1987

Effect of Manufacturing Tolerances on the Number of Load Carrying Fasteners in a Joint Subjected to a Shear Load: A Statistical Approach

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EFFECT OF MANUFACTURING TOLERANCES ON THE NUMBER OF LOAD CARRYING FASTENERS IN A JOINT SUBJECTED TO A SHEAR LOAD -- A STATISTICAL APPROACH

BY

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THESIS

Submitted in partial fulfillment of the requirements for the Master of Science in Engineering in the Graduate Studies Program of the College of Engineering University of Central Florida Orlando, Florida

Summer Term
1987

ABSTRACT

Within the elastic range, the number of load-carrying fasteners in an interchangeable manufactured joint subjected to a shear load is dependent upon the following characteristics:

1. Material properties of the constituent parts in the shear joint.
2. Geometry of the shear joint.
3. Manufacturing tolerances of the constituent parts in the shear joint.
4. Number of fasteners in the shear joint.
5. Preload on the fasteners in the joint.
6. Static coefficient of friction between the joint surfaces.

Neglecting the effects of preload and friction, the number of load-carrying fasteners is determined for a theoretical bolted joint design as a function of the remaining four (above) parameters. The analysis is accomplished by assuming all deformation in the constituent parts of the joint remain within the elastic range and then examining the stress-strain relationship existent in the shear joint. Based on simplifying assumptions, the total deflection is calculated and then, statistics are applied to the manufacturing tolerances of the constituent parts of the shear joint. The results suggest that plastic deformation occurs in all classically designed shear joints and the predicted number of load carrying fasteners using this analysis approach is in error. Suggestions for future research are presented.

ACKNOWLEDGEMENTS

I would like to thank the Martin Marietta Corporation for their financial support bestowed upon me to complete this work and further my education. I would also like to thank all members of the Graduate Committee for their help and their time spent reviewing all the relevant information and status reports. In addition, I especially want to thank my wife, Gail, for her continued support during the completion of my education and this work.

TABLE OF CONTENTS

LIST OF FIGURES

INTRODUCTION

In our society, most mass manufactured mechanical assemblies are made to be interchangeable to cut down on assembly and production costs. A shear joint is made interchangeable through the use of oversized holes in the constituent parts for the fasteners which hold the joint together. The larger the hole size in the joint, the easier the joint is to assemble and the less expensive the production costs are for the constituent parts. However, oversized holes in a shear joint have a detrimental effect on the stiffness of that shear joint. In the absence of friction, only those fasteners which physically bear against the inner diameter of the oversized holes in the joint are physically carrying some of the shear force. Some of the fasteners in the joint will not be carrying any of the shear load and could be deleted from the assembly, saving material and production costs. For an efficient and safe joint design, the assembly should not yield when subjected to its expected environment (i.e. applied loads) while making the most efficient use of its constituent materials at the lowest possible production costs. The ideal shear joint would be economical to produce while having 100% of the fasteners equilibrating the shear load with all of the fasteners stressed right up to their design value.

In the classical approach to the design of a shear joint, the simplifying assumption is made that all of the fasteners share the load equally. Although this assumption holds approximately true at the ultimate strength of the joint, it is grossly in error at the yield strength of the joint (3), (9). To account for the uncertainty associated with this assumption, the expected loads in the shear joint are typically multiplied by "load factors (3)" or "fitting factors (7)." The size and number of fasteners required in the joint are then determined by assuming the entire area of the fasteners react the shear force. Although this methodology has proved to be very practical and safe, it is not the most efficient use of the materials. The joints are always "over-designed" with respect to their applied loads and could be improved upon.

The quest for a stiff, economical shear joint design has lead to a statistical approach to the design process. A literature search on the subject using this type of approach was made. The only papers found which combined statistics and manufacturing were associated the shear strength of pins or fasteners in joints constructed of composite materials. In all cases, non of the papers found dealt with fasteners or pins bearing against oversized holes when loaded in shear. The analysis approach taken was then to examine the stress-strain relationship existent in a joint with one bolt in shear. Then, based on simplifying assumptions, deflection was calculated in this shear joint at its yield point. This deflection was then applied to the statistics of the manufacturing tolerances to determine the number of load-carrying fasteners in the joint. The effective stiffness of a shear joint is a function of to the number of load-carrying fasteners in that joint. In this respect, the following analysis and associated algorithm can be used to optimize the stiffness of a shear joint based upon the manufacturing tolerances, joint geometry, materials comprising the joint and number of fasteners in the joint.

THEORY

The first step in optimizing the number of load-carrying fasteners in a shear joint within the elastic limit is to calculate the maximum allowable shear force in a single bolt-hole combination of that joint at its yield point. For the optimum design, all parts of the joint should yield at approximately the same applied shear force. This can be accomplished by varying the materials comprising the joint and the joint geometry.

After establishing the maximum allowable shear force in the joint, the deflection in the shear joint due to the applied load must be calculated. This deflection is then utilized to statistically calculate the number of load-carrying fasteners in the shear joint assembly. This is dependent on the joint geometry, materials comprising the joint, manufacturing tolerances on the constituent parts of the joint and the number of fasteners in the joint.

