of testing the data and discusses their compatibility with the quality control system charted in Figure 3-2.

FIGURE 3-9

FlowChart of TSTAR
(Paired-data T-Test)

CHAPTER 4

PROGRAM EVALUATION

A picture is worth a thousand words--UNKNOWN

Results and Discussion

As stated previously, two forgings were chosen based on the available data as test cases for testing the capabilities of the proposed quality control system in general and the QC charting/statistic programs derived in Chapter 3. In order to present the test cases as concisely as possible, only one test measurement (Tensile test-yield for part No. 3072112 and Tensile test-ultimate for part No. 3072316) will be used to demonstrate the capabilities of the programs. These were selected only because they were the first data sets input for each part and were used to verify the accuracy of the program. The remainder of the tests run are presented in Appendix E for reference.

Part Number 3072112--

Forged Turbine Disk of Astraloy, Condition A

Table 4-1 presents the input data as read by the main program for the vendor certification (CERT) while table 4-2 presents the data for the AiResearch Chemical/Metallurgical report (CMR).

TABLE 4-1

81

Part No. 3072112 Vendor (CERT) Data

••ROOM TEMP.TENSILE TESTS-YIELD LAC.PAC.(11/77 TO 5/79) CERT
 --3072112--TFF731 ENGINE PART DATA

12 4 0 0 0

FORMAT(15,4F10.2)

NOTE: MOST RECENT DATA
 IS AT TOP OF THE
 TABLE.

FORMAT(4A4)

POS3POS4POS5POS7

SERIAL #

INPUT DATA BY POSITION

2237	132.20	133.90	132.90	133.20
2164	132.70	137.90	135.10	134.30
395	135.90	137.00	132.70	133.70
2392	137.60	139.60	140.70	139.10
404	137.20	136.40	135.50	136.90
2374	139.50	139.30	142.20	139.70
3015	135.60	135.20	130.90	136.50
3345	139.90	139.50	137.50	139.50
9900	136.40	134.00	135.90	135.90
3040	133.30	131.10	131.30	135.70
3046	132.30	131.60	131.20	136.30
3010	144.30	142.70	141.50	140.20

THE MEAN = 136.21 STAND DEV = 3.30

SUM = 6539.00 SUM OF SQUARES = 991040.99

TABLE 4-2

82

Part No. 3072112 CMR Data

**ROOM TEMP. TENSILE TESTS-YIELD LAC-PACIFIC(1/77 TO 10/78)CMP
DATA

--3072112--TFE731 ENGINE PART

14 3 0 0 0

FORMAT(15,3F10.2)

FORMAT(3A4)

POS3POS4POS5

NOTE: MOST RECENT DATA
IS AT TOP OF THE
TABLE.

SERIAL # INPUT DATA BY POSITION

2164 133.90 134.70 135.40

395 134.40 135.00 129.40

2392 139.90 139.30 139.90

2361 135.60 140.60 134.10

3004 130.43 134.90 132.40

3443 133.00 135.30 132.70

1011 133.60 134.40 134.60

1049 133.30 136.60 132.40

900 139.10 139.70 135.70

3337 133.40 135.40 132.40

3369 134.40 134.40 130.30

3040 132.60 135.50 131.20

3046 132.20 132.20 132.60

3010 139.20 139.90 136.50

THE MEAN = 134.71 STANF DEV = 2.69

SUM = 5657.73 SUM OF SQUARES = 762436.50

Note that the CERT data carried 4 testing positions (3, 4, 5 & 7) while the CMR data only carried 3. This was due to AiResearch only conducting (or reporting) tests at three locations while still requiring the vendor to test in four locations. Whether this was a transitory event that occurred while the author was obtaining data, or it was a standard occurrence (perhaps the vendor was working under a different set of testing specifications) was unclear. Another item of note is that there are 14 test samples in the CMR data covering the time period 1/77 to 10/78 while the CERT data contained 12 test samples covering 1/77 to 5/79. The decision was made to continue with all the data available to see if it gave a good indication of the properties of the populations.

Also, it should be noted that the results of the most recent testing is the first data entry with older data following. Tables 4-3 and 4-4 present the analysis of variance calculations performed in subroutine ANALVR in the standard tabular format as presented in Chapter 3. There are significant differences at first glance between the CMR and CERT data. Initially, it might be supposed that the calculation of data is incorrect. Reference to Appendix F, however, verifies that the calculations for the CERT data are correct, making it comparatively safe to say that since the CMR data was calculated with the same program it's assumed accurate.

TABLE 4-3

84

Part No. 3072112 CERT ANALVR Results

TREATMENT	TOTAL	MEAN	SUM SQR DIFF	STANDARD DEV
1 (POS3)	1635.90	136.32	134.92	12.63
2 (POS4)	1636.00	136.33	125.31	11.39
3 (POS5)	1627.20	135.60	195.49	16.96
4 (POS7)	1639.90	136.57	54.72	4.97
HIGH STD.DEV. =	16.96	TOTAL ALL TREAT. STD. DEVS. = 45.96		

ONE-WAY ANALYSIS OF VARIANCE RESULTS

NULL HYPOTHESIS = ALL TREATMENT MEANS EQUAL
 ALTERNATE HYPOTH. = ALL TREATMENT MEANS NOT EQUAL

SOURCE	DEGREES OF FREEDOM	SUM OF SQUARES	MEAN SQUARE	F
SAMPLE POSITION	3.	6.406	2.135	.196
ERROR	44.	504.469	11.465	
TOTAL	47.	510.975		

COCHRAN'S EQUALITY OF VARIANCES STATISTIC "G" = .3677 K = 12

NULL HYPOTH. = ALL BLOCK VARIANCES ARE EQUAL N = 4

ALT. HYPOTH. = ALL BLOCK VARIANCES ARE NOT EQUAL

TWO-WAY ANALYSIS OF VARIANCE RESULTS

NULL HYPOTHESIS = 1) ALL TREATMENT MEANS ARE EQUAL
 2) ALL BLOCK MEANS ARE EQUAL

ALTERNATE HYPOTH. = 1) ALL TREAT. MEANS ARE NOT EQUAL
 2) ALL BLOCK MEANS ARE NOT EQUAL

SOURCE	DEGREES OF FREEDOM	SUM OF SQUARES	MEAN SQUARE	F
SAMPLE POSITION	3.	6.406	2.135	.695
CAST./FORG. NO.	11.	403.055	36.641	11.923
ERROR	33.	101.414	3.073	
TOTAL	47.	510.975		

NOTE: BOTH TWO- AND ONE-WAY ANOVA INFORMATION PROVIDED TO
 SHOW SYSTEM CAPABILITY. ONE-WAY ANOVA SHOULD ONLY
 BE USED IF IT IS KNOWN THAT BLOCKING EFFECT (CAST./
 FORG. NO.) EFFECT IS NEGLIGIBLE.

TABLE 4-4

85

Part No. 3072112 CMR ANALVR Results

TREATMENT	TOTAL	MEAN	SUM SQR DIFF	STANDARD DEV
1 (POS3)	1884.03	134.57	95.30	7.33
2 (POS4)	1905.10	136.09	67.00	5.15
3 (POS5)	1868.60	133.47	85.59	6.58
HIGH STD.DEV. =	7.33	TOTAL ALL TREAT. STD. DEVS. = 19.07		

ONE-WAY ANALYSIS OF VARIANCE RESULTS

NULL HYPOTHESIS = ALL TREATMENT MEANS EQUAL
 ALTERNATE HYPOTH. = ALL TREATMENT MEANS NOT EQUAL

SOURCE	DEGREES OF FREEDOM	SUM OF SQUARES	MEAN SQUARE	F
SAMPLE POSITION	2.	47.969	23.984	3.773
ERROR	39.	247.906	6.357	
TOTAL	41.	295.875		

COCHRAN'S EQUALITY OF VARIANCES STATISTIC "G" = .3844 K = 24
 NULL HYPOTH. = ALL BLOCK VARIANCES ARE EQUAL N = 3
 ALT. HYPOTH. = ALL BLOCK VARIANCES ARE NOT EQUAL

TWO-WAY ANALYSIS OF VARIANCE RESULTS

NULL HYPOTHESIS = 1) ALL TREATMENT MEANS ARE EQUAL
 2) ALL BLOCK MEANS ARE EQUAL

ALTERNATE HYPOTH. = 1) ALL TREAT. MEANS ARE NOT EQUAL
 2) ALL BLOCK MEANS ARE NOT EQUAL

SOURCE	DEGREES OF FREEDOM	SUM OF SQUARES	MEAN SQUARE	F
SAMPLE POSITION	2.	47.969	23.984	10.796
CAST./FORG. NO.	13.	190.094	14.623	6.576
ERROR	26.	57.913	2.224	
TOTAL	41.	295.875		

NOTE: BOTH TWO- AND ONE-WAY ANOVA INFORMATION PROVIDED
 TO SHOW SYSTEM CAPABILITY. ONE-WAY ANOVA SHOULD
 ONLY BE USED IF IT IS KNOWN THAT BLOCKING (CAST./
 FORG. NO.) EFFECT IS NEGLIGIBLE.

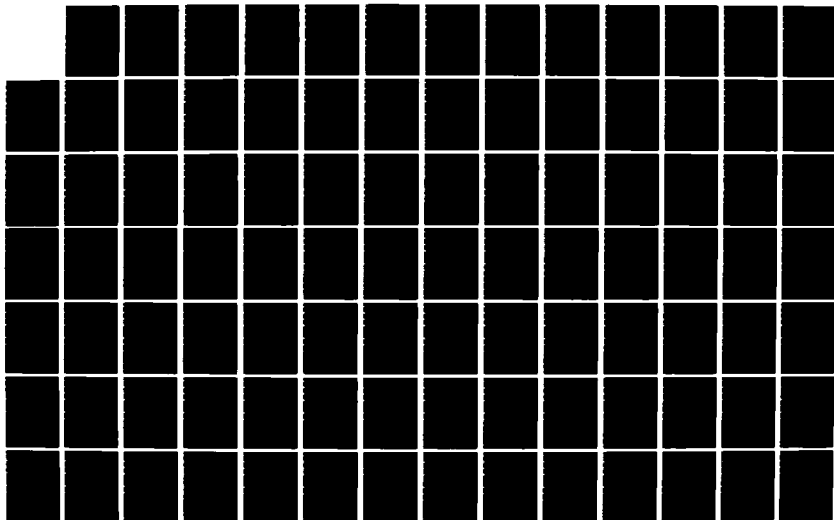
AD-A166 418

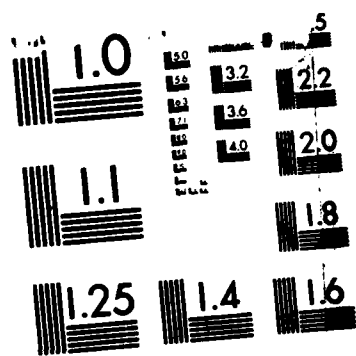
AN APPLICATION OF QUALITY CONTROL THEORY TO
VENDOR-SUPPLIED PARTS AT AN A. (U) AIR FORCE INST OF
TECH WRIGHT-PATTERSON AFB OH D E GELLENBECK AUG 85
AFIT/CI/NR-86-13T F/G 5/1

2/3

UNCLASSIFIED

NL





MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS 1963-A

Beginning with the one-way ANOVA results, note the degrees of freedom are different (CERT = 3 for position, 39 error, 41 total; CMR = 2 for position, 44 for error, 47 total) which yields differing critical F_0 values (19:397-401). The CERT F_0 (0.186) becomes significant at $\alpha > 0.25$ while the CMR F_0 (3.773) is significant at $\alpha =$ approximately 0.05.

The Cochran's homogeneity of variances statistic "g" differs only slightly, but again there are different degrees of freedom. The "g's" and their points of significance as determined by comparison to the charted values (8:688) are:

$$g_{\text{CERT}} (n = 4, k = 12) = .3677 \text{ significant at } \alpha > .05$$

$$g_{\text{CMR}} (n = 3, k = 14) = .3844 \text{ significant at } \alpha \approx .04$$

$$\begin{aligned} (\alpha &= .05, g = .35) \\ (\alpha &= .01, g = .43) \end{aligned}$$

Thus, it is safe to say that at $\alpha = .01$, the variances of measures among the different sample pieces are the same.

The two-way analysis of variance in the case of the CERT data, verifies what had been determined in the one-way analysis of variance; the blocking (different test forgings/castings) is responsible for most of the variability, something that was suspected at the outset. The CERT two-way results are:

$$F_{\text{Tr}}(3.33) = .695 \text{ significant at } \alpha > 0.25$$

$$F_{\text{Bl}}(11.33) = 11.923 \text{ significant at } \alpha < 0.01.$$

The CMR two-way ANOVA, however, displays different information from the one-way:

$$F_{Tr(2.26)} = 10.786 \text{ significant at } \alpha > 0.25$$

$$F_{BL(13.26)} = 6.576 \text{ significant at } \alpha > 0.25$$

leading to rejection of both null hypothesis.

These may indicate significant differences between the vendor and AiResearch testing, data inconsistencies, "out-of-control" situations, or bad product. Quality control charts may help to clarify this situation.

Before presenting the control charts, it's appropriate to discuss which provides more information, the control charts or the analysis of variance. Basically, they both can provide the same information, but in different ways. The analysis of variance tests for variation between populations (treatments) for selected levels of confidence $(1-\alpha)$ by using extensive and somewhat complicated mathematical calculations that employ the sample standard deviation as an estimate of variance. Quality control charts also test variation between populations, but this is accomplished by utilizing simpler calculations that employ range (in the simplest case), sample standard deviation, etc., as estimates of variance and in most cases using set values of $(1-\alpha)$,

(i.e. the three-sigma (3σ) or 99.73% $1-\alpha$) confidence levels can be investigated by recalculating the control limits with values other than three as mentioned in Chapter 3. The advantage of control charts is that they provide a picture of the analysis that makes decision-making much easier for the user who is not familiar with the statistical background and/or manipulation required.²⁴

A look at the control charts for the CERT and CMR test data for part number 3072112 should give a visual indication of what the one-way and two-way ANOVA results were designating. Figures 4-1 and 4-2 are the results of plotting the CERT and CMR data respectively. The "3-SIGMA X-BAR CHART" for the CERT data shows that while all the results were above the minimum specification level (the vertical line of "m"'s), they did not stay within the 3 control limits (the vertical lines of "l's") and the process appears out of control. The two-way ANOVA, it may be recalled, indicated considerable variation between the sample pieces (blocking), thus the two methods as proposed above do indeed provide the same information, though in different ways. The ranges on the "3-SIGMA R CHART" stayed well within the control limits, however, indicating the range of values within each test sample was relatively consistent as indicated by Cochran's test.

²⁴See Duncan (9:618-19) for an in-depth discussion of this.

FIGURE 4-1:

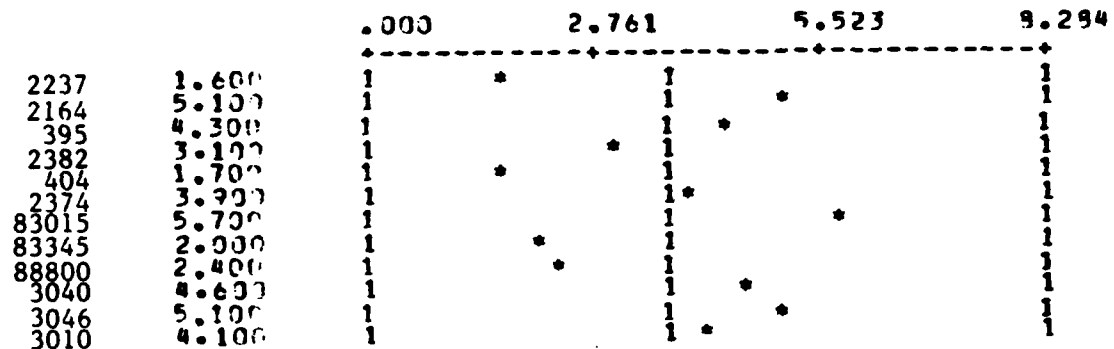
89

Part No. 3072112 CERT Control Charts
(Sheet 1 of 3)

3 SIGMA-
RANGE CHART

SERIAL
NUMBER

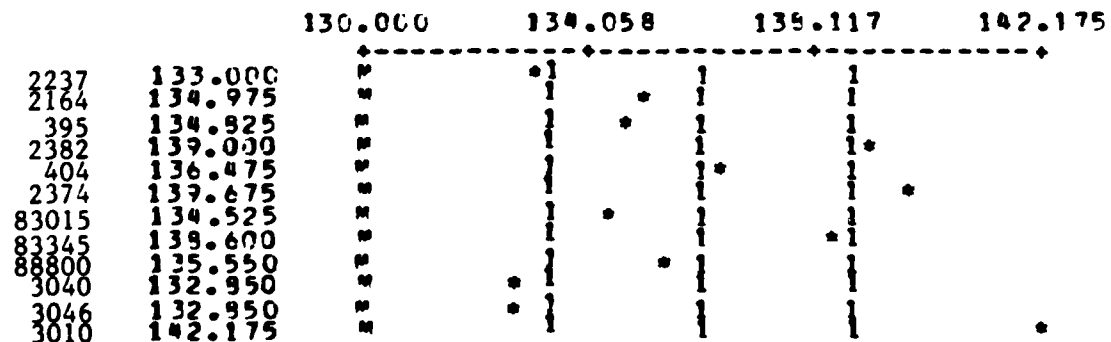
LCL = .0000
CENTER = 3.6333
UCL = 9.2940



3 SIGMA-
X-RAR CHART

SERIAL
NUMBER

LCL = 133.5560
CENTER = 136.2083
UCL = 138.9607



NOTE: THE MOST RECENT DATA IS DISPLAYED AT TOP OF CHARTS.

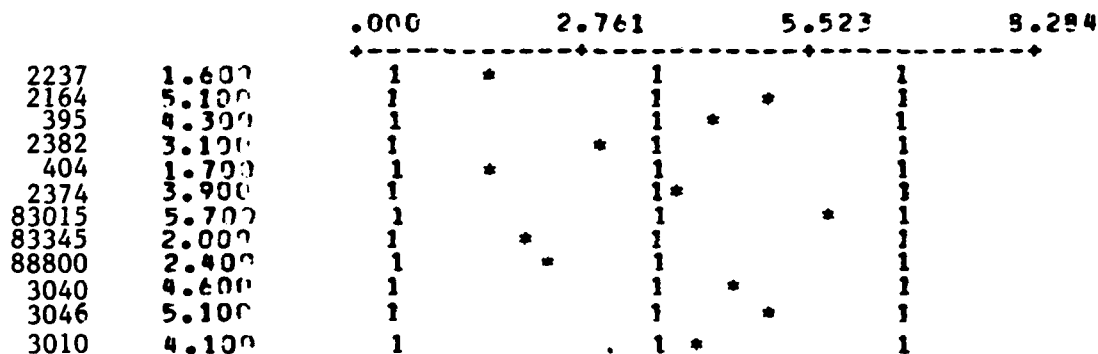
FIGURE 4-1:

Part No. 3072112 CERT Control Charts
(Sheet 2 of 3)

2 SIGMA-
RANGE CHART

SERIAL
NUMBER

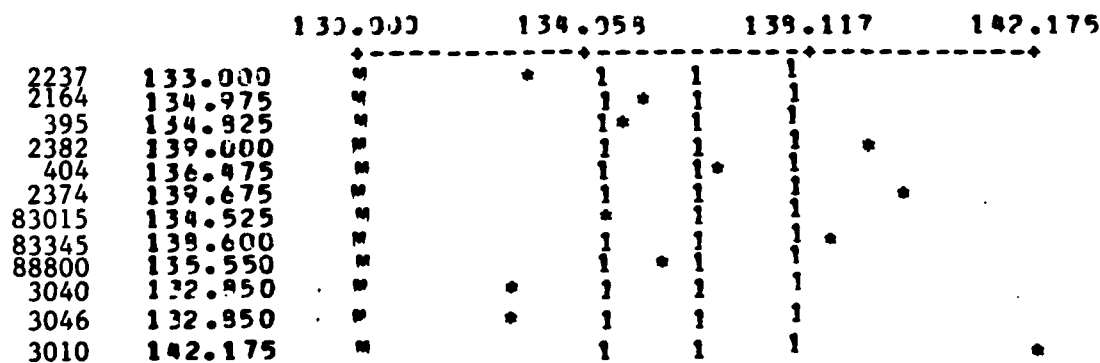
LCL = .5291
CENTER = 3.6333
UCL = 6.7319



2 SIGMA-
X-RAP CHART

SERIAL
NUMBER

LCL = 134.4401
CENTER = 136.2983
UCL = 137.9765



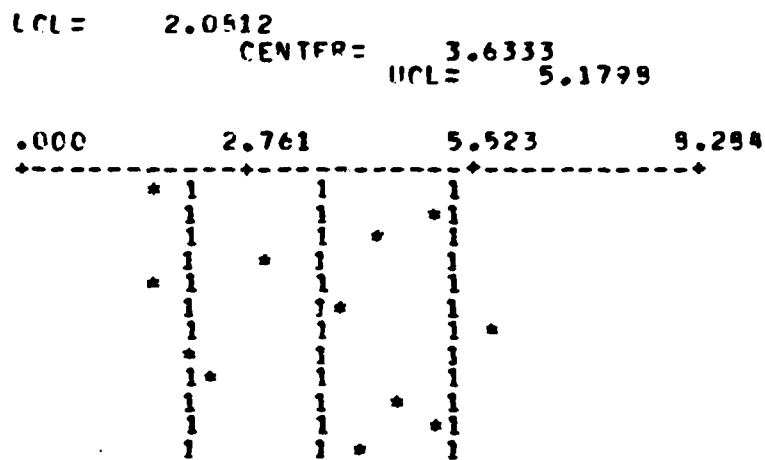
NOTE: THE MOST RECENT DATA IS AT THE TOP OF THE CHARTS.

FIGURE 4-1:

Part No. 3072112 CERT Control Charts
(Sheet 3 of 3)

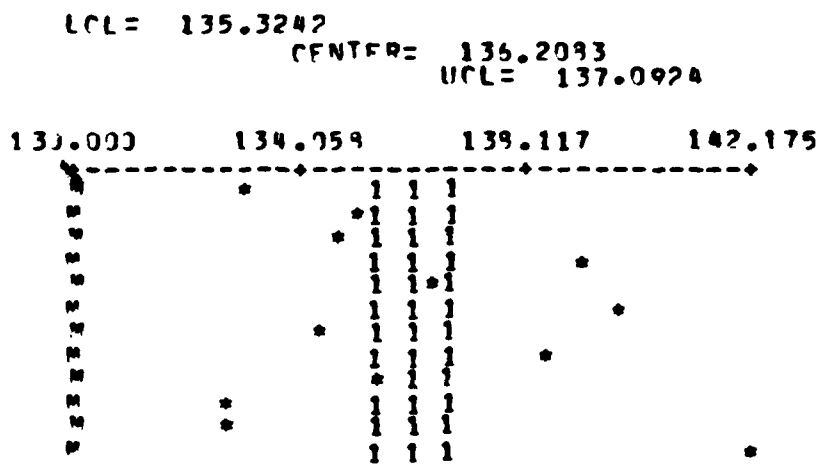
1 SIGMA-
RANGE CHART

SERIAL
NUMBER



1 SIGMA-
X-BAR CHART

SERIAL
NUMBER



NOTE: THE MOST RECENT DATA IS DISPLAYED AT THE TOP OF CHARTS.

FIGURE 4-2:

92

Part No. 3072112 CMR Control Charts
(Sheet 1 of 3)

3 SIGMA-
RANGE CHART

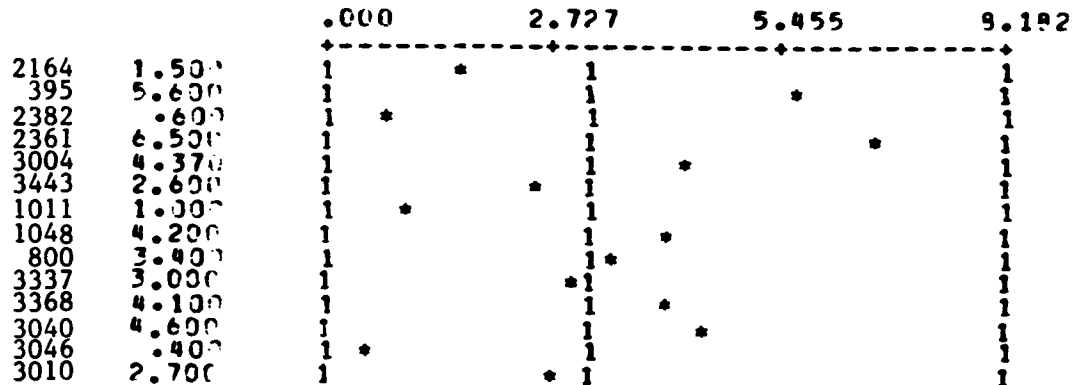
SERIAL
NUMBER

LCL = .0000

CENTER =

3.1936

UCL = 9.1919



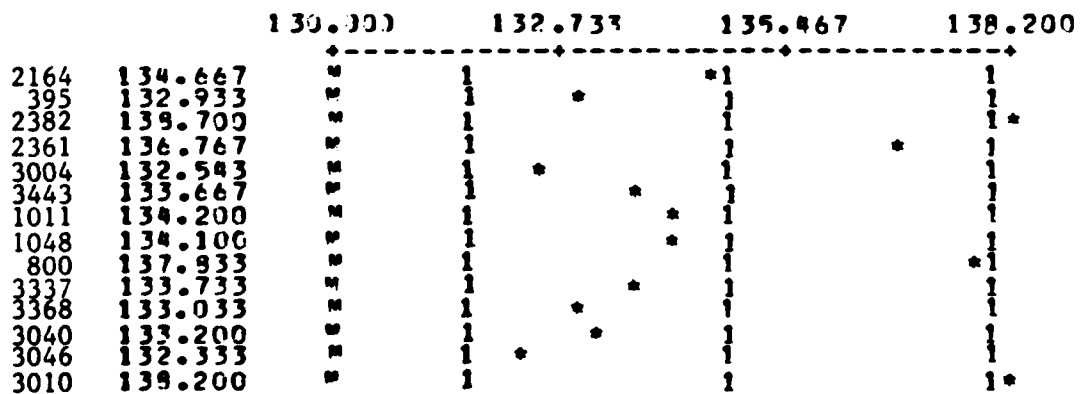
3 SIGMA-
X-BAR CHART

SERIAL
NUMBER

LCL = 131.4606

CENTER = 134.7079

UCL = 137.9551



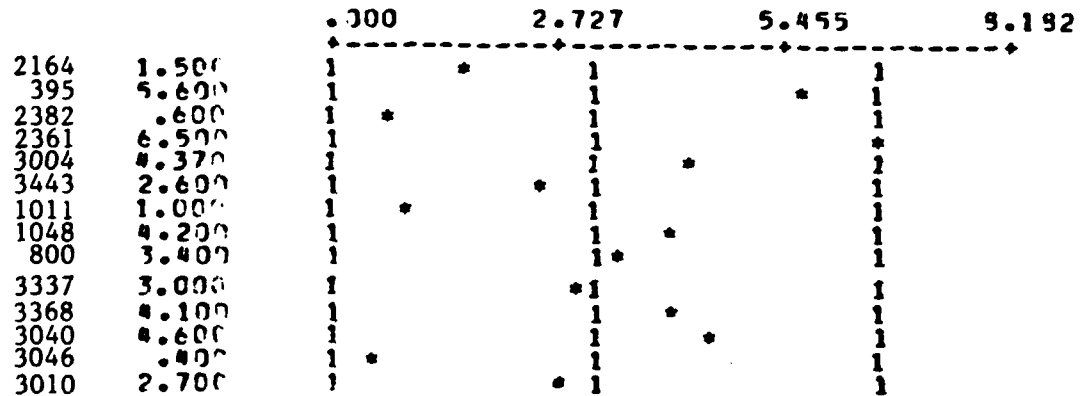
NOTE: THE MOST RECENT DATA IS DISPLAYED AT THE TOP OF CHARTS.

Part No. 3072112 CMR Control Charts
(Sheet 2 of 3)

2 SIGMA-
RANGE CHART

SERIAL
NUMBER

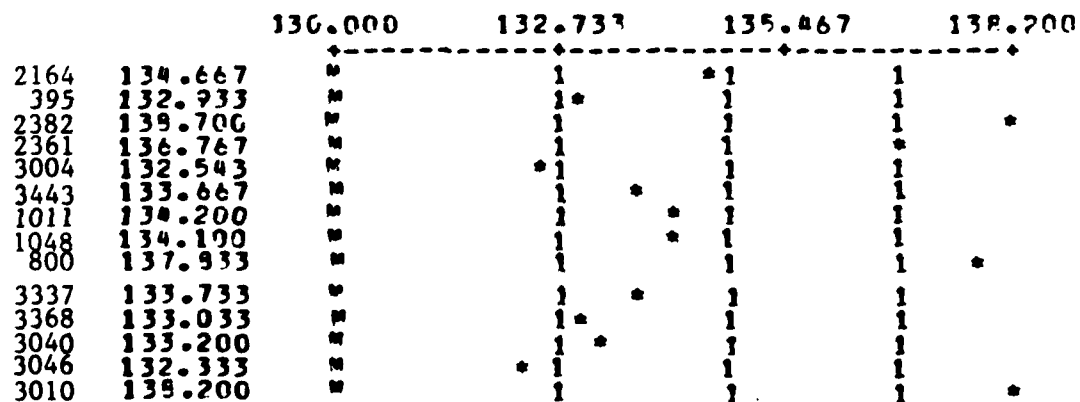
LCI = .0000
CENTER = 3.1936
UCL = 6.5052



2 SIGMA-
X-BAR CHART

SERIAL
NUMBER

LCI = 132.5430
CENTER = 134.7079
UCL = 136.8727



NOTE: THE MOST RECENT DATA IS DISPLAYED AT THE TOP
OF CHARTS.

FIGURE 4-2:

94

Part No. 3072112 CMR Control Charts
(Sheet 3 of 3)

1 SIGMA-
RANGE CHART

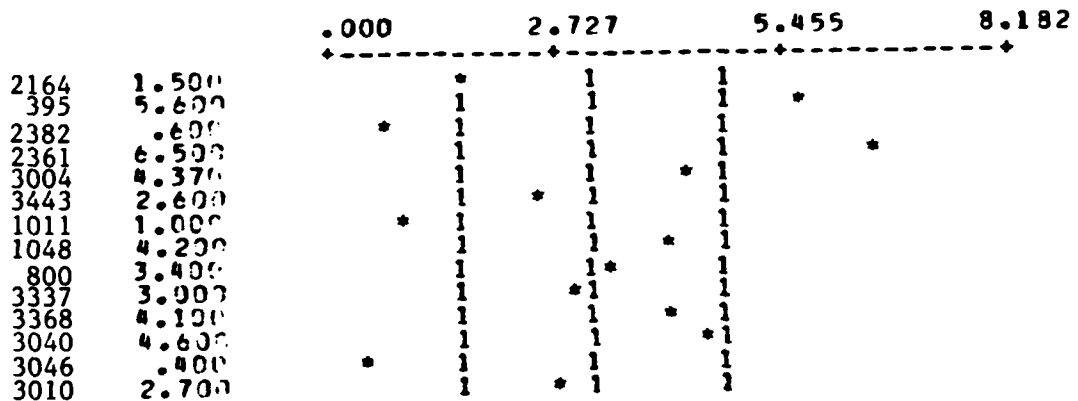
SERIAL
NUMBER

LCL= 1.5070

CENTER=

3.1836

UCL= 4.8287



1 SIGMA-
X-BAR CHART

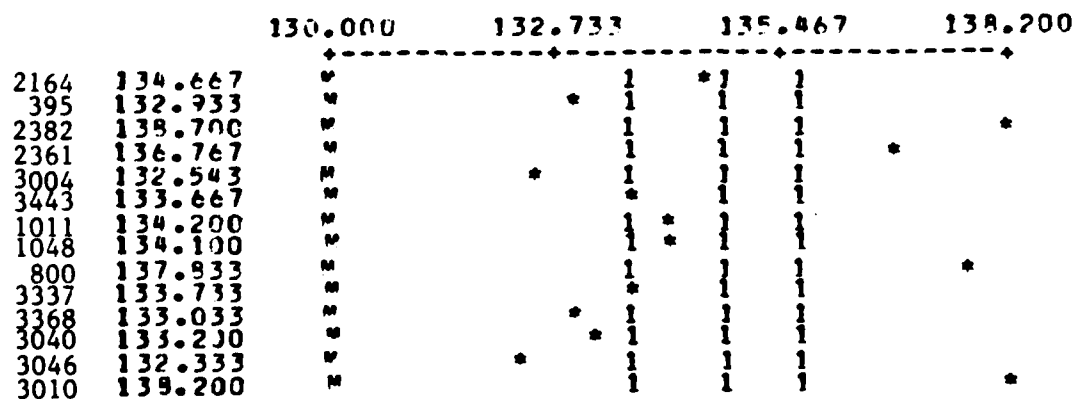
SERIAL
NUMBER

LCL= 133.6254

CENTER=

134.7079

UCL= 135.7903



NOTE: THE MOST RECENT DATA IS DISPLAYED AT THE TOP
OF CHARTS.

The CMR charts for part number 3072112 show somewhat better control than those for the CERT data, but there are still points outside the three-sigma limits. The range charts show good control. While the result of the two-way ANOVA can be seen in the charts it is not as clear as in the case of the CERT data. Plots of the individual data points, however, may aid in this.

Figures 4-3 and 4-4 depict these plots. Even a quick glance shows what the control charts had depicted in detail. For the CERT data, there is a wide dispersion of values, but the range of each piece doesn't appear excessive; the situations the control charts showed for the CMR data, the true worth of the plot is seen with one of the test results falling below minimum specifications. The dispersion of values and the differing of values that the range chart and two-way analysis of variance showed, and Cochran's "g" confirmed, can be seen.

To compare the two sets of data is difficult, if not impossible with the out-of-control situations observed. Since the data for the matched pairs is dependent, however, it may be beneficial to at least look at the results of the T^* testing. Table 4-5 presents the data and results for the paired test data means (the mean values of yield tests on respective halves of each tested casting/forging) and reference to the tables of t^* values (18:488) for 9 degrees of freedom leads to the following: $t^* = 2.0811$

••••• TEMP. TENSILE TESTS-VIELL LAR.PAC.(1/77 TO 5/79) CERY GATA

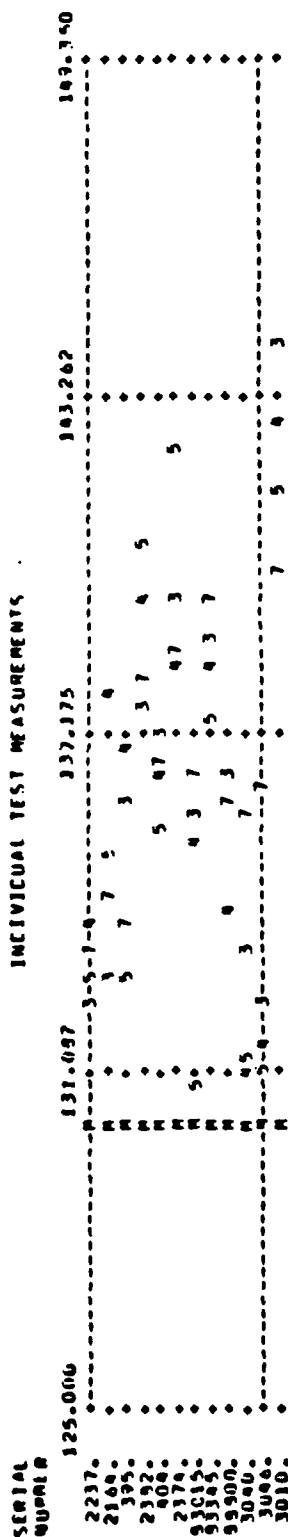
VALUE PLOT:

(SERIAL NUMBER VS. INDIVIDUAL TEST MEASUREMENTS)

PART NUMBER: --3072112--YFE731 ENGINE PART

NUMBER ON PLOT CORRESPONDS TO POSITION NUMBER
(I.E., 3 = TEST SAMPLE FROM POSITION 3 OF CASTING/FORGING

INDIVIDUAL TEST MEASUREMENTS



NOTE: 1) MISSING NUMBERS INDICATE DUPLICATION.
CHECK DATA (ACCORDING TO SERIAL NUMBER) FOR DUPLICATES.

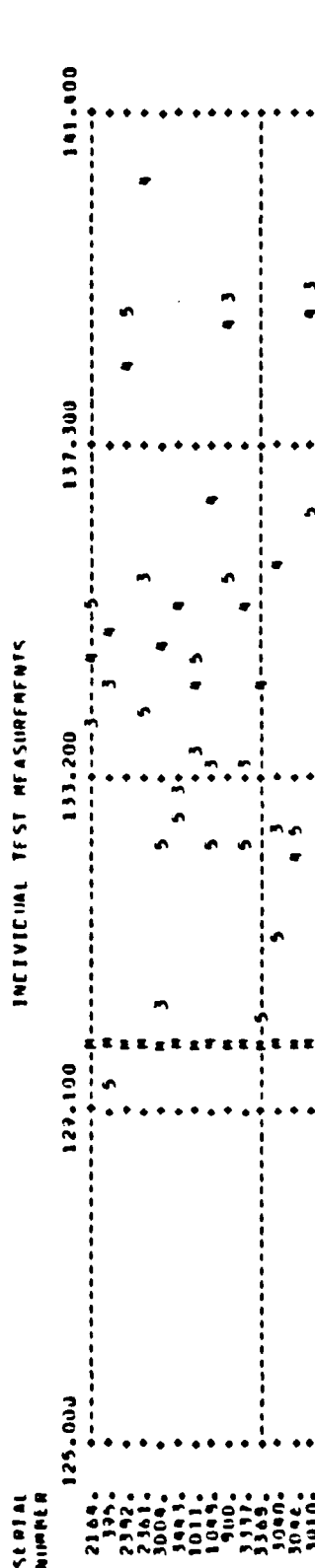
2) AN ASTERISK (*) INDICATES A VALUE OUT OF LIMITS.

3) MOST RECENT DATA IS AT TOP OF PLOT.

FIGURE 4-3

Part No. 3072112 CERT Individual Data Plot

ROOM TEMP. TENSILE TESTS-VIELD LAC-PACIFIC(11/77 TO 11/19)CMR DATA
 VALUE PLOT:
 (SERIAL NUMBER VS. INDIVIDUAL TEST MEASUREMENTS)
 PART NUMBER: --3072112--TFE731 ENGINE PART
 NUMBER ON PLOT CORRESPONDS TO POSITION NUMBER
 (I.F.O.S = TEST SAMPLE FROM POSITION 3 OF CASTING/FORGING
 INDIVIDUAL TEST MEASUREMENTS)



NOTE: 1) MISSING NUMBERS INDICATE DUPLICATION.
 CHECK DATA (ACCORDING TO SERIAL NUMBER) FOR DUPLICATES.
 2) AN ASTERISK (*) INDICATES A VALUE OUT OF LIMITS.

3) MOST RECENT DATA IS AT TOP OF PLOT.

FIGURE 4-4

Part No. 3072112 CMR Individual Data Plot

TABLE 4-5

Part No. 3072112 CERT vs. CMR Paired T-test

DETERMINATION OF A DIFFERENCE IN TESTING FOR

PART NUMBER: 3072112 LALISH PACIFIC TESTING VS. ARC CO. TESTING
DATA FROM 1/77 TO 5/79 (YIELD DATA)

NOTE: MOST RECENT DATA IS AT TOP OF TABLE.

SER. NO.	CERT DATA	CMR DATA	DIFFERENCE	DIFF. SCORE
2164	134.975	134.667	.3080	.0949
395	134.825	132.933	1.8920	3.5797
2382	139.000	138.700	.3000	.0900
82874	139.675	136.767	2.9080	8.4565
83015	134.525	132.548	1.9770	3.9085
83545	138.600	133.667	4.9330	24.3345
88000	135.550	137.833	-2.2830	5.2121
3040	132.850	133.200	-.3500	.3225
3046	132.950	132.333	.5170	.2673
3010	142.175	138.200	3.9750	15.8006
TOTAL			14.1770	61.8665

AVERAGE DIFFERENCE = 1.0177 DEG. OF FREEDOM = 9

SAMPLE VARIANCE = 4.641 SAMPLE STANDARD DEV. = 2.15

THE "T" STATISTIC FOR TESTING THE DIFFERENCE IN THE TWO TESTING MEANS = 2.0911

NULL HYPOTH.: U1-U2 = CMU

ALT. HYPOTH.: U1-U2 > NE.CMU

ASSUMPTION: THE DISTRIBUTION UNDERLYING THE DIFFERENCES IS NORMAL.

Critical value: at $\alpha = .05$ $|t^*| > t_{.05,9} = 1.833$

reject $H_0: \mu_{\text{CERT}} - \mu_{\text{CMR}} = 0$

$H_1: \mu_{\text{CERT}} - \mu_{\text{CMR}} = 0$

at $\alpha = .01$ $|t^*| < t_{.01,9} = 2.821$

accept $H_0: \mu_{\text{CERT}} - \mu_{\text{CMR}} = 0$

and the means can be considered equal, something that was intuitively obvious, but now can be statistically proven. The fact that H_0 must be rejected at $\alpha = .05$ would caution the user to investigate factors that might cause the means to be unequal such as differences in testing technique.

As a point of interest, it may be noted that the values of the difference between each pair of data are provided. This could be used to test data from two different vendors manufacturing the same part through use of the Wilcoxon two sample test in the event the distributions underlying the values is decidedly normal (33:254-258). Such data was not available for this study and, hence no examples of such a test are provided.

Part Number 3072316--

Forged Turbine Disk of Waspaloy, Condition B

Reviewing the control charts for test results of part number 3072316 illustrates the use of the developed programs in analyzing individual (one sample/test forging) measurement data. Tables 4-6 and 4-7 present the individual measurement data for the ultimate stress portion of the room temperature Tensile test for the CERT and CMR data while

TABLE 4-6
Part No. 3072316 CERT Individual
Measurements Data

SERIAL #	INPUT DATA BY POSITION	
275	157.10	1209
230	150.40	1300
267	152.00	1301
223	157.50	960
152	155.90	909
155	156.00	969
4096	152.90	381
4069	159.60	2509
4025	151.50	2543
4016	150.40	1962
2607	151.60	1967
2609	153.60	1165
2575	157.60	390
2673	154.50	9919
1226	154.50	570
1202	159.40	

NOTE: MOST RECENT DATA IS AT TOP
OF TABLES.