As with any engineering analysis, there are many simplifying assumptions which accompany the analysis in order to arrive at a solution. The assumptions used in this analysis are listed below.

1. The materials comprising the joint are made of homogeneous isotropic linear elastic materials.
2. The geometry of the fasteners will be restricted to bolts which have an unthreaded portion or shank in the area that will equilibrate the shear load. The analysis is specifically directed at fasteners which do not fill the entire hole in a given joint (i.e., an interchangeable mechanical assembly).
3. The shear load that will be applied to the joint will be applied statically (i.e., non-fluctuating) and load fluctuations and fatigue considerations will not be addressed.
4. The fasteners will be loaded in single shear.
5. The joint will be comprised of two flat plates or two concentric cylinders.
6. In the case of two flat plates, it is assumed that the plates will shift relative to one another when loaded until at least two of the fasteners come into bearing (i.e., the plates have two degrees of freedom of motion with respect to one another; these are translation and rotation). The bolt-hole combination will deform a certain amount. All deformation is assumed to remain within the elastic range of the materials. As the bolt-hole combination elongates, more fasteners will come into bearing. The number of

fasteners that come into bearing will be directly related to how much the original two bolt-hole combinations can deform within the elastic region and the tolerances on the constituent parts.

7. In the case of two concentric cylinders with the fasteners loaded in single shear due to an applied torque, it is assumed that the cylinders will rotate until at least one of the fasteners comes into bearing (i.e., the two cylinders have one degree of freedom of motion with respect to one another; this is rotation). The first bolt that comes into bearing will "clock" the two cylinders, preventing further rotation. This bolt-hole combination will then elongate within the elastic region, permitting other fasteners to come into bearing.

8. In regard to the manufacturing tolerances, it is assumed that the tolerances on the position of the hole, size of the hole and size of the fastener are independent random variables approximating a Gaussian Distribution.

9. The fact that the plates or concentric cylinders shift slightly under load also needs to be considered. Since the analysis is based on all independent random variables, when the plates or cylinders "shift" a random amount, it is assumed that the resulting

assembly is still comprised of independent random variables. Essentially, the fact that the plates have shifted does not affect the statistical model except for reducing the number of "degrees of freedom" of the model.

10. All fasteners have the same nominal cross-sectional area and tolerance in a given joint.
11. All holes in the joint in each of the plates or concentric cylinders have the same nominal size and tolerance limits.
12. The "true position tolerance" of the fastener hole pattern in each plate or cylinder has the same nominal value and tolerance limits.
13. It is assumed that the fastener spacing is sufficiently large so that the stress-strain distributions around the fastener holes do not couple into one another. This requires that the hole spacing from centerline to centerline be physically separated by at least two hole diameters (5).
14. The friction force in the joint is negligible in comparison to the applied shear force and will be neglected in the analysis.
15. It is assumed that the edge distance of the fasteners in the joint is sufficiently large to neglect edge effects. This requires that the centerline of the

holes for the fasteners be located at least two hole diameters from any edge of the plate or cylinder (10).

16. All the parts comprising the joint are manufactured to the specified tolerance with the corresponding expected values (MU = μ) and standard deviations (SD = σ) known.

17. It is assumed that the loading due to the Hertzian Contact Stress is perpendicular to the surface, and the effect of surface shear stresses is neglected.

18. The contact area dimensions due to the Hertzian Contact Stresses are small in comparison to the radii of curvature of the bodies under load.

19. Upon application of the shear force, the radii of curvature of the contact areas are very large compared to the dimensions of these contact areas.

20. It is assumed that the bolts used in the joint are stronger than the constituent materials used in the joint itself (i.e., the two concentric cylinders or flat plates). This restriction is necessary to insure that the constituent materials will yield before the bolts yield. Specifically, the yield strength of the constituent materials shall be lower than the stress induced in the bolt from the combined bending and shear loads.

21. The bolt is modeled as a cantilevered beam. Using the principle of superposition and applying elementary beam theory, the deflections due to the shear and bending moment on the bolt are calculated by assuming the net shear force in a single bolt-hole combination of the shear joint acts at the centroid of each plate or cylinder. It is assumed that the error introduced into the overall calculation because of the simplistic model is negligible.

22. For purposes of calculating the deformation due to the Hertzian Contact Stress, the contacting bodies are assumed to be perfectly smooth.

23. The Hertzian Contact Stresses experienced by a bolt bearing against a hole are analogous to the stresses seen by a cylindrical roller bearing in contact with the bearing raceways.

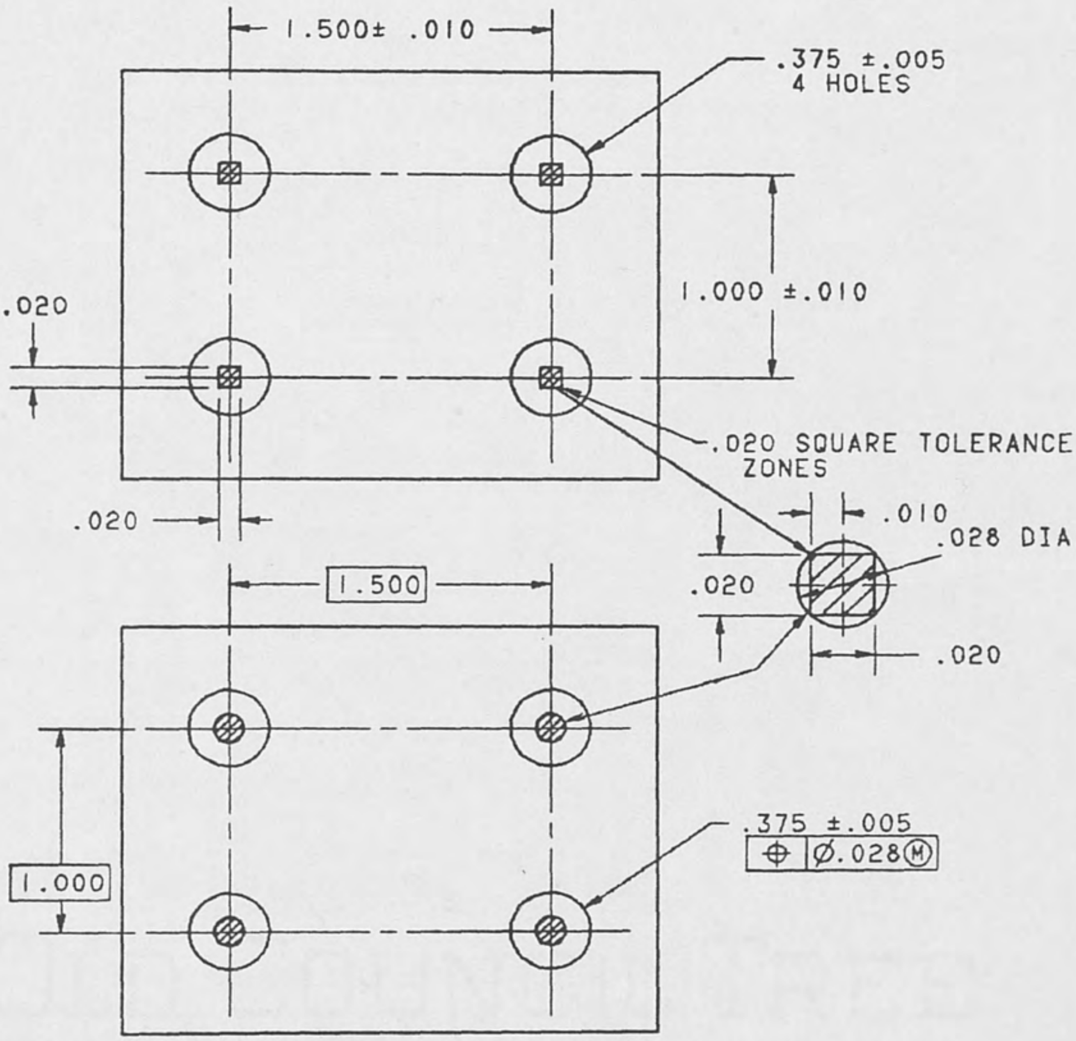
24. The tolerance on the thickness of the flat plates or concentric cylinders is assumed to be zero. Therefore, the thickness tolerance will be neglected in the analysis.

To complete our analysis, one must apply statistics to the manufacturing tolerances of the constituent parts (i.e., the two flat plates or concentric cylinders and the bolts). In order to accomplish this, the mathematics for combining statistical sets of data is applied to Dimensioning and

Tolerancing - ANSI Y14.5 (1). Details of the mathematics involving the statistical sets of data are derived by Haugen (4).

In the assembly of a joint, you have tolerances on the size of the hole and the size of the fastener. The location of the hole that the fastener must pass through is permitted to deviate from a theoretical centerline within a specified amount (e.g., +/- .010 inch or within a diameter of .028 inches). See Figure 1. This is referred to as the "True Position Tolerance" of the hole in "Dimensioning and Tolerancing." The method by which mechanical assemblies are made interchangeable is by making sure the maximum size fastener will always fit through the minimum size hole even when the hole deviates from the theoretical centerline the maximum specified amount. As a result, the hole is always at least the maximum size of the fastener plus the true position tolerance. This is referred to as the "Maximum Material Condition" in " Dimensioning and Tolerancing." The worst case condition occurs when all parts have the maximum amount of material (i.e., the smallest allowable hole in plate mating with the largest allowable bolt).

To proceed with the analysis, one must first examine the geometry of the shear joint and how it reacts to the application of a shear force. See Figure 2. The figure shown is representative of the first bolt-hole combination