THE MEAN = 150.67 SUM OF SQUARES = 1127595.59

STAND LEV = 4.34 SUM = 5910.90

TABLE 4-8
Part No. 3072316
CERT Grouped Data

1	157.10	140.40	152.00
2	157.50	155.70	154.00
3	152.90	155.60	151.50
4	150.40	151.60	153.60
5	152.60	154.90	154.50
6	155.40	151.40	156.40
7	156.40	151.00	150.00
8	155.00	156.80	157.40
9	156.40	155.20	152.00
10	155.60	151.10	151.20

TABLE 4-7
Part No. 3072316 CMR Individual
Measurements Data

SERIAL #	INPUT DATA BY POSITION
207	191.90 2509 194.30
223	192.30 2543 192.70
152	191.40 1962 190.60
155	191.50 1967 191.30
2607	195.90 1165 197.50
2609	192.70 390 194.90
2575	195.10 9392 195.20
2673	199.60 9919 193.10
1226	200.00 570 199.60
1202	199.50 2000 191.50
1209	197.40 1950 193.90
960	197.60 THE PLAN = 193.29
909	196.50 STAFF LEN = 5.69
999	190.00 CORR = 5219.70
9711	195.40 SUM OF CORRECTIONS = 1069099.79
391	199.50

TABLE 4-9
Part No. 3072316
CMR Grouped Data

1	191.90	192.40	193.40
2	191.50	195.90	195.70
3	195.10	199.60	200.00
4	199.90	197.50	197.10
5	196.50	190.60	195.50
6	199.50	196.30	192.70
7	190.60	191.30	197.40
8	196.30	195.20	193.10
9	197.60	191.50	193.90

NOTE: MOST RECENT DATA IS AT
TOP OF TABLES.

tables 4-8 and 4-9 present the grouped data. The values were grouped in three's by simply taking the three most recent values (top three on individual data table), then the next three, etc. A decision was made to bypass the ANOVA calculations since, with the grouped data, it wasn't necessary.

Figures 4-5 and 4-6 present the grouped "3-SIGMA" and "2-SIGMA X-BAR" and "RANGE" charts for the CERT and CMR data. Looking at the CERT $\bar{X}$ charts shows some interesting behavior in the grouped average; the trend toward lower average ultimate stress values over time is of particular interest. The average of the latest three tests (group 1) has fallen close to the lower three-sigma limit and is in fact below the two-sigma limit. The range charts show things "in-control". The CMR control charts don't really depict this trend. The charts of individual measurements with the grouped X-bar control limits (3σ), figures 4-7 and 4-8, shows how the samples performed over time. Note the trend indicated on the grouped CERT X-bar chart is quite obvious on the CERT individual chart while the CMR individual chart shows little or no trend.

The reasons for such a discrepancy are difficult to pinpoint, but may be due to a degradation in the vendor's test equipment, a process trend in the manufacturing, or problems in AiResearch test procedures.

FIGURE 4-5:

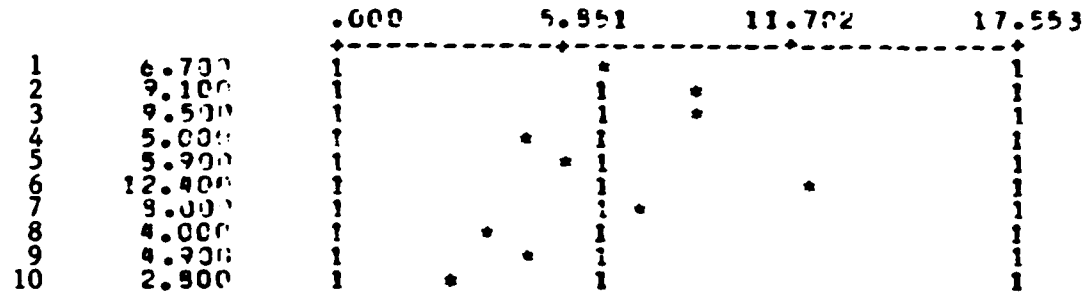
103

Part No. 3072316 CERT Grouped Control Charts
(Sheet 1 of 2)

3 SIGMA -
RANGE CHART

SERIAL
(GROUP)
NUMBER

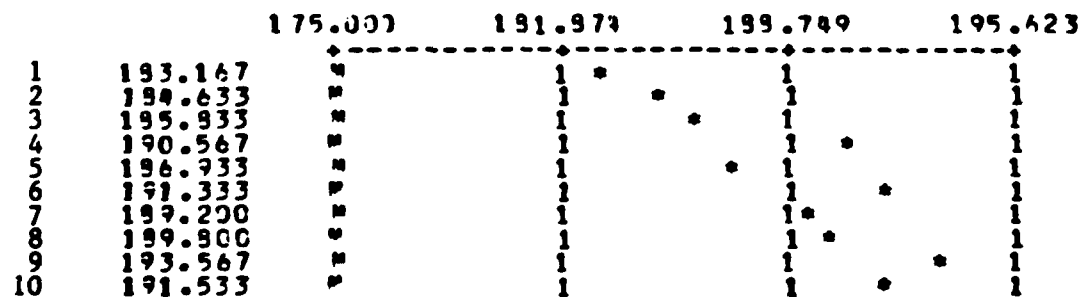
LCL = .0000
CENTER = 6.9300
UCL = 17.5531



3 SIGMA -
X-BAR CHART

SERIAL
(GROUP)
NUMBER

LCL = 181.6901
CENTER = 188.6567
UCL = 195.6233



NOTE: THE MOST RECENT DATA IS DISPLAYED AT THE TOP OF CHARTS.

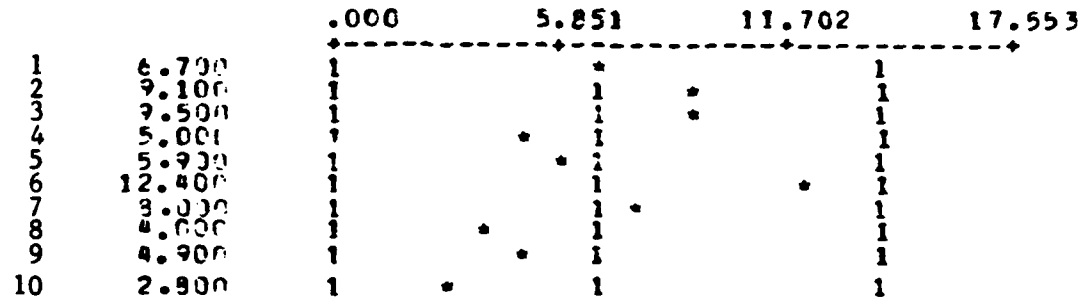
FIGURE 4-5:

Part No. 3072316 CERT Grouped Control Charts
(Sheet 2 of 2)

2 SIGMA-
RANGE CHART

SERIAL
(GROUP)
NUMBER

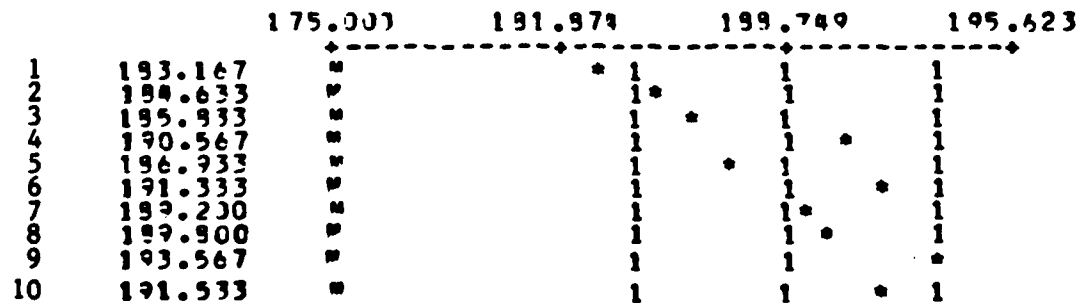
LCL = .0000
CENTER = 6.8300
UCL = 13.9562



2 SIGMA-
X-BAR CHART

SERIAL
(GROUP)
NUMBER

LCL = 184.0123
CENTER = 199.6567
UCL = 193.3011



NOTE: THE MOST RECENT DATA IS DISPLAYED AT THE TOP OF CHARTS.

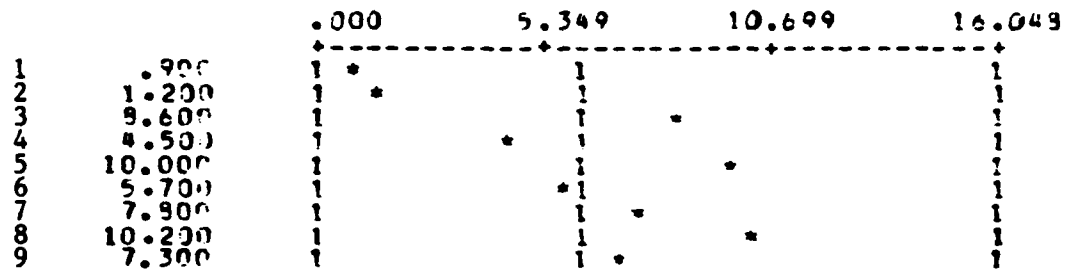
FIGURE 4-6:

Part No. 3072316 CMR Grouped Control Charts
(Sheet 1 of 2)

3 SIGMA-
RANGE CHART

SERIAL
(GROUP)
NUMBER

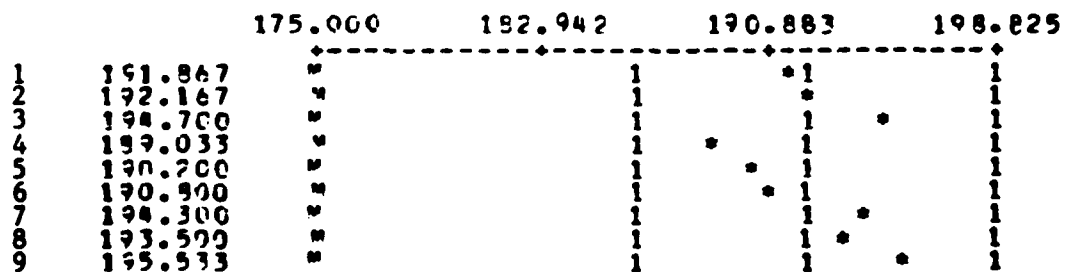
LCL = .0000
CENTER = 6.2444
UCL = 16.0482



3 SIGMA-
X-BAR CHART

SERIAL
(GROUP)
NUMBER

LCL = 186.0962
CENTER = 192.4555
UCL = 198.8249



NOTE: THE MOST RECENT DATA IS DISPLAYED AT THE TOP OF CHARTS.

FIGURE 4-6:

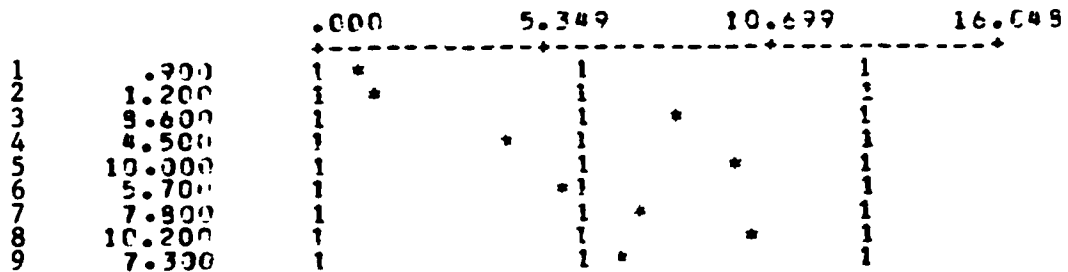
106

Part No. 3072316 CMR Grouped Control Charts
(Sheet 2 of 2)

2 SIGMA -
RANGE CHART

SERIAL
(GROUP)
NUMBER

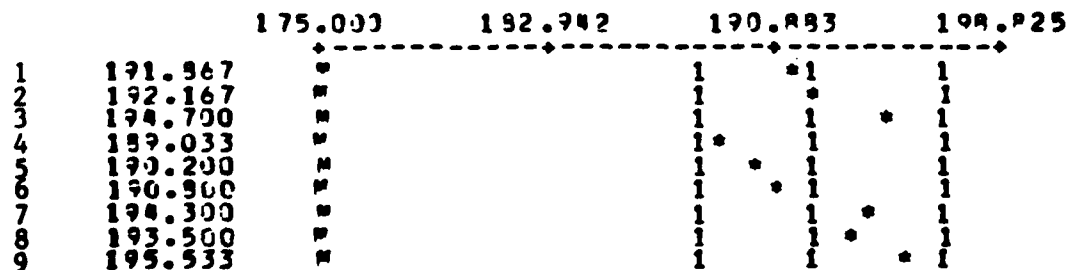
LCL = .0000
CENTER = 6.2444
UCL = 12.7597



2 SIGMA -
X-BAR CHART

SERIAL
(GROUP)
NUMBER

LCL = 189.2093
CENTER = 192.4555
UCL = 196.7018



NOTE: THE MOST RECENT DATA IS DISPLAYED AT THE TOP OF CHARTS.

FIGURE 4-7

107

Part No. 3072316 CERT Individual
Measurements Control Chart

INDIVIDUAL VALUE
X CHART

LCL= 176.5328 CENTER= 199.6567
UCL= 200.7809

SERIAL
NUMBER

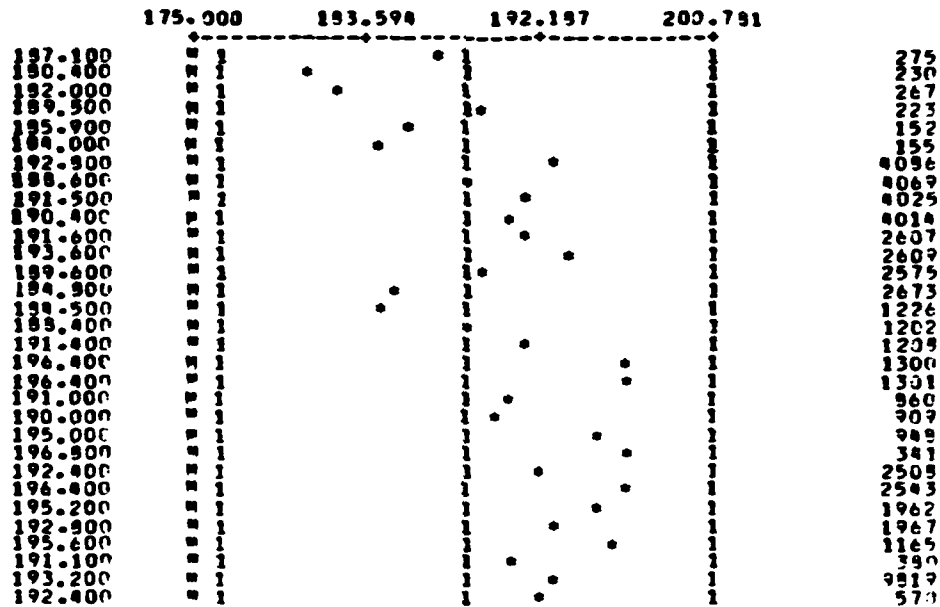


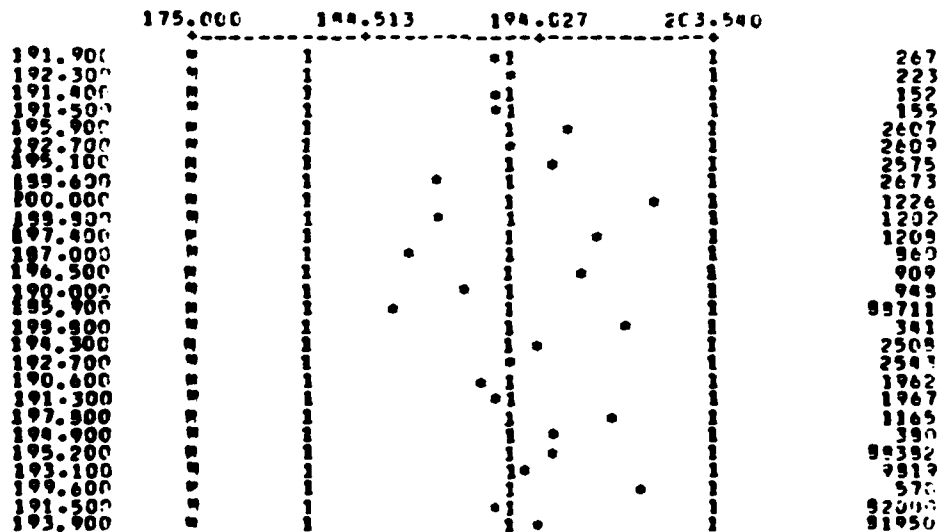
FIGURE 4-8

Part No. 3072316 CMR Individual
Measurements Control Chart

INDIVIDUAL VALUE
X CHART

LCL= 191.3707 CENTER= 192.4555
UCL= 203.5404

SERIAL
NUMBER



NOTE: THE MOST RECENT DATA IS DISPLAYED AT TOP OF FIGURES.

The test for equality of means of the paired observations (again, the respective halves of the tested forgings) is presented in table 4-10. Testing at $\alpha = .01$ and $.05$ shows

$t^* = -2.7153$ with 22 degrees of freedom

critical value at $\alpha = .05$ $|t^*| > t_{.05, 22} = 1.717$

reject $H_0: \mu_{\text{CERT}} - \mu_{\text{CMR}} = 0$

at $\alpha = .01$ $|t^*| > t_{.01, 22} = 2.508$

reject $H_0: \mu_{\text{CERT}} - \mu_{\text{CMR}} = 0$

and as stated previously, the user would have to investigate to determine the cause for the inequality since it would be expected that they would be statistically equivalent.

In both cases (both selected parts) there was a limited amount of data available, making it difficult to get a good estimate of the statistics of the populations. Most sources recommended at least 25 samples of good data to give such an estimate (6:112), but this amount was not available. Also, the condition of test results reports (CERT's and CMR's) made it difficult to obtain any more data. The rough data sheets (see Appendix B) summarize the data the author was able to glean from extensive research of the records. Additionally, it was particularly difficult to pick values from the CMR's due to poor organization and lack of consistency in the original AiResearch and vendor data.

The programs developed in this study were verified by manually analyzing the data. An example for part No.

TABLE 4-10

Part No. 3072316 CERT vs. CMR Paired T-test

SER. NO.	CERT DATA	CMR DATA	DIFFERENCE	DIFF. SQRE
267	192.000	191.900	-9.9000	99.0100
223	199.500	192.300	-7.2000	51.8400
152	195.900	191.400	-4.5000	20.2500
155	194.000	191.500	-2.5000	6.2500
2617	191.600	195.900	4.3000	18.4900
2609	193.600	192.700	.9000	.8100
2575	199.600	195.100	-4.5000	20.2500
2673	194.900	199.600	4.7000	22.0900
1296	194.500	200.000	5.5000	30.2500
1202	199.400	199.900	.5000	.2500
1204	191.400	197.400	6.0000	36.0000
960	191.000	197.000	6.0000	36.0000
909	190.700	196.500	5.8000	33.6400
948	195.000	190.000	-5.0000	25.0000
341	196.400	199.900	3.5000	12.2500
2508	192.400	194.300	1.9000	3.6100
2543	196.400	192.700	-3.7000	13.6900
1962	195.200	190.600	-4.6000	21.1600
1967	192.400	191.300	-1.1000	1.2100
1165	195.600	197.900	2.3000	5.2900
391	191.100	194.900	3.8000	14.4400
9519	193.200	193.100	-.1000	.0100
570	192.400	199.600	7.2000	51.8400
TOTAL			-65.0000	731.8399

AVERAGE DIFFERENCE = -2.8261 DEG. OF FREEDOM = 22

SAMPLE VARIANCE = 24.916 SAMPLE STANDARD DEV. = 4.99

THE "T" STATISTIC FOR TESTING THE DIFFERENCE IN THE TWO TESTING MEANS = -2.7153

NULL HYPOTH.: $\mu_1 - \mu_2 = 0$ ALT. HYPOTH.: $\mu_1 - \mu_2 \neq 0$

ASSUMPTION: THE DISTRIBUTION UNDERLYING THE DIFFERENCES IS NORMAL.

NOTE: MOST RECENT DATA IS AT TOP OF TABLE.

3072112 CERT yield data analysis of variance (ANOVA) is presented in Appendix F, along with analysis of the three treatment means of the CMR yield data using Duncan's test.

The results obtained by analyzing the two test cases provided a means of evaluating, in particular, the capabilities and applicability of the two programs developed and, in general, the quality control system designed for AiResearch forging/casting testing.

Admittedly, the data available to evaluate the quality control system developed in Chapter 3 failed to illustrate how the computer outputs/analyses produced can aid management in making decisions to reduce cost of inspection, change specifications, reduce testing frequency of volume, etc. Three examples have been developed to aid in understanding application of the system.

Example 1 (Figure 4-9) illustrates a "borderline" case where a trend in the "X-BAR" chart toward the lower control limit and the specified minimum value, in both the 2- and 3-sigma cases, may indicate impending trouble. The chronologically latest measurements are presented at the top of the charts, i.e. the most recent data is on top.

Assuming the process, in the past, was "under control," such a trend may indicate that a mold or die is deteriorating, faulty materials are being supplied to the vendor, or that the vendor is adjusting the process to bring the average value closer to the minimum specified. Such

FIGURE 4-9:

111

Control Charts for Example 1
(Sheet 1 of 2)

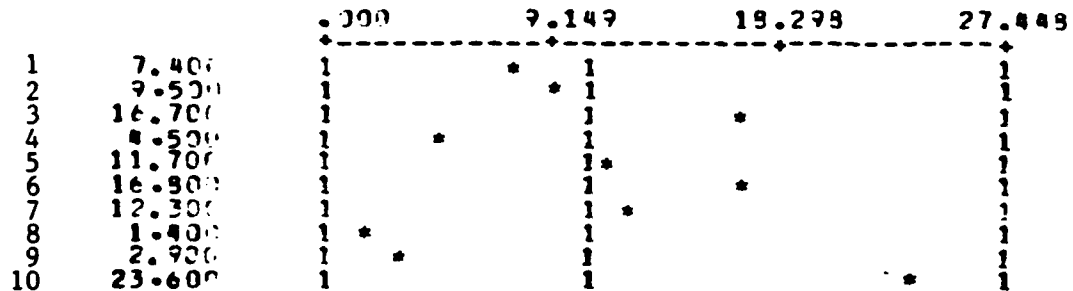
3 SIGMA-
RANGE CHART

ITEM
NUMBER

LCL = .0000

CENTER = 10.6500

UCL = 27.4476



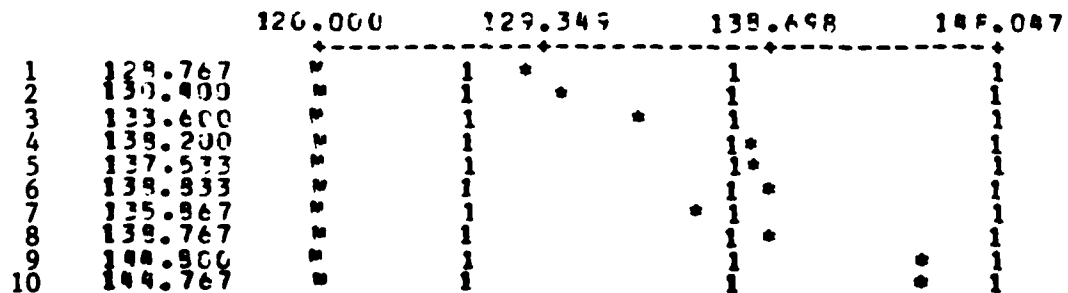
3 SIGMA-
X-RAR CHART

ITEM
NUMBER

LCL = 126.2597

CENTER = 137.1533

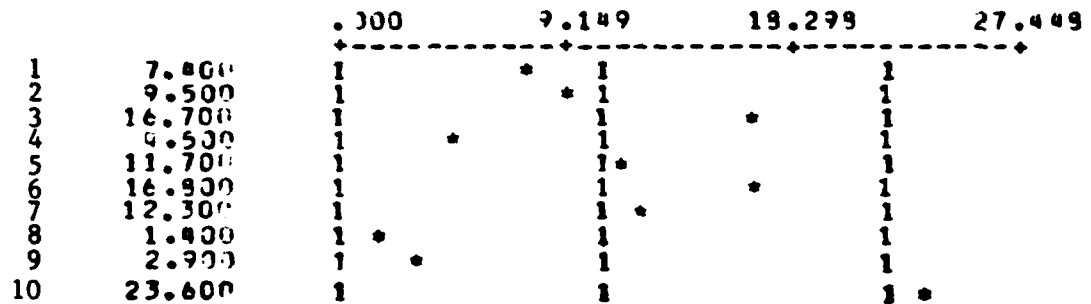
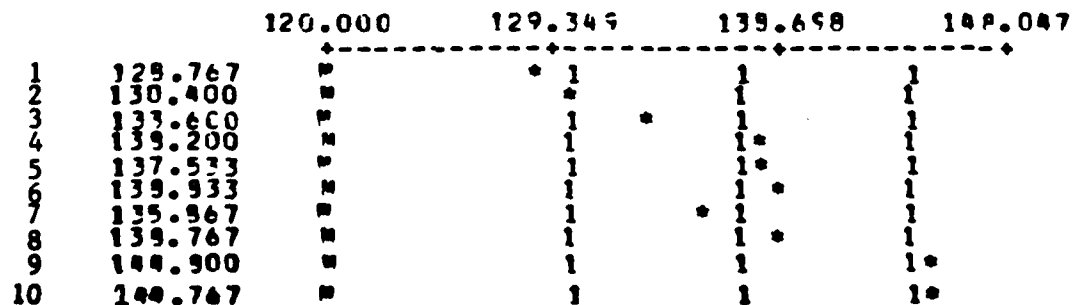
UCL = 148.0469



NOTE: THE MOST RECENT DATA IS ON TOP OF THE CHARTS
(ITEM NO. 1).

FIGURE 4-9:

112

Control Charts for Example 1
(Sheet 2 of 2)2 SIGMA-
RANGE CHARTITEM
NUMBERLCL = .0000
CENTER = 10.6960
UCL = 21.92322 SIGMA-
X-RAR CHARTITEM
NUMBERLCL = 129.9909
CENTER = 137.1533
UCL = 144.4157NOTE: THE MOST RECENT DATA IS ON TOP OF THE CHARTS
(ITEM NO. 1).

information can be used to warn the vendor of impending problems in the hope it can be quickly corrected before quality drops below the minimum specification. Complaints from customers, then, can be minimized. This can also be used as a basis for improvement of vendor/manufacturer relations; early notification of the trend allows the vendor to investigate the cause(s) before quality falls, a situation that could jeopardize a contract. Testing in this case would be continued at the same level to provide monitoring of any corrective measures taken.

Presentation of data in control chart form can provide a concise, chronological record of performance that can be used to present a case to the appropriate persons in an organization. Such a record can also be used to provide evidence in liability cases brought against a manufacturer or vendor (7:207-9).

A process in "good control" is presented in Example 2 (Figure 4-10). The 3-sigma "X-BAR" chart shows all values clustered near the center line ($\bar{\bar{X}}$) as are most values on the 3-sigma "RANGE" chart. The 2-sigma charts confirm that there are no points even approaching the "warning limits" (2-sigma control limits) indicating quite good control. Such a chart indicates that a reduced testing frequency is a possibility, thus reducing the cost of testing. Also, the high average ($\bar{\bar{X}}$) value indicates that investigation of the minimum specification value is called for. Perhaps material

FIGURE 4-10:

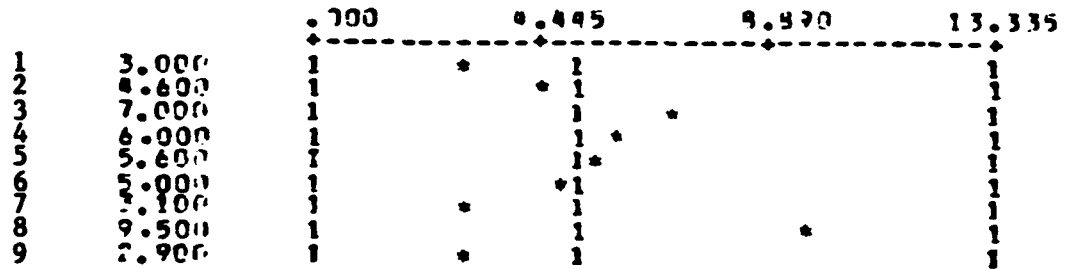
114

Control Charts for Example 2
(Sheet 1 of 2)

3 SIGMA-
RANGE CHART

ITEM
NUMBER

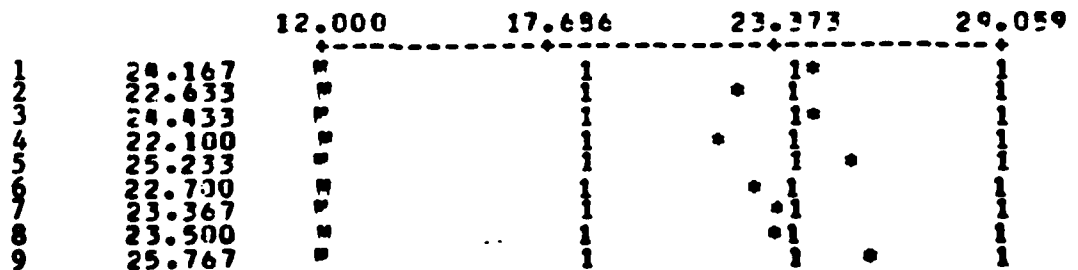
LCL= .0000
CENTER= 5.1999
UCL= 13.3350



3 SIGMA-
X-BAR CHART

ITEM
NUMBER

LCL= 19.4747
CENTER= 23.7667
UCL= 29.0593



NOTE: MOST RECENT DATA IS AT THE TOP OF THE CHARTS.

FIGURE 4-10:

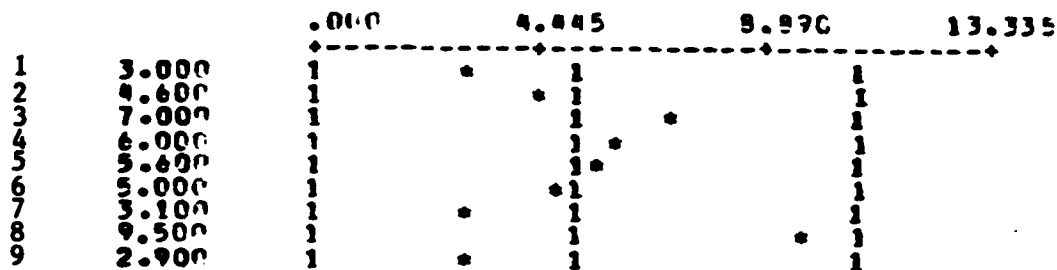
115

Control Charts for Example 2 (Sheet 2 of 2)

2 SIGMA- RANGE CHART

ITEM
NUMBER

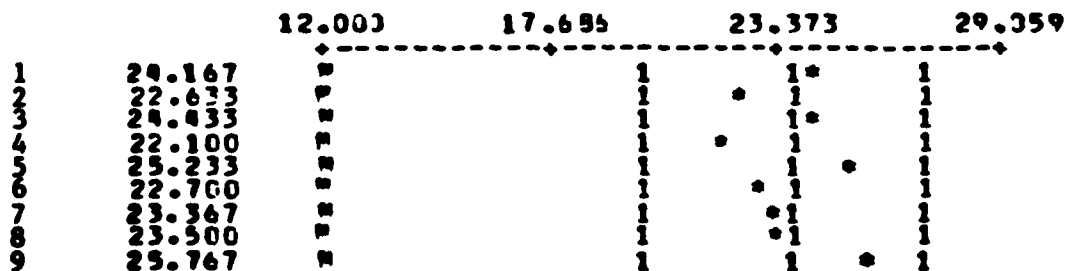
LCL = .0000
CENTER = 5.1999
UCL = 10.6025



2 SIGMA- X-BAR CHART

ITEM
NUMBER

LCL = 20.2392
CENTER = 23.7667
UCL = 27.2951



NOTE: MOST RECENT DATA IS AT THE TOP OF THE CHARTS.

composition or processing could be changed or eliminated. If the higher value is in some way beneficial to the manufactured product, cash awards or other incentives might be given to the vendor, or a higher "vendor certification" (giving that vendor a preference over others supplying the same product) could be assigned that vendor. It may also be used to reduce inspection/testing by either vendor or manufacturer; testing of only one item per heat of material versus three, elimination of one type of test (say, % elongation) conducted on a sample, etc.

Finally, Example 3 demonstrates how to handle the testing position problem in order to reduce testing. Table 4-10 shows the values used to obtain the plot of all the individual measurements by position (Figure 4-11). Looking at the values and averages for each position, and assuming the process is "in control," it becomes obvious that position 5 values are significantly lower than the position 3 or 4 values, and the average values of positions 3 and 4 are almost the same. The individual measurement plot provides a picture of the situation. A measure that might be taken is a reduction in testing positions, i.e., testing in only 1 or 2 positions. The author's recommendation would be to only test position 5 on a regular basis, as its average value is closer to the specification minimum. The other positions could be tested less frequently. Also, as in Example 2 above, the minimum specification value should

TABLE 4-11:

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Values of Individual Measurements for Example 3

ITEM NO.	POS. 3	POS. 4	POS. 5
2164	192.10	193.30	190.20
395	192.70	191.00	189.40
2392	196.10	191.40	192.90
2361	194.50	196.20	192.10
3004	193.43	194.90	193.10
3443	199.00	195.70	192.30
1011	196.90	194.10	195.30
1049	196.50	197.50	193.90
900	206.10	203.30	202.70
3337	196.30	195.10	193.90
3368	194.90	194.90	192.00
3040	192.70	195.30	193.80
3046	200.80	201.60	200.60
3010	205.50	204.70	204.90
TOTAL	2756.53	2749.00	2727.10
AVERAGE	196.90	196.36	194.79

ITEM NUMBER	INDIVIDUAL TEST MEASUREMENTS				
	165.000	182.517	200.033	217.550	
2164.	M	5	34		
395.	M	5	3		
2392.	M	4	5		
2361.	M	5	3		
3004.	M	53	4		
3423.	M	5	4	3	
1011.	M	5	45	3	
1048.	M	5	34		
900.	M	5	4	3	
3337.	M	5	4	3	
3369.	M	5	4	3	
3040.	M	35	4		
3044.	M		54		
3010.	M		53		

NOTE: 1) MISSING NUMBERS INDICATE MEASUREMENTS ALMOST EQUAL IN VALUE.
CHECK DATA (ACCORDING TO ITEM NUMBER) FOR EXACT VALUES.
2) AN ASTERISK (*) INDICATES A VALUE OUT OF LIMITS.

FIGURE 4-11:

Individual Measurements Chart for Example 3

be looked at due to the difference between the average values for each position and the specification minimum. If this value is changed, changes in the overall specifications of the item might result.

"In control" control charts can be used to verify there are few (or no) assignable causes for a test result that may approach or slightly exceed a control limit. This can eliminate labor hours required to change settings, tools, etc.

While there are other possible uses of the quality control charts, they are too numerous to completely detail. Reference to the various publications listed as references to this report may indicate even more uses.

Chapter 5 presents the conclusions derived from this evaluation and some recommendations for further research.

CHAPTER 5

SUMMARY, CONCLUSIONS, AND RECOMMENDATIONS

It is in [the] rather uneasy balance between customer desires for perfection and manufacturer's desire to minimize cost that quality control operates (31:8).

Summary and Conclusions

The quality control system proposed by this report provides a viable means of monitoring the quality of vendor product received by AiResearch and providing useful, statistically sound data for use in managerial decisions concerning vendor reliability and testing sufficiency. In this way, the cost of testing may be reduced as may the cost of the product and/or it may simply precipitate better relations with the vendor.

Likewise, the computer programs designed in support of this QC system provide quality control charts and statistical analysis of testing performed by both the vendor and AiResearch and may be utilized to analyze any typical quality control data. The programs possess both the flexibility and the efficiency to apply to any quality control analysis and can present it in a format understandable to either the statistically experienced or the inexperienced user.

The study of the quality control process at AiResearch, both preliminary to and during development of the proposed system, highlighted some shortcomings in the existing quality control program; most notably, the lack of a summary of testing information from the CERT's and CMR's and the reliance on intuitive evaluations of these results for acceptance/rejection of material. The computer files designed for the system, and use of the proposed system should alleviate both of these problems. Initially, educating the inexperienced users may require some investment in time and money, but not unreasonable amounts. It should be recovered in a very short period.

The data chosen for testing of the programs did not exhibit the properties of a process in-control, but this was not necessary. It provided better indications of the accuracy and flexibility of the programs, however, than would "canned" data that displayed "in-control" situations. It is probably typical of data that a user would encounter in the workplace. While cost considerations were not covered in depth, it's obvious that if a process was shown to be "in-control" and there was no statistical difference in the means (or a constant difference) then testing of some positions could be eliminated. Of course, this would reduce the combined \$1.4 million annual testing costs (32:1) of AiResearch and the vendors and theoretically, the cost of engines. Another benefit might be the establishment of a vendor

certification process that would allow vendors of particular parts with processes "in-control" for an appropriate period of time to have their parts tested less frequently. This would also result in savings. In summary, the data used, in particular part No. 3072112, had insufficient data to accomplish this. The other sample case, while showing good control and meeting, in general, the specifications, presented a discrepancy between mean values, at least in the ultimate yield testing and trends in the testing that disqualified it also. This indicates, however, that the charting and analysis programs are capable of identifying these variations.

In gathering the data and developing the system, there were assumptions made to fit the specific situation and to provide simpler, yet statistically accurate solutions for the benefit of understanding by inexperienced users. While most of these were explained and justified, all are reasonable and required for solution.

The system provides the user with the capability to set acceptance levels for the statistical testing, to select and input different control limits, specifications, etc., to provide solutions to an infinite number of quality control problems, and to choose the ANOVA approach or the control chart approach.

This system, while designed for the situation at AiResearch could be adopted for use by anyone with quality

control situations either requiring or desiring a computerized approach to the control of quality. It is easily modifiable to fit any situation and is compatible with any processing system having FORTRAN IV capability.

Recommendations

Development of the quality control system as a solution to this study indicated a number of areas where improvements could be made to provide better and/or easier analysis.

First, redesign of the AiResearch test result form (CMR) to provide a better organized presentation of the data would allow a more rapid and complete analysis of the data. As an addendum, it would perhaps be more efficient to input the results directly through an on-site terminal (preferable) or a daily punched card input versus filing the CMR and extracting this data later. This approach could streamline and improve data collection.

An expansion of the data file format from that described in this report would be of benefit. Inclusion of the testing date, heat number, and results of additional tests run on a sample of material in one part No. file might be more logical and would require only minor format changes in order to be analyzed by use of the computer programs. This would allow a better chronological view of the process, and could be used instead of part number, test item number, and type of test to store the test data.

Also, application of MIL-STD-414²⁵ should be investigated for setting up of sampling plans. While the ASTM STP 15D²⁶ might provide a less costly, faster setting up of destructive testing plans, the MIL-STD recognizes the destructive testing situation and utilizes acceptable quality level (AQL) versus the OC curve. AQL is the quality level of the supplier's process that the consumer would consider to be acceptable as the process average for the purposes of acceptance sampling (9:153). This could conceivably reduce the necessary testing.

After identifying test data that exhibits "in-control" behavior and good equivalence between CERT and CMR data, it will be beneficial to study the flow patterns and analysis of variance results. It may be possible to eliminate testing at a particular location if it could be determined that the results of testing at a location were (statistically) always less or greater than that at another location. This could reduce testing costs and costs overall.

If testing of means and variances indicates equality between vendor and company testing, company and/or vendor testing could be reduced. If not, as in the test parts

²⁵MIL-STD-414, "Sampling Procedures and Tables for Inspection by Variables of Percent Defective" (21:57-70).

²⁶ASTM STP 15D, American Society for Testing and Materials, "Manual on Presentation of Data and Control Chart Analysis" (1:71-146).

investigated in this report, the same level of testing should be retained and causes investigated. Such an approach, reminiscent of the MIL-STD-414 approach, could benefit not only in reduced cost, but better company vendor relations.

Modifying the plotting subroutine to draw connecting lines between the points would make trends easier to see. Also, if and when sufficient data becomes available, a histogram of the test data values would help to identify the underlying distribution.

As part of the vendor certification process, in the situation where a part is being supplied by more than one vendor, using the programs to indicate which vendor is producing the higher quality part can produce cost reductions by buying more from that producer resulting in possible lower cost per item, or by assigning a higher rating of reliability and/or reducing required testing level.

Finally, adapting the programs and quality control system to the new generation personal and business computers might allow a wider application of the system throughout the AiResearch Manufacturing Company, resulting in a better product at a lower cost--the goal of quality control.

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APPENDICES

APPENDIX A

APPENDIX A

USING THE QCC*PROGRAMS--

A USER'S MANUAL

Introduction

The QCC*Programs were designed to complement, in particular, the quality control system designed for the AiResearch Manufacturing Company evaluation of casting and forging acceptance testing. They have sufficient flexibility, however, to be applied to any problem requiring quality control charts and/or an analysis of data, so long as proper care is exercised in the application. The programs are written in FORTRAN IV, and while an extensive knowledge of this language is not required for using them, any modifications do require it, and should only be attempted by those who are intimately familiar with the program.

The programs produce $\bar{X}$ - and R charts for grouped data, plot the individual values of the grouped data, provide analysis of variance and other statistics for grouped data, will group individual measurement data and produce grouped and individual measurement control charts for this data, and can provide statistics for testing the means of paired data groups.

Data Files

Data can be stored in any standard format; those shown here are used for illustration purposes only. The data must, however, be stored in a particular order to gain the desired result.

For the main program and subroutines

The first two lines or cards (an 80-column card; means the same as line in this manual) provide 72 spaces each to identify the contents of the file. The first line can be used to identify the type of information, dates the file covers, manufacturer, etc. and the second can identify the particular item with, for instance, a part number or description, etc.

The third line contains five values used in the program and are written in the following form.

```

NG          N          ISKIP      INLIM      IPLOT
III(no space)II(no space)II(no space)II(no space)II: FORMAT(I3,4I2)
I3          I2          I2          I2          I2

```

NG = Number of groups (MAX = 400)

N = Number of data points in each group (MAX 10)

= 0 = Program stops

ISKIP = Means of suppressing printing of means and ranges

= 0 = normal condition

> 0 = printing of means and ranges suppressed

INLIM = Means of suppressing use of calculated means and
ranges

= 0 = normal condition

> 0 = use of calculated means and ranges suppressed;
user must supply them; see final card description

IPLOT = Means of suppressing printing of the plot of
individual values of grouped data ($N > 1$)

= 0 = Normal condition

= 1 = no plot of individual values will be produced.

NOTE: If this card is blank, processing stops.

The fourth card states the format the data in the particular file is stored in. There are 72 available spaces here to describe this format. The suggested input for the card is:

FORMAT(I5,NF10.2) N(maximum) = 10

The I5 spaces at the beginning of each data group can be used to identify it with, for instance, a part number, date, etc. The design of the control charts allows only 5 characters to be used for this.

The fifth card contains the format for reading the labels that are to be applied to each N, if $N > 1$. For example, the card might read:

FORMAT(4A4) (if $N = 4$)

and the sixth card, containing the labels applying to the individual N might read

POS3POS4POS5POS6

Thus for N_1 the label would be POS3 (corresponding to the position a sample was taken from), the N_2 label would be POS4, etc. The seventh card contains the minimum acceptable value for the data in the file in FORMAT(F10.3). If the card is blank, the program will consider F as a zero. The eighth card contains the first set of data in the format specified in card 4. For example,

1112ssl32.5ssssssl33.7sssssl32.9sssssl33.15s

is the data for part no. 1112 in the example format specified for card 4. NOTE: If this card is blank, it will be included in the data and plotting computations!!!

The final card of the data set will be the values for control chart means and limits, if the user has specified INLIM>0 in the format (6F10.0). For our example, we might know the characteristics of the population being sampled and wish to put in the following:

0ssssssssl0.0ssssssl22.0ssssssl15.0sssssl35.0sssssl55.0

This option normally won't be used, unless a large historical bank of data is available.

In summary, then, the data file should consist of the following:

CARD DESCRIPTION

- 1 72 spaces, FORMAT (18A4), for data identification
- 2 72 spaces, FORMAT (18A4), for data identification
- 3 FORMAT (I3,4I2) for specification of NG, N, ISKIP, INLIM, and IPLOT values

- 4 User-selected FORMAT for data--first 5 spaces formatted "I5"
- 5 User-selected FORMAT for labels to apply to each "N"
- 6 User-selected labels in FORMAT of card 5
- 7 FORMAT (F10.3) for value of minimum specification value
- 8 First data set in FORMAT of card 4
- .
- .
- .
- LAST FORMAT (6F10.0)-specification of range lower control limit (BCL), mean range (R $\bar{B}$ AR), range upper control limit (UCL), $\bar{X}$ lower control limit (BCLL), $\bar{X}$ (X $\bar{B}$ AR) and $\bar{X}$ upper control limit (UCLL) if INLIM = 01 in card 3.

For the TSTAR Program

The first card in the program contains the number of data pairs (NG:MAX=400) and the value to be used in investigating the difference between the paired data (DMU) explained below.

The second card in the program provides 28 spaces and the third 24 spaces for data identification. The program, as it will be presented below, is set up to handle these two cards as a date (period of testing) on the second card and a part number on the third.

The fourth card is the first data card. Data is written in FORMAT (I5, 2F10.3) with the first 5 integer spaces used to identify the paired data and the other 20 (2 sets of 10 spaces) for the two values of the paired data). Any zero values on this card will be used in the calculations.

In summary, the data file for the TSTAR program should appear as follows:

CARD DESCRIPTION

- 1 FORMAT (I4,F10.2) for specification of NG (number of groups/pairs), DMU (difference between means to be tested)
- 2 FORMAT (7A4); 28 spaces for data identification
- 3 FORMAT (24A1); 24 spaces for data identification
- 4 First data card in FORMAT (I5, 2F 10.0)

Program Operation

Control Chart Program

The control chart program is the director program for moving data through the appropriate subroutines to attain the user's desired result. This program is capable of directing analysis of variance and production of $\bar{X}$ - and R-charts for grouped data (more than one data point, per group; $N > 1$) with control limits of 3-, 2- and 1-sigma. It will also group individual data (only one data point per group) into groups of size 3 (or another value if the program is modified). These grouped individual data points are then used to

calculate control limits for 3- and 2-sigma $\bar{X}$ and R control charts and a control chart for the individual data is produced with the $\bar{X}$ (3-sigma) control limits. Finally, the program can produce a plot of all the values in the $N \geq 1$ data situation in relation to their part number (or identification) along with the minimum specified value from the data file (card 7). This information can then be used to establish the need for further testing, verify a controlled situation (process, etc.) or of the other decisions that can be made using a control chart.

This program and the subroutines will automatically perform these operations when the data file is set up as described and the limits specified are adhered to. The only exception is in the event the input and output mediums are not "5" and "6," respectively, designating punch card input and printer output. These may differ in the user's system. In this event, lines 30 and 31 of the main program (LR [reader] and LW [writer]) must be changed to the proper values. Modifications to the program and subroutines are described in the section titled "Modification," below.

TSTAR Program

This program is designed to calculate the "T" statistic for paired, dependent data points that are normally distributed and will also yield the differences between the pairs for use in the non-parametric Wilcoxon paired "T" test. It can be used to determine if testing of

the same material by two different entities is producing equivalent results as well as if it is separated by a constant value (through specification of DMU, the difference between the two to be investigated). It will yield not only the difference between each data pair, but also the difference squared (for calculating standard deviation), the totals of these, the sample variance and standard deviation, the average difference of all pairs, the degrees of freedom of the "T" statistic and the "T" statistic itself.

This program will automatically perform the operations just described as long as the procedures outlined are adhered to in setting up the data files. The only exception, as in the main program and subroutines, is if the input and output codes are not "5" and "6," respectively. All READ and WRITE statements will have to be changed to reflect the proper values (lines 11, 42-45, 47, 52, 54 & 59-60). The remainder of this manual will cover possibilities for tailoring the programs to the requirements of any specific situation or organization.

Modification

NOTE: THE FOLLOWING PARAGRAPHS ARE FOR MODIFICATION ONLY--
THEY ARE NOT REQUIRED TO "RUN" THE PROGRAM!

Main Program

The main program (see printout in Appendix D) contains data tables, constants, FORMATS, and dimensions that can be

changed to accomodate most situations requiring quality control charts.

The first of these is the data table for the constant values for calculating the control limits. It could be expanded to include values for N (number of samples in a group) >10 in accordance with the values cited in the literature. Also, the table might be changed to use the sample standard deviation constants if the program was modified to calculate and use this in determining control limits.

If the values of $N>10$ and/or NG (number of groups) >400 , the dimensions of $X()$, $NSER()$, $HOLD()$ in line 8, $LABEL()$ in line 10, and all in line 12 might have to be changed, along with many of the "DO" instructions, etc. Extreme care will have to be taken to re-dimension all appropriate items.

If the method of calculating the control limits is to be changed, lines 94 through 112 should be looked at closely. In most cases, it will be more advantageous to simply input the desired values utilizing the $INLIM>0$ option in the data file as described previously, versus a major program change.

Throughout the main program and subroutines, comment statements have been included to define variables, highlight important areas, and to clarify what operation is being performed.

Subroutine Charts

This subroutine, while designed to produce $\bar{X}$ - and range charts could conceivably be used to produce other control charts. As can be seen in line 1, it uses values for limits, etc. that come from the main program so all that would be required is changing the titles to be printed at the top of the charts; line 105. Line 21, by the way, could also be changed to reflect a better description of the user's product.

As in the main program, increasing N greater than 10 and/or NG greater than 400 would require changes, but only in the DIMENSION line (11 & 12). KALER(), KALEX(), RANGE(), SUBAR() and M() would have to be increased to the maximum NG+3. The value +3 is used to allow for printing of the control limits and mean value in addition to the data points. If another value, such as a warning limit or upper specification limit, is to be used, these dimensions would have to be increased 1 for each additional value. Also, in this case, an additional figure to be used for plotting would have to be included in the DATA statement along with additional statements in the subroutine to allow their inclusion. Variables would have to be calculated or read in the main program and included in the COMMON/PLOT1/ statements so they would move between the program and subroutine CHARTS. Reference to lines 37 through 74 of CHARTS will aid in accomplishing such a modification. Note:

TMIN = specified minimum value read into the main
program

M(I) = the "location" used to put this value in the
chart array

IM = M = the "value" of the location M(I) that is
printed on the chart

Subroutine SORTS

The only value that might be changed is the dimension
of CH(), line 2, if max NG greater than 400 is used and/or
there are additional points plotted in CHARTS.

Subroutine SCALE

No changes necessary.

Subroutine ASTATS

In the event a maximum NG greater than 400 is
anticipated, or there are additional points plotted, the
dimensions in line 10 would have to be increased to reflect
the change.

This subroutine could, theoretically, be used to
determine the values for calculating limits if another
estimate of variation were to be used, such as sample
standard deviation, etc. Such a calculation could be
inserted in place of the calculations for range in lines 53
through 62.

Subroutine VALPLT

This subroutine plots the individual values for data
groups with more than 1 value (i.e., $N > 1$). It is the

author's opinion that more than 10 values ($N > 10$) could make the plot crowded and meaningless, but if conditions warrant using this chart with $N > 10$ (for instance, searching for one or two values out of a group of supposedly identical measurements), the subroutine could be so modified. It would probably be best in such a situation to convert the subroutine into a short program, although not necessary.

If N greater than 10 is to be utilized, then changes similar to those above are necessary. The dimensions of `MON()` and `NAME()`, line 12, would be increased to $(N+1)$ and $(N+5)$, respectively and an identifying label for each N would have to be included in the `DATA` statement, line 13. If the situation being investigated was searching for unequal values out of supposedly equal values, only those labels for the unequal values and one (the largest) of the equal values would be on the plot.

Finally, the `FORMAT` statements, lines 66-78, might require changes for labeling the chart.

Subroutine ANALVR

This subroutine performs the one- and two-way analyses of variance for grouped data ($N > 1$) only. The only changes necessary would be to re-dimension `TRT()`, `TRM()`, `SSPOS()`, `DIFSQR()` and `TSDEV()` if N greater than 10 is desired and `BLK()` if NG greater than 400 is anticipated.

It also may be desired to have different statistical values used in the calculations displayed. This is easily

done by including the appropriate WRITE and FORMAT statements at the end of the subroutine. The WRITE statement must be placed in the deck prior to the return statement, and the FORMAT prior to the END.

TSTAR Program

This program, being rather specialized, requires, and is tolerant of, very little modification. The only values that could be changed are if NG greater than 400 is to be used, requiring DFF() and DIF2() of line 7 to be redimensioned and the length of the identification variables PNUM and DATE, requiring their redimensioning also. Note that if this is done, the FORMATS for titling the results table, lines 77 through 81, would have to be modified.

Conclusion

While modifications to the programs and subroutines require forethought and a knowledge of FORTRAN IV, they can be accomplished. The results of such changes could help save money, and improve the quality of a product or service. It may be that the programs you develop are more comprehensive than the author ever anticipated.

APPENDIX B

FORM 773a-69

AIRSEARCH MANUFACTURING COMPANY IN REPLY REFER TO:
A DIVISION OF THE GARRETT CORPORATION 15-10340106
PHOENIX, ARIZONA

OFFICE MEMO

DATE: October 17, 1978

TO: C. White DEPT. 84-80 COPIES TO: Distribution
FROM: R. Wagner DEPT. 93-391 EXT. 4066
SUBJECT: Critical Parts List &
Applicable Specifications

After several meetings, the subject of which was the analysis of vendor generated and CMR data, it was the consensus of Materials Engineering, Quality Assurance and Manufacturing Engineering personnel that the use of control charts would be the best method. In order to initiate the program it was requested that Materials Applications prepare a list of the most critical components and the specifications which control them, such that the data could be collected and analyzed and thus control charts produced.

It is the goal to put the control charts into the EMS specification.

Tabulated below is a parts list for disks and wheels presently used on the ATF3-6, TFE731-2, -3, TPE331, GTC660 and TSCP700 engines.

<u>Part Name</u>	<u>Part No.</u>	<u>Material</u>	<u>Substantiation Testing Instructions (STI) Requirements</u>	<u>Metallurgical Control Specification</u>
<u>ATF3-6</u>				
Fan	3001249	Ti-6-4	5001 Cl.-1	EMS52458
Fan	3002539	Ti-6-4	5001 Cl.-1	EMS52458
1st Stg. Comp.	3002191	Ti-6-4	5001 Cl.-1	EMS52458
2nd Stg. Comp.	3002192	Ti-6-4	5001 Cl.-1	EMS52458
3rd Stg. Comp.	3002193	Ti-6-4	5001 Cl.-1	EMS52458
4th Stg. Comp.	3002194	Ti-6-4	5001 Cl.-1	EMS52458
5th Stg. Comp.	3002145	Ti-6-4	5001 Cl.-1	EMS52458
HP Comp.	3002128	Ti-6-2-4-2Si	5001 Cl.-1	AF5395
HP Turbine	3001919	Astroloy	5001 Cl.-2	EMS52433
2nd Stg. Turbine	3001281	Waspaloy	5001 Cl.-2	EMS52449
3rd Stg. Turbine	3001282	Waspaloy	5001 Cl.-2	EMS52449
4th Stg. Turbine	3001283	Waspaloy	5001 Cl.-2	EMS52449
5th Stg. Turbine	3002095	Super Waspaloy	5001 Cl.-1	EMS52434
6th Stg. Turbine	3002097	Super Waspaloy	5001 Cl.-1	EMS52434
<u>TFE731-2, -3</u>				
Fan	3072162	Ti-6-4	5001 Cl.-2	EMS52458
1st Stg. Comp.	3072190	Ti-6-4	5001 Cl.-1	AF5395
2nd Stg. Comp.	3072191	Ti-6-4	5001 Cl.-1	AF5395
3rd Stg. Comp.	3072192	Ti-6-4	5001 Cl.-1	AF5395

TO: C. White

15-10340106

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<u>Part Name</u>	<u>Part No.</u>	<u>Material</u>	<u>Substantiation Testing Instruct. (STI) Requirements</u>	<u>Metallurgical Control Specification</u>
<u>TFE731-2, -3</u>				
4th Stg. Comp.	3072193	Ti-6-4	5001 Cl.-1	AF5395
HP Comp.	3072639	Ti-6-2-4-2Si	5001 Cl.-1	AF5395
	3070274			
HP Turbine	3072112	Astroloy	5001 Cl.-1or2	EMS52476
HP Turbine	3072316	Waspaloy	5001 Cl.-2	EMS52449
1st Stg. Turbine	3072070	Waspaloy	5001 Cl.-2	EMS52449
1st Stg. Turbine	3072351	Waspaloy	5001 Cl.-2	EMS52449
2nd Stg. Turbine	3072069	Waspaloy	5001 Cl.-2	EMS52449
3rd Stg. Turbine	3072068	Waspaloy	5001 Cl.-2	EMS52449
<u>TPE331</u>				
1st Stg. Comp.	868219	Ti-6-4	5001	-
1st Stg. Comp.	896223	Ti-6-4	No SCS	-
2nd Stg. Comp.	868220	Ti-6-4	5001	-
1st Stg. Turbine	867569	IN-100	5000	-
	(867571-25)			
1st Stg. Turbine	3101520	Waspaloy	5001	EMS52449
2nd Stg. Turbine	868272	IN-100	5000	EMS52466
2nd Stg. Turbine	3101514	IN-100	5000	EMS52466
3rd Stg. Turbine	867571-11	IN-713LC	5000	AF5358
3rd Stg. Turbine	895539	IN-713LC	5000	AF5358
3rd Stg. Turbine	868630	IN-713LC	5000	AF5358
3rd Stg. Turbine	3101516	Waspaloy	5001	EMS52449
3rd Stg. Turbine	3101660	IN-713LC	5000	AF5358
<u>GTCP660</u>				
1st Stg. Comp.	977328	Ti-6-4	5001 Cl.-10	AF5395
2nd Stg. Comp.	968819	Ti-6-4	5001 Cl.-10	AF5395
3rd Stg. Comp.	968822	Ti-6-4	5001 Cl.-10	AF5395
4th Stg. Comp.	968825	Ti-6-4	5001 Cl.-10	AF5395
1st Stg. Turbine	892812	Waspaloy	5001 Cl.-2	EMS52449
2nd Stg. Turbine	892813	Waspaloy	5001 Cl.-2	EMS52449
<u>TSCP700</u>				
1st Stg. Comp.	969600	Ti-6-4	5001 Cl.-10	AF5395
1st Stg. Comp.	3606429	Ti-6-4	5001 Cl.-10	AF5395
2nd Stg. Comp.	977201	Ti-6-4	5001 Cl.-9or10	AF5395
3rd Stg. Comp.	977200	Ti-6-4	5001 Cl.-9or10	AF5395
HP Comp.	3601186	Ti-6-4	5001 Cl.-9	AF5395
HP Turbine	977156	Waspaloy	5001 Cl.-2	EMS52449
1st Stg. Turbine	969562	Waspaloy	5001 Cl.-5	EMS52449
2nd Stg. Turbine	969561	Waspaloy	5001 Cl.-2	EMS52449

669-1

669-2

MATERIAL SPECIFICATION		CODE IDENT NO. 99193	SPECIFICATION NO. ENS55389	REV LTR E								
1. APPLICATION 1.1 This specification is applicable to forging stock and forgings used primarily for turbine disks at operating temperatures up to 1700°F. 2. APPLICABLE DOCUMENTS 2.1 The following documents form a part of this specification to the extent referenced herein. 2.1.1 Government Publications - Federal Test Method Standard No. 151 - Metals; Test Methods 2.1.2 Aerospace Material Specifications AMS 2261 - Tolerances, Nickel, Nickel Base, and Cobalt Base Alloy Bars and Forging Stock AMS 2269 - Chemical Check Analysis Limits, Wrought Nickel and Nickel Base Alloys AMS 2808 - Identification, Forgings 2.1.3 American Society for Testing and Materials Specifications ASTM E 8 - Tension Testing of Metallic Materials ASTM E 10 - Brinell Hardness of Metallic Materials ASTM E 112 - Estimating Average Grain Size of Metals ASTM E 139 - Conducting Creep and Time-for-Rupture Tension Tests of Materials ASTM E 354 - Chemical Analysis of High-Temperature, Electrical, Magnetic, and Other Similar Iron, Nickel, and Cobalt-Base Alloys 3. TECHNICAL REQUIREMENTS 3.1 Chemical composition shall conform to the following percentages by weight, determined by wet chemical methods in accordance with ASTM E 354, or by spectrographic methods in accordance with Federal Test Method Standard No. 151, Method 112:		Carbon 0.03 - 0.09 Manganese 0.15 max. Sulfur 0.015 max. Phosphorus 0.015 max. Silicon 0.10 max. Cobalt 16.0 - 18.0 Chromium 14.0 - 16.0 Molybdenum 4.5 - 5.5 Titanium 3.25 - 3.75 Aluminum 3.75 - 4.25 Boron 0.02 - 0.03 Iron 0.50 max. Copper 0.10 max. Zirconium 0.05 max. Nickel Remainder 3.1.1 Variations shall conform to the requirements of AMS 2269. 3.2 Condition 3.2.1 Forgings - Forgings shall be in the following condition unless otherwise specified: Condition A - solution- and stabilization-heat-treated; Condition B - stabilization-heat-treated only; Condition C - solution-heat-treated and stabilization-heat-treated only. 3.2.2 Forging Stock - As ordered by the forging manufacturer. 3.3 Forgings (Condition A) - Forgings requiring maximum elevated-temperature stress-rupture properties. 3.3.1 The forging shall be solution-heat-treated at a selected temperature and time, and cooled at a rate to obtain the specified properties. 3.3.2 Stabilize at 1975°F ±25 for 4 hours and cool at a rate equivalent to a rapid air-cool. 3.3.3 Precipitation heat treat at 1550°F ±25 for 4 hours and air-cool. Heat to 1400°F for 16 hours and air-cool. 3.3.4 Properties after Precipitation Heat Treatment - Test specimens shall be taken from the locations shown in Figure 1. 3.3.4.1 Tensile test specimens cut from the forging and tested at room temperature shall conform to the following requirements: <table border="0"> <tr> <td>Yield strength (0.2 percent offset), psi</td> <td>130,000 min</td> </tr> <tr> <td>Ultimate tensile strength, psi</td> <td>170,000 min</td> </tr> <tr> <td>Elongation, percent in 4D</td> <td>6.0 min</td> </tr> <tr> <td>Reduction of area, percent</td> <td>6.0 min</td> </tr> </table>			Yield strength (0.2 percent offset), psi	130,000 min	Ultimate tensile strength, psi	170,000 min	Elongation, percent in 4D	6.0 min	Reduction of area, percent	6.0 min
Yield strength (0.2 percent offset), psi	130,000 min											
Ultimate tensile strength, psi	170,000 min											
Elongation, percent in 4D	6.0 min											
Reduction of area, percent	6.0 min											

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669-4

MATERIAL SPECIFICATION	CODE IDENT NO 99193	SPECIFICATION NO. ZMS55389	REV LTR E																
3.3.4.2 Stress-rupture specimens cut from the forgings shall be maintained at 1800°F ±5, under a continuously applied axial stress of 20,000 psi, and shall not rupture in less than 30 hours. The test shall be continued to rupture and the elongation, measured at room temperature, shall not be less than 5 percent in 4D.	3.4.3.5 Stabilization-heat-treated forgings shall have a substantially uniform grain size of ASTM 3 or finer, with occasional grains as large as 1 permissible, as determined by comparison of a polished and etched specimen with the chart in ASTM E 112. When a dispute over grain size results, the Heyn's intercept method shall be used.																		
3.3.4.3 The Brinell hardness shall be 300 to 400.	3.5 Forgings (Condition C) - Forgings requiring maximum tensile and creep properties up to 1500°F.																		
3.3.4.4 Solution-heat-treated forgings shall have a uniform grain size of ASTM 2 or finer, with occasional grains as large as 0 permissible, as determined by comparison of a polished and etched specimen with the chart in ASTM E 112.	3.5.1 Solution heat treat at a temperature within the range 1975-2075°F, hold at the selected temperature ±15°F for four hours, and quench into molten salt bath at 600°F ±10, stabilize at bath temperature, and air cool. Parts may be oil quenched if configuration permits.																		
3.4 Forgings (Condition B) - Forgings with maximum operating temperature of 1500°F, requiring maximum tensile properties.	3.5.2 Stabilize at 1600°F ±15 for eight hours, and cool to room temperature at a rate equivalent to air-cool; heat to 1800°F ±15, hold at heat for four hours, and cool at a rate equivalent to air-cool.																		
3.4.1 The forging shall be stabilized at 1975°F ±25 for 4 hours and cooled at a minimum rate equivalent to air-cooling.	3.5.3 Precipitation heat treat at 1200°F ±25 for 24 hours, and air-cool to room temperature; heat to 1400°F ±25, hold at heat for eight hours, and air-cool.																		
3.4.2 Precipitation heat treat at 1550°F ±25 for 4 hours and air-cool. Heat at 1400°F ±25 for 16 hours and air-cool.	3.5.4 Properties after Precipitation Heat Treatment - Test specimen location shall be as specified.																		
3.4.3 Properties after Precipitation Heat Treatment - Test specimens shall be taken from the locations shown in Figure 1.	3.5.4.1 Tensile test specimens cut from the forging and tested at room temperature shall conform to the following requirements:																		
<table border="0"> <tr> <td>Yield strength (0.2 percent offset), psi</td> <td>140,000 min</td> </tr> <tr> <td>Ultimate tensile strength, psi</td> <td>195,000 min</td> </tr> <tr> <td>Elongation, percent in 4D</td> <td>10.0 min</td> </tr> <tr> <td>Reduction of area, percent</td> <td>10.0 min</td> </tr> </table>	Yield strength (0.2 percent offset), psi	140,000 min	Ultimate tensile strength, psi	195,000 min	Elongation, percent in 4D	10.0 min	Reduction of area, percent	10.0 min	<table border="0"> <tr> <td>Yield strength (0.2 percent offset), psi</td> <td>140,000 min</td> </tr> <tr> <td>Ultimate tensile strength, psi</td> <td>195,000 min</td> </tr> <tr> <td>Elongation, percent in 4D</td> <td>16 min</td> </tr> <tr> <td>Reduction of area, percent</td> <td>18 min</td> </tr> </table>		Yield strength (0.2 percent offset), psi	140,000 min	Ultimate tensile strength, psi	195,000 min	Elongation, percent in 4D	16 min	Reduction of area, percent	18 min	
Yield strength (0.2 percent offset), psi	140,000 min																		
Ultimate tensile strength, psi	195,000 min																		
Elongation, percent in 4D	10.0 min																		
Reduction of area, percent	10.0 min																		
Yield strength (0.2 percent offset), psi	140,000 min																		
Ultimate tensile strength, psi	195,000 min																		
Elongation, percent in 4D	16 min																		
Reduction of area, percent	18 min																		
3.4.3.2 Stress-rupture specimens cut from the forging shall be maintained at 1400°F ±5 under a continuously applied axial stress of 85,000 psi, and shall not rupture in less than 23 hours. The test shall be continued to rupture and the elongation, measured at room temperature, shall not be less than 3 percent in 4D.	3.5.4.2 Tensile test specimens cut from the forging and tested at 1400°F ±10 shall conform to the following requirements:																		
3.4.3.3 Stress-rupture specimens cut from the forging shall be maintained at 1800°F ±5 under a continuously applied axial stress of 18,000 psi until rupture. The elongation measured at room temperature and stress-rupture life shall be reported.	<table border="0"> <tr> <td>Yield strength (0.2 percent offset), psi</td> <td>125,000 min</td> </tr> <tr> <td>Ultimate tensile strength, psi</td> <td>150,000 min</td> </tr> <tr> <td>Elongation, percent in 4D</td> <td>20 min</td> </tr> <tr> <td>Reduction of area, percent</td> <td>30 min</td> </tr> </table>		Yield strength (0.2 percent offset), psi	125,000 min	Ultimate tensile strength, psi	150,000 min	Elongation, percent in 4D	20 min	Reduction of area, percent	30 min									
Yield strength (0.2 percent offset), psi	125,000 min																		
Ultimate tensile strength, psi	150,000 min																		
Elongation, percent in 4D	20 min																		
Reduction of area, percent	30 min																		
3.4.3.4 The Brinell hardness shall be 300 to 400.																			

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649-3

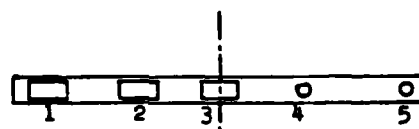
649-6

MATERIAL SPECIFICATION		CODE IDENT NO 99193	SPECIFICATION NO. EN555389	REV LTR E
3.5.4.3 Stress-rupture specimens cut from the forgings shall be maintained at 1400°F ±5, under a continuously applied axial stress of 85,000 psi, and shall not rupture in less than 30 hours. The test shall be continued to rupture and the elongation, measured at room temperature, shall not be less than 17 percent in 4D. 3.5.4.4 A smooth specimen shall be maintained at 1300°F ±5 under continuously applied stress of 74,000 psi. Time to 0.1 percent plastic deformation shall average not less than 150 hours, with no value below 110 hours. Creep measurements shall be taken until 0.1 percent plastic extension is attained. Gauge dimensions of specimens and techniques used to measure creep shall be as agreed upon by purchaser and supplier. 3.5.4.5 The Brinell hardness shall be 313 to 403. 3.5.4.6 Fully heat-treated forgings shall have a substantially uniform grain size of ASTM 4 or finer, with occasional grains as large as 3 permissible, as determined by comparison of a polished and etched specimen with the chart in ASTM E 112. When a dispute over grain size results, the Heyn's intercept method shall be used. 3.6 Forging Stock 3.6.1 When a sample of forging stock is forged to a test coupon and heat treated as in Paragraph 3.3, 3.4 or 3.5, test specimens taken from the heat-treated coupon shall have properties as specified in Paragraphs 3.3, 3.4 or 3.5, as applicable. 3.6.2 If test specimens taken from the forging stock after heat treatment conform to the requirements of Para. 3.3, 3.4 or 3.5, as applicable, the tests shall be accepted as equivalent to the tests of the forged coupon of 3.6.1. Neither of these tests is required in routine inspection. 4. PROCESS CONTROL 4.1 Forgings shall be supplied decaled unless otherwise specified. 5. INSPECTION 5.1 Tolerances shall be in accordance with AMS 2261. 5.2 Tensile testing shall be performed in accordance with ASTM E 8. 5.3 Stress-rupture testing shall be performed in accordance with ASTM E 139. 5.4 Hardness shall be determined in accordance with ASTM E 10.		6 IDENTIFICATION 6.1 Forgings shall be identified in accordance with AMS 2808. 6.2 The forging serial number shall be traceable to the billet, position in the billet, forging lot identification, and mill heat identification. 7. APPROVAL AND PROCUREMENT 7.1 If necessary to make any change in equipment, procedures, or techniques after approval is granted, the source (forging or material) making the change shall obtain written permission from AiResearch Materials Engineering and Manufacturing Engineering Casting/Forging Design prior to the first shipment incorporating such a change. 8. REPORTS 8.1 The supplier of forgings shall furnish to AiResearch Receiving Inspection with each shipment a report of chemical composition test results of each heat in the shipment and test results of each size from each heat to determine conformance to the technical requirements of this specification. This report shall include the purchase order number, material specification number and its revision letter, heat number, size, and quantity from each heat. The forging part number and the size of stock used to make the forgings shall also be included. 8.2 The supplier of finished or semifinished parts shall furnish to AiResearch Receiving Inspection with each shipment a report showing the purchase order number, material specification number and its revision letter, name of contractor or other direct supplier of material, part number, and quantity. When material for making parts is produced or purchased by the parts supplier, that supplier shall inspect each lot of material to determine conformance to the requirements of this specification, and shall include in his report a statement that the material conforms, or shall include copies of laboratory test reports showing the results determining conformance. 9. QUALITY CONTROL 9.1 Forging stock shall be produced by vacuum-induction melting or by vacuum-induction melting followed by vacuum-arc remelting. 9.2 Forgings shall have substantially uniform macrostructure and grain flow. 9.3 The product, as received by the purchaser, shall be uniform in quality and condition, sound, and free from foreign materials and from internal and external imperfections detrimental to usage of the product. 9.4 Material not conforming to the requirements of this specification shall be rejected.		

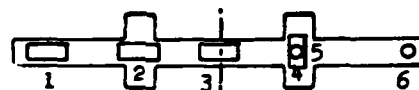
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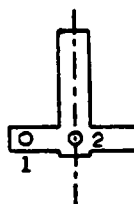
EMS55389
REV. E



A: FLAT DISK CONFIGURATIONS



B: INTEGRAL COUPLING DISK CONFIGURATIONS



C: INTEGRAL SHAFT DISK CONFIGURATIONS

- NOTE: A: DISKS LESS THAN 6 INCHES IN DIAMETER USE ONLY SAMPLES 1, 3 AND 5. STRESS-RUPTURE SAMPLES FROM RIM AREA POSITIONS 1 AND 5, RT TENSILES FROM POSITIONS 2, 3 AND 4.
- B: POSITIONS 1 AND 6 TO BE USED FOR STRESS-RUPTURE, POSITIONS 2,3,4 AND 5 TO BE USED FOR RT TENSILES.
- C: POSITION 1 FOR STRESS-RUPTURE, POSITION 2 FOR RT TENSILE. ON DISK DIAMETERS LARGER THAN 6 INCHES, OTHER TEST LOCATIONS MAY APPLY.

FIGURE 1

TEST SPECIMEN LOCATIONS
FOR FORGED TURBINE DISKS

99-1

99-2

MATERIAL SPECIFICATIONCODE IDENT NO.
99193

SPECIFICATION NO.

EMS52476

REV LTR
C**1. APPLICATION**

1.1 This specification provides metallurgical control procedures and acceptance criteria for forged Astroloy Condition A turbine disks specified with or specified without integrally forged test rings.

1.1.1 Forged components shall be classed as follows:

Class I - Forgings required to have integrally forged test rings.

Class II - Forgings without integrally forged test rings.

1.1.2 If no class is specified, Class I shall apply.

1.2 The following manufacturing procedures and controls are specified:

1.2.1 Fixed-process verification

1.2.2 Forging lot control

1.3 The following inspection procedures and tests are specified:

1.3.1 Nondestructive mechanical-property testing

1.3.2 Destructive mechanical-property testing

1.4 The following terms used in this specification shall have the meaning as defined below:

1.4.1 Forging Lot Definitions

1.4.1.1 Class I - All forgings made consecutively, to the final configuration, from a single master heat, without removal of the dies from the forging equipment.

1.4.1.2 Class II - Less than or equal to 33 forgings, made consecutively, to the final configuration, from a single master heat, without removal of the dies from the forging equipment.

1.4.1.3 A forging lot number is a number assigned to a forging lot.

1.4.2 When one hundred (100) percent inspection is specified, the forging vendor shall perform one tensile test at room temperature on a specimen taken from the integrally forged test ring from each forging in all forging lots.

1.4.2.1 One hundred (100) percent inspection applies only to Class I forgings.

1.4.3 A forging sample is a sample selected at random from a forging lot.

2. APPLICABLE DOCUMENTS

2.1 The following documents form a part of this specification to the extent referenced herein.

2.1.1 Air Research Specifications

EMS55389 Alloy, Corrosion- and Heat-Resistant, Nickel-Base 15 Cr-17 Co-5 Mo-3.5 Ti-4 Al-0.025B (Astroloy and Udmet 700)

EMS52406 Forgings, General

EMS52321 Ultrasonic Inspection

EMS52309 Fluorescent-Penetrant Inspection

2.1.2 American Society for Testing and Materials

E 8-Tension Testing of Metallic Materials

3. TECHNICAL REQUIREMENTS

3.1 All requirements of EMS55389 shall apply except that the minimum mechanical-property requirements shall be as specified herein.

3.2 Forging Identification

3.2.1 Each forging shall be identified by a part number and a forging lot number to provide traceability to starting mill heat number. When specified, each forging shall also be identified by a serial number to provide traceability to starting billet number and position within the billet.

3.3 Condition

3.3.1 Heat-treated in accordance with EMS55389 Condition A unless otherwise specified.

3.3.1.1 Forgings with their test rings intact shall be solution and stabilization heat-treated.

3.4 Mechanical Properties

3.4.1 Test specimens taken from forgings and test rings shall be in the fully heat-treated condition and shall exhibit the minimum properties specified in Table I.

3.5 Fixed Process Verification

3.5.1 The vendor shall establish a fixed process in accordance with EMS52406.

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MATERIAL SPECIFICATIONCODE IDENT NO
99193SPECIFICATION NO.
EMS52476REV LTR
C**3.6 Forging Lot Control****3.6.1 Nondestructive Testing Requirements**

3.6.1.1 A 100-percent inspection shall be performed on all Class I forging lots by the forging vendor until sufficient statistical data is obtained and reversion to a lot sampling method is agreed upon via established procedures.

3.6.1.2 A 100-percent inspection of all Class I forgings shall be accomplished by any new forging vendor until sufficient test data has been obtained to justify a statistical sampling method.

3.6.1.3 A 100-percent inspection shall be accomplished by any forging vendor when there has been an agreed-upon permanent change in the forging process and until sufficient data has been obtained to justify a new sampling method.

3.6.1.4 When the forging vendor has made an inadvertent change in the fixed process during the production of forgings, except as noted, and when approval through AiResearch has been obtained, then 100-percent inspection shall be accomplished for those forgings.

3.6.1.5 If any of the test ring tensile properties are below minimum, two additional test bars from the same test ring shall be tested. If the values of the retests from the test ring exceed the minimum values, the forging is to be accepted. If either of the retests falls below the minimum, that forging shall be rejected.

3.6.2 Destructive Mechanical-Property Testing

3.6.2.1 A forging sample for destructive testing shall also be taken from each production forging lot by the forging vendor.

3.6.2.2 The forging vendor shall perform the destructive testing on test specimens removed from each sample forging, as specified.

3.6.2.3 One-half of each sample forging shall be sent to AiResearch.

4. INSPECTION

4.1 Each forging shall be acid etched and visually inspected in accordance with Appendix I at 4X minimum magnification.

4.2 Each forging shall then be fluorescent-penetrant inspected in accordance with AMS11399, Class 1, using a Group V penetrant.

4.3 When ultrasonic inspection is specified, each forging shall be inspected in accordance with EMS52321, and the appropriate class. The class of inspection shall be determined by the maximum cross-sectional thickness of the forging, as follows:

Thickness (inches)	Class of Inspection
0-1	I
Over 1-2	II
Over 2-3.75	III

4.3.1 For thicknesses over 3.75 inches, consult AiResearch Quality Assurance for alternate methods of inspection.

4.4 All Class I and Class II forging samples shall be tested for mechanical properties.

4.4.1 The vendor shall remove and test the specified integrally forged test ring from each forging.

4.4.1.1 When serialization is required, the test ring shall bear the same serial number as the forging from which it was removed.

4.4.2 Tensile specimens shall be machined and tested in accordance with ASTM E 8.

5. APPROVAL OR PROCUREMENT

5.1 One-half of each sample forging selected from each production lot for destructive mechanical-properties testing shall be forwarded to AiResearch.

5.2 The forging vendor shall store the integrally forged test rings for a period of two years from the date of the test reported, and these rings shall be made available to AiResearch upon request.

6. QUALITY CONTROL

6.1 A test report shall be sent to AiResearch Receiving Inspection with each shipment and shall indicate the forging lot number and quantity represented and, when serialization is required, each serial number represented.

6.2 The test report shall list the results of the destructive lot sample tests and the tensile results from all test rings representing the shipped forgings by lot number and, when serialization is required, by serial number.

6.3 One-half of each sample forging selected for destructive testing shall be shipped prior to or with the first production forging from the lot. A list of serial numbers in the lot shall be submitted with each sample forging, when serialization is required.

6.4 Forgings not conforming to this specification shall be rejected.

MATERIAL SPECIFICATION				CODE IDENT NO. 99193	SPECIFICATION NO. ZMS52476		REV LTR -
TABLE I MECHANICAL PROPERTIES (Minimum)							
Test	Temp (°F)	Stress (psi)	Test Time (hrs)	Ultimate (psi)	Yield 0.2% Offset (psi)	Elongation (% in 4D)	Reduction of Area (%)
Tensile	Room [?]	-	-	170,000	130,000	6 ~~4~~	6
	*1200	-	-	Report	Report	Report	Report
Stress Rupture (Smooth)	1400	85,000	30	-	-	5	-

*Elevated 1200°F temperature tensile test results are to be reported.

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MATERIAL SPECIFICATION		CODE IDENT NO. 99193	SPECIFICATION NO. ZMS52449	REV LTR D
1. APPLICATION 1.1 This specification provides metallurgical control procedures and acceptance criteria for forged Waspaloy turbine components specified with or specified without integrally forged test rings. 1.1.1 Forged components shall be classed as follows: Class I - Forgings required to have integrally forged test rings. Class II - Forgings without integrally forged test rings. 1.1.2 If no class is specified, Class I shall apply. 1.2 The following manufacturing procedures and controls are specified: 1.2.1 Fixed-process verification 1.2.2 Forging lot control 1.3 The following inspection procedures and tests are specified: 1.3.1 Nondestructive mechanical-property testing 1.3.2 Destructive mechanical-property testing 1.4 The following terms used in this specification shall have the meaning as defined below: 1.4.1 Forging Lot Definitions 1.4.1.1 Class I - All forgings made consecutively, to the final configuration, from a single master heat, without removal of the dies from the forging equipment. 1.4.1.2 Class II - Less than or equal to 33 forgings, made consecutively, to the final configuration, from a single master heat, without removal of the dies from the forging equipment. 1.4.1.3 A forging lot number is a number assigned to a forging lot. 1.4.2 One hundred (100) percent inspection requires the forging vendor to perform two tensile tests--one at room temperature and one at 1000°F--on specimens taken from the integrally forged test ring from each forging in all forging lots.		1.4.2.1 One hundred percent inspection applies only to Class I forgings. 1.4.3 A forging sample is a forging selected at random from a forging lot. 2. APPLICABLE DOCUMENTS 2.1 The following documents are a part of this specification to the extent referenced herein. 2.1.1 AiResearch Specifications ZMS55388 Alloy, Corrosion- and Heat-Resistant, Nickel-Base 19.5 Cr-13 Co-4 Mo-1.4 Al Multiple Vacuum Melted Solution Heat-Treated (Waspaloy) ZMS52406 Forgings, General ZMS52321 Ultrasonic Inspection ZMS52309 Fluorescent-Penetrant Inspection MC5014 Marking and Traceability Requirements 3. TECHNICAL REQUIREMENTS 3.1 Forging Identification 3.1.1 Each forging shall be identified by a part number and a forging lot number to provide traceability to starting mill heat number. When specified, each forging shall also be identified by a serial number to provide traceability to starting billet number and position within the billet. 3.2 Condition 3.2.1 Solution heat-treated in accordance with ZMS55388 unless otherwise specified. 3.2.1.1 The forging vendor shall solution heat-treat each forging. 3.2.2 After solution heat treatment, and prior to mechanical-property testing, each test ring shall be stabilized and precipitation heat-treated as specified. 3.2.2.1 If the forgings are to be supplied in the solution heat-treated condition, the test rings shall be separated from the forgings after solutioning, then stabilized and precipitation heat-treated prior to testing.		