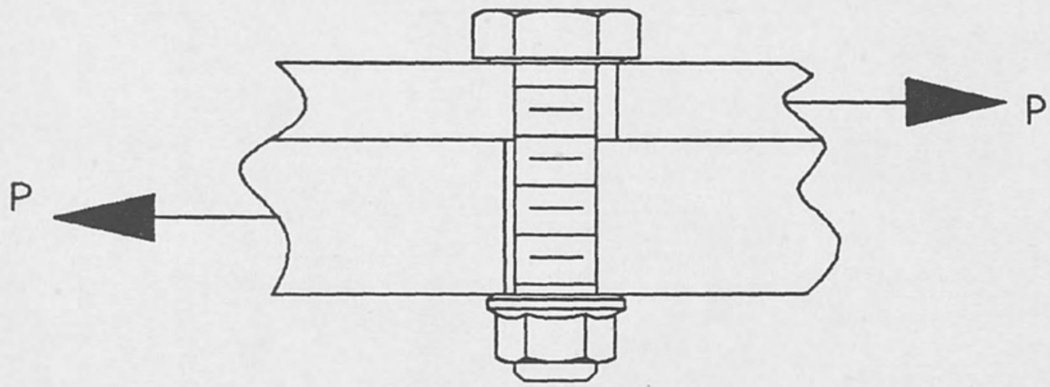


⌖ -SYMBOL FOR "TRUE POSITION TOLERANCE"

Ø -SYMBOL FOR DIAMETER

Ⓜ -SYMBOL FOR "MAXIMUM MATERIAL CONDITION"

FIGURE 1. TRUE POSITION TOLERANCE



SHOWN IS REPRESENTATIVE OF FIRST BOLT-HOLE
COMBINATION WHICH EQUILIBRATES THE SHEAR LOAD
P- MAXIMUM ALLOWABLE SHEAR LOAD

FIGURE 2. BOLTED SHEAR JOINT

in the shear joint which comes into bearing upon applicaton of the shear force. As the shear force is increased, the bolt-hole combination elongates, effectively shifting the hole location from its theoretical centerline. The entire hole pattern will in fact shift by the amount that the bolt-hole combination elongates, thereby increasing the true position tolerance. The net effect of the deflection on the statistical model is that it would increase the expected value (average) of the true position tolerance and leave the standard deviation unchanged. The tolerance increase will effectively decrease the useable portion of the hole relative to the theoretical centerline. If one obtains the relationship between the effective size of the hole relative to the theoretical centerline and then compares the percentage of the population of bolts which would be larger than the effective hole size, the amount of bolts in bearing can be estimated. Therefore, one needs to determine the amount that the bolt-hole combination elongates and a relationship between true position tolerance and the effective hole size. From "dimensioning and tolerancing," the relationship between true position tolerance and effective hole size is already known. That is, the effective hole size relative to the theoretical centerline is decreased by the same amount of its true position tolerance. The theoretical centerline is used as the reference point because it is analogous to the centerline of the Gaussian Distribution and all tolerances should be distributed approximately normally around it.

In order to keep this discussion in general terms without specifying the geometry of the joint (i.e., two plates or two concentric cylinders), the constituent materials comprising the shear joint shall be referred to as Body One and Body Two henceforth in this paper. A list of definitions, symbols and nomenclature used in this discussion is presented in Appendix VII and should be referred to as needed.

The total deflection in the bolt-hole combination will be due to the Hertzian Contact Stresses and the deformation in the bolt due to the shear force and bending moment seen by the bolt due to the applied shear load. For purposes of calculating the deformation due to the Hertzian Contact Stress, the equations used in the analysis have been derived from manipulation of some equations from an article entitled "Theory of Roller Bearing Lubrication and Deformation (6)." The relevant equations are extracted from appendix 19.III of that article. In their article, they derive equations to calculate the deformation of a single cylindrical roller bearing in contact with its races due to an applied load. Their equations are derived in terms of the material properties of the bearing and race by calculating the approach of a semi-infinite solid towards a point in a body. In our analogy, the bolt is loaded perpendicular to Body One and Body Two as shown. See Figure 3. At any given cross section in Body One or Body Two, the pressure distribution is assumed uniform as depicted in Figure 4. Dowson et al (6) then further simplify their equations by substituting material properties of typically used roller bearing materials into their general expressions. In our case, these equations were not simplified; rather, they retained the general relations enabling one to vary the material properties of the shear joint. In order to calculate the deformation of the bolt-hole combination at the yield point, the maximum contact pressure is set equal to the "compressive yield strength (10)" of the body of the hole. This is a result of assumption number twenty-one listed previously. Exact formulation and manipulation of the equations to calculate the deformation due to the contact stresses is shown in Appendix I.

In order to calculate the maximum allowable shear load in a single bolt-hole combination of the shear joint, the pressure distribution(shown in figures 3 and 4) is integrated over the length of the body. This is done for both bodies comprising the joint and the relative magnitudes of the total shear force is noted. The maximum allowable shear force (P) in the bolt-hole combination is set equal to