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MATERIAL SPECIFICATION		CODE IDENT NO. 99193	SPECIFICATION NO. EM552449	REV LTR C
3.2.2.2 If the forgings are ordered in the fully heat-treated condition, the integral test rings shall be attached to the forgings during stabilization and precipitation heat-treatment, then removed and tested. 3.2.3 Stabilization Heat Treatment - Heat to 1550°F ±25°F, hold at heat for 4 hours, cool in air. 3.2.4 Precipitation Heat Treatment - Heat to 1400°F ±25°F, hold at heat for 16 hours, cool in air. 3.3 Test specimens taken from forgings and test rings shall be in the fully heat-treated conditions and shall exhibit the minimum properties specified in EMS5388. 3.4 Fixed Process Verification 3.4.1 The vendor shall establish a fixed process in accordance with EMS52406. The established fixed process shall be submitted to AiResearch for approval prior to acceptance of production parts. 3.4.2 If it becomes necessary for the vendor to make any change in the fixed process, written approval and disposition shall be obtained from AiResearch in accordance with established procedures. 3.4.3 Each supplier shall keep on file, for the period of time specified in MCS014, the daily records of all control items in the fixed process that are recorded continuously on strip charts or circular charts or checked and recorded by hand. All process controls shall be personally audited by the supplier's quality control section once every month and a report filed. 3.5 Forging Lot Control 3.5.1 Nondestructive Testing Requirements 3.5.1.1 A 100-percent inspection shall be performed on all Class I forging lots by the forging vendor until sufficient statistical data is obtained and reversion to a lot sampling method is agreed upon via established procedures.		3.5.1.2 A 100-percent inspection of all Class I forgings shall be accomplished by any new forging vendor until sufficient test data shall have been obtained to justify a statistical sampling method. 3.5.1.3 A 100-percent inspection shall be accomplished by any forging vendor when there has been an agreed-upon permanent change in the forging process and until sufficient test data shall have been obtained to justify a new sampling method. 3.5.1.4 When the forging vendor has made an inadvertent change in the fixed process during the production of forgings, except as noted, and when approval through AiResearch has been obtained, then 100-percent inspection shall be accomplished for those forgings. 3.5.1.5 If any of the test ring tensile properties are below minimum, two additional test bars from the same test ring shall be tested. If the values of the retests from the test ring exceed the minimum values, the forging is to be accepted. If either of the retests falls below the minimum, that forging shall be rejected. 3.5.2 Destructive Mechanical-Property Testing 3.5.2.1 A forging sample for destructive testing shall also be taken from each production forging lot by the forging vendor. 3.5.2.2 The forging vendor shall perform the destructive testing on test specimens removed from each sample forging, as shown in Figure 1, in accordance with EMS5388. 3.5.2.3 One-half of each sample forging shall be sent to AiResearch. 4. INSPECTION 4.1 Each forging shall be acid etched and visually inspected in accordance with Appendix I. 4.2 Each forging shall then be fluorescent penetrant inspected in accordance with EMS2309, Class 1, using a Group V penetrant.		

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MATERIAL SPECIFICATION		CODE IDENT NO. 99193	SPECIFICATION NO. EMS52449	REV LTR E										
4.3 Each forging shall be ultrasonic inspected in accordance with EMS52321 and the appropriate class. The class of inspection shall be determined by the maximum cross-sectional thickness of the forging, as follows: <table border="1" style="margin: 10px auto; border-collapse: collapse;"> <thead> <tr> <th style="text-align: center;">Thickness (inches)</th> <th style="text-align: center;">Class of Inspection</th> </tr> </thead> <tbody> <tr> <td style="text-align: center;">0-1</td> <td style="text-align: center;">I</td> </tr> <tr> <td style="text-align: center;">over 1-3</td> <td style="text-align: center;">II</td> </tr> <tr> <td style="text-align: center;">over 3-5</td> <td style="text-align: center;">III</td> </tr> <tr> <td style="text-align: center;">over 5-7</td> <td style="text-align: center;">IV</td> </tr> </tbody> </table> 4.3.1 If pancake forgings with flat, parallel faces are produced as an intermediate forging operation, these forged pancakes may be ultrasonically inspected in lieu of the finished forging. 4.3.1.1 The thickness dimension of the forged pancake shall be substituted for the maximum cross-sectional thickness of the finished forging in order to determine the ultrasonic inspection classification. 4.4 All Class I and Class II forging samples shall be tested for mechanical properties. 4.4.1 The vendor shall remove and test the specified integrally forged test ring from each forging. 4.4.1.1 When serialization is required, the test ring shall bear the same serial number as the forging from which it was removed. 4.4.2 Tensile test specimens shall be machined with 0.250-inch reduced sections and a 1-inch minimum gauge length. 4.4.3 Tensile test specimens shall be strained at a rate of 0.005-inch per inch per minute, and the rate may be increased to 0.02-inch per inch per minute for strains beyond the yield point.		Thickness (inches)	Class of Inspection	0-1	I	over 1-3	II	over 3-5	III	over 5-7	IV	5. APPROVAL OR PROCUREMENT 5.1 One-half of each sample forging selected from each production lot for destructive mechanical-properties testing shall be forwarded to AiResearch. 5.2 The forging vendor shall store the integrally forged test rings for a period of two years from the date of the test reported, and these rings shall be made available to AiResearch upon request. 6. QUALITY CONTROL 6.1 A test report shall be sent to AiResearch Receiving Inspection with each shipment and shall indicate the forging lot number and quantity represented and, when serialization is required, each serial number represented. 6.2 The test report shall list the results of the destructive lot sample tests and the tensile results from all test rings representing the shipped forgings by lot number and, when serialization is required, by serial number. 6.3 The test results shall meet the requirements of EMS5388. 6.4 One-half of each sample forging selected for destructive testing shall be shipped prior to or with the first production forging from the lot. A list of serial numbers in the lot shall be submitted with each sample forging, when serialization is required. 6.5 Forgings not conforming to this specification shall be rejected.		
Thickness (inches)	Class of Inspection													
0-1	I													
over 1-3	II													
over 3-5	III													
over 5-7	IV													

POSITION 1	COMBINATION STRESS RUPTURE
POSITION 2	SMOOTH STRESS RUPTURE
POSITION 3	1000°F TENSILE
POSITION 4	ROOM-TEMPERATURE TENSILE

FIGURE 1 - DESTRUCTIVE TEST SPECIMEN REQUIREMENTS
FOR FORGED WASPALOY TURBINE DISKS.

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MATERIAL SPECIFICATION		CODE IDENT NO. 99193	SPECIFICATION NO. ENS55388	REV LTR C																																						
1. APPLICATION 1.1 This material is primarily for turbine disks, shafts, bolts and fittings operating to 1600°F. 1.2 This document defines the requirements for forgings and cross-rolled plate in Conditions A, B, and C, as specified. Condition A - Material requiring maximum stress-rupture properties. Condition B - Material requiring maximum tensile properties. Condition C - Thermally-mechanically processed (TMP) material. 1.3 The following terms used in this specification shall have the meaning as defined below: 1.3.1 TMP refers to thermal mechanical processing, which involves warm working below the recrystallization temperature. 1.3.2 Cross-rolling consists of carefully controlling reductions throughout deformation processing from ingot to final product so that there are essentially equal amounts of elongation in the two orthogonal directions of width and length. 2. APPLICABLE DOCUMENTS 2.1 The following documents form a part of this specification to the extent referenced herein. 2.1.1 ASTM Specifications E 8 Tension Testing of Metallic Materials E 112 Average Grain Size of Metals, Estimating the 2.1.2 AMS Specifications AMS 2261 Tolerances - Nickel, Nickel Base, and Cobalt Base Alloy Bars and Forging Stock AMS 2269 Chemical Check Analysis Limits - Wrought Nickel and Nickel Base Alloys 2.1.3 Aerospace Specifications MSC014 Marking and Traceability Requirements 3. TECHNICAL REQUIREMENTS 3.1 Composition <table border="0"> <tr><td>Carbon</td><td>0.10 max</td></tr> <tr><td>Manganese</td><td>0.50 max</td></tr> <tr><td>Silicon</td><td>0.75 max</td></tr> <tr><td>Sulfur</td><td>0.015 max</td></tr> <tr><td>Chromium</td><td>18.00 - 21.00</td></tr> <tr><td>Cobalt</td><td>12.00 - 15.00</td></tr> <tr><td>Molybdenum</td><td>3.50 - 5.00</td></tr> <tr><td>Titanium</td><td>2.75 - 3.25</td></tr> <tr><td>Aluminum</td><td>1.20 - 1.60</td></tr> <tr><td>Zirconium</td><td>0.02 - 0.12</td></tr> <tr><td>Boron</td><td>0.01 max</td></tr> <tr><td>Iron</td><td>2.00 max</td></tr> <tr><td>Copper</td><td>0.10 max</td></tr> <tr><td>Nickel</td><td>Remainder</td></tr> </table> 3.1.1 Composition variations shall meet the requirements of the latest issue of AMS 2269. 3.2 Condition 3.2.1 Forging and cross-rolled plate stock shall be supplied as ordered by the manufacturer. 3.2.2 Forgings and cross-rolled plate shall be supplied solution heat treated and descaled, unless otherwise specified. 3.3 Heat Treatment 3.3.1 Solution Heat Treatment (Conditions A and B): Condition A and B forgings and cross-rolled plate shall be heated to a temperature within the range of 1825 to 1900°F, held at this selected temperature within ±25°F for 4 hours, then cooled rapidly in air, oil or water. 3.3.2 Solution Heat Treatment (Condition C): In lieu of the solution heat treatment specified above, Condition C forgings and cross-rolled plate shall be given a modified solution heat treatment at a temperature below the gamma-prime solvus temperature in accordance with the supplier's fixed process. 3.3.3 Stabilization Heat Treatment (Conditions A, B and C): Heat to 1550 ±25°F, hold at heat for 4 hours, cool in air. 3.3.4 Precipitation Heat Treatment (Conditions A, B and C): Heat to 1400 ±25°F, hold at heat for 16 hours, cool in air. 3.4 Mechanical Properties 3.4.1 Condition A 3.4.1.1 Tensile test specimens cut from forgings or cross-rolled plate and tested at room temperature in accordance with ASTM E 8 shall meet the following minimum requirements: <table border="0"> <tr><td>Ultimate tensile strength,</td><td>160,000</td></tr> <tr><td>psi</td><td></td></tr> <tr><td>Yield strength, (0.2 percent offset) psi</td><td>110,000</td></tr> <tr><td>Elongation, percent in 4D</td><td>12.0</td></tr> <tr><td>Reduction of area, percent</td><td>15.0</td></tr> </table> 3.4.1.2 Condition A Stress-Rupture Properties: Specimens cut from forgings or cross-rolled plate shall be tested under the following conditions. 3.4.1.2.1 A smooth test specimen shall be maintained at 1500 ±5°F, under a continuously applied axial stress of 47,500 psi, and shall not rupture in less than 23 hours. The test shall be continued to rupture, and elongation after rupture, measured at room temperature, shall be a minimum of 5 percent in 4D.					Carbon	0.10 max	Manganese	0.50 max	Silicon	0.75 max	Sulfur	0.015 max	Chromium	18.00 - 21.00	Cobalt	12.00 - 15.00	Molybdenum	3.50 - 5.00	Titanium	2.75 - 3.25	Aluminum	1.20 - 1.60	Zirconium	0.02 - 0.12	Boron	0.01 max	Iron	2.00 max	Copper	0.10 max	Nickel	Remainder	Ultimate tensile strength,	160,000	psi		Yield strength, (0.2 percent offset) psi	110,000	Elongation, percent in 4D	12.0	Reduction of area, percent	15.0
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MATERIAL SPECIFICATION		CODE IDENT NO. 99193	SPECIFICATION NO. ENS55188	REV LTR C															
3.4.1.2.2 A combination smooth and notched test specimen, machined to the dimensions of Figure 1, shall be maintained at 1350 $\pm$ 5°F under a continuously applied axial stress of 80,000 psi and shall not rupture in less than 23 hours. The test shall be continued to rupture. Failure of the smooth section shall not occur in less than 23 hours, but it shall fail in less time than the notched section. Elongation of the smooth section after rupture shall be a minimum of 5 percent in 4D, measured at room temperature. 3.4.1.2.3 Separate smooth and notched test specimens, machined from adjacent sections of the same piece with gauge sections conforming to the respective dimensions of Figure 1, may be tested as an alternate procedure, using the same test conditions. The smooth specimen shall not rupture in less than 23 hours, and elongation after rupture measured at room temperature shall be not less than 5 percent in 4D. The notched specimen need not be tested to rupture, but rupture shall not occur in less time than the smooth section. 3.4.1.2.4 The tests may be conducted at a higher stress level, but the stress shall not be increased while the test is in progress. Time to rupture and elongation requirements shall be as specified. 3.4.1.3 Hardness of the fully heat-treated material shall be Brinell 313 to 403. 3.4.1.4 Grain Size: Forgings and cross-rolled plate heat treated to meet the property requirements of Condition A shall have a substantially uniform grain size of 3 or finer, with occasional grains as large as 1 permissible, as determined by comparison of an etched specimen with the ASTM E 112 chart. In the case of a dispute, the Heyn's intercept method shall be used. 3.4.2 Condition B 3.4.2.1 Tensile test specimens, cut from the forging or cross-rolled plate and tested at the temperatures indicated in accordance with ASTM E 8, shall conform to the following requirements. Specimens to be tested at 1000°F shall be held at heat for 30 minutes prior to testing. Rate of strain for testing at 1000 $\pm$ 10°F shall be maintained at approximately 0.005 inch per inch per minute to the 0.2 percent yield strength. <table border="1"> <thead> <tr> <th></th> <th>R.T.</th> <th>1000°F</th> </tr> </thead> <tbody> <tr> <td>Ultimate tensile strength, psi</td> <td>175,000</td> <td>160,000</td> </tr> <tr> <td>Yield strength, (0.2 percent offset) psi</td> <td>120,000</td> <td>110,000</td> </tr> <tr> <td>Elongation, percent in 4D</td> <td>12.0</td> <td>12.0</td> </tr> <tr> <td>Reduction of area, percent</td> <td>15.0</td> <td>15.0</td> </tr> </tbody> </table> 3.4.2.2 Condition B Stress-Rupture Properties: Specimens cut from forgings or cross-rolled plate shall be tested under the following conditions. 3.4.2.2.1 A smooth test specimen shall be maintained at 1500 $\pm$ 5°F, under a continuously applied axial stress of 42,500 psi, and shall not rupture in less than 23 hours. The test shall be continued to rupture, and the elongation after rupture, measured at room temperature, shall be a minimum of 5 percent in 4D. 3.4.2.2.2 A combination smooth and notched test specimen, machined to the dimensions of Figure 1, shall be maintained at 1350 $\pm$ 5°F under a continuously applied axial stress of 75,000 psi and shall not rupture in less than 23 hours. The test shall be continued to rupture. Failure of the smooth section shall not occur in less than 23 hours, but it shall fail in less time than the notched section. Elongation of the smooth section after rupture shall be a minimum of 5 percent in 4D, measured at room temperature. 3.4.2.2.3 Separate smooth and notched test specimens, machined from adjacent sections of the same piece with gauge sections conforming to the respective dimensions of Figure 1, may be tested as an alternate procedure, using the same test conditions. The smooth specimen shall not rupture in less than 23 hours, and elongation after rupture measured at room temperature shall be not less than 5 percent in 4D. The notched specimen need not be tested to rupture, but rupture shall not occur in less time than the smooth section. 3.4.2.2.4 The tests may be conducted at a higher stress level, but the stress shall not be increased while the test is in progress. Time to rupture and elongation requirements shall be as specified. 3.4.2.3 Hardness of the fully heat-treated material shall be Brinell 313 to 403. 3.4.2.4 Grain Size: Forgings and cross-rolled plate heat treated to meet the property requirements of Condition B shall have a substantially uniform grain size of 3 or finer, with occasional grains as large as 1 permissible, as determined by comparison of an etched specimen with the ASTM E 112 chart. In the case of a dispute, the Heyn's intercept method shall be used. 3.4.3 Condition C 3.4.3.1 Tensile test specimens, cut from the forging or cross-rolled plate and tested at the temperatures indicated in accordance with ASTM E 8, shall conform to the following requirements. Specimens to be tested at 1000 $\pm$ 10°F shall be held at heat for 30 minutes prior to testing. Rate of strain for testing at 1000 $\pm$ 10°F shall be maintained at approximately 0.005 inch per inch per minute to the 0.2 percent yield strength.						R.T.	1000°F	Ultimate tensile strength, psi	175,000	160,000	Yield strength, (0.2 percent offset) psi	120,000	110,000	Elongation, percent in 4D	12.0	12.0	Reduction of area, percent	15.0	15.0
	R.T.	1000°F																	
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Elongation, percent in 4D	12.0	12.0																	
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MATERIAL SPECIFICATION		CODE IDENT NO. 99193	SPECIFICATION NO. EN55388	REV LTR C															
	<table border="1"> <thead> <tr> <th></th> <th>RT</th> <th>1000°F</th> </tr> </thead> <tbody> <tr> <td>Ultimate tensile strength, psi</td> <td>190,000</td> <td>170,000</td> </tr> <tr> <td>Yield strength, (0.2 percent offset) psi</td> <td>140,000</td> <td>125,000</td> </tr> <tr> <td>Elongation, percent in 4D</td> <td>10.0</td> <td>11.0</td> </tr> <tr> <td>Reduction of area, percent</td> <td>13.0</td> <td>12.0</td> </tr> </tbody> </table>		RT	1000°F	Ultimate tensile strength, psi	190,000	170,000	Yield strength, (0.2 percent offset) psi	140,000	125,000	Elongation, percent in 4D	10.0	11.0	Reduction of area, percent	13.0	12.0	3.4.3.4 Grain Size: Forgings and cross-rolled plate heat treated to meet the property requirements of Condition C shall have a substantially uniform grain size of 3 or finer, with occasional grains as large as 1 permissible, as determined by comparison of an etched specimen with the ASTM E 112 chart. In the case of a dispute, the Rayn's intercept method shall be used.		
	RT	1000°F																	
Ultimate tensile strength, psi	190,000	170,000																	
Yield strength, (0.2 percent offset) psi	140,000	125,000																	
Elongation, percent in 4D	10.0	11.0																	
Reduction of area, percent	13.0	12.0																	
3.4.3.2 Condition C Stress-Rupture Properties: Specimens cut from forgings or cross-rolled plate shall be tested under the following conditions. 3.4.3.2.1 A combination smooth and notched test specimen, machined to the dimensions of Figure 1, shall be maintained at 1200 ±5°F under a continuously applied axial stress of 95,000 psi and shall not rupture in less than 125 hours. The test shall be continued to rupture. Failure of the smooth section shall not occur in less than 125 hours, but it shall fail in less time than the notched section. Elongation of the smooth section after rupture shall be a minimum of 10 percent in 4D, measured at room temperature. 3.4.3.2.2 A combination smooth and notched test specimen, machined to the dimensions of Figure 1, shall be maintained at 1350 ±5°F under a continuously applied axial stress of 75,000 psi and shall not rupture in less than 23 hours. The test shall be continued to rupture. Failure of the smooth section shall not occur in less than 23 hours, but it shall fail in less time than the notched section. Elongation of the smooth section after rupture shall be a minimum of 5 percent in 4D, measured at room temperature. 3.4.3.2.3 Separate smooth and notched test specimens, machined from adjacent sections of the same piece with gauge sections conforming to the respective dimensions of Figure 1, may be tested as an alternate procedure to the above using the same test conditions. The smooth specimen shall not rupture in less than 23 or 125 hours, as applicable, and elongation after rupture measured at room temperature shall be not less than 5 or 10 percent in 4D, as applicable. The notched specimen need not be tested to rupture, but rupture shall not occur in less time than the smooth section. 3.4.3.2.4 The above stress-rupture tests may be conducted at a higher stress level, but the stress shall not be increased while the test is in progress. Time to rupture and elongation requirements shall be as specified above. 3.4.3.3 Hardness of the fully heat-treated material shall be Brinell 313 to 403.		3.5 Forging Stock 3.5.1 When a sample of forging or cross-rolled plate stock is forged or rolled to a test coupon and heat treated, specimens taken from the coupon shall have properties conforming to the requirements specified. 3.5.2 If specimens taken from the forging or cross-rolled plate stock are heat treated and have properties conforming to the requirements specified, the test shall be accepted as equivalent to the test of a forged or rolled coupon. 4. PROCESS CONTROL 4.1 Forging and cross-rolled plate material shall be produced by vacuum induction melting followed by vacuum arc remelting. 4.1.1 Material for cross-rolled plate may be electro-slag remelted. 5. INSPECTION 5.1 Tolerances shall conform to the latest issue of AMS 2261 as applicable. 6. IDENTIFICATION AND PACKING 6.1 Forgings and cross-rolled plate shall be identified in accordance with MC5014. 7. APPROVAL OR PROCUREMENT 7.1 If necessary to make any change in equipment, procedures, and techniques after approval is granted, the source (forging or material) shall obtain permission from AlResearch Materials Engineering and Manufacturing Engineering prior to the first shipment incorporating such change. 8. REPORTS 8.1 The supplier of the material shall furnish with each shipment a report of chemical composition and test results on each heat to determine conformance to the technical requirements of this specification. This report shall include size of the original heat, the purchase order, material specification, heat number, forging or cross-rolled plate part number, and size of stock used to make the forgings or plate.																	

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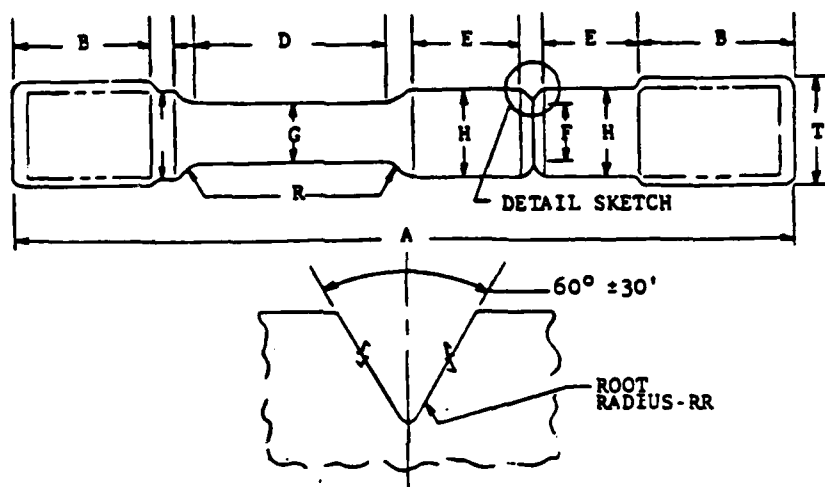
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MATERIAL SPECIFICATION	CODE IDENT NO. 99193	SPECIFICATION NO. ZMS55388	REV LTR C
8.3 The supplier of finished or semi-finished parts shall furnish with each shipment a report showing the quantity, purchase order, materials specification, contractor or other direct supplier of material, and part number. When material for making parts is produced or purchased by the parts supplier, the supplier shall inspect each lot of material to determine conformance to the requirements of this specification, and shall include in his report a statement that the material conforms, or shall include the results of laboratory tests that determine conformance. 9. QUALITY CONTROL 9.1 The material shall be uniform in quality and condition, sound, and free from foreign materials and from internal and external imperfections detrimental to usage of the material. 9.2 Material not conforming to the requirements of this specification shall be rejected.			

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Specimen Number	Center Gage Diameter G, Inch	C	D, min	E, min	F	H	R, min	RR
1	0.160	1/8	0.65	3/8	0.160	0.226	0.125	0.005
2	0.178	1/8	0.75	3/8	0.178	0.250	0.125	0.005
3	0.252	1/8	1.0	3/8	0.252	0.375	0.125	0.007
Tolerance ±0.001		±1/16	--	--	±0.001	±0.003	--	±0.0005

Note 1. Finish the specimen to 8 or better on all "f" surfaces.

Note 2. The difference between dimensions "f" and "G" shall not exceed 0.0005 in. for specimens 1 and 2. The difference shall not exceed 0.001 in. for specimen 3.

Note 3. Taper gage length "D" to center so that diameter "G" at the ends of the gage length exceeds diameter "G" at the center of the gage length by 0.0005 - 0.0015 inch.

Note 4. All sections shall be concentric about the specimen axis within 0.001 inch.

Note 5. Thread size "T" shall be equal to or greater than "H".

Note 6. Dimensions "A" and "B" are not specified.

FIGURE 1
COMBINATION SMOOTH-AND-NOTCHED TEST SPECIMEN



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A DIVISION OF THE SARGENT CORPORATION
PHOENIX, ARIZONA

SUBSTANTIATION TEST INSTRUCTION - FORGINGS

1. SCOPE

1.1 Purpose

This substantiation test instruction (STI) document establishes substantiation test requirements and procedures to establish and approve a source for a forging represented in a unit that requires qualification (military) or certification (civil, which includes commercial and industrial) tests.

Testing shall be performed for the following conditions:

- (a) A change in the fixed process.
- (b) The modification of part configuration.
- (c) The addition of new sources.

NOTE: Testing for conditions (a) and (b) shall be accomplished only when it is established by the Engineering Project that the change or modification is significant enough to affect mechanical properties.

1.2 Definitions

Product-Line Category - A product-line category is the alphabetical designation for the originating Engineering Project. See Table I.

Test Class - A test class is the numerical designation for a specific test. See Section 3.



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 PHOENIX, ARIZONA

TABLE I

PRODUCT-LINE ENGINEERING PROJECT CATEGORIES

Category	Engineering Project	Applicable Project Test Classes
A	Aircraft Propulsion Engines	1, 2, or 3
(H) B	Gas Turbines (Non-Aircraft Propulsion)	1 through 10
C	Turbine Starters	1, 2, or 3
D	Air Motor Actuator Systems	1, 2, or 3
E	Control Systems	1, 2, or 3
F	Turbine Motors	1, 2, or 3



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2. REQUIREMENTS

2.1 Source Selection Approval

Vendors must qualify as either a Trial or Approved Supplier in accordance with AiResearch Operational Procedure 4.90 before inspection of the vendor's forging is initiated.

2.2 Test Requirements and Acceptance Criteria

The following analyses and tests shall be conducted on a candidate forging or forgings as appropriate. Proposed alternate-source forgings used in substantiation tests shall be identical in materials, fabrication, processing, and all other respects with subsequent production forgings. No changes shall be made without AiResearch approval.

2.2.1 Chemical Analysis

Material certification by the vendor is required. When deemed necessary, a certified copy of the chemical analysis report from a source acceptable to AiResearch, to determine that the forging material(s) comply with the specified materials, shall be furnished to AiResearch with the candidate forging.

2.2.2 Physical Analysis

Material certification by the vendor is required. When deemed necessary, a certified copy of the physical analysis report from a source acceptable to AiResearch, to determine that the forging complies with applicable data, shall be furnished to AiResearch with the candidate forging(s).

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2.2.3 Engineering Samples

Prior to beginning a forging test program, at least one sample forging representative of the type to be tested that has undergone complete chemical and dimensional inspection, as appropriate, shall be submitted by the Quality Control Department to Engineering for a comprehensive process analysis and evaluation. A record of any deviations from the forging requirements on a First-Article Inspection Report shall accompany the sample.

2.3 Substantiation Data

2.3.1 Retention

Retention of substantiation test data shall be in accordance with the applicable operational procedure(s) in the AiResearch Operational Procedures Manual.

2.3.2 Data

Quality Control shall verify receipt of and shall check conformance with the following data, when applicable, except for chemical analysis, which shall be checked by the Chemical Laboratory as applicable.

- (a) Material, chemical, and physical analysis reports or certifications, as applicable
- (b) Heat-treat certification compliance, as applicable



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- (c) Plating certification compliance, as applicable
- (d) Supplier process sheets, as applicable
- (e) Zyglo report or magnetic-particle inspection report
- (f) X-ray acceptability
- (g) Vendor certificate of compliance
- (h) Inspection layout report
- (i) Measured-data sheet
- (j) First-article inspection record
- (k) Test reports (required class tests)
- (l) Receiving reports
- (m) Weld certification, as applicable
- (n) Vendor drawing(s), as required
- (o) Grain flow sample

2.4 Class Test Data

Test data shall be recorded on the appropriate data sheets. In addition, a test log similar to Data Sheet Form DS-3967, Qualification Test Log Form P5330, or Laboratory Data Sheet Form PS177A shall be used by the test technicians, where applicable, and shall be maintained for the complete test.



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3. TEST CLASSES

3.1 Applicability

Test classes that follow in this section shall be applicable. Field evaluation in the end unit, acceptable to Engineering, may be substituted for test Class 1. Such evaluation must be appropriately documented and data retained as prescribed in Paragraph 2.3.1. AiResearch shall conduct the testing for these classes.

3.2 Test Class 1

The Engineering Project will determine if a forged part from an alternate vendor shall be subjected to a supplemental qualification test. They shall also specify the quality and magnitude of the test.

3.3 Test Class 2

Class 2 testing is to be conducted in accordance with the procedure in the following subparagraphs. This procedure may be modified by Engineering Project by issuing supplemental instructions.

3.3.1 Material Properties

- (a) Turbine (Waspaloy) - A minimum of five forgings from each of a minimum of two master heats incorporating two heat-treat lots (10 forgings minimum) shall be destructively tested prior to fixed process approval. Testing shall consist of the following:



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- (1) Two room-temperature tensiles per forging
- (2) Two 1000°F tensiles per forging
- (3) Two 1350°F stress-rupture per forging
- (4) One 1500°F stress-rupture per forging
- (5) Ten room-temperature and 10 elevated-temperature low-cycle fatigue specimens

NOTE: The location on the forging from which the test specimens are to be machined shall be established by Engineering for each configuration. Temperature for low-cycle fatigue testing shall be defined by Engineering.

- (b) Turbine (Super Waspaloy) - A minimum of five forgings from each of a minimum of two master heats, incorporating two heat treat lots (10 forgings minimum), shall be destructively tested prior to fixed-process approval. Testing shall consist of the following:

- (1) Two room-temperature tensiles per forging
- (2) Four 1200°F tensiles per forging
- (3) Two 1150°F stress-ruptures per forging
- (4) Two 1250°F stress-ruptures per forging
- (5) Ten room-temperature and six elevated-temperature low-cycle fatigue specimens

NOTE: The location on the forging from which the test specimens are to be machined and the exact test conditions shall be established by Engineering for each configuration. Temperature for low-cycle fatigue testing shall be defined by Engineering.

- (c) Compressor - If a change in the fixed process or configuration is required with a current vendor, a minimum of two forgings from two master heats incorporating two heat-treat lots (four forgings minimum) shall be destructively tested prior to fixed-process or configuration-change approval.

MATERIAL SPECIFICATION		CODE IDENT NO 99193	SPECIFICATION NO. ELIS 52406	REV LTR C
APPLICATION				
1.1	This specification covers aircraft-quality forged parts produced by processes in which controlled plastic deformation under impact or pressure is used.			
1.2	Forgings in accordance with this specification shall be classified as follows:			
	CLASS I	(A) Rotating parts operating at temperatures in excess of 1000°F, such as integral turbine wheels, turbine disks, and ex-ducers.		
		(B) Rotating parts operating at temperatures, from room temperature to 1000°F, such as integral compressor wheels, compressor wheel disks, inducers, impellers, and fans.		
	CLASS II	Inserted blades, buckets, and vanes.		
	CLASS III	Containment rings.		
	CLASS IV	General application shafts, structural parts, housings, fittings, rings, and gears.		
		(A) Forging fixed process NOT required.		
		(B) Forging fixed process required.		
	CLASS V	Forgings for cryogenic applications.		
1.3	Forging class shall be specified when referencing this specification.			
1.3.1	When Class IV is specified without a subclass of either "A" or "B", then Class IV A shall apply.			
2.	APPLICABLE DOCUMENTS			
2.1	The following documents are applicable to the extent herein referenced.			
2.1.1	<u>AirResearch Material Specification</u>			
	NC5014	Marking requirements		

MATERIAL SPECIFICATION		CODE IDENT NO 99193	SPECIFICATION NO. EHS 52406	REV LTR B
3.6	<u>Heat Treatment</u> - Heat treatment shall be as specified. Only approved vendors shall be used for heat treating.			
3.7	<u>Cleaning</u> - Forgings shall be furnished descaled. Titanium forgings shall not be cleaned by immersion in acid without the prior approval of AiResearch.			
3.8	<u>Grain Flow</u> - Grain flow shall be as specified. Grain flow shall also show no evidence of the billet having been cocked when upsetting.			
3.8.1	Displacement of the centerline of the billet, with respect to the centerline of the forging, shall not exceed one-tenth the outer diameter of the wheel, impeller, disk, and gear forgings, or shall not exceed 3/4 inch, whichever is the smallest.			
3.8.2	No evidence of buckling of the billet shall be permissible.			
4.	PROCESS CONTROL			
4.1	Class I forgings shall be forged from round or octagon billets. Round cornered square billets may be used only if a separate forging operation is used to shape the billet into a round or octagon.			
4.1.1	Billets shall be prepared such that the ends are essentially parallel.			
4.1.2	Initial upset shall be on end grain.			
4.1.3	Where radial properties are necessary close to the center of upset type forgings, similar to Sketches 1B, 2B, 3B and 4B billets shall be forged tapered on the ends before performing the initial upsetting operation.			
4.1.4	For Class I forgings, relief shall be provided in blocker and/or finish dies to center billets.			
4.2	Figures 1 through 11 show typical forging configurations and grain flow patterns.			
4.3	Figures 1 through 5 show disk, integral shaft, impeller and finger forgings applicable to Class I forgings.			
4.4	Figure 6 shows typical grain flow pattern for shrouded and unshrouded blades representative of Class II forgings.			
4.5	Figure 7 shows grainflow requirements for Class III containment rings.			

MATERIAL SPECIFICATION		CODE: GENT NO 99193	SPECIFICATION NO. EHS 52406	REV LTR A
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4.5.1 Class III rings shall be manufactured by ring rolling or mandrel forging.

4.6 Figures 8 through 11 show typical configurations applicable to Class IV gear blanks.

4.7 Proposed forgings for Classes I and II or of an unusual or special size for other classes shall be coordinated with the applicable engineering groups, Manufacturing Engineering Group, and Materials Engineering.

5. INSPECTION

5.1 Inspection tests required shall be performed by the vendor or other AiResearch-approved source.

6. IDENTIFICATION AND PACKING

Forgings shall be identified in accordance with AiResearch Specification NC5014.

7. APPROVAL OR PROCUREMENT

7.1 Destructive Testing - The first representative part produced of a forged configuration shall be sectioned and tested to assure conformance with the applicable engineering requirements. Vendor shall not proceed with the production forgings for Classes I through III and V until test results on the destruct forging have been approved by AiResearch Materials Engineering.

7.2 Changes in Forging Procedure - The following shall be considered as changes in the forging procedure and shall be cause for re-evaluation of technical requirements in accordance with paragraph 7.1.

7.2.1 Changes in size or configuration of forging stock.

7.2.2 Significant changes in die configuration.

7.2.3 Changes in die sequence and heating and forging cycles.

7.2.4 Changes in heating temperatures and times.

7.2.5 Any change in the amount of final hot work reduction imparted to the forging following the last heating operation.

MATERIAL SPECIFICATION	CODE IDENT NO 99193	SPECIFICATION NO EIMS 52406	REV LTR C
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REPORTS

8.1 Forging Procedures - Forging vendors shall prepare a written forging procedure for Class I through Class III, and Class IV B forgings, and submit a copy to AiResearch for approval of the procedure with first-order shipments and prior to forging second-order parts. This forging procedure shall list in detail all operations and procedures used by the vendor in the manufacture of the forged parts, along with upper and lower control limits for these operations where applicable.

A forging procedure shall consist of, but shall not be limited to, the following items:

8.1.1 Forgings stock; size and weight. In addition, for rings, starting OD, thickness, and initial ID hole size.

8.1.2 Die lubricant.

8.1.3 Preheat furnace; identity, atmosphere, and temperature.

8.1.4 Forging equipment; identification, type, and size.

8.1.5 Initial furnace soak time and temperature range .

8.1.6 On-die temperature/off-die temperature for each forging cycle.

8.1.7 Number of blows, revolutions, and passes for each forging cycle, give range

8.1.8 Number of reheats required specific number , soak time range , and temperature range .

8.1.9 In-process conditioning, grinding, and inspections.

8.1.10 Heat-treat cycle, if required, including type of furnace, temperature, atmosphere, and time at temperature.

8.2 Once established and approved by AiResearch, the forging procedure shall be considered a "fixed process" and cannot be changed without prior approval from AiResearch. All operational deviations from the "fixed process" shall be noted on the certified test report that accompanies each shipment of forgings. Variations from the "fixed process"-- i.e., changes in heating times, temperature, forging sequence, etc.--shall be submitted to AiResearch on an RMA form, Request for Material Review Action, for disposition of the forgings involved.

MATERIAL SPECIFICATION	CODE IDENT NO 99193	SPECIFICATION NO. EHS 52406	REV LTR A
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8.2 (Contd.) Operations and processes considered proprietary by the forging vendor may be listed on a master copy of the "fixed process" which is kept in the vendor's file; however, the range of control for such operations must be shown on the copy of the "fixed process" submitted to AiResearch with the parts.

8.3 The forging vendor shall furnish with each shipment three copies of a report showing the purchase order number, part number, material specification, heat or lot number, size of stock used, quantity of parts, and the results of applicable tests for chemical composition, mechanical properties, grain size, grain flow, and hardenability.

9. QUALITY CONTROL

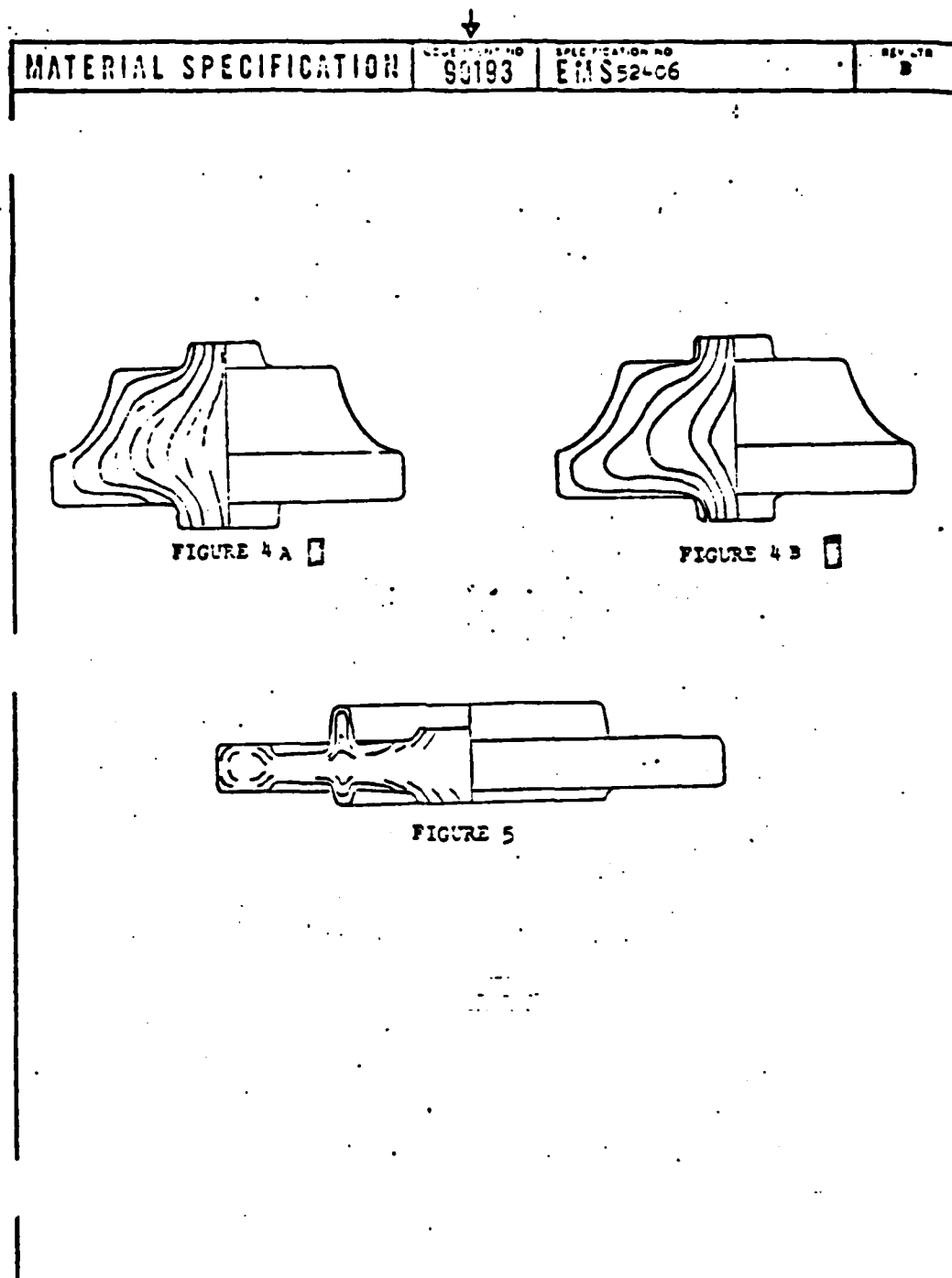
9.1 ☐ Forging stock shall be clean, sound, and free of imperfections detrimental to the fabrication and/or performance of the parts and subject to the applicable inspection requirements for aircraft-quality material. Forging stock shall be air- or vacuum-melt material as required by the applicable materials specification.

9.2 ☐ Process controls applicable to forgings produced under this specification shall be audited by the vendor's Quality Control Department, group, or representative on a monthly basis, and reports of this audit shall be made available for review.