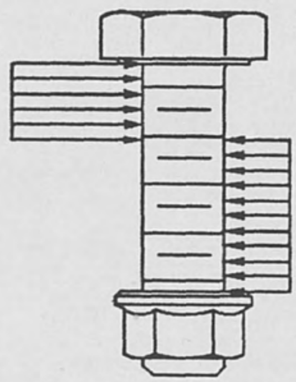
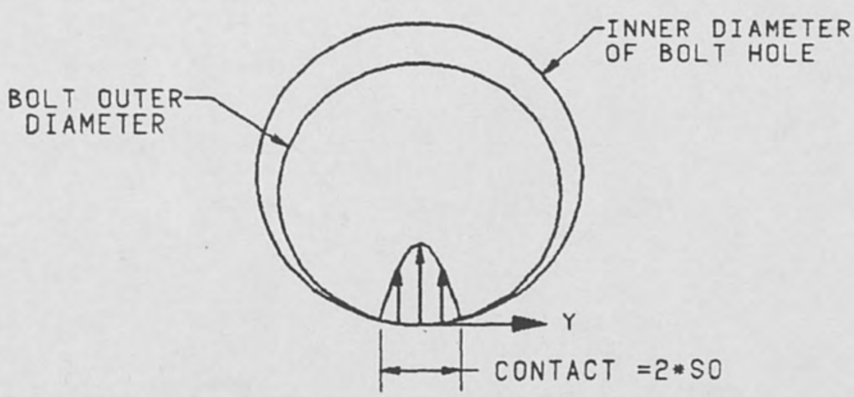


FIGURE 3. HERTZIAN CONTACT STRESS DISTRIBUTION IN PLANE PERPENDICULAR TO APPLIED SHEAR FORCE



P(Y)=(2*PL/(PI*(SO**2))*(((SO**2)-(Y**2))**0.5)

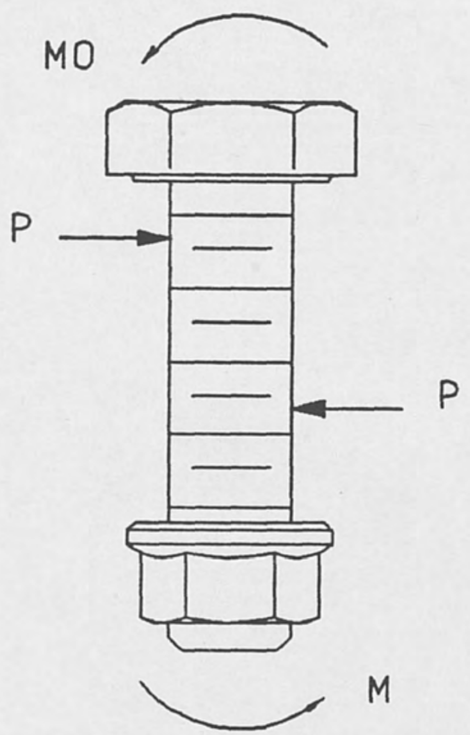
PL = FORCE PER UNIT LENGTH

FIGURE 4. HERTZIAN CONTACT STRESS DISTRIBUTION IN PLANE PARALLEL TO APPLIED SHEAR FORCE

the smaller of these two values. This is done because any increase in the shear force above this value would yield one of the bodies. This case would be in direct violation of our stated assumptions.

Having the maximum allowable shear load P in a joint, we can estimate the deflection in the bolt due to bending. For simplicity, the integral of the pressure distribution along each body is replaced by a concentrated force (P) assumed to act at the centroid of each contact area. Referring to Figure 5, the free body diagram of the bolt would then look as shown. Modeling the bolt as a cantilevered beam with zero slope at both ends, the deflection due to bending can be estimated using elementary beam theory. See Appendix II for the formulation of displacement equations due to the shear and moment load in the bolt. Using the principle of superposition, the total deflection of the bolt-hole combination can be calculated by adding the deformation due to Hertzian Stresses to the deformation due to the shear and moment loading on the bolt.

To proceed with the analysis, this total deflection then needs to be incorporated into a statistical model. Under the assumption of a Gaussian Distribution, there are two relevant statistical models which govern the relationships between the independent random events. These statistical models are the normal distribution and the



MO = MOMENT UNDER HEAD OF BOLT

M = MOMENT UNDER NUT

P = ALLOWABLE SHEAR FORCE

FIGURE 5. FREE BODY DIAGRAM OF BOLT

t-distribution. The normal distribution is typically used for sample sizes which have thirty or more degrees of freedom. The t-distribution is typically used for populations which have less than thirty "degrees of freedom." The primary difference between the t-distribution and the normal distribution is attributed to the fluctuation of the sample variance taken from a population which is normally distributed. If the sqare root of the sample variance is a good estimate of the standard deviation of the normal population, we have the statistical model which is defined as the t-distribution (11).

The normal or Z-distribution shall be used interchangeably henceforth in this paper. The designation (Z) is given to a normal distribution which has been normalized such that the expected value or mean is equal to zero and with a variance equal to one. This is defined in statistics texts (11) as the "standard normal distribution." This distribution will be used as the statistical model where the degrees of freedom after the initial shift of the bodies due to the applied shear load is greater than or equal to thirty. Z(x) is defined by the equation below. (Consult Appendix VII for definitions.)