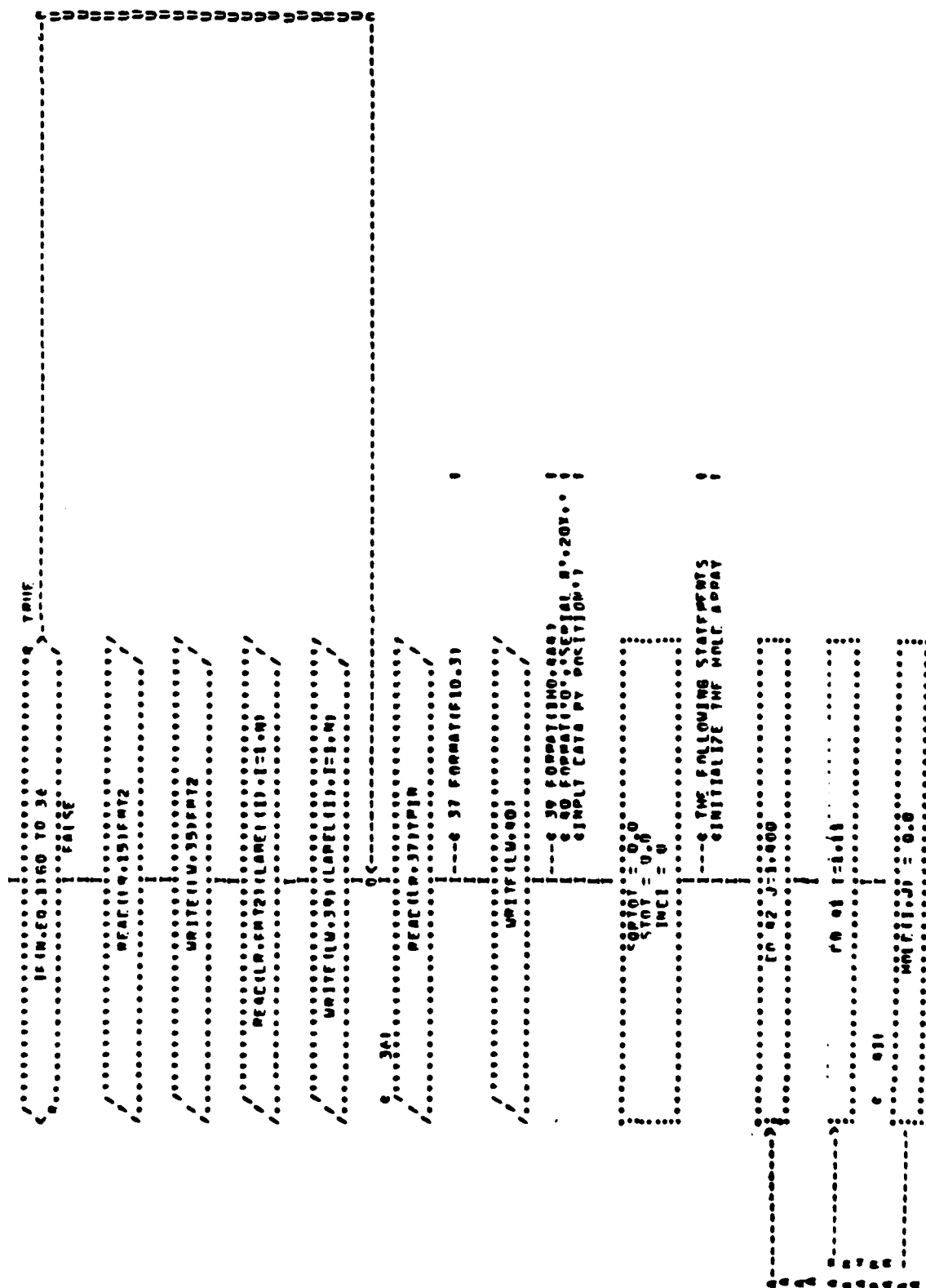
9.3 ☐ Vendors shall keep records of conformance to all control items in a fixed process for a period of four years after date of shipment.

In the case of parts requiring traceability, the above records shall be kept for a period of seven years after date of shipment.

9.4 ☐ Forged parts not conforming to this specification shall be rejected.



APPENDIX C




```

      ---c NOW CALCULATE WRAP
      CWRP = 0.0
      C0 50 10000
      e 301
      SUBP = SUBP + RANGE(1)
      PPR = CWRP/R
      ---c NOW CALCULATE LIMITS FOR
      ECCHARTS
      UCL = C0(1000000)
      LCL = C0(1000000)
      ---c NOW CALCULATE LIMITS FOR WRAP
      ECCHARTS
      SIG3 = A2(1000000)
      UCL = WRAP + SIG3
      LCL = WRAP - SIG3
      ---c REPLACE CONTROL LIMIT VALUES IF
      CUSER CFSIG3 IN INPUT TMEP.
      IF (UCL.P,0.1) .FALSE.
      THEN
      /PRFILMQUICPLWRAP=UCL,MLL,VRP=UCL,
      /PRFILMQUICPLWRAP=LCL,MLL,VRP=LCL,
      ---c GO INFORMATION.0)
      ---c THE FOLLOWING STATEMENTS CALL
      SUBROUTINE CHARTS FOR PRODUCTION
      c THE DESIRED FORMAT CHARTS.
      /PRFILMQUICPLWRAP=UCL,MLL,VRP=UCL,
      /PRFILMQUICPLWRAP=LCL,MLL,VRP=LCL,
  
```

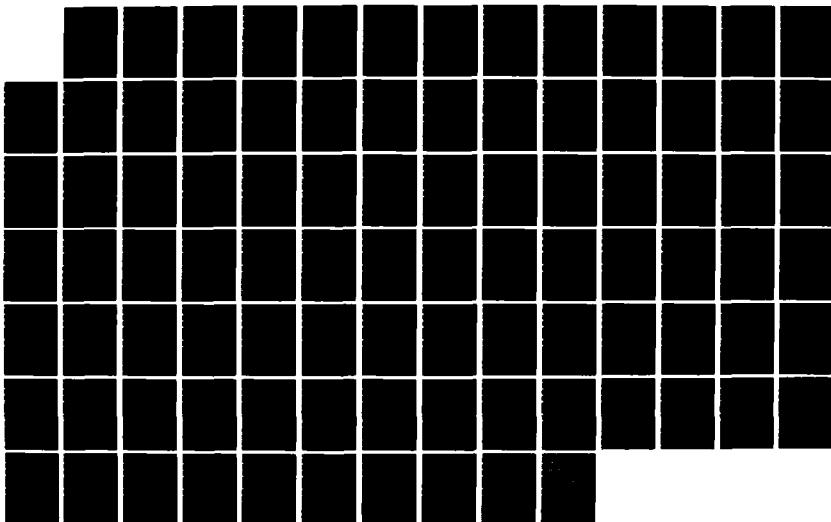

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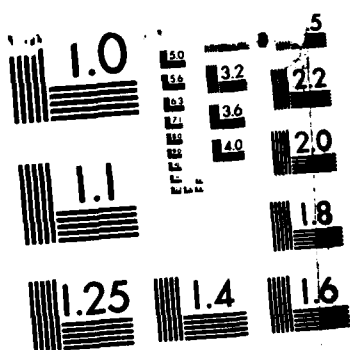
AN APPLICATION OF QUALITY CONTROL THEORY TO
VENDOR-SUPPLIED PARTS AT AN A. (U) AIR FORCE INST OF
TECH WRIGHT-PATTERSON AFB OH D E GELLENBECK AUG 85
AFIT/CI/NR-86-137 F/G 5/1

3/3

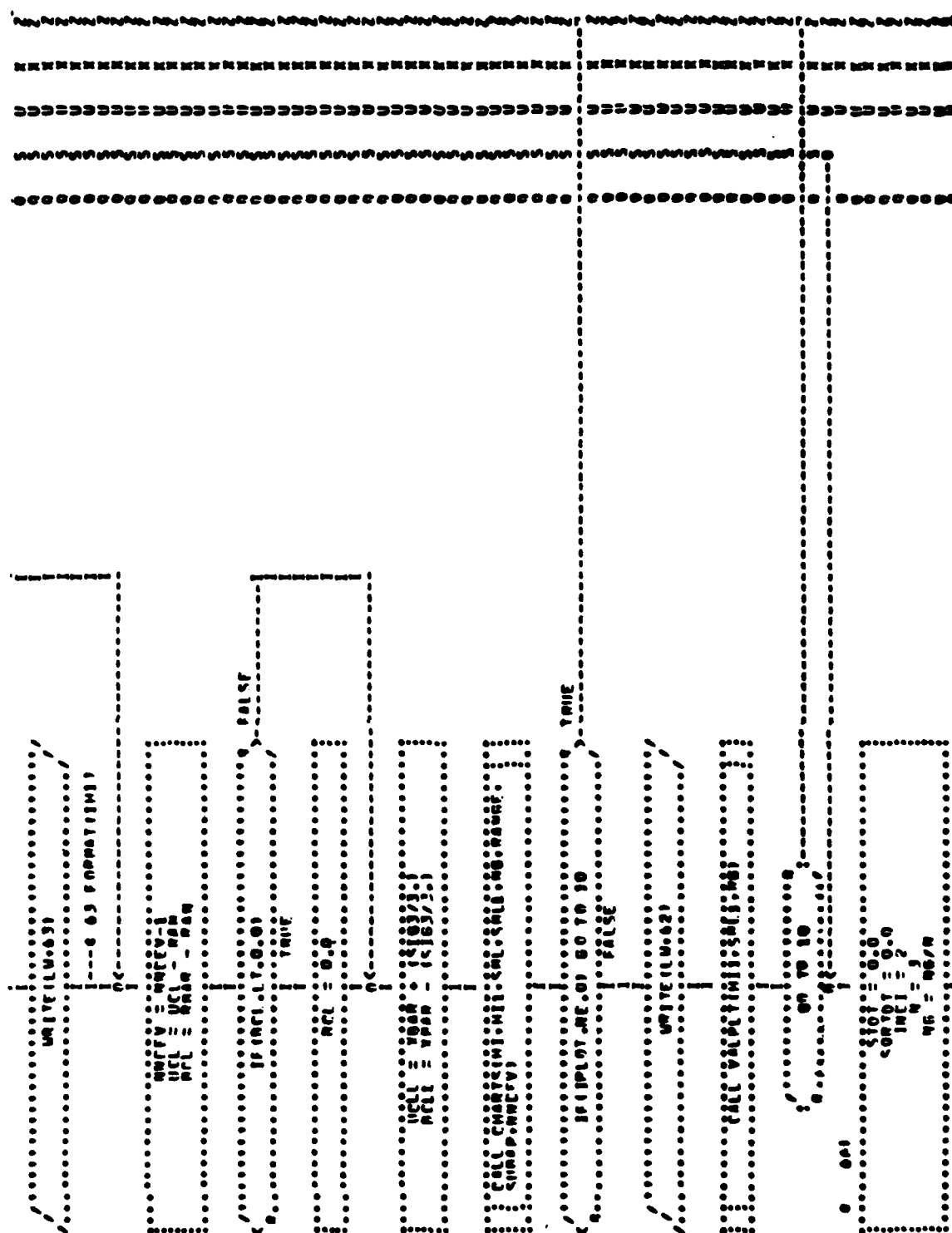
UNCLASSIFIED

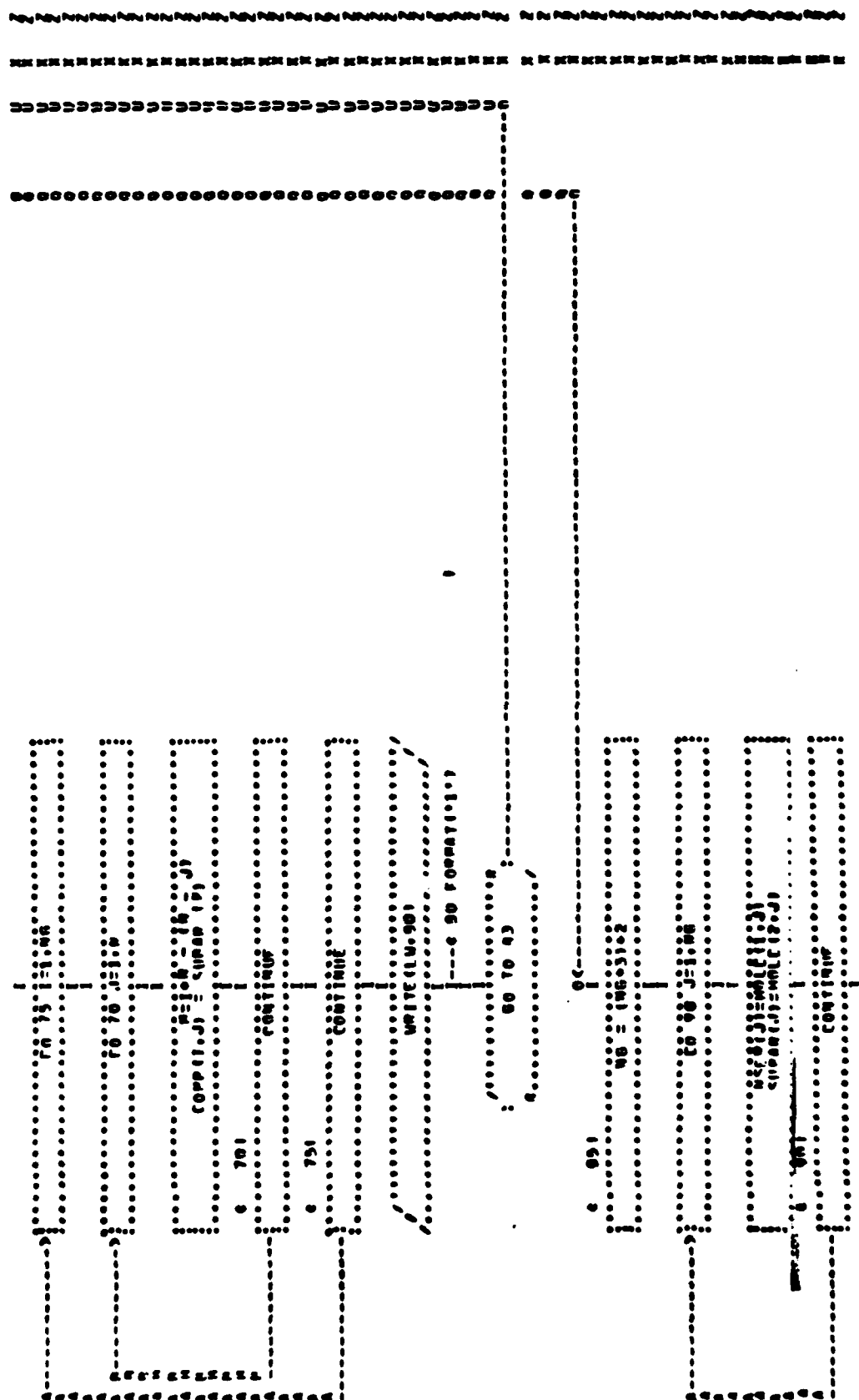
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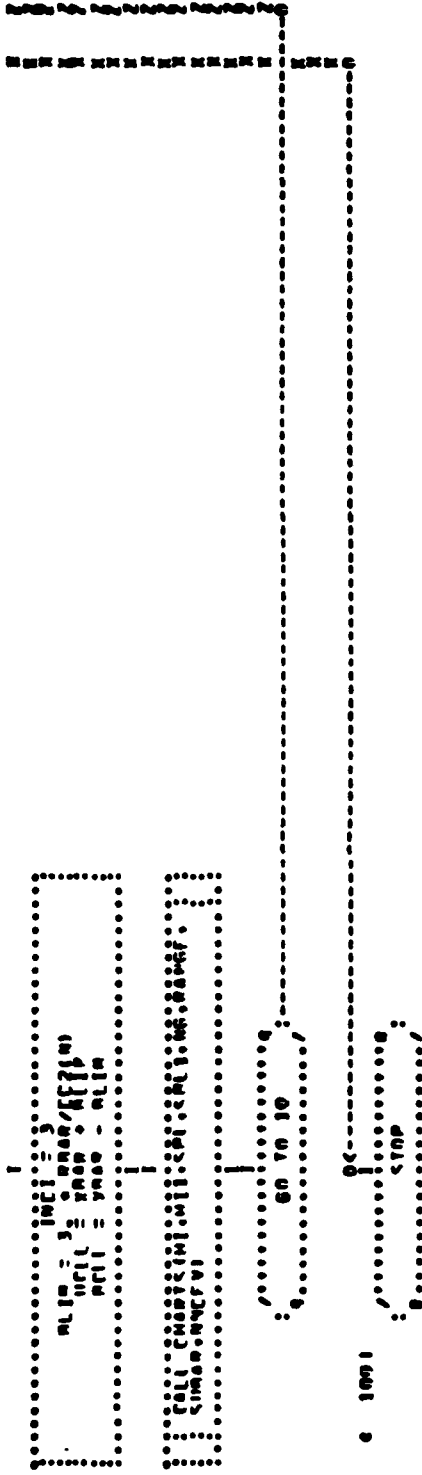


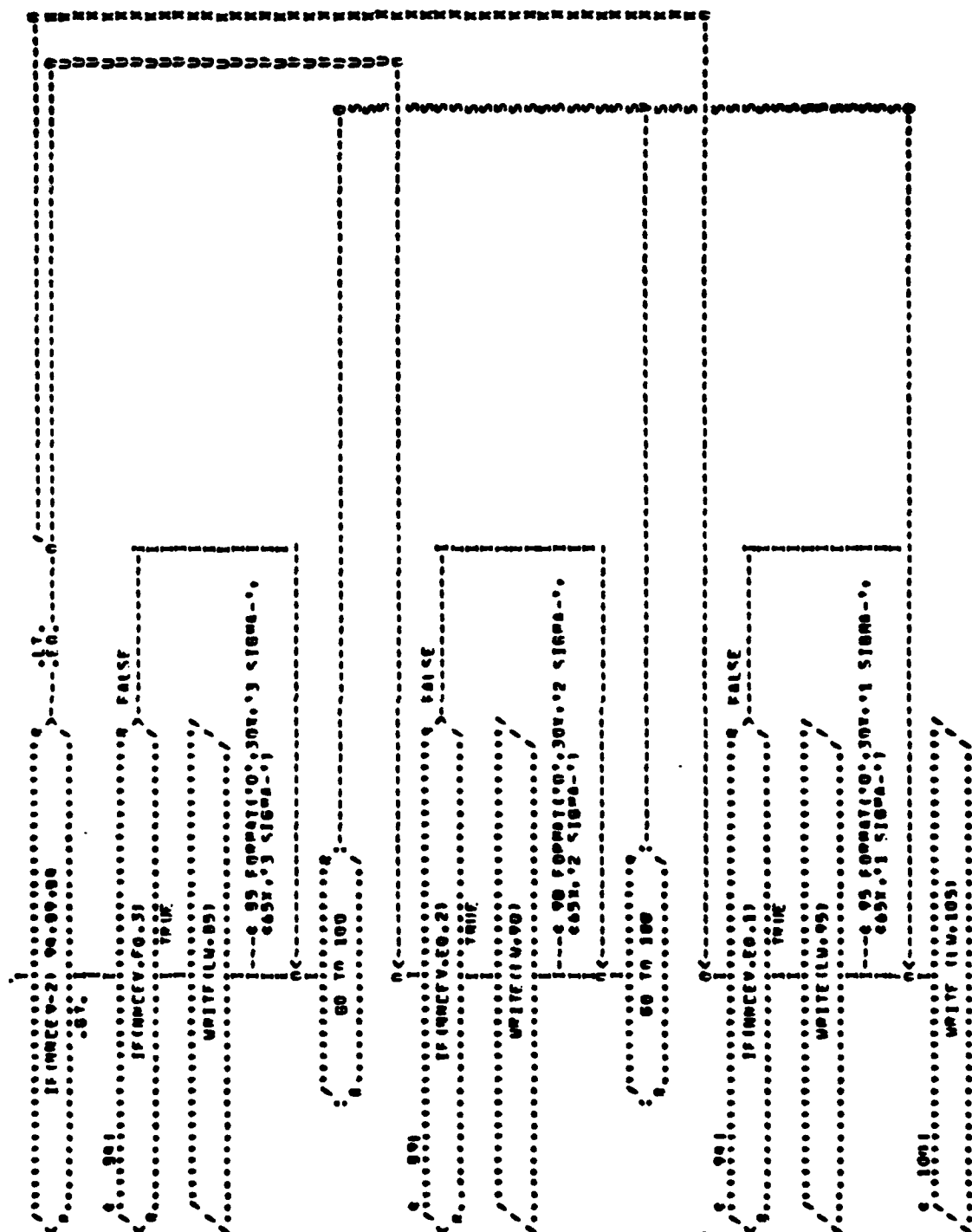


MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A









105 FORMAT(1H,29X,'RANGE CHART'
 0.02H,1H,29X,'RANGE CHART')

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/UPITF (LU,110) ARL,ARL1,ARAP,TRAP,UCL,
/URL

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--C 110 FORMAT(1H,29X,'RANGE CHART'  

  0.02H,1H,29X,'RANGE CHART')  

  0.02H,1H,29X,'RANGE CHART')  

  0.02H,1H,29X,'RANGE CHART')  

  0.02H,1H,29X,'RANGE CHART')

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/UPITF (LU,110) ARL,ARL1,ARAP,TRAP,UCL,
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--C 110 FORMAT(1H,29X,'RANGE CHART'  

  0.02H,1H,29X,'RANGE CHART')  

  0.02H,1H,29X,'RANGE CHART')  

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--C 110 FORMAT(1H,29X,'RANGE CHART'  

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/UPITF (LU,110) ARL,ARL1,ARAP,TRAP,UCL,
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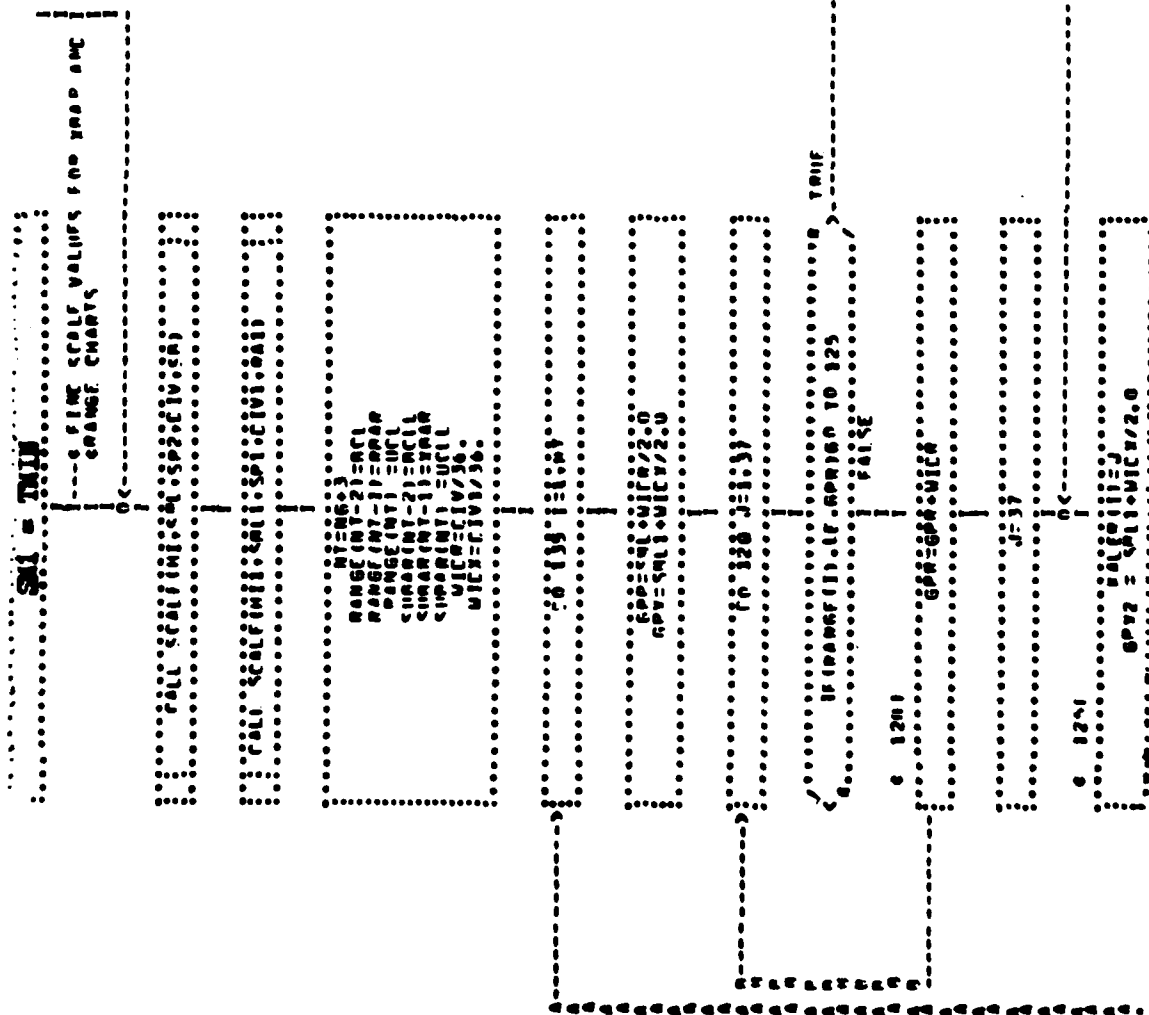
  0.02H,1H,29X,'RANGE CHART')

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/UPITF (LU,110) ARL,ARL1,ARAP,TRAP,UCL,
/URL

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140 FORMAT ('0',17X, '- YOUR
 ELIMITE MAY COME OUT')

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IF (MATH(MT-2),FO,HALF) MT-1,NO,HALF) >
  (MT-1),FO,HALF) WRITE (ILU,150)
  TRUE
```

```
MT-1),FO,HALF) WRITE (ILU,150)
  TRUE
```

```
---E 155 FORMAT ('0',17X, '- YOUR  

  ELIMITE MAY COME OUT')
```

```
---E PRINT SCALE VALUES FOR EACH BWC  

  ON CRAPYS
```

```
IF (MATH(MT-2),FO,HALF) MT-1,NO,HALF) >
  (MT-1),FO,HALF) WRITE (ILU,150)
  TRUE
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MT-1),FO,HALF) WRITE (ILU,150)
  TRUE
```

```
60 TO 175
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```
IF (MATH(MT-2),FO,HALF) MT-1,NO,HALF) >
  (MT-1),FO,HALF) WRITE (ILU,150)
  TRUE
```

```
---E 160 FORMAT ('0',17X, '- YOUR  

  ELIMITE MAY COME OUT')
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MT-1),FO,HALF) WRITE (ILU,150)
  TRUE
```

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---E 170 FORMAT ('0',17X, '- YOUR  

  ELIMITE MAY COME OUT')
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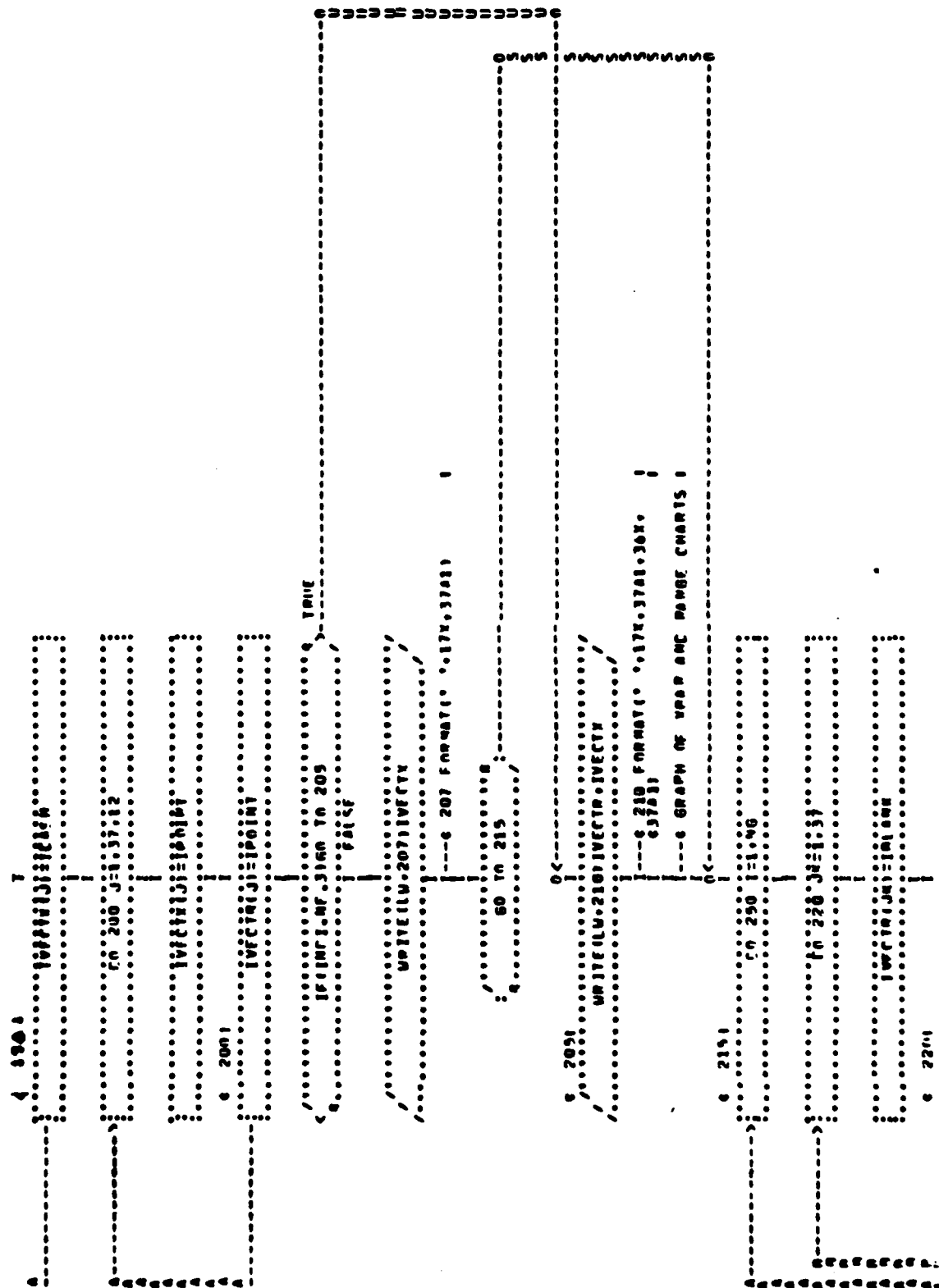
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---E PRINT SCALE VALUES  

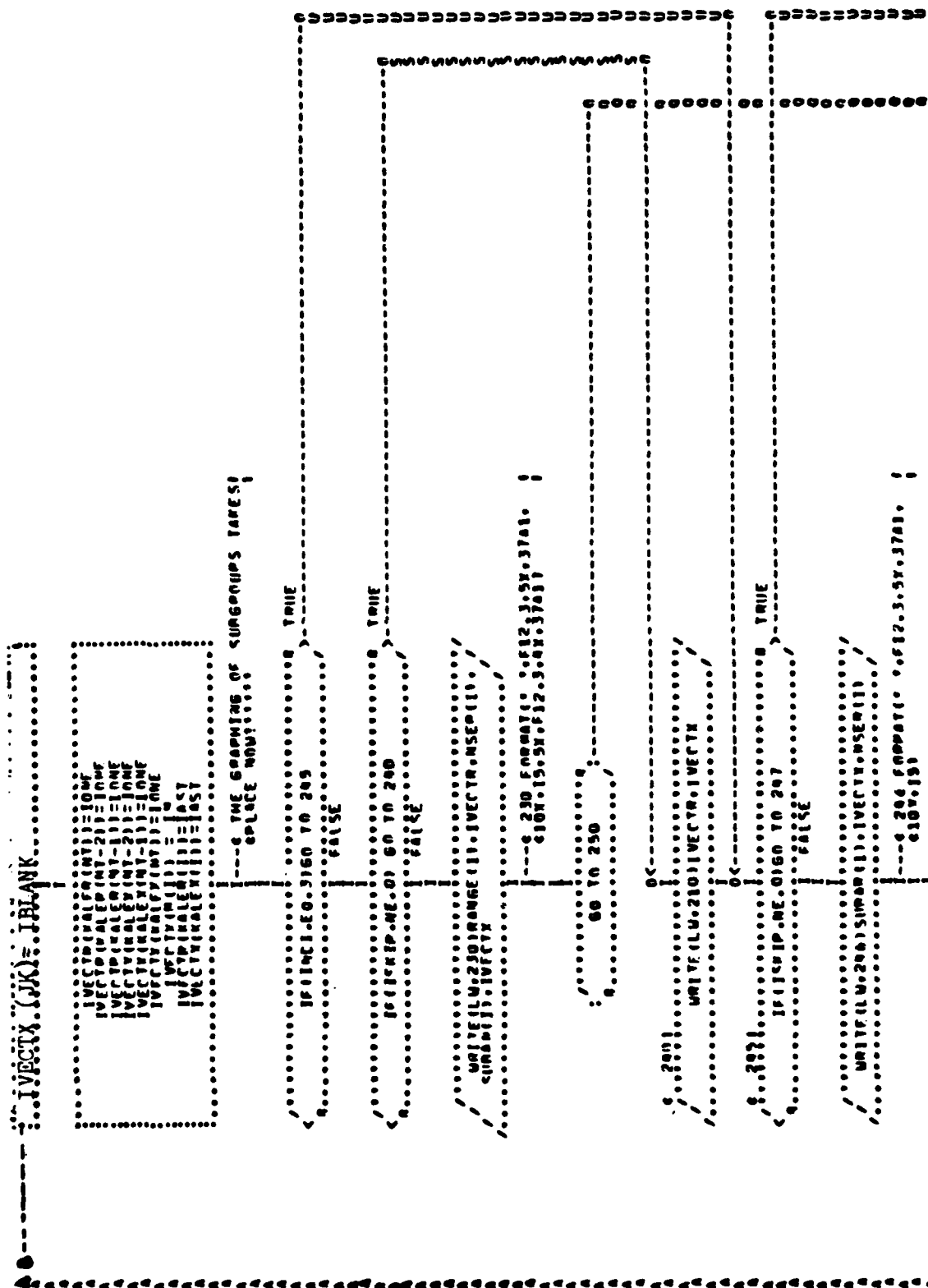
  ON CRAPYS
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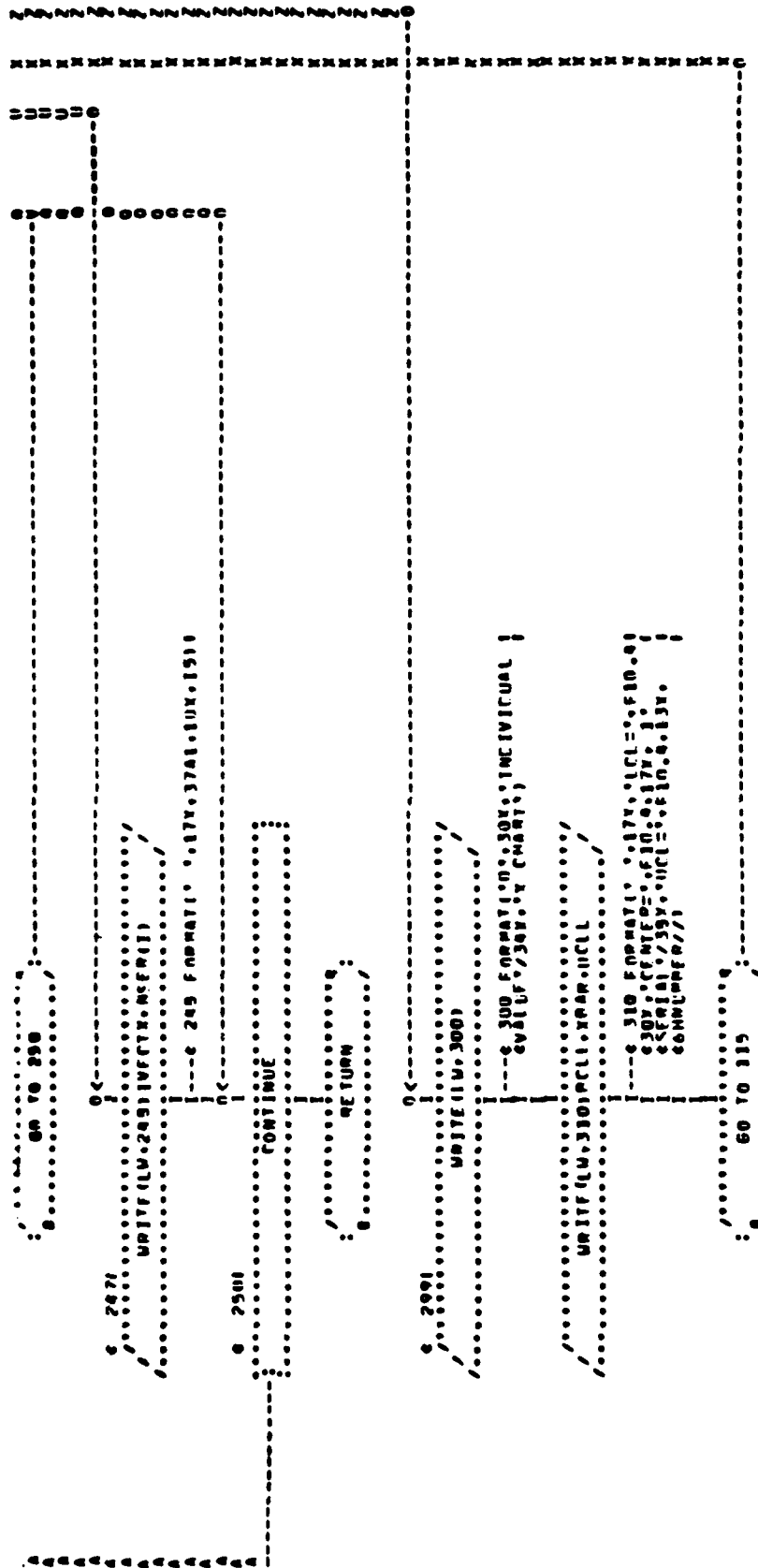
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60 TO 175
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IF (MATH(MT-2),FO,HALF) MT-1,NO,HALF) >
  (MT-1),FO,HALF) WRITE (ILU,150)
  TRUE
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MT-1),FO,HALF) WRITE (ILU,150)
  TRUE
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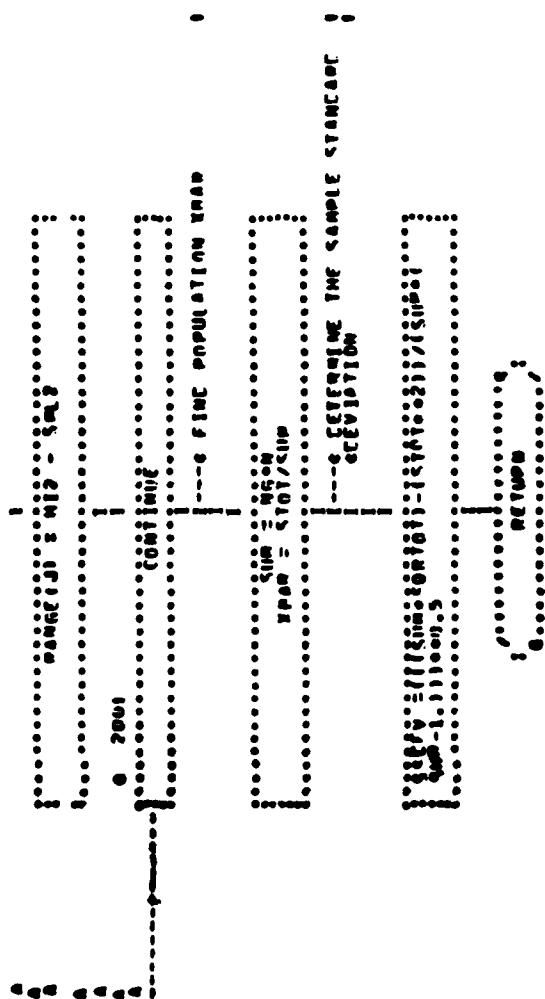




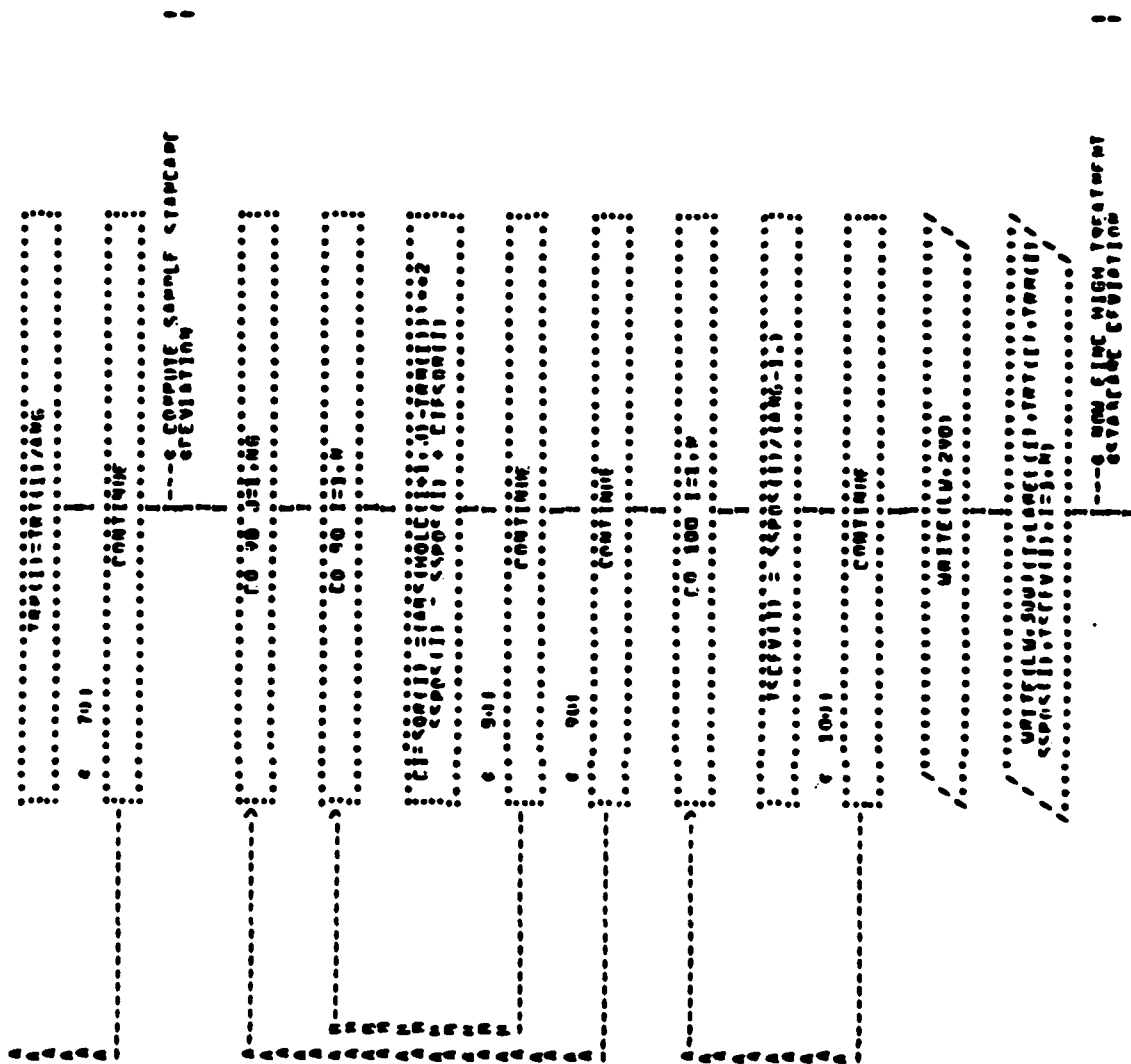

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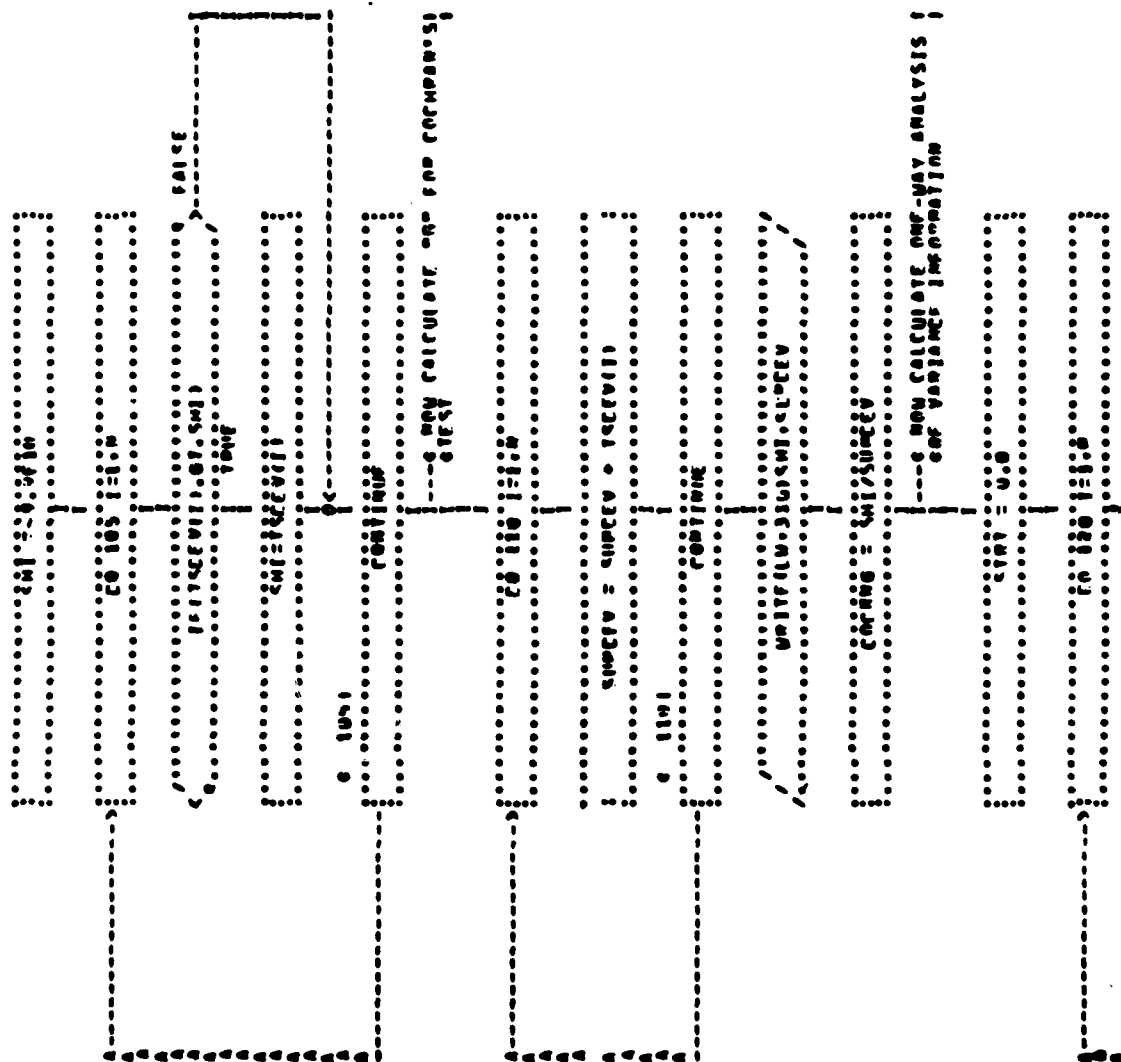
WRITE(10,13)M(J),X(J),J7=1,N)
WRITE(10,13)FORMAT('0',13,5F10.2)
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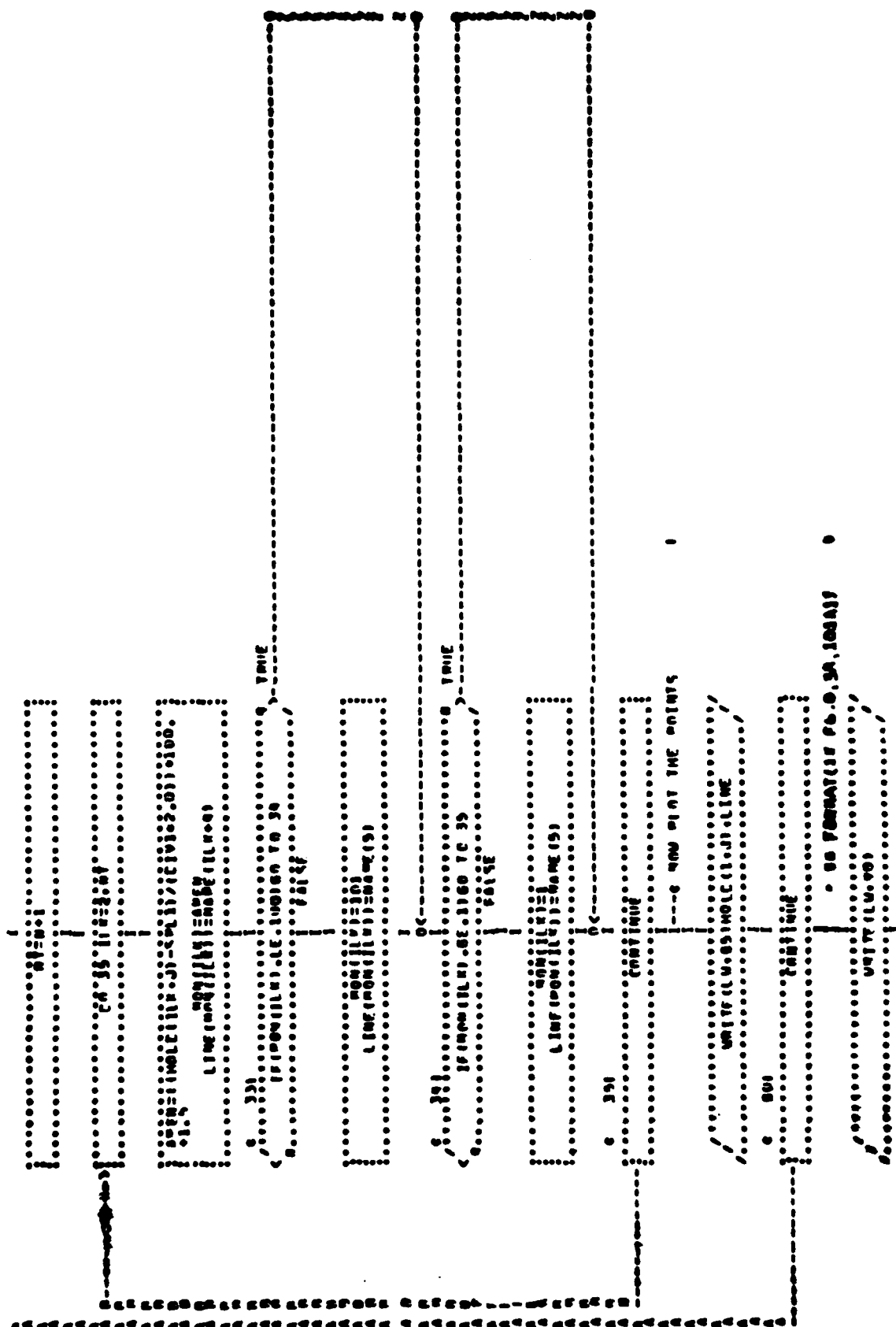
WRITE(LU,20)CFTOT,SSTOT,AMSTOT,A
/
WRITE(LU,20)CEMR,SSE,ANSE
/
WRITE(LU,20)CFTOT,SST
/
WRITE(LU,20)CFCRMB,M,MB
/
WRITE(LU,270)
/
WRITE(LU,290)
/
WRITE(LU,210)
/
WRITE(LU,220)CFTOT,SSTOT,AMSTOT,CZTOT
/
WRITE(LU,250)CPMLV,CCOIN,ACCPLM,FZMLN
/
WRITE(LU,280)CFE2,SSE2,ANSE2
/
WRITE(LU,290)CFTOT,SST
/
      WRITE(
/
/---6 PAGES FOR PRINTING