$$Z(x) = (X - \mu)/\sigma$$

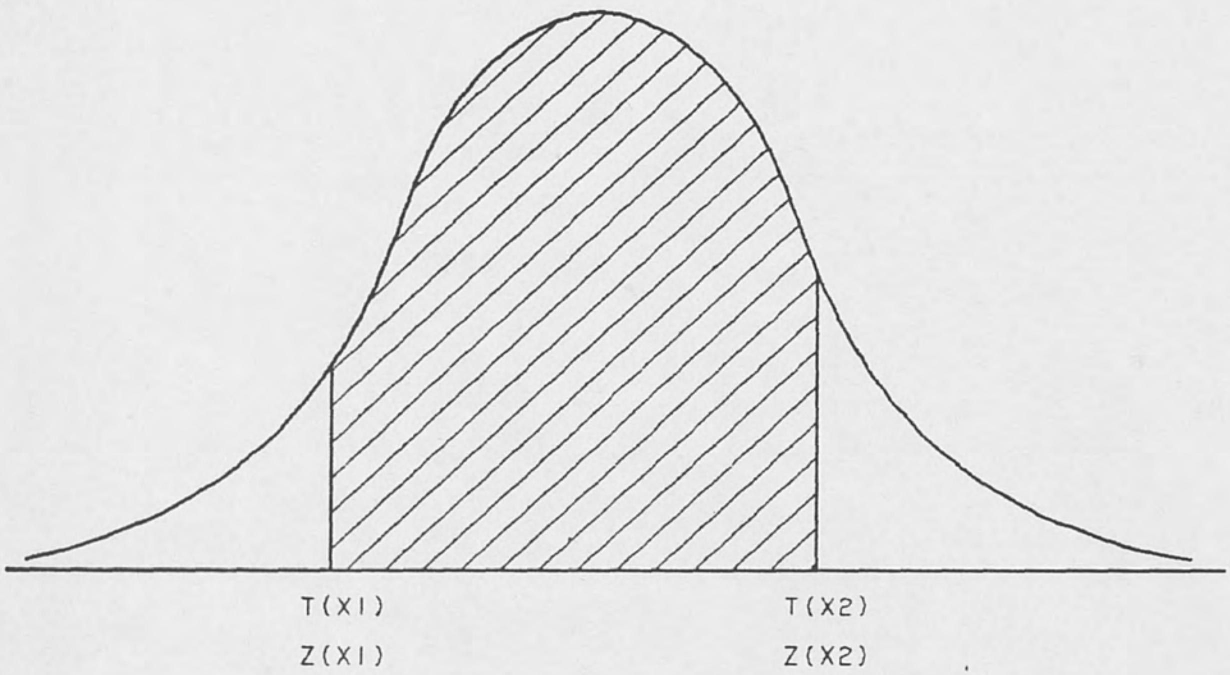
Z(x) is equal to the probability that the random variable takes on a value less than X. The probability that the random variable X takes on a value between X=x1 and X=x2 is equal to the area under the Normal Curve and is numerically equal to the difference between the values Z(x1) and Z(x2). See Figure 6. In the algorithm used in the analysis, the Z-distribution will be approximated by a binomial expansion (8).

The t-distribution is defined slightly different than the normal distribution, as shown below. (Consult Appendix VII for definitions.)

$$T(x) = (X - \mu)/(\sigma / \sqrt{N})$$

T(x) is the probability that the random variable takes on a value greater than X. It is very similar to the Z-distribution. The probability that the random variable X takes on a value between X=x1 and X=x2 is equal to the area under the t-curve and is numerically equal to the difference between T(x1) and T(x2). Both the t and Z distributions take on the same familiar bell shape as shown in Figure 6. In order to calculate the area under the t-curve in the algorithm, "critical values of the t-distribution" will be input into a matrix. These can be found in almost any text-book on statistics (4), (11). Interpolation between the values in the matrix at the appropriate number of "degrees of freedom" will then yield a value for T(x).

The manner by which the application of statistics can be used to determine the number of load-carrying fasteners



T(X)- USED FOR CALCULATIONS IN THE T-DISTRIBUTION

Z(X)- USED FOR CALCULATIONS IN THE NORMAL DISTRIBUTION

FIGURE 6. PLOT OF THE NORMAL AND T- DISTRIBUTION

in a joint subjected to shear loading is as follows:

1. Determine the statistics (μ_H , σ_H) of the hole size in each body; μ_H= HMU is equal to the expected value of the hole size in each body ; σ_H= HSD is equal to the standard deviation of the hole size in each body.
2. Determine the statistics (μ_T , σ_T) of the "true postion tolerance" of the holes in each body; μ_T = TMU is equal to the expected value of the true position tolerance in each body; σ_T = TSD is equal to the standard deviation of the true position tolerance is each body.
3. Determine the statistics (μ_D , σ_D) of the deformation in the bolt-hole combinations in each body; μ_D = DMU is equal to the expected value of the total deformation in each body; σ_D = DSD is equal to the standard deviation of the total deformation in each body.
4. Add the deformation statistics due to the shear load to the true postion tolerance statistics using the mathematics for addition of sets of random variables.
5. Calculate the effective hole size statistics(μ_E , σ_E) relative to the theoretical centerline for each body; μ_E = EMU is equal to the expected value of the effective hole size in each body; σ_E = ESD is equal to the standard deviation of the effective hole size in each body.