```

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[illegible]

APPENDIX D

[illegible]

```

93. C
94. C NOW CALCULATE PPAR
95. C
96. SUMR = 0.0
97. DO 50 I=1,NG
98. 50 SUMR = SUMR + PANGF(I)
99. R = NG
100. PPAR = SUMR/R
101. C
102. C NOW CALCULATE LIMITS FOR RCHARTS
103. C
104. UCL = C4(N)*PPAR
105. BCL = C3(N)*PPAR
106. C
107. C NOW CALCULATE LIMITS FOR XBAR CHARTS
108. C
109. CIG3 = A2(N)*PPAR
110. UCLL = XBAR + CIG3
111. BCLL = YBAR - CIG3
112. C
113. C REPLACE CONTROL LIMIT VALUES IF USER DESIRES TO INPUT THEM.
114. C
115. IF (IINLEQ.1) DEACILR.60) RCL. RBAR. UCL. PCLL. XBAR. UCLL
116. 60 FORNAY(6F10.0)
117. C
118. C THE FOLLOWING STATEMENTS CALL SUBROUTINE CHARTS FOR PRODUCTION OF
119. C THE DESIRED CONTROL CHARTS.
120. C
121. WRITE(LU.61)
122. 61 FORMAT('1')
123. NCEV = 3
124. CALL CHARTS (MI. MII. SML. SML1. NG. RANGE. SUMR. NCEV)
125. IF (ING. GT. 15) WRITE(LU.62)
126. 62 FORMAT(1H1)
127. NCEV = NCEV - 1
128. REC = 2./3.
129. PAN = PPAR * C3(N) / C2(N)
130. UCL = UCL - PAN
131. BCL = RBAR - 2. * PAN
132. IF (ACL. LT. 0.0) RCL = 0.0
133. UCLL = XBAR + (SIG3 * REC)
134. BCLL = YBAR - (SIG3 * REC)
135. CALL CHARTS (MI. MII. SML. SML1. AG. PANGF. SUMR. NCEV)
136. IF (INCL. EQ. 2) GO TO 95
137. IF (ING. GT. 15) WRITE(LU.63)
138. 63 FORMAT(1H1)
139. NCEV = NCEV - 1
140. UCL = UCL - PAN
141. BCL = RBAR - PAN
142. IF (ACL. LT. 0.0) RCL = 0.0
143. UCLL = XBAR + (SIG3 / 3.)
144. BCLL = YBAR - (SIG3 / 3.)
145. CALL CHARTS (MI. MII. SML. SML1. AG. PANGF. SUMR. NCEV)
146. C
147. IF (IPLY. NE. 0) GO TO 10
148. WRITE(LU.62)
149. CALL VALPLT (MI. SML1. NG)
150. C
151. GO TO 10
152. 64 STOT = 0.0
153. SRTOT = 0.0
154. INCI = 2
155. N = 3
156. NG = NG / N
157. DO 75 I=1,NG
158. DO 70 J=1,N
159. RTI = N - (N - J)
160. COMPI(J) = SUMR (N)
161. 70 CONTINUE
162. 75 CONTINUE
163. WRITE(LU.90)
164. 90 FORMAT('1')
165. GO TO 93
166. 95 NG = (NG-3) * 2
167. DO 90 J=1,NG
168. NCEV(J) = MOLT(1,J)
169. SUMR(J) = MOLT(2,J)
170. 90 CONTINUE
171. INCI = 3
172. PLI = 3. * PPAR / C2(N)
173. UCLL = XBAR + PLI
174. BCLL = YBAR - PLI
175. CALL CHARTS (MI. MII. SML. SML1. NG. PANGF. SUMR. NCEV)
176. GO TO 10
177. STOP
178. END

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1. SUBROUTINE CHARTS (HI,MII,SML,SPL,NG,RANGE,CURAR,NRCEV)
2. C
3. C THIS SUBROUTINE WILL PRODUCE X-BAR AND RANGE CHARTS FOR THE
4. C INPUT DATA. USE CAUTION WHEN MODIFYING!!!!
5. C
6. C COMMON/INPUT/LB,LU,FMT(19),TITLE(19),PNUM(19),FMT2(19)
7. C COMMON/STAT1/CONTOT,CTOT,XBAR,INCL
8. C COMMON/STAT2/ X(10),NSER(403),SCEV,COMP(99,5),MOLC(11,400)
9. C COMMON/PLOT1/UCL,RCL,RRAR,UCLL,RCLL,TMIN,M
10. C COMMON/VALU1/LABEL(11),CIV1,CPI(4)
11. C DIMENSION KALER(403),IVCTR(37),IVCTY(37),KALEX(403)
12. C 1,RANGE(403),SURAR(403),SP2(19),P(403)
13. C DATA INLANR/' ','IPOINT/' ','IONE/' ','ICASH/' ','
14. C 1BLANK/' ','IAT/' ','IM/' '
15. C WRITE(LU,50)TITLE
16. C WRITE(LU,51)PNUM
17. 91 FORMAT('0','PART NUMBER: ',19A4)
18. IF (INCL.EQ.3) GO TO 299
19. 90 FORMAT(1H0,'//19A4)
20. IF (INCL.EQ.2) WRITE(LU,93)M
21. 93 FORMAT('0','CHARTS FOR GROUPS OF '.12,' CASTINGS/FORGINGS')
22. IF (NRCEV.EQ.2) 74,99,94
23. 94 IF (NRCEV.EQ.3) WRITE(LU,95)
24. 95 FORMAT('0',30X,'3 SIGMA=''.65X,'3 SIGMA='')
25. GO TO 100
26. 99 IF (NRCEV.EQ.2) WRITE(LU,90)
27. 90 FORMAT('0',30X,'2 SIGMA=''.65X,'2 SIGMA='')
28. GO TO 100
29. 94 IF (NRCEV.EQ.1) WRITE(LU,95)
30. 95 FORMAT('0',30X,'1 SIGMA=''.65X,'1 SIGMA='')
31. 100 WRITE (LU,105)
32. 105 FORMAT(1H ,29X,'RANGE CHART',62X,'X-BAR CHART'//)
33. WRITE (LU,110) RCL,RCLL,RRAR,XBAR,UCL,UCLL
34. 110 FORMAT(' ',17X,'LCL=''.F10.4,59X,'LCL=''.F10.4/
35. 130X,'CENTER=''.F10.4,17X,'SERIAL',33X,'CENTER=''.F10.4/39X,'UCL=''.
36. 2F10.4,13X,6HNUMBER,40X,'UCL=''.F10.4//)
37. 115 IF (UCL.GT.MI) MI=UCL
38. IF (UCLL.GT.MII) MII=UCLL
39. IF (RCL.LT.CML) CML=RCL
40. IF (RCLL.LT.CML) CML=RCLL
41. IF (TMIN.LT.PCLL) SPL=TMIN
42. C
43. C FIND SCALE VALUES FOR XBAR AND RANGE CHARTS
44. C
45. CALL SCALF(MI,SPL,SP2,CIV,SB)
46. CALL SCALE(MII,SML,SPI,CIV1,WA1)
47. NT=NG+3
48. RANGE(NT-2)=RCL
49. RANGE(NT-1)=RRAR
50. RANGE(NT)=UCL
51. SURAR(NT-2)=RCLL
52. SURAR(NT-1)=RRAR
53. SURAR(NT)=UCLL
54. WICW=CIV/36.
55. WICY=CIV1/36.
56. CO 135 I=1,NT
57. GPR=SPL+WICW/2.0
58. GPX=SML+WICY/2.0
59. CO 120 J=1,37
60. IF (RANGE(I).LT.GPR) GO TO 125
61. 120 GPR=GPR+WICW
62. J=37
63. 125 KALEX(I)=J
64. GPX2 = SML+WICY/2.0
65. CO 126 J=1,37
66. IF (TMIN.LT.GPX2) GO TO 127
67. 126 GPX2 = GPX2+WICY
68. J=1
69. 127 K(I) = J
70. CO 130 J=1,37
71. IF (CURAR(I).LT.GPX) GO TO 135
72. 130 GPX=GPX+WICY
73. J=37
74. 135 KALEX(I)=J
75. C
76. C LOGIC FOR COINCIDING LIMITS
77. C
78. IF (KALER(NT-2).EQ.KALER(NT-1).OR.KALER(NT-1).EQ.
79. 1KALER(NT)) WRITE(LU,140)
80. 140 FORMAT('0',17X,' - YOUR LIMITS MAY COINCIDE')
81. IF (KALEX(NT-2).EQ.KALEX(NT-1).OR.KALEX(NT-1).EQ.

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92.      IKALEX(NT)IWRITE(ILU,150)
93.      150 FORMAT('0.0,94V.0 - YOUR LIMITS MAY COINCIDE')
94.
95.      C
96.      C PRINT SCALE VALUES FOR XBAR AND D CHARTS
97.      C
98.      IF(INCI.NE.3)GO TO 155
99.      WRITE(ILU,160)CP1
100.      GO TO 175
101.      155 WRITE(ILU,160)CP2
102.      160 FORMAT('0.9X.0(F12.3)')
103.      WRITE(ILU,170)CP1
104.      170 FORMAT('0.92V.0(F12.3)')
105.
106.      C
107.      C PRINT FOR SCALES
108.      C
109.      175 CO 199 J=1.37
110.      IVECTR(J)=ICASH
111.      190 IVECTY(J)=ICASH
112.      CO 200 J=1.37.12
113.      IVECTY(J)=IPOINT
114.      200 IVECTR(J)=IPOINT
115.      IF(INCI.NE.3)GO TO 205
116.      WRITE(ILU,207)IVECTY
117.      207 FORMAT('0.17V.37A1)')
118.      GO TO 215
119.      205 WRITE(ILU,210)IVECTR,IVECTY
120.      210 FORMAT('0.17X.37A1.36X.37A1)')
121.
122.      C
123.      C GRAPH OF XBAR AND RANGE CHARTS
124.      C
125.      215 CO 250 I=1.N6
126.      CO 220 JK=1.37
127.      IVECTR(JK)=IRLANK
128.      220 IVECTY(JK)=IRLANK
129.      IVECTR(KALEX(NT))=IONE
130.      IVECTR(KALER(NT-2))=IONE
131.      IVECTR(KALER(NT-1))=IONE
132.      IVECTY(KALEX(NT-2))=IONE
133.      IVECTY(KALEX(NT-1))=IONE
134.      IVECTY(KALEX(NT))=IONE
135.      IVECTY(M(I)) = IM
136.      IVECTR(KALER(I))=IAST
137.      IVECTY(KALER(I))=IAST
138.
139.      C
140.      C THE GRAPHING OF SUBGROUPS TAKES PLACE NOW!!!!!!
141.      C
142.      IF(INCI.CO.3)GO TO 245
143.      IF(ISHIP.NE.0) GO TO 240
144.      WRITE(ILU,230)RANGE(I),IVECTR,NSER(I),SUBAR(I),IVECTY
145.      230 FORMAT('0.F12.3.5X.37A1.10V.15.5X.F12.3.4X.37A1)')
146.      GO TO 250
147.      240 WRITE(ILU,210)IVECTR,IVECTY
148.      245 IF(ISHIP.NE.0)GO TO 247
149.      WRITE(ILU,246)SUBAR(I),IVECTY,NSER(I)
150.      246 FORMAT('0.F12.3.5X.37A1.10V.15)')
151.      GO TO 250
152.      247 WRITE(ILU,249)IVECTY,NSER(I)
153.      249 FORMAT('0.17V.37A1.10X.15)')
154.      250 CONTINUE
155.
156.      RETURN
157.      299 WRITE(ILU,303)
158.      300 FORMAT('0.0.30V.0*INDIVIDUAL VALUE*/34X.0X CHART*')
159.      WRITE(ILU,310)ACLL,XBAR,UCLL
160.      310 FORMAT('0.17V.17X.0X*CENTER=*F10.4.17X.1*SEPTAL*/39X.0XCL=*F10.4.13X.0XNUMBER//)')
161.      GO TO 115
162.      END

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```

1.      SUBROUTINE SORTS (AL,RR,CH,NA)
2.      DIMENSION CH(403)
3.      DO 50 I=1,NN
4.      IF (CH(NN).LT.AL) AL=CH(NN)
5.      IF (CH(NN).GT.RR) RR=CH(NN)
6.      50 CONTINUE
7.      RETURN
8.      END

```

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1.      SUBROUTINE SCALE (H,B,SP,RAP,SR)
2.      C
3.      C THIS SUBROUTINE MUST BE INCLUDED WITH SUBROUTINE CHARTS
4.      C FOR SUCCESSFUL CHARTING OF DATA!!!!!!
5.      C
6.      DIMENSION CRE(9),SP(4)
7.      SP(1)=R
8.      SP(4)=H
9.      SP(2)=R+(H-P)/3.
10.     SP(3)=H-(H-P)/3.
11.     SP=R
12.     RAP=SP(4)-SP(1)
13.     RETURN
14.     END

```

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1.      SUBROUTINE ASTATS (RANGE,SUMR,NB,N)
2.
3.      C THIS SUBROUTINE WILL DETERMINE THE SAMPLE AVERAGE,SUBGROUP
4.      C AVERAGES,SUBGROUP RANGES,AND SAMPLE STANDARD DEVIATION
5.      C OF THE INPUT DATA
6.
7.      COMMON/INPUT/IR,LU,FMT(19),TITLE(19),PNUM(19),FMT2(19)
8.      COMMON/STAT1/SORTOT,STOT,XBAR,INCI
9.      COMMON/STAT2/V(10),NSER(403),SSECV,COMP(95,5),HOLE(11,400)
10.     DIMENSION RANGE(403),SUBAR(403)
11.     CO 200 J=1,NB
12.
13.     C THE FOLLOWING STATEMENT READS IN THE TEST DATA.
14.     C "NSER" IS THE SERIAL NUMBER OF THE CASTING/FORGING -
15.     C IF THIS IS NOT TO BE INCLUDED, CHANGE FORMAT STATEMENTS
16.     C NUMBER 13 AND FMT.
17.
18.     IF (INCI.EQ.2) GO TO 10
19.     GO TO 14
20.     10 NSER(J)=J
21.     CO 12 I=1,N
22.     XI(I) = COMP(J,I)
23.     12 CONTINUE
24.     WRITE(LU,13)NSER(J),(X(J7),J7=1,4)
25.     13 FORMAT('0',I5,5F10.2)
26.     GO TO 25
27.     14 READ (IR,FMT)NSER(J),(X(J7),J7=1,4)
28.     24 HOLP(1,J)=NSER(J)
29.     CO 15 I=1,N
30.     HOLP(I+1,J)=X(I)
31.     15 CONTINUE
32.     WRITE(LU,20)
33.     20 FORMAT(1HC)
34.     WRITE(LU,FMT)NSER(J),(X(J7),J7=1,4)
35.
36.     C NOW SUM THE X VALUES
37.
38.     25 SUMX = 0.0
39.     SUMSQ= 0.0
40.     CO 100 I=1,N
41.     SUMX = SUMX + XI(I)
42.     SUMSQ = SUMSQ + (XI(I)**2)
43.     100 CONTINUE
44.
45.     C FIND THE GRAND SUMS
46.
47.     STOT = STOT + SUMX
48.     SORTOT= SORTOT + SUMSQ
49.
50.     C FIND THE SUBGROUP MEAN ** XBAR
51.     SUBAR(J) = SUMX/N
52.
53.     C SORT TO FIND THE HI AND LO VALUES FOR RANGE
54.
55.     HI2 = -9.9E10
56.     SML2= 9.9E10
57.     CO 150 I=1,N
58.     IF (XI(I).LT.SML2) SML2=XI(I)
59.     IF (XI(I).GT.HI2) HI2=XI(I)
60.     150 CONTINUE
61.     RANGE(J) = HI2 - SML2
62.     200 CONTINUE
63.
64.     C FIND POPULATION XBAR
65.
66.     SUM = NB*N
67.     XBAR = STOT/SUM
68.
69.     C DETERMINE THE SAMPLE STANDARD DEVIATION
70.
71.     SSECV = (((SUM-SORTOT)-(STOT**2))/(SUM*(SUM-1)))**0.5
72.     RETURN
73.     END

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1.      SUBROUTINE ANALVR(N,NB)
2.      C
3.      C THIS SUBROUTINE ANALYZES THE TEST RESULT DATA FOR EQUALITY OF MEANS
4.      C SO THAT A DETERMINATION CONCERNING CONTINUED TESTING FREQUENCY CAN
5.      C BE MADE. IT IS A GENERAL ANALYSIS OF VARIANCE THAT CAN BE USED FOR
6.      C OTHER APPLICATIONS, IF DESIRED.
7.      C
8.      C      COMMON/INPUT/LR,LW,FMT(10),TITLE(10),PNUM(10),FMT2(10)
9.      C      COMMON/STAT1/SORTOT,STOT,XBAR,INCL
10.     C      COMMON/STAT2/Y(10),NSP(40),SSCEV,COMP(95,5),HOLE(11,400)
11.     C      COMMON/VALUE1/LABFL(11),CIV1,S2(4)
12.     C      DIMENSION TRT(10),BLK(400),TRM(10),SSPOS(10),CIFSOR(10),TSCEV(10)
13.     C
14.     C SORTOT = SUM OF ALL VALUES SQUARED
15.     C STOT = SUM OF ALL VALUES
16.     C TRT(I) = TOTAL OF VALUES FOR EACH TEST POSITION (TREATMENT)
17.     C TRM(I) = MEAN VALUE FOR EACH POSITION (TREATMENT)
18.     C BLK(I) = TOTAL OF VALUES FOR EACH PIECE (BLOCK)
19.     C SSPOS(I) = SUM OF SQUARED DIFFERENCES
20.     C TSCEV(I) = TREATMENT SAMPLE STANDARD DEVIATION
21.     C SURCEV = SUM OF ALL TSCEV'S
22.     C CIFSOR(I) = SQUARED DIFFERENCE BETWEEN TEST VALUE AND MEAN OF POSITION
23.     C
24.     C INITIALIZATION
25.     C
26.     C      DO 20 I=1,N
27.     C      TRT(I) = 0.0
28.     C      TSCEV(I) = 0.0
29.     C      SSPOS(I) = 0.0
30.     C
31.     C      DO 30 J=1,NB
32.     C      BLK(J) = 0.0
33.     C
34.     C      DO 30 J=1,NB
35.     C      AN = N
36.     C      SURCEV = 0.0
37.     C
38.     C BEGIN CALCULATION
39.     C
40.     C      TOTN = AN*AN
41.     C      CON = (STOT**2)/TOTN
42.     C      SST = SORTOT - CON
43.     C      DO 40 J=1,NB
44.     C      DO 50 I=1,N
45.     C      BLK(J) = BLK(J) + HOLE(I+1,J)
46.     C      TRT(I) = TRT(I) + HOLE(I+1,J)
47.     C
48.     C      DO 50 CONTINUE
49.     C
50.     C COMPUTE TREATMENT MEANS
51.     C
52.     C      DO 70 I=1,N
53.     C      TRM(I) = TRT(I)/AN
54.     C      DO 70 CONTINUE
55.     C
56.     C COMPUTE SAMPLE STANDARD DEVIATION
57.     C
58.     C      DO 90 J=1,NB
59.     C      DO 90 I=1,N
60.     C      CIFSOR(I) = (AN*(HOLE(I+1,J)-TRM(I)))**2
61.     C      SSPOS(I) = SSPOS(I) + CIFSOR(I)
62.     C
63.     C      DO 90 CONTINUE
64.     C
65.     C      DO 100 I=1,N
66.     C      TSCEV(I) = SSPOS(I)/(AN-1.)
67.     C
68.     C      DO 100 CONTINUE
69.     C      WRITE(LW,290)
70.     C      WRITE(LW,300)(I,LABFL(I),TRT(I),TRM(I),SSPOS(I),TSCEV(I),I=1,N)
71.     C
72.     C NOW FIND HIGH TREATMENT STANDARD DEVIATION

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72.      SHI = -9.9E10
73.      CO 105 I=1,N
74.      IF (TSCEV(I).GT.SHI) SHI=TSCEV(I)
75. 105 CONTINUE
76. C
77. C      NOW CALCULATE "G" FOR COCHRAN'S TEST
78. C
79.      CO 110 I=1,N
80.      SUMCEV = SUMCEV + TSCEV(I)
81. 110 CONTINUE
82.      WRITE(10,310) SHI,SUMCEV
83.      COCRNG = SHI/SUMCEV
84. C
85. C      NOW CALCULATE ONE-WAY ANALYSIS OF VARIANCE INFORMATION
86. C
87.      STRT = 0.0
88.      CO 120 I=1,N
89.      STRT = STRT + (TRY(I)**2)
90. 120 CONTINUE
91.      SSTRT = (STRT/ANG) - COM
92.      SSE = SST - SSTRT
93.      CFTRY = AN-1
94.      CFOTY = AN*ANG-1
95.      CFRLK = ANG-1
96.      CFERR = AN * CFRLK
97.      ANSTRT = SSTRT/CFTRY
98.      AMSE = SSE/CFERR
99.      F = ANSTRT/AMSE
100. C
101. C      NOW CALCULATE TWO-WAY ANALYSIS OF VARIANCE RESULTS
102. C
103.      SRLK = 0.0
104.      CO 130 J=1,NG
105.      SRLK = SRLK + (BLK(J)**2)
106. 130 CONTINUE
107.      SSRLK = (SRLK/AN) - COM
108.      SSE2 = SST - (SSTRT+SSRLK)
109.      CF2 = CFTRY+CFRLK
110.      AMSRLK = SSRLK/CFRLK
111.      AMSE2 = SSE2/CF2
112.      F2TRY = ANSTRT/AMSE2
113.      F2RLK = AMSRLK/AMSE2
114. C
115. C      NOW PRINT OUT RESULTS
116. C
117.      WRITE(10,200)
118.      WRITE(10,210)
119.      WRITE(10,220) CFTRY,SSTRT,ANSTRT,F
120.      WRITE(10,240) CFERR,SSE,AMSE
121.      WRITE(10,250) CFOTY,SST
122.      WRITE(10,260) COCRNG,N,NG
123.      WRITE(10,270)
124.      WRITE(10,280)
125.      WRITE(10,210)
126.      WRITE(10,220) CFTRY,SSTRT,ANSTRT,F2TRY
127.      WRITE(10,230) CFRLK,SSRLK,AMSRLK,F2RLK
128.      WRITE(10,240) CF2,SSE2,AMSE2
129.      WRITE(10,250) CFOTY,SST
130.      RETURN
131. C
132. C      FORMATS FOR PRINTOUT
133. C
134. 200 FORMAT(10D,13X,'ONE-WAY ANALYSIS OF VARIANCE RESULTS',//13X,'NULL H
135. 1YPOTHESIS = ALL TREATMENT MEANS EQUAL'/10X,'ALTERNATE HYPOTH. = AT
136. 2L TREATMENT MEANS NOT EQUAL')
137. 210 FORMAT(10H,19X,'DEGREES',7X,'SUM',10X,'MEAN',6X,'SOURCE',10X,'OF',
138. 111V,'OF',9X,'SQUARE',9X,'F',20X,'FREQUENCY',5X,'SQUARES')
139. 220 FORMAT(10D,'SAMPLE POSITION',5X,F4.0,5X,F11.3,3X,F10.3,3X,F7.3)
140. 230 FORMAT(10D,'CAST',/FORG, 40,5X,F4.7,5X,F11.3,3X,F10.3,3X,F7.3)
141. 240 FORMAT(10D,'FRROR',15X,F4.0,5X,F11.3,3X,F10.3)
142. 250 FORMAT(10D,'TOTAL',15X,F4.0,5X,F11.3,1//)
143. 260 FORMAT(10D,'7MCOCHRAN'S EQUALITY OF VARIANCES <TATISTIC "G" =,F7.4
144. 1,3X,'N = ',12,3X,'N = ',13)
145. 270 FORMAT(10D,'NULL HYPOTH. = ALL BLOCK VARIANCES ARE EQUAL '/1X,
146. 1'ALT. HYPOTH. = ALL BLOCK VARIANCES ARE NOT EQUAL'//)
147. 290 FORMAT(10D,13X,'TWO-WAY ANALYSIS OF VARIANCE RESULTS',//,10X,'NULL
148. 1YPOTHESIS = 1) ALL TREATMENT MEANS ARE EQUAL',2X,'2) ALL BLOCK M
149. 2EANS ARE EQUAL'//10X,'ALTERNATE HYPOTH. = 1) ALL TREAT. MEANS ARE
150. 3NOT EQUAL',30X,'2) ALL BLOCK MEANS ARE NOT EQUAL')
151. 290 FORMAT(10H,'TREATMENT',6X,'TOTAL',9X,'MEAN',6X,'SUM SQR DIFF',3X,'
152. 1STANDARD DEV',1)
153. 300 FORMAT(10H,'13,1X,'(',40,')',9X,F10.2,3X,F10.2,4X,F10.2,5X,F10.2)
154. 310 FORMAT(10D,'HIGH STC.CEV. 2 ',F10.2,3X,'TOTAL ALL TREAT. STC. CEVS
155. 1. = ',F10.2,1//)
156.      END

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SUBROUTINE VALPLY(INI1,SML1,N6)
C
C THIS SUBROUTINE IS DESIGNED TO PLOT TEST RESULTS FROM MULTIPLE
C POSITIONS ON EACH CASTING OR FORGING. IF THIS SITUATION EXISTS,
C THE LABEL PUT ON EACH PLOTTED POINT CORRESPONDS TO THE POSITION
C WITHIN THE FORGING/CASTING FROM WHICH THE TEST SAMPLE WAS TAKEN.
C
COMMON/UIINPUT/LR,LW,FMT(19),TITLE(19),PNUM(19),FMT2(19)
COMMON/PLOT1/UCL,PCL,QBAR,UCLL,BCLL,TWIN,W
COMMON/STAT2/X(10),NUSER(403),SSECV,CORP(35,5),MOLC(11,403)
COMMON/VALUF1/LABEL(11),CIV1,SP1(4)
DIMENSION MON(11),NAME(19),LINE(101)
DATA NAME/' ','-','.',',','*','+','-','3','0','.5','2'/'
DO K=1,(K/13)+10
IF (N6.GT.15)WRITE(LW,105)
WRITE(LW,100)TITLE
WRITE(LW,110)PNUM
WRITE(LW,112)
WRITE(LW,113)
SML1=SML1-.5
CP1(1)=SML1
SPOT=SML1+(CIV1+.2)
CP1(2)=SML1+(CIV1+.05)
SP1(3)=SML1+(CIV1)
SP1(4)=SML1+(CIV1+.5)
WRITE(LW,115)CP1,SPOT
CO 90 J=J.NG
I=J-1
DO 10 K=1,101
10 LINE(K)=NAME(I)
IF(MAC(I)) 25,15,25
15 CO 20 N=1,131
20 LINE(N)=NAME(2)
25 CO 30 K=1,101,25
30 LINE(K)=NAME(3)
C
C THE PREVIOUS STATEMENTS HAVE SET UP THE TITLE OF THE PLOT
C AND SOME OF THE SCALE FACTORS. NOW WE DETERMINE THE PLOT POINTS.
C FIRST POINT
MON(1)=(TWIN-SML1)/(CIV1+.2.J)+100.+1.5
LINE(MON(1))=NAME(4)
C
C NOW DETERMINE OTHER POINTS
NT=N+1
CO 35 ILK=2,NT
AMEN=(MOLC(ILK,J)-SML1)/(CIV1+.2.O)+100.+1.5
MON(ILK)=AMEN
LINE(MON(ILK))=NAME(ILK+4)
33 IF(MON(ILK).LE.100)GO TO 34
MON(ILK)=101
LINE(MON(ILK))=NAME(5)
34 IF(MON(ILK).GE.1)GO TO 35
MON(ILK)=1
LINE(MON(ILK))=NAME(5)
35 CONTINUE
C
C NOW PLOT THE POINTS
C
WRITE(LW,95)MOLC(1,J),LINE
90 CONTINUE
95 FORMAT(1X,F6.0,3X,101A1)
WRITE(LW,90)
90 FORMAT(1H0,'//.9X,"NOTE: 1) MISSING NUMBERS INDICATE DUPLICATION.'
1/19X,"CHECK DATA (ACCORDING TO SERIAL NUMBER) FOR DUPLICATES.'
2//16X,"2) AN ASTERISK (*) INDICATES A VALUE OUT OF LIMITS.")
RETURN
100 FORMAT(1H0,19A4)
105 FORMAT(1H1)
110 FORMAT(1H0,"VALUE PLOT:"//15X,"(SERIAL NUMBER VS. INDIVIDUAL TEST M
1EASUREMENTS)"//30X,"PART NUMBER:"//19A4)
112 FORMAT(1H0,"45X,"NUMBER ON PLOT CORRESPONDS TO POSITION NUMBER"/60X
1,"(1,2,...,3 = TEST SAMPLE FROM POSITION 3 OF CASTING/FORGING)")
113 FORMAT(1H0,"SERIAL"/36X,"INDIVIDUAL TEST MEASUREMENTS"/1X,"NUMBER"
1)
115 FORMAT(1H0,1X,4(F12.3,13X),F12.3)
END

```


APPENDIX E

APPENDIX E

225

••ROOM TEMP.TENSILE TESTS-ULTIMATE LAC.PAC.(1/77 TO 5/79) CFRT
DATA

--3072112--TFE731 ENGINE PART

12 4 0 0 0

FORMAT(I5,4F10.2)

FORMAT(4A4)

POS3POS4POS5POS7

SERIAL # INPUT DATA BY POSITION

2237 191.50 190.30 195.50 190.70

2164 190.90 191.40 195.90 194.70

395 192.00 193.90 194.40 191.50

2392 199.40 200.90 197.60 195.50

404 197.60 190.10 199.00 196.40

2374 196.40 195.20 209.90 196.00

3015 195.20 196.00 190.90 199.00

3345 176.30 175.50 176.90 149.70

9900 193.60 195.20 196.40 193.60

3040 193.30 193.30 199.00 192.90

3046 200.00 201.60 199.30 202.40

3010 209.40 206.90 206.70 204.90

THE MEAN = 193.69 STANC DEV = 9.76

SUM = 9297.20 SUM OF SQUARES = 1005270.00

TREATMENT	TOTAL	MEAN	SUM SQR DIFF	STANDARD DEV
1 (POS3)	2333.60	194.47	614.07	55.92
2 (POS4)	2330.10	194.17	652.76	59.34
3 (POS5)	2329.30	194.02	929.20	64.47
4 (POS7)	2305.20	192.10	2242.98	203.91
HIGH STD.DEV. =		203.91	TOTAL ALL TREAT. STD. DEVS.=403.55	

ONE-WAY ANALYSIS OF VARIANCE RESULTS

NULL HYPOTHESIS = ALL TREATMENT MEANS EQUAL
 ALTERNATE HYPOTH. = ALL TREATMENT MEANS NOT EQUAL

SOURCE	DEGREES OF FREEDOM	SUM OF SQUARES	MEAN SQUARE	F
SAMPLE POSITION	3.	41.750	13.917	.139
ERROR	44.	4439.062	100.999	
TOTAL	47.	4480.812		

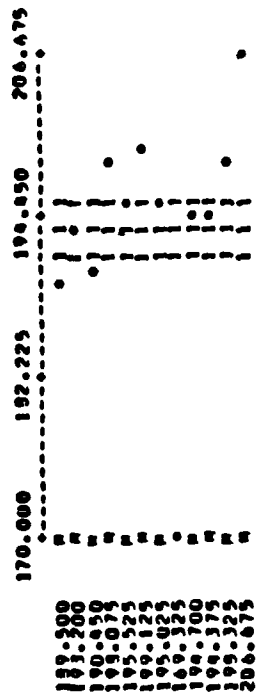
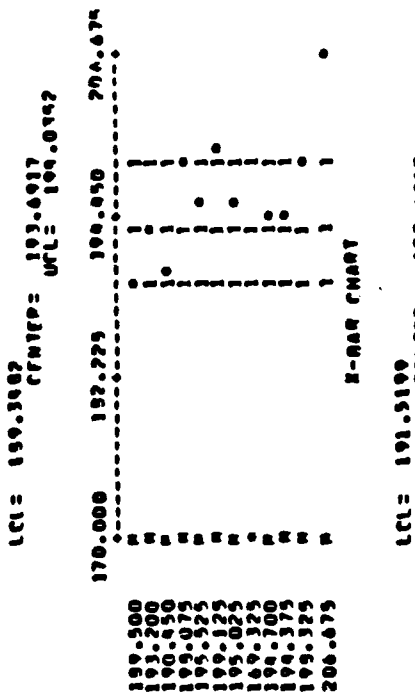
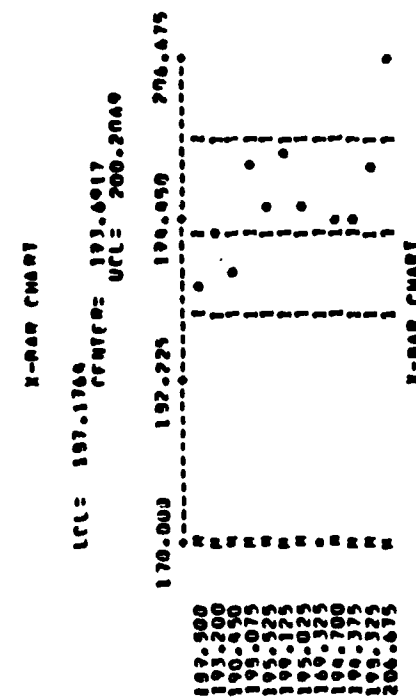
COCHRAN'S EQUALITY OF VARIANCES STATISTIC "G" = .5053 N = 4
 NULL HYPOTH. = ALL BLOCK VARIANCES ARE EQUAL K = 12
 ALT. HYPOTH. = ALL BLOCK VARIANCES ARE NOT EQUAL

TWO-WAY ANALYSIS OF VARIANCE RESULTS

NULL HYPOTHESIS = 1) ALL TREATMENT MEANS ARE EQUAL
 2) ALL BLOCK MEANS ARE EQUAL

ALTERNATE HYPOTH. = 1) ALL TREAT. MEANS ARE NOT EQUAL
 2) ALL BLOCK MEANS ARE NOT EQUAL

SOURCE	DEGREES OF FREEDOM	SUM OF SQUARES	MEAN SQUARE	F
SAMPLE POSITION	3.	41.750	13.917	.474
CAST./FORG. NO.	11.	3469.828	315.439	10.740
ERROR	33.	969.234	29.371	
TOTAL	47.	4480.812		



ROOM TEMP. TENSILE TESTS-ULTIMATE LAC-PACIFIC(1/77 TO 10/78)CNR
 --3072112--TFE731 ENGINE PART DATA

14 3 0 0 0

FORMAT(I5.3F10.2)

FORMAT(3A4)

POS3POS4POS5

SERIAL # INPUT DATA BY POSITION

2164 192.10 193.30 190.20

395 192.70 191.00 189.40

2392 196.10 191.40 192.90

2361 194.50 196.20 192.10

3004 193.43 194.90 193.10

3443 198.00 195.70 192.30

1011 196.90 194.10 195.30

1049 196.50 197.50 193.90

900 206.10 203.30 202.70

3337 196.30 195.10 193.90

3369 194.90 194.90 192.00

3040 192.70 195.30 193.80

3046 200.90 201.60 200.60

3010 205.50 204.70 204.90

THE MEAN = 196.01 STANC DEV = 4.39

SUM = 9232.63 SUM OF SQUARES =1614509.40

TREATMENT	TOTAL	MEAN	SUM SQR DIFF	STANDARD DEV
1 (POS3)	2756.53	196.99	256.30	19.72
2 (POS4)	2749.00	196.36	221.71	17.05
3 (POS5)	2727.10	194.79	279.13	21.47
HIGH STD.DEV. =		21.47	TOTAL ALL TREAT. STD. DEVS. = 58.24	

ONE-WAY ANALYSIS OF VARIANCE RESULTS

NULL HYPOTHESIS = ALL TREATMENT MEANS EQUAL
 ALTERNATE HYPOTH. = ALL TREATMENT MEANS NOT EQUAL

SOURCE	DEGREES OF FREEDOM	SUM OF SQUARES	MEAN SQUARE	F
SAMPLE POSITION	2.	33.344	16.672	.959
ERROR	39.	757.219	19.416	
TOTAL	41.	790.562		

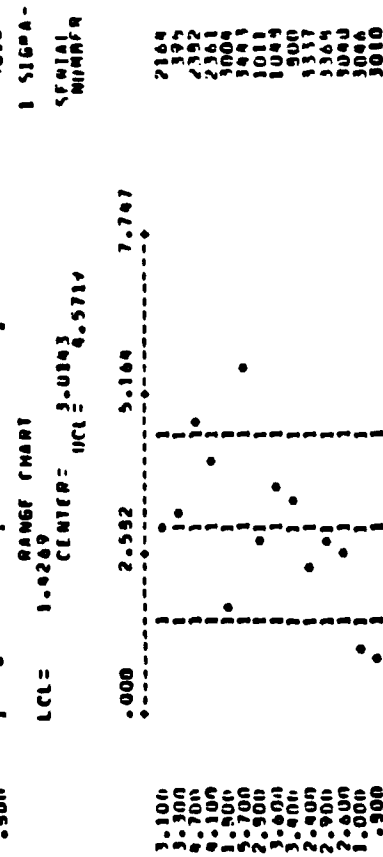
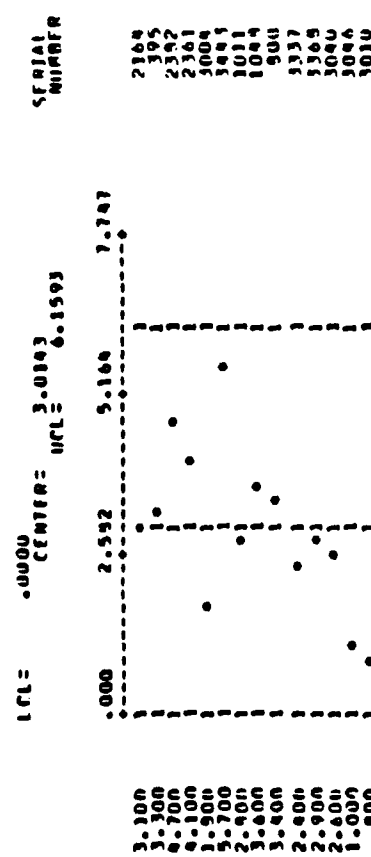
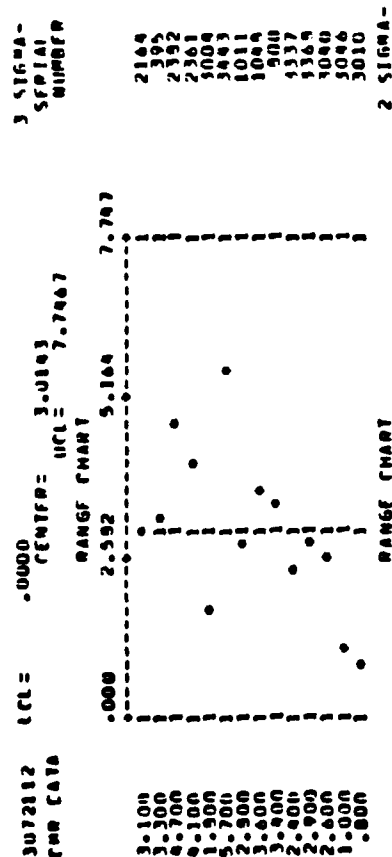
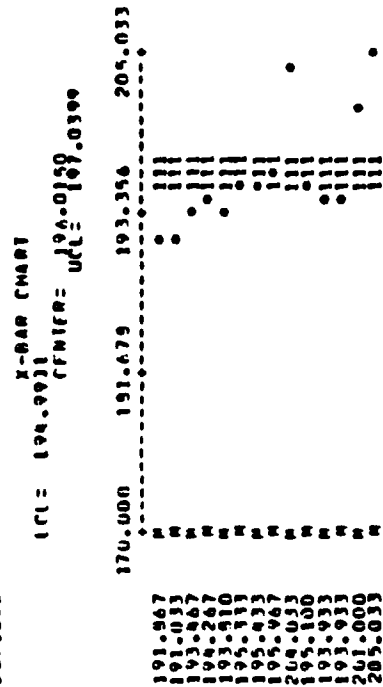
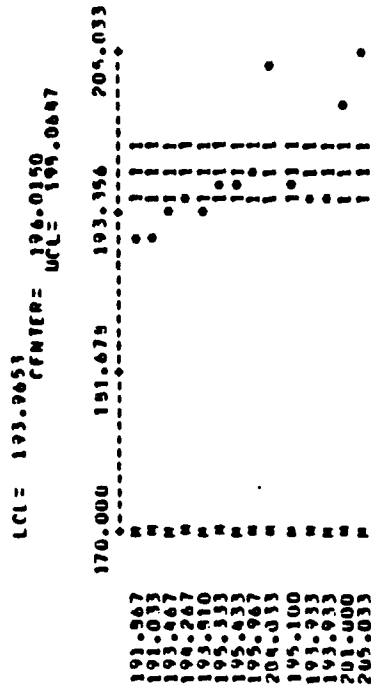
COCHRAN'S EQUALITY OF VARIANCES STATISTIC "G" = .3697 K = 14
 NULL HYPOTH. = ALL BLOCK VARIANCES ARE EQUAL N = 3
 ALT. HYPOTH. = ALL BLOCK VARIANCES ARE NOT EQUAL

TWO-WAY ANALYSIS OF VARIANCE RESULTS

NULL HYPOTHESIS = 1) ALL TREATMENT MEANS ARE EQUAL
 2) ALL BLOCK MEANS ARE EQUAL

ALTERNATE HYPOTH. = 1) ALL TREAT. MEANS ARE NOT EQUAL
 2) ALL BLOCK MEANS ARE NOT EQUAL

SOURCE	DEGREES OF FREEDOM	SUM OF SQUARES	MEAN SQUARE	F
SAMPLE POSITION	2.	33.344	16.672	9.520
CAST./FORG. NO.	13.	711.697	54.745	31.261
ERROR	26.	45.531	1.751	
TOTAL	41.	790.562		



ROOM TEMP. TENSILE TESTS-ULTIMATE LAC-PACIFIC 11/77 TO 10/79 (CMR DATA)

VALUE PLOT:

(SERIAL NUMBER VS. INDIVIDUAL TEST MEASUREMENTS)

PART NUMBER: --3072112--TFE731 ENGINE PART

NUMBER ON PLOT CORRESPONDS TO POSITION NUMBER

(I.E., 3 = TEST SAMPLE FROM POSITION 3 OF CASTING/FORGING

SERIAL
NUMBER

INDIVIDUAL TEST MEASUREMENTS

	185.000	192.517	200.033	217.550	235.067
2164	M	5	3		
304	M	5	3		
2142	M	5	3		
2161	M	5	3		
3004	M	5	3		
3003	M	5	3		
3011	M	5	3		
3004	M	5	3		
3001	M	5	3		
3317	M	5	3		
3369	M	5	3		
3040	M	5	3		
3046	M	5	3		
3010	M	5	3		

ROOM TEMP. TENSILE TESTS-ULTIMATE LAC-PAC. (11/77 TO 5/79) (CERT DATA)

VALUE PLOT:

(SERIAL NUMBER VS. INDIVIDUAL TEST MEASUREMENTS)

PART NUMBER: --3072112--TFE731 ENGINE PART

NUMBER ON PLOT CORRESPONDS TO POSITION NUMBER

(I.E., 3 = TEST SAMPLE FROM POSITION 3 OF CASTING/FORGING

SERIAL
NUMBER

INDIVIDUAL TEST MEASUREMENTS

	185.010	193.337	201.675	220.012	239.350
2237	M	5	7		
2164	M	5	7		
304	M	5	7		
2142	M	5	7		
4008	M	5	7		
2374	M	5	7		
43015	M	5	7		
43345	M	5	7		
3040	M	5	7		
3046	M	5	7		
3010	M	5	7		

NOTE: 1) MISSING NUMBERS INDICATE DUPLICATION.

CHECK DATA (ACCORDING TO SERIAL NUMBER) FOR DUPLICATES.

2) AN ASTERISK (*) INDICATES A VALUE OUT OF LIMITS.

DETERMINATION OF A DIFFERENCE IN TESTING FOR
 PART NUMBER: 3072112 LACISH PACIFIC TESTING VS. ARC CO. TESTING
 DATA FROM 1/77 TO 5/79 (ULTIMATE)

SER. NO.	CERT DATA	CMR DATA	DIFFERENCE	DIFF. SCORE
2164	193.200	191.867	1.3330	1.7769
395	190.450	191.033	-.5830	.3399
2392	198.075	193.467	4.6080	21.2337
82374	199.125	194.267	4.8580	23.6002
93015	195.025	193.810	1.2150	1.4762
93345	169.325	195.333	-26.0080	676.4160
98800	194.700	204.033	-9.3330	87.1049
3040	194.375	193.933	.4420	.1934
3046	198.325	201.000	-2.6750	7.1556
3010	206.675	205.033	1.6420	2.6962
TOTAL			-24.5010	821.9949
AVERAGE DIFFERENCE =	-2.4501	CEG. OF FREEDOM =	9	
SAMPLE VARIANCE =	84.663	SAMPLE STANDARD DEV. =	9.20	

THE "T" STATISTIC FOR TESTING THE DIFFERENCE IN THE TWO TESTING MEANS = -.9420
 NULL HYPOTH.: $\mu_1 - \mu_2 = \text{CMU}$
 ALT. HYPOTH.: $\mu_1 - \mu_2 \neq \text{CMU}$
 ASSUMPTION: THE DISTRIBUTION UNDERLYING THE DIFFERENCES IS NORMAL.

ROOM TEMP. TENSILE TESTS-RELONG. LAC. PAC. (1/77 TO 5/79) CERT
 --3072112--TFE731 ENGINE PART DATA

12 4 0 0 0

FORMAT(I5.4F10.2)

FORMAT(4A4)

POS3POS4POS5POS7

SERIAL # INPUT DATA BY POSITION

2237 17.00 17.00 17.00 12.00

2164 21.30 20.00 20.00 22.00

395 23.00 23.00 15.00 23.00

2392 20.00 19.00 20.00 16.00

404 20.00 14.00 26.00 23.00

2374 19.00 15.00 19.00 19.00

3015 24.00 24.00 20.00 23.00

3345 12.00 12.00 13.00 4.00

9900 19.00 21.00 20.00 19.00

3040 22.00 22.00 22.00 20.00

3046 26.00 24.00 16.00 25.00

3010 13.00 21.00 21.00 24.00

THE MEAN = 19.29 STANC DEV = 4.39

SUM = 925.30 SUM OF SQUARES = 19741.69

TREATMENT	TOTAL	MEAN	SUM SQ. DIFF	STANDARD DEV
1 (POS3)	236.30	19.69	199.55	17.23
2 (POS4)	231.00	19.25	179.25	16.20
3 (POS5)	229.00	19.00	132.00	12.00
4 (POS7)	230.00	19.17	401.67	36.92
HIGH STD.DEV. = 36.52 TOTAL ALL TREAT. STD. DEVS. = 81.95				

ONE-WAY ANALYSIS OF VARIANCE RESULTS

NULL HYPOTHESIS = ALL TREATMENT MEANS EQUAL
 ALTERNATE HYPOTH. = ALL TREATMENT MEANS NOT EQUAL

SOURCE	DEGREES OF FREEDOM	SUM OF SQUARES	MEAN SQUARE	F
SAMPLE POSITION	3.	3.139	1.046	.051
ERROR	44.	901.466	20.499	
TOTAL	47.	904.605		

COCHRAN'S EQUALITY OF VARIANCES STATISTIC W^* = .4456 $W = 4$
 NULL HYPOTH. = ALL BLOCK VARIANCES ARE EQUAL $K = 12$
 ALT. HYPOTH. = ALL BLOCK VARIANCES ARE NOT EQUAL

TWO-WAY ANALYSIS OF VARIANCE RESULTS

NULL HYPOTHESIS = 1) ALL TREATMENT MEANS ARE EQUAL
 2) ALL BLOCK MEANS ARE EQUAL
 ALTERNATE HYPOTH. = 1) ALL TREAT. MEANS ARE NOT EQUAL
 2) ALL BLOCK MEANS ARE NOT EQUAL

SOURCE	DEGREES OF FREEDOM	SUM OF SQUARES	MEAN SQUARE	F
SAMPLE POSITION	3.	3.139	1.046	.094
CAST./FORG. NO.	11.	535.637	48.694	4.393
ERROR	33.	365.929	11.096	
TOTAL	47.	904.605		

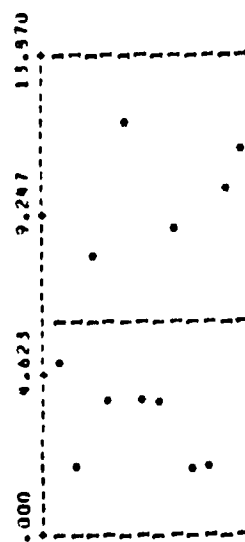
3072312
CERT DATA

1 SIGMA-

RANGE CHART

LCL = .000
CENTER = 6.0933
UCL = 13.970

5.000
2.000
4.000
12.000
4.000
9.000
2.000
2.000
10.000
11.000

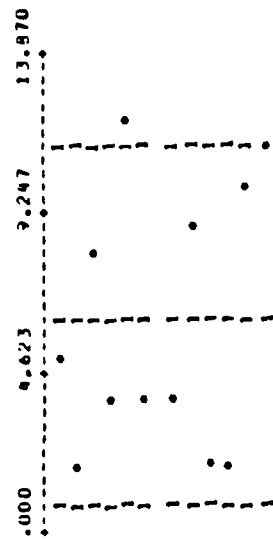
SERIAL
NUMBER

2237
2164
195
2392
404
2374
93015
93345
94400
1040
1046
3010

RANGE CHART

LCL = .000
CENTER = 6.0933
UCL = 13.970

5.000
2.000
4.000
12.000
4.000
9.000
2.000
2.000
10.000
11.000

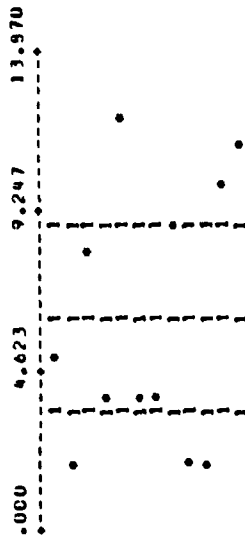
SERIAL
NUMBER

2237
2164
195
2392
404
2374
93015
93345
94400
1040
1046
3010

RANGE CHART

LCL = 3.4946
CENTER = 6.0933
UCL = 9.6726

5.000
2.000
4.000
12.000
4.000
9.000
2.000
2.000
10.000
11.000

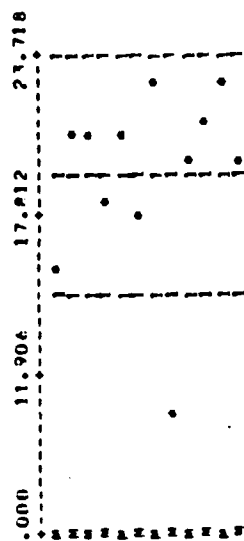
SERIAL
NUMBER

2237
2164
195
2392
404
2374
93015
93345
94400
1040
1046
3010

X-RAR CHART

LCL = 14.3163
CENTER = 17.412
UCL = 23.718

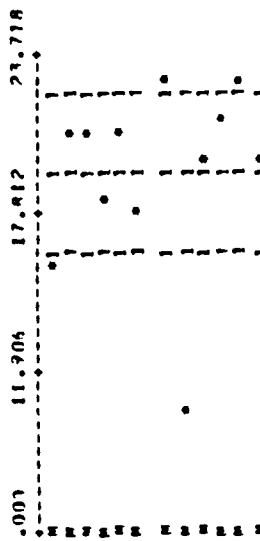
15.750
20.425
21.000
19.500
20.750
17.750
22.750
10.250
19.750
21.500
22.750
19.750



X-RAR CHART

LCL = 16.3165
CENTER = 17.412
UCL = 22.2376

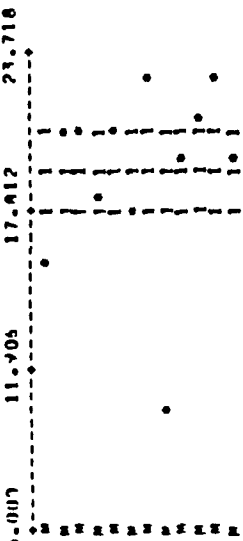
15.750
20.425
21.000
19.500
20.750
17.750
22.750
10.250
19.750
21.500
22.750
19.750



X-RAR CHART

LCL = 17.7969
CENTER = 17.412
UCL = 20.7578

15.750
20.425
21.000
19.500
20.750
17.750
22.750
10.250
19.750
21.500
22.750
19.750



ROOM TEMP. TENSILE TESTS--BELONG LAC-PACIFIC(1/77 TO 10/79) CWR
 --3072112--TFE731 ENGINE PART CAT A

14 3 0 0 0

FORMAT(I5,3F10.2)

FORMAT(3A4)

POS3POS4POS5

SERIAL #

INPUT DATA BY POSITION

2164	19.50	21.20	19.90
395	21.60	20.70	20.70
2392	16.20	16.90	19.40
2361	19.40	21.90	20.90
3004	22.47	22.90	21.90
3443	22.70	23.20	22.20
1011	22.90	22.90	22.90
1049	21.30	22.50	21.90
900	25.00	22.50	23.90
3337	22.70	25.70	24.00
3369	22.00	24.20	24.70
3040	21.00	23.60	24.60
3046	21.60	25.50	25.50
3010	21.40	22.90	26.00

THE MEAN = 22.16 STANE DEV = 2.26

SUM = 930.67 SUM OF SQUARES = 20831.30

TREATMENT	TOTAL	MEAN	SUM SQR DIFF	STANDARD DEV
1 (POS3)	299.77	21.34	59.75	4.60
2 (POS4)	316.20	22.59	61.99	4.77
3 (POS5)	315.70	22.55	72.97	5.61
HIGH STD.DEV. =	5.61	TOTAL ALL TREAT. STD. DEVS. = 24.99		

ONE-WAY ANALYSIS OF VARIANCE RESULTS

NULL HYPOTHESIS = ALL TREATMENT MEANS EQUAL
 ALTERNATE HYPOTH. = ALL TREATMENT MEANS NOT EQUAL

SOURCE	DEGREES OF FREEDOM	SUM OF SQUARES	MEAN SQUARE	F
SAMPLE POSITION	2.	14.064	7.032	1.409
ERROR	39.	194.699	4.992	
TOTAL	41.	209.763		

COCHRAN'S EQUALITY OF VARIANCES STATISTIC "G" = .3749 $\nu = 14$
 NULL HYPOTH. = ALL BLOCK VARIANCES ARE EQUAL $N = 3$
 ALT. HYPOTH. = ALL BLOCK VARIANCES ARE NOT EQUAL

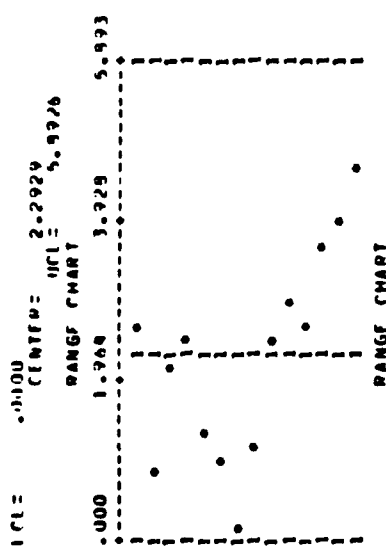
TWO-WAY ANALYSIS OF VARIANCE RESULTS

NULL HYPOTHESIS = 1) ALL TREATMENT MEANS ARE EQUAL
 2) ALL BLOCK MEANS ARE EQUAL

ALTERNATE HYPOTH. = 1) ALL TREAT. MEANS ARE NOT EQUAL
 2) ALL BLOCK MEANS ARE NOT EQUAL

SOURCE	DEGREES OF FREEDOM	SUM OF SQUARES	MEAN SQUARE	F
SAMPLE POSITION	2.	14.064	7.032	4.769
CAST./FORG. NO.	13.	156.356	12.027	9.156
ERROR	26.	39.342	1.475	
TOTAL	41.	209.763		

3072112
CNR DATA



3 SIGMA-
SERIAL
NUMBER

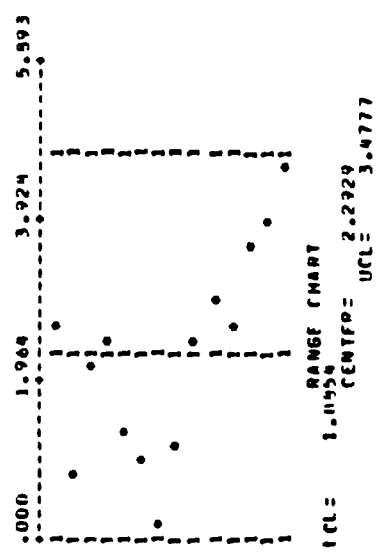
2164
395
2342
2361
3004
3443
1011
1044
900
3337
3364
3040
3046
3010

2 SIGMA-



SERIAL
NUMBER

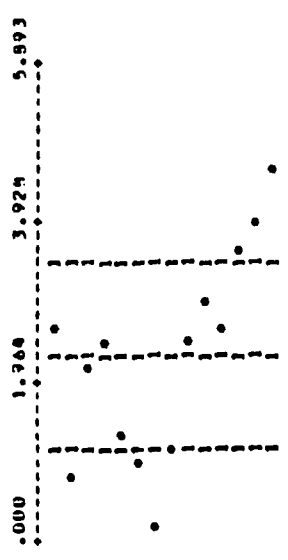
2.700
2.900
2.200
2.400
1.500
1.000
1.200
2.500
3.000
2.700
3.600
3.500
4.600



1 SIGMA-

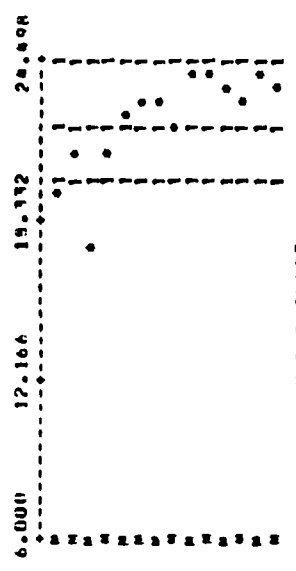
SERIAL
NUMBER

2.700
2.900
2.200
2.400
1.500
1.000
1.200
2.500
3.000
2.700
3.600
3.500
4.600



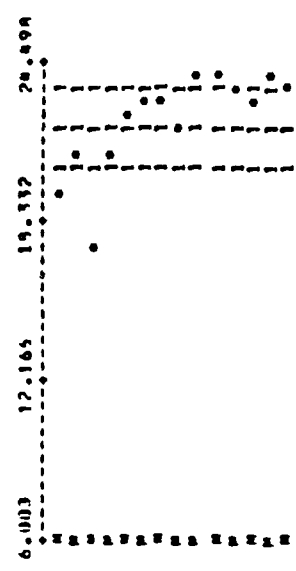
2164
395
2342
2361
3004
3443
1011
1044
900
3337
3364
3040
3046
3010

LCL = 12.9231 CENTER = 22.1588 UCL = 24.0975
X-RAR CHART



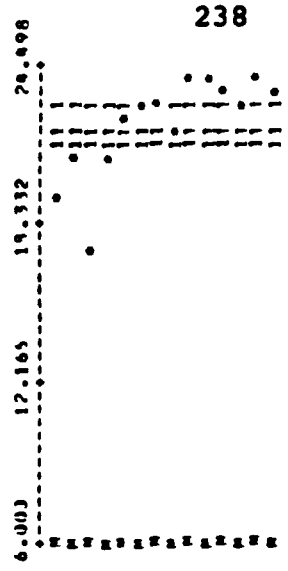
X-RAR CHART

LCL = 20.5997 CENTER = 22.1588 UCL = 23.7180
X-RAR CHART



X-RAR CHART

LCL = 21.3792 CENTER = 22.1588 UCL = 22.9384
X-RAR CHART



ROOM TEMP. TENSILE TESTS--BILONG LAC-PARTICULAR 77 TO 80/79) FOR DATA

VALUE PLOT:

IS: OIAL NUMBER VS. INDIVIDUAL TEST MEASUREMENTS)

PART NUMBER: --3072882--T6E733 (ENGINE PART

NUMBER ON PLOT CORRESPONDS TO POSITION NUMBER

(I.F.. 3 = TEST SAMPLE FROM POSITION 3 OF CASTING/FORGING

INDIVIDUAL TEST MEASUREMENTS

SERIAL NUMBER	1.00U	11.209	19.099	29.796	37.995
2100.	M				
2101.	M				
2102.	M				
2103.	M				
2104.	M				
2105.	M				
2106.	M				
2107.	M				
2108.	M				
2109.	M				
2110.	M				
2111.	M				
2112.	M				
2113.	M				
2114.	M				
2115.	M				
2116.	M				
2117.	M				
2118.	M				
2119.	M				
2120.	M				
2121.	M				
2122.	M				
2123.	M				
2124.	M				
2125.	M				
2126.	M				
2127.	M				
2128.	M				
2129.	M				
2130.	M				

ROOM TEMP. TENSILE TESTS--BILONG LAC-PAC-11/77 TO 2/79)CENT DATA

VALUE PLOT:

IS: OIAL NUMBER VS. INDIVIDUAL TEST MEASUREMENTS)

PART NUMBER: --3072112--T6E731 (ENGINE PART

NUMBER ON PLOT CORRESPONDS TO POSITION NUMBER

(I.F.. 3 = TEST SAMPLE FROM POSITION 3 OF CASTING/FORGING

INDIVIDUAL TEST MEASUREMENTS

SERIAL NUMBER	1.00U	9.459	19.719	27.577	36.436
2237.	M				
2238.	M				
2239.	M				
2240.	M				
2241.	M				
2242.	M				
2243.	M				
2244.	M				
2245.	M				
2246.	M				
2247.	M				
2248.	M				
2249.	M				
2250.	M				
2251.	M				
2252.	M				
2253.	M				
2254.	M				
2255.	M				
2256.	M				
2257.	M				
2258.	M				
2259.	M				
2260.	M				
2261.	M				
2262.	M				
2263.	M				
2264.	M				
2265.	M				
2266.	M				
2267.	M				
2268.	M				
2269.	M				
2270.	M				

NOTE: 1) MISSING NUMBERS INDICATE DUPLICATION.
CHECK DATA (ACCORDING TO SERIAL NUMBER) FOR DUPLICATES.

2) AN ASTERISK (*) INDICATES A VALUE OUT OF LIMITS.

DETERMINATION OF A DIFFERENCE IN TESTING FOR
 PART NUMBER: 3072112 LACISH PACIFIC TESTING VS. ARC CO. TESTING
 DATA FROM 1/77 TO 5/79 (2ELONG. DATA)

SER.NO.	CEPT DATA	CMR DATA	DIFFERENCE	DIFF.SORD
2164	20.925	19.500	1.3250	1.7556
395	21.000	21.000	.0000	.0000
2392	19.500	17.133	1.3670	1.9697
92374	17.750	20.667	-2.9170	9.5099
93015	22.750	22.257	.4930	.2430
93345	10.250	22.700	-12.4500	155.0025
99900	19.750	23.900	-4.0500	16.4025
3040	21.500	23.067	-1.5670	2.4555
3046	22.750	24.200	-1.4500	2.1025
3010	19.750	23.433	-3.6830	13.5645
TOTAL			-22.9320	201.9037
AVERAGE DIFFERENCE = -2.2932 CEG. OF FREEDOM = 9				
SAMPLE VARIANCE = 16.591 SAMPLE STANDARD DEV. = 4.07				

THE "T" STATISTIC FOR TESTING THE DIFFERENCE IN THE TWO TESTING MEANS = -1.7804
 NULL HYPOTH.: $\mu_1 - \mu_2 = 0$
 ALT. HYPOTH.: $\mu_1 - \mu_2 \neq 0$
 ASSUMPTION: THE DISTRIBUTION UNDERLYING THE DIFFERENCES IS NORMAL.

**ROOM TEMP.TENSILE TESTS-8REC.AREA LAC.PAC.(1/77 TO 5/79) CERT
DATA

--3072112--TFE731 ENGINE PART

12 4 0 0 0

FORMAT(I5.4F10.2)

FORMAT(4A4)

POS3POS4POS5POS7

SERIAL N

INPUT DATA BY POSITION

2237	19.20	19.20	19.20	16.00
2164	17.60	20.50	22.30	24.60
395	27.90	24.70	15.20	19.00
2392	23.10	16.70	21.00	19.30
404	22.40	13.10	26.70	20.30
2374	20.20	12.40	17.60	20.20
3015	22.30	23.70	21.50	24.00
3345	14.40	12.20	15.20	9.60
9900	17.50	19.50	19.90	19.20
3040	23.70	21.50	20.40	21.50
3046	29.20	22.60	19.90	29.20
3010	22.40	20.90	25.50	29.90

THE MEAN = 20.33 STANC DEV = 4.54

SUM = 975.90 SUM OF SQUARES = 20907.36

TREATMENT	TOTAL	MEAN	SUM SQR DIFF	STANDARD DEV
1 (POS3)	259.90	21.57	204.04	18.95
2 (POS4)	226.00	19.93	210.11	19.10
3 (POS5)	241.20	20.10	141.69	12.89
4 (POS7)	249.70	20.91	365.47	33.22

HIGH STD.DEV. = 33.22 TOTAL ALL TREAT. STD. DEVS. = 33.75

ONE-WAY ANALYSIS OF VARIANCE RESULTS

NULL HYPOTHESIS = ALL TREATMENT MEANS EQUAL
 ALTERNATE HYPOTH. = ALL TREATMENT MEANS NOT EQUAL

SOURCE	DEGREES OF FREEDOM	SUM OF SQUARES	MEAN SQUARE	F
SAMPLE POSITION	3.	48.961	16.297	.779
ERROR	44.	921.299	20.939	
TOTAL	47.	970.160		

COCHRAN'S EQUALITY OF VARIANCES STATISTIC "G" = .3967 N = 4
 NULL HYPOTH. = ALL BLOCK VARIANCES ARE EQUAL N = 12
 ALT. HYPOTH. = ALL BLOCK VARIANCES ARE NOT EQUAL

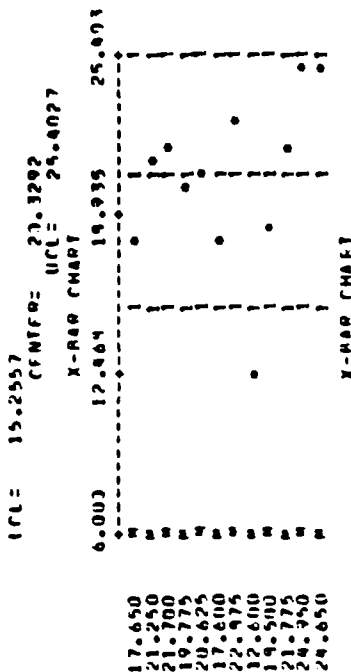
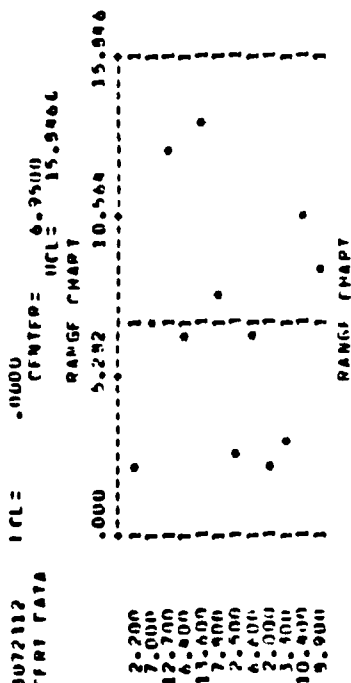
TWO-WAY ANALYSIS OF VARIANCE RESULTS

NULL HYPOTHESIS = 1) ALL TREATMENT MEANS ARE EQUAL
 2) ALL BLOCK MEANS ARE EQUAL

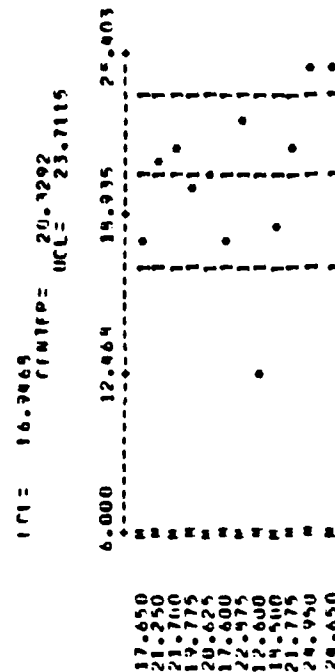
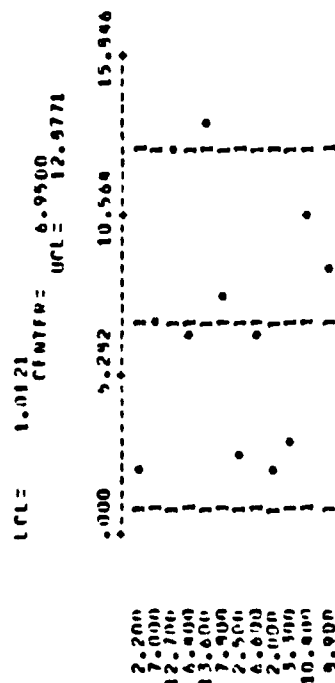
ALTERNATE HYPOTH. = 1) ALL TREAT. MEANS ARE NOT EQUAL
 2) ALL BLOCK MEANS ARE NOT EQUAL

SOURCE	DEGREES OF FREEDOM	SUM OF SQUARES	MEAN SQUARE	F
SAMPLE POSITION	3.	48.961	16.297	1.332
CAST./FORG. NO.	11.	517.710	47.065	3.949
ERROR	33.	403.599	12.230	
TOTAL	47.	970.160		

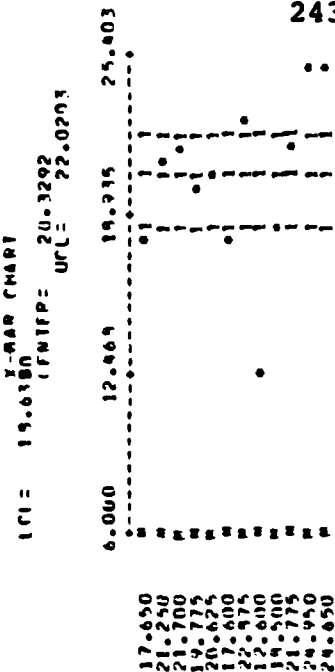
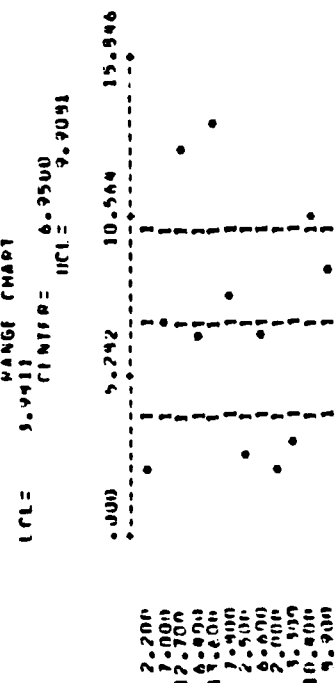
3072112
CFMT DATA



3072112
CFMT DATA



3072112
CFMT DATA



ROOM TEMP. TENSILE TESTS-3REC. AREA LAC-PACIFIC(1/77 TO 10/79) CRR
DATA

--3072112--TFE731 ENGINE PART

14 3 0 0 0

FORMAT(I5,3F10.2)

FORMAT(3A4)

POS3POS4POS5

SERIAL # INPUT DATA BY POSITION

2164 19.00 17.50 19.60

395 22.60 21.50 20.10

2392 16.10 15.40 17.90

2361 20.90 21.90 22.90

3004 22.60 24.00 21.10

3443 24.00 25.40 22.90

1011 24.00 22.90 21.50

1049 24.40 20.90 24.00

900 26.70 26.00 24.40

3337 24.00 26.00 24.00

3369 20.40 26.30 24.40

3040 20.40 24.30 24.70

3046 20.40 26.70 24.00

3010 21.10 23.30 26.50

THE MEAN = 22.91 STANC DEV = 2.04

SUM = 949.40 SUM OF SQUARES = 21411.10

TREATMENT	TOTAL	MEAN	SUM SQR DIFF	STANDARD DEV
1 (POS3)	306.50	21.89	94.15	7.24
2 (POS4)	321.90	22.99	147.67	11.96
3 (POS5)	317.00	22.64	79.93	6.15

HIGH STD.DEV. = 11.36 TOTAL ALL TREAT. STD. DEVS. = 20.75

ONE-WAY ANALYSIS OF VARIANCE RESULTS

NULL HYPOTHESIS = ALL TREATMENT MEANS EQUAL
 ALTERNATE HYPOTH. = ALL TREATMENT MEANS NOT EQUAL

SOURCE	DEGREES OF FREEDOM	SUM OF SQUARES	MEAN SQUARE	F
SAMPLE POSITION	2.	8.944	4.422	.536
ERROR	39.	321.753	8.250	
TOTAL	41.	330.597		

COCHRAN'S EQUALITY OF VARIANCES STATISTIC "G" = .4590 K = 14
 NULL HYPOTH. = ALL BLOCK VARIANCES ARE EQUAL N = 3
 ALT. HYPOTH. = ALL BLOCK VARIANCES ARE NOT EQUAL

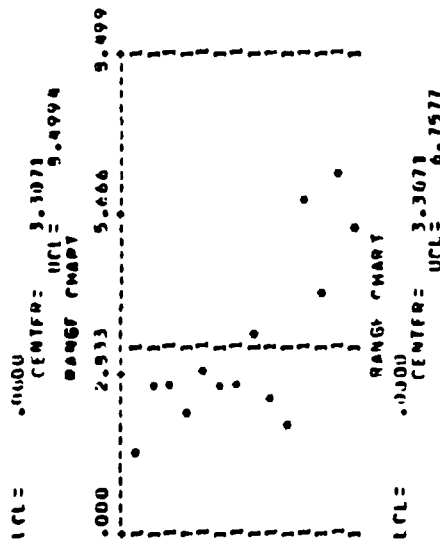
TWO-WAY ANALYSIS OF VARIANCE RESULTS

NULL HYPOTHESIS = 1) ALL TREATMENT MEANS ARE EQUAL
 2) ALL BLOCK MEANS ARE EQUAL

ALTERNATE HYPOTH. = 1) ALL TREAT. MEANS ARE NOT EQUAL
 2) ALL BLOCK MEANS ARE NOT EQUAL

SOURCE	DEGREES OF FREEDOM	SUM OF SQUARES	MEAN SQUARE	F
SAMPLE POSITION	2.	8.944	4.422	1.293
CAST./FORG. NO.	13.	232.944	17.911	5.239
ERROR	26.	99.910	3.420	
TOTAL	41.	330.597		

3072332
CAR DATA



LCL = 19.1367
 CFMTR = 22.5095
 X-RAR CHART
 UCL = 25.0028

LCL = 19.1367
 CFMTR = 22.5095
 X-RAR CHART
 UCL = 25.0028

SERIAL NUMBER	X-RAR
2164	19.1367
2165	19.1368
2166	19.1369
2167	19.1370
2168	19.1371
2169	19.1372
2170	19.1373
2171	19.1374
2172	19.1375
2173	19.1376
2174	19.1377
2175	19.1378
2176	19.1379
2177	19.1380
2178	19.1381
2179	19.1382
2180	19.1383
2181	19.1384
2182	19.1385
2183	19.1386
2184	19.1387
2185	19.1388
2186	19.1389
2187	19.1390
2188	19.1391
2189	19.1392
2190	19.1393
2191	19.1394
2192	19.1395
2193	19.1396
2194	19.1397
2195	19.1398
2196	19.1399
2197	19.1400
2198	19.1401
2199	19.1402
2200	19.1403
2201	19.1404
2202	19.1405
2203	19.1406
2204	19.1407
2205	19.1408
2206	19.1409
2207	19.1410
2208	19.1411
2209	19.1412
2210	19.1413
2211	19.1414
2212	19.1415
2213	19.1416
2214	19.1417
2215	19.1418
2216	19.1419
2217	19.1420
2218	19.1421
2219	19.1422
2220	19.1423
2221	19.1424
2222	19.1425
2223	19.1426
2224	19.1427
2225	19.1428
2226	19.1429
2227	19.1430
2228	19.1431
2229	19.1432
2230	19.1433
2231	19.1434
2232	19.1435
2233	19.1436
2234	19.1437
2235	19.1438
2236	19.1439
2237	19.1440
2238	19.1441
2239	19.1442
2240	19.1443
2241	19.1444
2242	19.1445
2243	19.1446
2244	19.1447
2245	19.1448
2246	19.1449
2247	19.1450
2248	19.1451
2249	19.1452
2250	19.1453
2251	19.1454
2252	19.1455
2253	19.1456
2254	19.1457
2255	19.1458
2256	19.1459
2257	19.1460
2258	19.1461
2259	19.1462
2260	19.1463
2261	19.1464
2262	19.1465
2263	19.1466
2264	19.1467
2265	19.1468
2266	19.1469
2267	19.1470
2268	19.1471
2269	19.1472
2270	19.1473
2271	19.1474
2272	19.1475
2273	19.1476
2274	19.1477
2275	19.1478
2276	19.1479
2277	19.1480
2278	19.1481
2279	19.1482
2280	19.1483
2281	19.1484
2282	19.1485
2283	19.1486
2284	19.1487
2285	19.1488
2286	19.1489
2287	19.1490
2288	19.1491
2289	19.1492
2290	19.1493
2291	19.1494
2292	19.1495
2293	19.1496
2294	19.1497
2295	19.1498
2296	19.1499
2297	19.1500
2298	19.1501
2299	19.1502
2300	19.1503
2301	19.1504
2302	19.1505
2303	19.1506
2304	19.1507
2305	19.1508
2306	19.150

ROOM TEMP. TENSILE TESTS--BRLC-ARFA LAC-PACIFIC 11/77 TO 10/79) CBR DATA

VALUE PLOT:

(SERIAL NUMBER VS. INDIVIDUAL TEST MEASUREMENTS)

PART NUMBER: --3072112--TTE731 ENGINE PART

NUMBER ON PLOT CORRESPONDS TO POSITION NUMBER

(I.E., 3 = TEST SAMPLE FROM POSITION 3 OF CASTING/FORGING

INDIVIDUAL TEST MEASUREMENTS

SERIAL NUMBER	1.000	10.941	20.993	30.924	40.766
2149.	M				
2154.	M				
2342.	M				
2361.	M				
3044.	M				
3443.	M				
1011.	M				
1044.	M				
910.	M				
3337.	M				
3363.	M				
3040.	M				
1046.	M				
3010.	M				

ROOM TEMP. TENSILE TESTS--BRLC-ARFA LAC-PAC. 11/77 TO 5/79) CERT DATA

VALUE PLOT:

(SERIAL NUMBER VS. INDIVIDUAL TEST MEASUREMENTS)

PART NUMBER: --3072112--TTE731 ENGINE PART

NUMBER ON PLOT CORRESPONDS TO POSITION NUMBER

(I.E., 3 = TEST SAMPLE FROM POSITION 3 OF CASTING/FORGING

INDIVIDUAL TEST MEASUREMENTS

SERIAL NUMBER	1.000	10.701	20.403	30.100	39.405
2237.	M				
2164.	M				
2154.	M				
2142.	M				
204.	M				
2174.	M				
23015.	M				
21425.	M				
24900.	M				
3040.	M				
3046.	M				
3010.	M				

NOTE: 1) MISSING NUMBERS INDICATE DUPLICATION.
CHECK DATA (ACCORDING TO SERIAL NUMBER) FOR DUPLICATES.
2) AN ASTERISK (*) INDICATES A VALUE OUT OF LIMITS.

DETERMINATION OF A DIFFERENCE IN TESTING FOR
 PART NUMBER: 3072112 LACISH PACIFIC TESTING VS. ARC CO. TESTING
 DATA FROM 1/77 TO 5/79 (2REC.AREA)

SER.NO.	TEST DATA	CMR DATA	DIFFERENCE	DIFF.SORC
2164	21.250	19.367	2.9830	9.3117
395	21.700	21.400	.3000	.0900
2392	19.775	16.467	3.3090	10.9429
92374	17.600	21.933	-4.2330	17.9193
93015	22.975	22.567	.3090	.0949
93345	12.600	24.100	-11.5000	132.2500
99900	19.500	25.700	-7.2000	51.9400
3040	21.775	23.133	-1.3590	1.8442
3046	24.950	23.700	1.2500	1.5625
3010	24.650	23.633	1.0170	1.0343
TOTAL			-15.2250	225.9897

AVERAGE DIFFERENCE = -1.5225 CFB. OF FREEDOM = 9

SAMPLE VARIANCE = 22.523 SAMPLE STANCIARE DEV. = 4.75

THE "T" STATISTIC FOR TESTING THE DIFFERENCE IN THE TWO TESTING MEANS = -1.0145

NUL HYPOTH.: $\mu_1 - \mu_2 = 0$

ALT. HYPOTH.: $\mu_1 - \mu_2 \neq 0$

ASSUMPTION: THE DISTRIBUTION UNDERLYING THE DIFFERENCES IS NORMAL.

***** TEMPO, TENCILLE TECTEC-VIFC 10R.PAF. 10/76 TO 2/79) PERDI RATA

--3072310--VF731 FNGINF PAWT

11 10 9 8 7

FORM T-15, F1J.21

TELETYPE

INPUT DATA POSITION

[illegible]

THE WEAH = 195.72 "TAP" (V) - 2.67

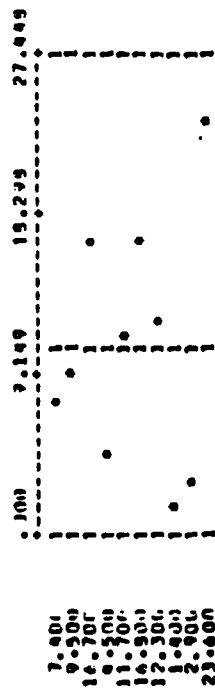
$\epsilon_{11} = 4306.3$, ϵ_{12} of $\epsilon_{000000} = 57909.02$

ROOM TEMP. TENSILE TESTS-VIFLE LAC.PAC.(4/76 TO 5/79) (EXT DATA)
 PART NUMBER: --3072310--TFF731 ENGINE PART
 CHARTS FOR GROUPS OF 3 CASTINGS/FORGINGS

3 SIGMA-
 RANGE CHART

UCL= .0000
 CENTER= 10.6900
 LCL= 27.4876

SPECIAL
 NUMBER

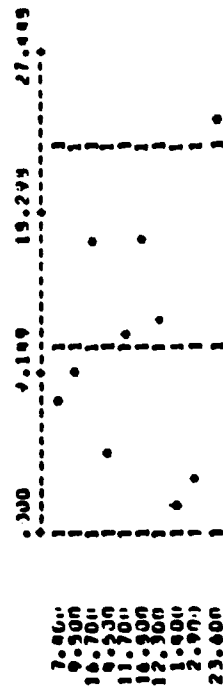


ROOM TEMP. TENSILE TESTS-VIFLE LAC.PAC.(4/76 TO 5/79) (EXT DATA)
 PART NUMBER: --3072310--TFF731 ENGINE PART
 CHARTS FOR GROUPS OF 3 CASTINGS/FORGINGS

2 SIGMA-
 RANGE CHART

UCL= .0000
 CENTER= 10.6900
 LCL= 21.5232

SPECIAL
 NUMBER



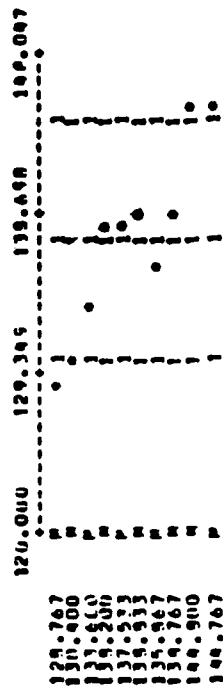
3 SIGMA-
 X-RANGE CHART

UCL= 126.2597
 CENTER= 137.1933
 LCL= 108.0849



2 SIGMA-
 X-RANGE CHART

UCL= 129.9907
 CENTER= 137.1933
 LCL= 108.0849

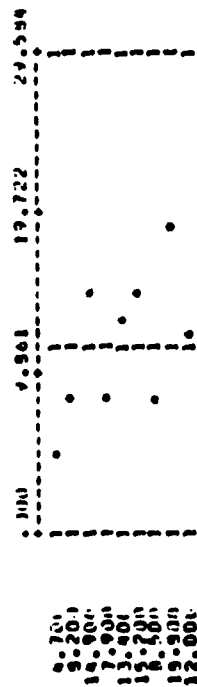


ROOM TEMP. TENSILE TESTS-VIFLC LAC-PAC-14/76 TO 5/791 CPM DATA
 PART NUMBER: --3072316--TFF/33 ENGINE PART
 CHARTS FOR GROUPS OF 3 CASTINGS/FORGINGS

3 SIGMA-
 RANGE CHART

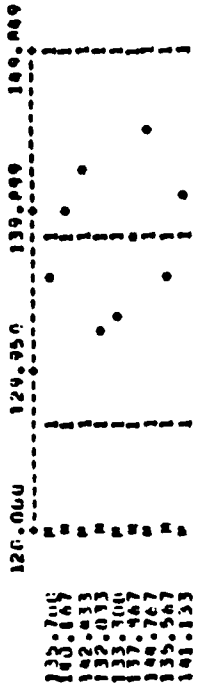
LCL = 9.300
 CENTRE = 11.511
 UCL = 23.594

SERIAL
 NUMBER



3 SIGMA-
 X-RAY CHART

LCL = 126.3661
 CENTRE = 139.1078
 UCL = 159.8697

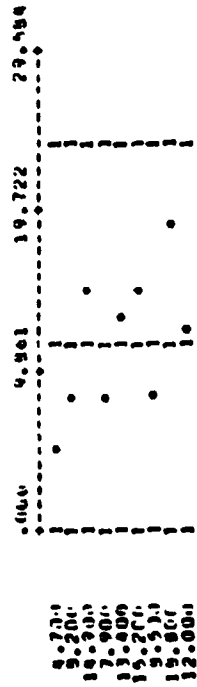


ROOM TEMP. TENSILE TESTS-VIFLC LAC-PAC-14/76 TO 5/791 CPM DATA
 PART NUMBER: --3072316--TFF/33 ENGINE PART
 CHARTS FOR GROUPS OF 3 CASTINGS/FORGINGS

2 SIGMA-
 RANGE CHART

LCL = 9.300
 CENTRE = 11.511
 UCL = 23.594

SERIAL
 NUMBER



2 SIGMA-
 X-RAY CHART

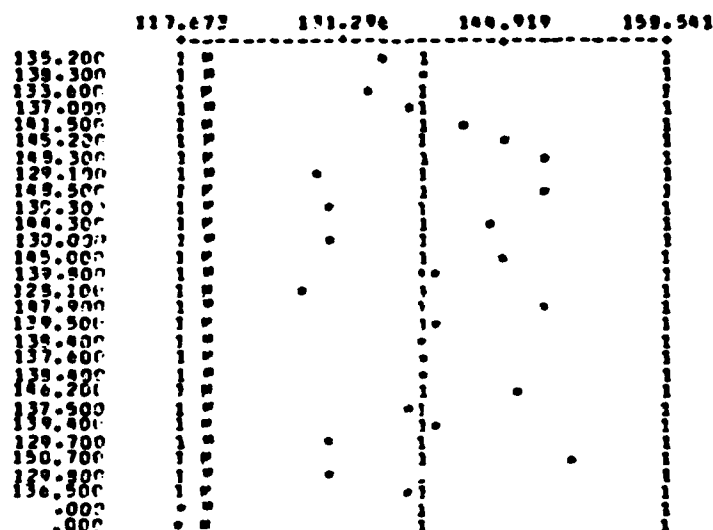
LCL = 130.2794
 CENTRE = 139.1078
 UCL = 149.9340



ROOM TEMP. TENSILE TESTS-VILE LOC. PAC. (4/76 TO 5/79) CEPT DATA
 PART NUMBER: --3072314--TFF732 ENGINE PART

INDIVIDUAL VALUE
 Y CHART
 LCL = 117.673
 CENTER = 138.1074
 UCL = 159.5413

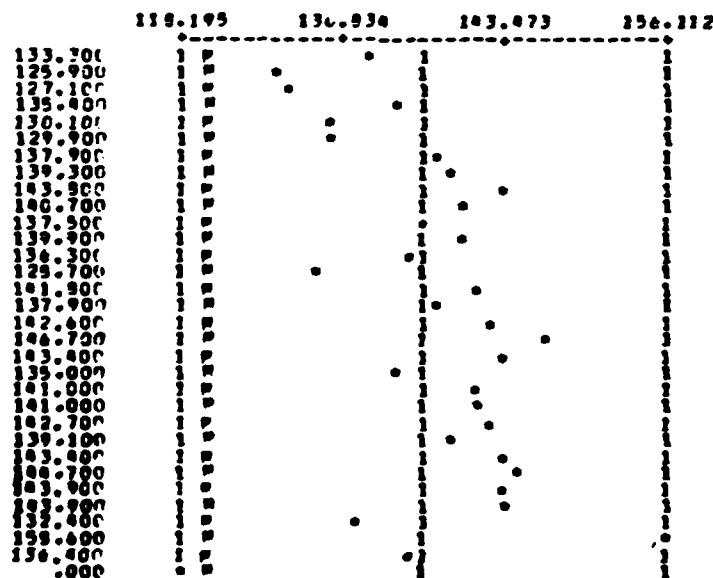
SERIAL
 NUMBER



ROOM TEMP. TENSILE TESTS-VILE LOC. PAC. (4/76 TO 5/79) CEPT DATA
 PART NUMBER: --3072314--TFF732 ENGINE PART

INDIVIDUAL VALUE
 Y CHART
 LCL = 119.195
 CENTER = 137.1533
 UCL = 156.1116

SERIAL
 NUMBER



DETERMINATION OF A DIFFERENCE IN VESSING FOR
 PART NUMBER 3072300 LOCISH PACIFIC TESTING VS. APC CO. VESSING
 DATA FROM 4/76 TO 5/78 (VIELC DATA)

SEP. NO.	LEFT DATA	CRP DATA	DIFFERENCE	DIFF. SQR
267	127.100	135.200	-8.1000	65.6100
223	135.470	139.300	-3.8300	14.6649
152	130.100	133.600	-3.5000	12.2500
155	129.970	137.000	-7.0300	49.4209
2617	137.900	141.500	-3.6000	12.9600
2679	139.900	145.200	-5.3000	28.0900
2575	136.300	149.300	-13.0000	169.0000
2673	129.700	129.100	-.6000	.3600
1276	141.900	149.500	-7.6000	57.7600
1202	137.900	130.300	7.6000	57.7600
1209	147.600	144.300	3.3000	10.8900
960	135.000	130.000	5.0000	25.0000
909	141.000	145.000	-4.0000	16.0000
949	141.000	139.900	1.1000	1.2100
341	142.700	147.900	-5.2000	27.0400
2529	139.100	139.500	-.4000	.1600
2543	143.400	139.400	4.0000	16.0000
1962	144.700	137.600	7.1000	50.4100
1967	143.900	139.400	4.5000	20.2500
1165	143.900	146.200	-2.3000	5.2900
390	132.400	137.500	-5.1000	26.0100
9919	159.600	129.700	29.9000	894.0100
570	136.400	150.700	-14.3000	204.4900
TOTAL			-22.7000	1676.7700

AVERAGE DIFFERENCE = -0.9970 CRP. OF FREEDOM = 22

SAMPLE VARIANCE = 75.794 SAMPLE STANDARD CRP. = 8.67

THE "T" STATISTIC FOR TESTING THE DIFFERENCE IN THE TWO TESTING MEANS = -0.5459

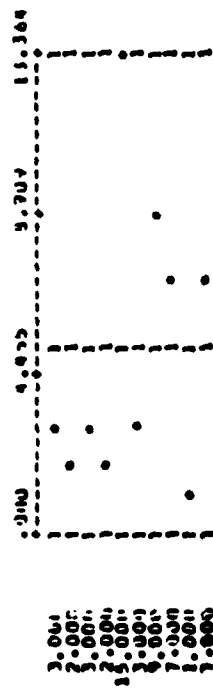
NULL HYPOTH.: $\mu_1 - \mu_2 = 0$
 ALT. HYPOTH.: $\mu_1 - \mu_2 \neq 0$

ASSUMPTION: THE DISTRIBUTION UNDERLYING THE DIFFERENCES IS NORMAL.

ROOM TEMP. TENSILE TESTS-BLOND. LAF. PAC. (4/76 TO 5/79) TEST DATA
 PART NUMBER: --3072310--1FF731 ENGINE PART
 CHARTS FOR GROUPS OF 3 CASTINGS/POURINGS

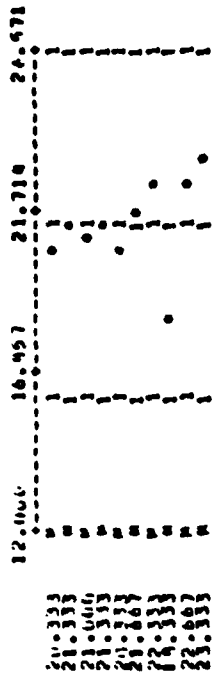
3 SIGMA-
 RANGE CHART

LCL = .0000 CENTER = 5.2000 UCL = 13.3600
 SPECIAL NUMBER



3 SIGMA-
 X-RANGE CHART

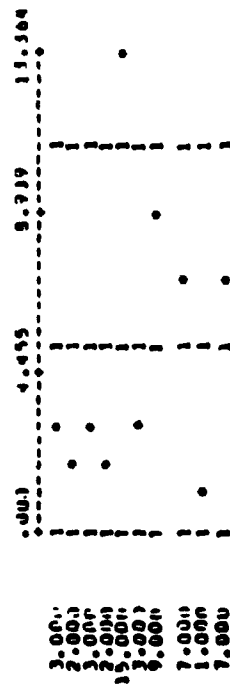
LCL = 15.9627 CENTER = 21.2667 UCL = 26.9707



ROOM TEMP. TENSILE TESTS-BLOND. LAF. PAC. (4/76 TO 5/79) TEST DATA
 PART NUMBER: --3072310--1FF731 ENGINE PART
 CHARTS FOR GROUPS OF 3 CASTINGS/POURINGS

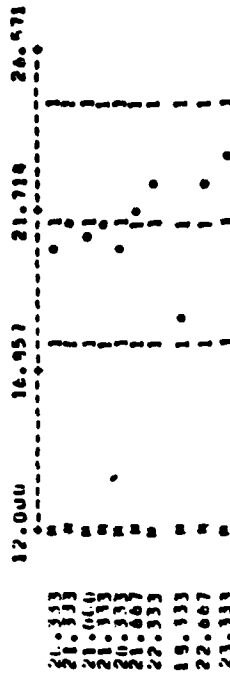
2 SIGMA-
 RANGE CHART

LCL = .0000 CENTER = 5.2000 UCL = 10.4200
 SPECIAL NUMBER



2 SIGMA-
 X-RANGE CHART

LCL = 17.7307 CENTER = 21.2667 UCL = 26.9707



000000 TEMP, TEMSILE TESTS-ALONG. 10C, PAC, 10/10 10 5/100 CND DATA

--3072300--707731 FMSIMZ PAWT

27 1 0 0 0

FORM07113.610.21

SCN14 0

INPUT F170 BY POSITION

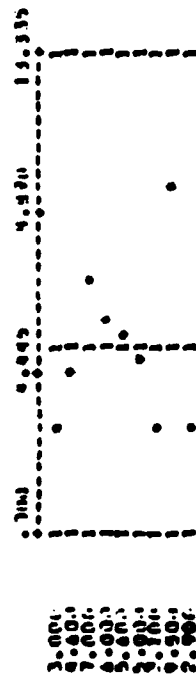
207	24.50	2509	26.50		1	24.50	22.50	25.50
223	22.50	2543	25.40		2	25.00	20.00	23.00
152	25.50	1962	24.00		3	21.70	19.00	27.00
155	24.00	1967	22.90		4	25.30	25.00	22.50
2007	20.00	1165	24.00		5	24.50	23.60	22.00
2009	20.00	380	24.70		6	23.00	24.30	25.00
2575	21.70	9392	21.40		7	22.70	24.30	24.80
2673	14.00	9919	29.50		8	24.70	21.00	29.50
1226	27.00	570	22.10		9	22.30	23.70	24.50
1202	25.30	2000	23.70					
1204	25.00	1950	24.50					
901	22.50	THE MEAN = 24.03						
909	24.50	STAF (1V - 2.20						
909	23.00	SUM = 645.80						
0711	22.40	SUM OF SQUARES = 15716.26						
301	23.00							

00000 TEMP-TABLE 1015-10100. 1015-10100 TO 1015-10100 RMP DATA
 PART NUMBER: --3022316--1015-10100 ENGINE PART
 CHARTS FOR GROUPS OF 3 FACTORS/POINTS

3 STEPS-
 RANGE CHART

1015 1015
 CENTER= 1015
 1015 1015

1015
 1015



00000 TEMP-TABLE 1015-10100. 1015-10100 TO 1015-10100 RMP DATA
 PART NUMBER: --3022316--1015-10100 ENGINE PART
 CHARTS FOR GROUPS OF 3 FACTORS/POINTS

3 STEPS-
 RANGE CHART

1015 1015
 CENTER= 1015
 1015 1015

1015
 1015



DETERMINATION OF A DIFFERENCE IN TESTING FOR
 PART NUMBER: 3072310 LACISM PACIFIC TESTING VS. APC CO. TESTING
 DATA FROM 4/76 TO 5/79 (RELONG. DATA)

SEP. NO.	FEET DATA	COB DATA	DIFFERENCE	DIFF. SQR
267	19.000	24.500	-5.5000	30.2500
223	22.000	22.500	-.5000	.2500
152	27.000	25.500	-3.5000	12.2500
155	22.000	25.000	-3.0000	9.0000
2607	27.000	29.000	-6.0000	36.0000
2609	20.000	29.000	-9.0000	81.0000
2575	19.000	21.700	-2.7000	7.2900
2673	17.000	19.000	-2.0000	4.0000
1226	17.000	27.400	-15.4000	237.1600
1232	15.000	25.300	-10.3000	106.0900
1208	16.000	25.000	-9.0000	81.0000
960	23.000	22.300	.7000	.4900
909	24.000	24.500	-.5000	.2500
988	24.000	23.600	.4000	.1600
341	21.000	23.000	-2.0000	4.0000
2538	19.000	26.300	-9.3000	86.4900
2543	20.000	25.400	-5.4000	29.1600
1962	19.000	24.000	-6.0000	36.0000
1967	23.000	22.900	.1000	.0100
1165	21.000	24.900	-3.9000	15.2100
390	22.000	24.700	-2.7000	7.2900
9919	20.000	29.500	-9.5000	90.2500
570	24.000	22.300	1.7000	2.8900
TOTAL			-100.2000	923.1200

AVERAGE DIFFERENCE = -4.3565 DEG. OF FREEDOM = 22

SAMPLE VARIANCE = 17.573 SAMP. STANDARD DEV. = 4.19

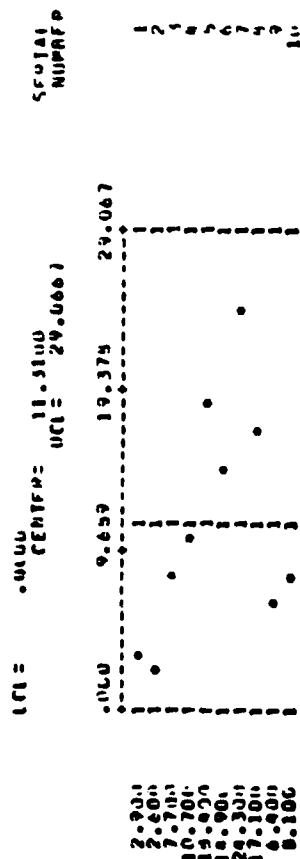
THE "T" STATISTIC FOR TESTING THE DIFFERENCE IN THE TWO TESTING MEANS = -4.9991

NULL HYPOTH.: $\mu_1 - \mu_2 = 0$
 ALT. HYPOTH.: $\mu_1 - \mu_2 \neq 0$

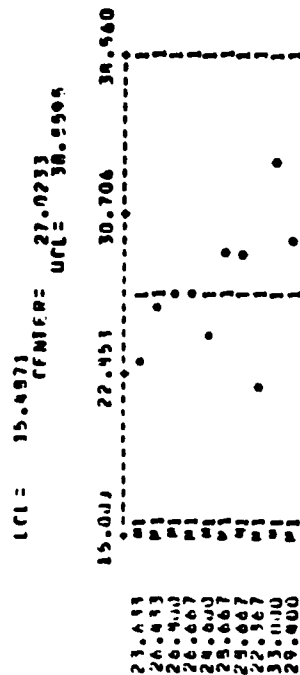
ASSUMPTION: THE DISTRIBUTION UNDERLYING THE DIFFERENCES IS NORMAL.

ROOM TEMP TENSILE TESTS--REF. AREA LAC.PAC.(4/76 TO 5/75) CFT DATA
 PART NUMBER: --3072310--TF731 ENGINE PART
 CHARTS FOR GROUPS OF 3 CASTINGS/OPERINGS

1 SIGMA-
 RANGE CHART



2 SIGMA-
 X-PAR CHART

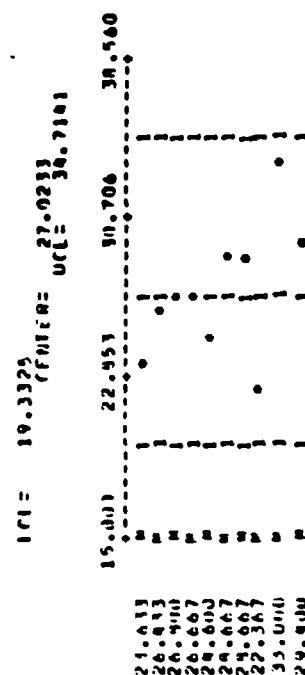


ROOM TEMP TENSILE TESTS--REF. AREA LAC.PAC.(4/76 TO 5/75) CFT DATA
 PART NUMBER: --3072310--TF731 ENGINE PART
 CHARTS FOR GROUPS OF 3 CASTINGS/OPERINGS

1 SIGMA-
 RANGE CHART



2 SIGMA-
 X-PAR CHART

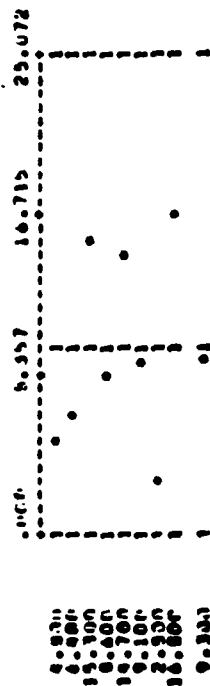


GROUP TEMP-TFMS-REF-AREA LAC-PAC-1076 TO 5/781 CMO DATA
 PART NUMBER: --3072310--TFE731 ENGINE PART
 CHARTS FOR GROUPS OF 3 CASTINGS/ENGINE

1 STEP-
 RANGE CHART

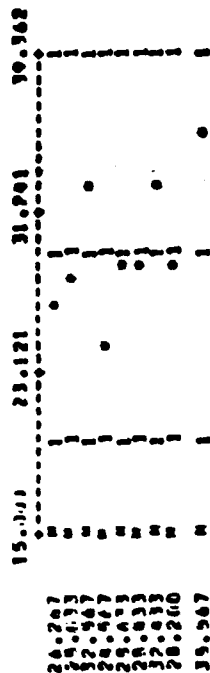
ICL = 0.000
 CFMTP = 9.755
 UCL = 25.072

SPECIAL
 NUMBER



3 STEP-
 X-RANGE CHART

ICL = 19.000
 CFMTP = 29.011
 UCL = 30.000

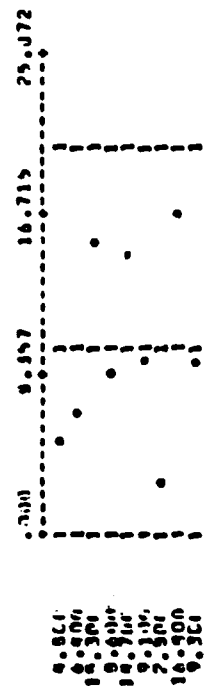


GROUP TEMP-TFMS-REF-AREA LAC-PAC-1076 TO 5/781 CMO DATA
 PART NUMBER: --3072310--TFE731 ENGINE PART
 CHARTS FOR GROUPS OF 3 CASTINGS/ENGINE

2 STEP-
 RANGE CHART

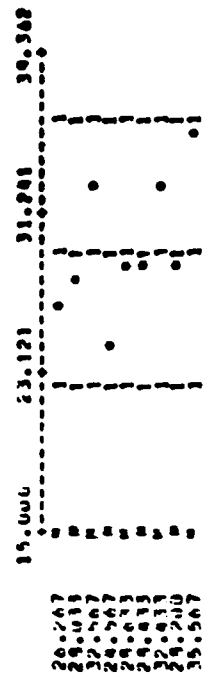
ICL = 0.000
 CFMTP = 9.755
 UCL = 19.072

SPECIAL
 NUMBER



3 STEP-
 X-RANGE CHART

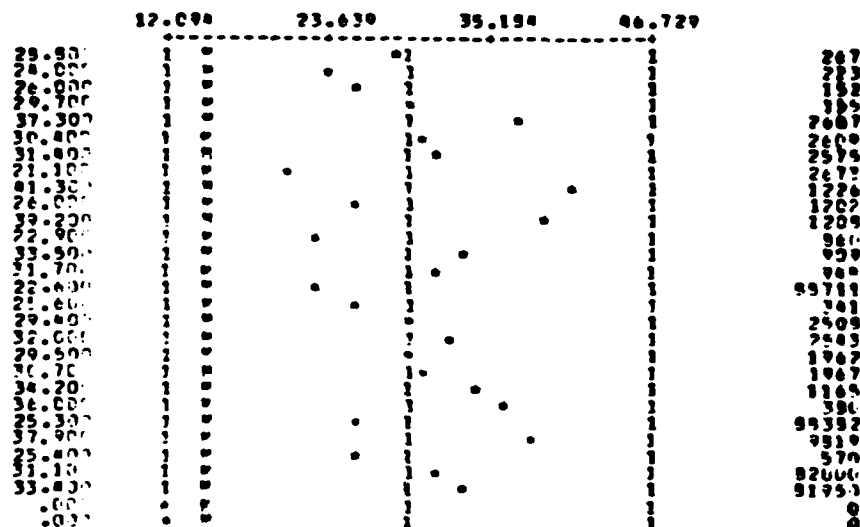
ICL = 22.773
 CFMTP = 25.011
 UCL = 30.000



000000 TENSILE TESTS-ROTC AREA LAC.PAC.(4/76 TO 5/78) CFRT DATA
 PART NUMBER: --3772316--757731 ENGINE PART

INDIVIDUAL VALUE
 X CHART
 LCL= 12.3936
 CENTER= 29.0131
 UCL= 46.7297

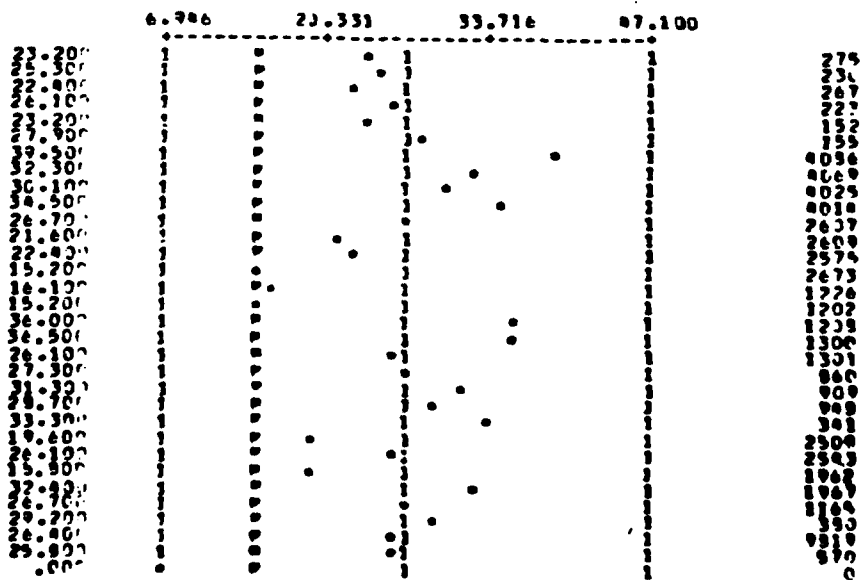
SERIAL
 NUMBER



000000 TENSILE TESTS-ROTC AREA LAC.PAC.(4/76 TO 5/78) CFRT DATA
 PART NUMBER: --3772316--757731 ENGINE PART

INDIVIDUAL VALUE
 X CHART
 LCL= 6.9466
 CENTER= 27.0233
 UCL= 47.1003

SERIAL
 NUMBER



DETERMINATION OF A DIFFERENCE IN VARIATION FOR

PART NUMBER: 2072300 LOCISH PACIFIC TESTING VS. WPT CO. TESTING
DATA FROM 4/76 TO 5/78 (3 REEL, 8 PAGES)

SER. NO.	PERT DATA	WPT DATA	DIFFERENCE	DIFF. SQR
267	22.400	29.800	-6.4000	40.9600
223	26.100	24.000	2.1000	4.4100
152	23.200	26.000	-2.8000	7.8400
155	27.400	29.700	-1.9000	3.2400
2607	26.700	37.300	-10.6000	112.3600
2639	21.600	30.400	-8.8000	77.4400
2575	22.400	31.400	-9.0000	81.0000
2672	15.200	21.100	-5.9000	34.8100
1226	16.100	41.300	-25.2000	635.0400
1202	15.200	26.000	-10.8000	116.6400
1206	36.000	39.200	-3.2000	10.2400
960	27.300	22.900	4.4000	19.3600
969	31.300	33.500	-2.2000	4.8400
984	29.700	31.700	-3.0000	9.0000
341	33.300	25.600	7.7000	59.2900
2530	19.400	29.400	-9.9000	98.0100
2543	26.100	32.000	-5.9000	34.8100
1962	19.900	29.500	-10.7000	114.4900
1967	32.400	30.700	1.7000	2.8900
1165	26.700	34.200	-7.5000	56.2500
390	29.200	36.000	-6.8000	46.2400
9919	26.400	37.900	-11.5000	132.2500
570	25.900	25.400	.4000	.1600
TOTAL			-125.6000	1699.5799

DIFFERENCE = -5.4609 DEG. OF FREEDOM = 22

SAMPLE DIFFERENCE = 46.774 SAMPLE STANDARD DEV. = 6.79

THE T-STATISTIC FOR TESTING THE DIFFERENCE IN THE TWO TESTING MEANS = -3.9592

NULL HYPOTH.: $\mu_1 - \mu_2 = 0$
ALT. HYPOTH.: $\mu_1 - \mu_2 \neq 0$

ASSUMPTION: THE DISTRIBUTION UNDERLYING THE DIFFERENCES IS NORMAL.

APPENDIX F

Given: The following data concerning test results (tensile yield) from four different positions on a Waspalloy forging Part No. 3072112.

PART#	POSITION #				x_i	x_i^2
	3	4	5	7		
1	132.2	133.8	132.8	133.2	532	70757.36
2	132.7	137.8	135.1	134.3	539.9	72886.63
3	135.9	137.	132.7	133.7	539.3	72722.79
4	137.6	139.6	140.7	138.1	556	77290.02
5	137.2	136.4	135.5	136.8	545.9	74503.29
6	139.5	138.3	142.2	138.7	558.7	78045.67
7	135.6	135.2	130.8	136.5	538.1	72407.29
8	138.9	138.5	137.5	139.5	554.4	76841.96
9	136.4	134.0	135.9	135.9	542.2	73498.58
10	133.3	131.1	131.3	135.7	531.4	70610.28
11	132.3	131.6	131.2	136.3	531.4	70612.98
12	144.3	142.7	141.5	140.2	568.7	80864.07
TOT	1635.9	1636.0	1627.2	1638.9	6538.0	
TOT ²	223152.99	223166.64	220833.80	223887.49		891040.92

Find: The results of analysis of variance including:

- 1) Equality of variances for the twelve items (Cochran's Test)
- 2) A one-way analysis to look @ equality of means of the different positions
- 3) A two-way analysis to look @ equality of means of both positions and parts.

SOLUTION:

$$1) s_1^2 = \frac{12(223152.99) - (1635.9)^2}{12(11)} = 12.629$$

$$2) s_2^2 = \frac{12(223166.64) - (1636.0)^2}{12(11)} = 11.392$$

$$3) s_3^2 = \frac{12(220833.80) - (1627.2)^2}{12(11)} = 16.862$$

$$4) s_4^2 = \frac{12(223887.49) - (1638.9)^2}{12(11)} = 4.97$$

SOLUTION (cont'd):

$$g = \frac{\text{Largest } S_i^2}{\text{Total } S^2} = \frac{16.862}{45.853} = .3677$$

significant @ $\alpha = .01$
 $n=4, k=12$

2)

$$\begin{aligned} SST &= \sum x_i^2 - \frac{(\sum x_i)^2}{n} \\ &= 891040.92 - \frac{(6538)^2}{48} = 510.8367 \end{aligned}$$

$$\begin{aligned} SS_{\text{trt}} &= \frac{(1635.9)^2 + (1627.2)^2 + (1638.9)^2 + (1636)^2}{12} \\ &\quad - \frac{(6538)^2}{48} = 6.405 \end{aligned}$$

$$SS_E = 510.8367 - 6.405 = 504.432$$

SOURCE	D.F.	SS_x	MS_x	F	
Position	3	6.405	2.135	.1862	not signif.
Error	44	504.432	11.464		
Total	47	510,837			

3)

$$\begin{aligned} SS_{b1} &= ((532)^2 + (539.9)^2 + (539.3)^2 + (556)^2 + (545.9)^2 + \\ &\quad (558.7)^2 + (538.1)^2 + 554.4^2 + (542.2)^2 + 2(531.4)^2 \\ &\quad + (568.7)^2) / 4 - \frac{(6538)^2}{48} \\ &= 403.03 \end{aligned}$$

$$SS_E = 510.837 - (403.03 + 6.405) = 101.410$$

SOURCE	D.F.	SS_x	MS_x	F	
Position	3	6.405	2.135	.6948	sig @ 1t.01
Item	11	403.03	36.639	11.9229	reject H_0
Error	33	101.410	3.073		
Total	47	510.837			

Duncan's Test on 3072112 CMR Data - Yield

Data Table:

Position	3	4	5
	133.9	134.7	135.4
	134.4	135.0	139.4
	138.9	138.3	138.9
	135.6	140.6	134.1
	130.43	134.8	132.4
	133.0	135.3	132.7
	133.6	134.4	134.6
	133.3	136.6	132.4
	139.1	138.7	135.7
	133.4	135.4	132.4
	134.4	134.4	130.3
	132.6	135.8	131.2
	132.2	132.2	132.6
	139.2	138.9	136.5
Total	1884.03	1905.10	1868.60
Average	134.57	136.08	133.47

$$MSE = 6.375$$

$$S_{\bar{x}} = \left(\frac{6.375}{14} \right)^{\frac{1}{2}} = 0.675$$

Test this Position

	Pos 5	Pos 3	Pos 4
	<u>133.47</u>	<u>134.57</u>	136.08
@ $\alpha = .05$	p	2	3
d.f.=39	$r_p =$	2.86	3.01
$R_p = S_{\bar{x}} \cdot r_p$	$R_p =$	1.93	2.03
@ p=3	136.08 - 133.47 = 2.61 $\neq$ 2.03		
@ p=2 (3:4)	136.08 - 134.57 = 1.51		
(5:3)	134.57 - 133.47 = 1.01 } both < 1.93		
@ $\alpha = .01$	<u>133.47</u>	<u>134.57</u>	<u>136.08</u>
d.f.=39	p	2	3
	$r_p =$	3.82	3.99
	$R_p =$	2.58	2.69
	None signif.		

Duncan's Test on 3072112 CERT Data - Yield

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Data Table: (see data of analysis of variance above)

Position	3	4	5	7
Total	1635.9	1636.0	1627.2	1638.9
Average	136.32	136.33	135.6	136.57

MSE = 11.465

$$S_{\bar{x}} = \left(\frac{11.465}{12} \right)^{1/2} = 0.977$$

	Pos 5	Pos 3	Pos 4	Pos 7
	135.6	136.32	136.33	136.57
@ $\alpha = .05$	p	2	3	4
	r_p	= 2.85	3.00	3.09
	R_p	= 2.78	2.93	3.02

@ $p=4$ $136.57 - 135.6 = 0.97 < 3.02$

No further testing necessary.

Conclusion: None are any less significant than any other mean value.

BIOGRAPHICAL SKETCH

Daniel E. Gellenbeck was born in Canton, Ohio on March 12, 1951. He received his elementary education in parochial schools in Canton and Charlotte, North Carolina and in the Phoenix, Arizona, public school system, where he also received his secondary education.

In 1969, he entered Arizona State University, graduating in 1973 with a Bachelor of Science in Mechanical Engineering and receiving a commission in the U. S. Air Force as a Second Lieutenant through the A. F. Reserve Officer Training Corps program.

November 1973 saw him enter active duty and undergraduate pilot training at Laughlin AFB, Texas. After receiving his pilot's wings in December 1974, he was assigned to Altus AFB, Oklahoma, remaining there until June, 1978 when he was assigned to Arizona State University for work on the Master of Science degree in Industrial Engineering. While there, he was inducted into the Alpha Pi Mu Honorary Society.

Reassigned to Myrtle Beach AFB, South Carolina, in September 1979, he was stationed at Myrtle Beach AFB to November 1981; Thule AB, Greenland November 1981 to November 1982, and Tinker AFB, Oklahoma November 1982 to present. Major Gellenbeck is presently serving as an Airborne Warning and Control System (AWACS) Aircraft Commander at Tinker, deploying frequently to locations around the world. He is a senior pilot and has received the Air Medal, two Air Force Commendation Medals, the Outstanding Unit Award, and several lesser commendations.

Major Gellenbeck and his wife, Debbie, have three daughters: Dawn Joann, Danna Marie, and Darla Ann.

END

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