6. Using the effective hole size, determine the amount of fasteners which are larger than the effective hole size. The manner in which the calculation is performed is determined by number of degrees of freedom in the bolt pattern after the initial shift of the bodies. For the degrees of freedom greater than or equal to thirty, the standard normal distribution is used for this calculation. This results in a calculation of Zeff(x). See Appendix III for details. If N is less than thirty, the t-distribution is used. (Details can be seen in Appendix IV.) This results in a calculation of teff(x).
7. The most probable number of bolts bearing on Body One after deformation = BBMU(1) is then determined. The standard deviation of this quantity is also calculated = BBSD(1).
8. The most probable number of bolts bearing on Body Two after deformation = BBMU(2) and the corresponding standard deviation of this quantity is also calculated = BBSD(2).
9. The probability that the bolts are bearing on both plates will then be determined = B12MU. From statistics, the product of two normally distributed random variables is not necessarily a normally

distributed random variable. However, under certain conditions defined as "Robust," the product of the two random variables closely approximates a normally distributed random variable. If the distribution is "Robust," then the probability of the two random events coinciding is equal to the product of their probabilities. According to the "central limit theorem," most products of independent random variables are "Robust." A sufficient condition for the "Robust" normal approximation by the product probability density function is that the "coefficient of variation"(=CVX; see Appendix VII for definition) for either set of data must be less than or equal to 0.075. This numerical test will be incorporated into the algorithm. In the event the distribution is not "Robust," the program will issue a statement stating the same and its implications on the calculation accuracy. In the absence of friction, only those bolts which bear against both bodies will be carrying some of the shear load. The relative magnitude of the shear force carried by each of the fasteners is proportional to its respective deformation.

10. The most probable number of bolts actually carrying the shear load could then be estimated by taking their geometry into account. All details of the preceding

calculations can be found in Appendix III if the normal distribution is used and Appendix IV if the t-distribution is used.

A condensed copy of the flowchart used in the algorithm is shown in Figure 7. The algorithm is user-friendly and is compatible with the IBM PC. For exact details on the calculations in the program, the program listing should be consulted. A copy of the user's manual and instructions is provided in Appendix V and the program listing is shown in Appendix VI. A copy of the algorithm on a "floppy disk" is located in Appendix VIII.

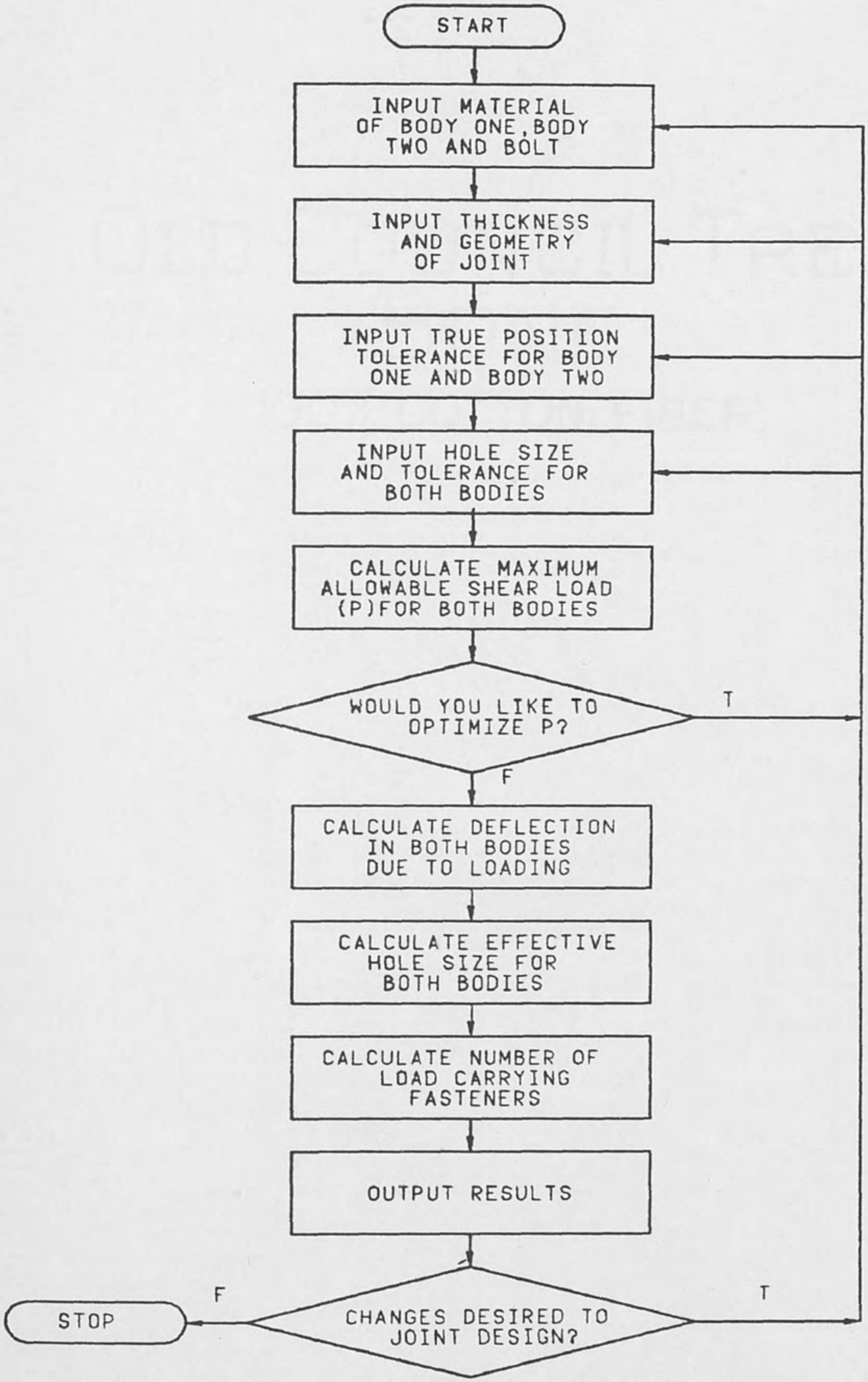


FIGURE 7. ALGORITHM FLOW CHART

RESULTS

Perhaps the best way to present the results of this analysis is through the use of an example. Details of the example are shown below:

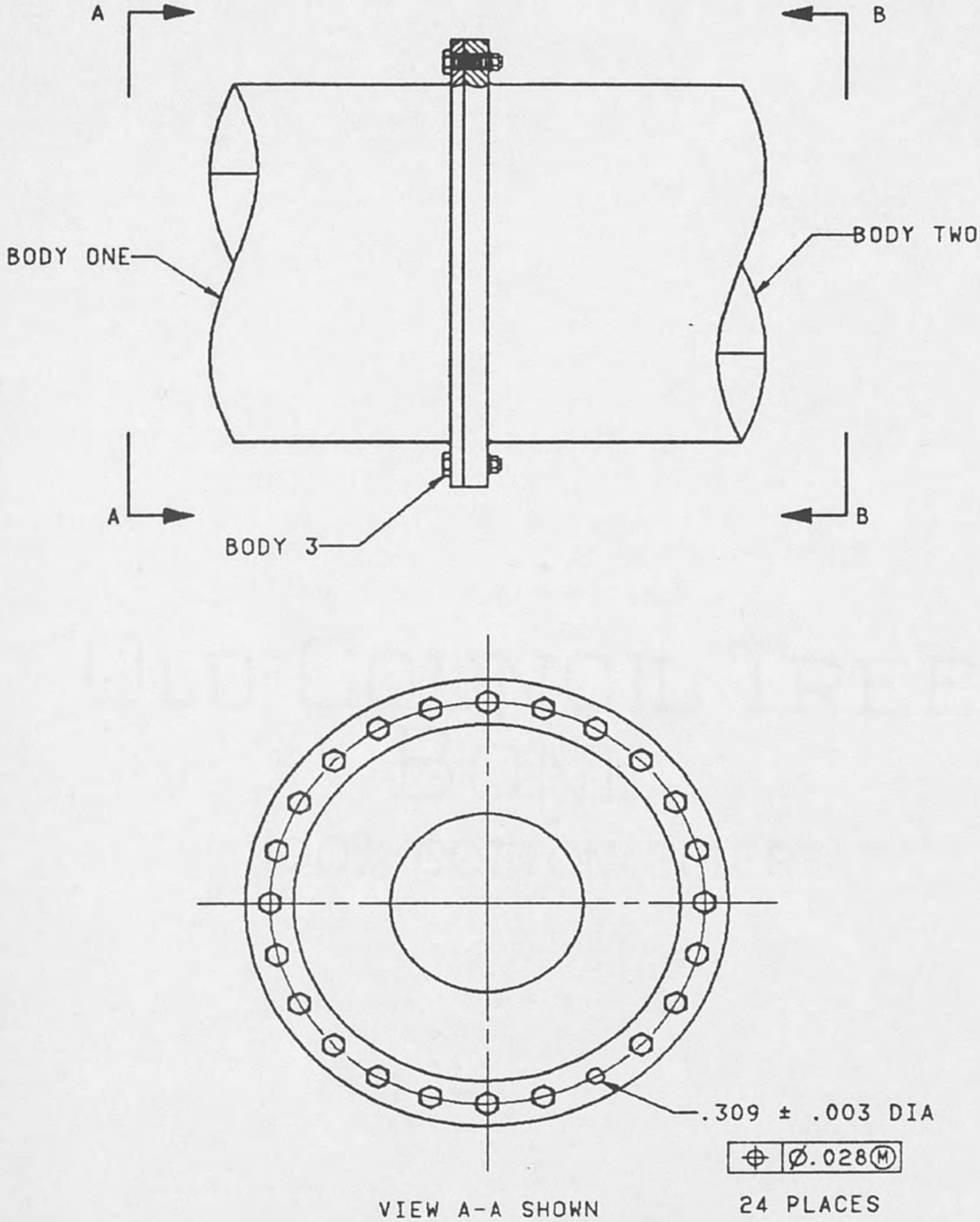
Given:

The power transmission coupling shown in Figure 8. The geometry of the joint and materials of the joint are as shown. It is assumed both bodies are manufactured to the same specified tolerance as indicated.

Find:

A. The number of load-carrying fasteners for this joint design and its corresponding standard deviation. Also, calculate the maximum allowable shear force in a single bolt-hole combination.

B. Allowing one to vary the material properties of body two, calculate the number of load-carrying fasteners and its corresponding standard deviation. Also, calculate the maximum allowable shear force in a single bolt-hole combination of this joint.



VIEW A-A SHOWN
VIEW B-B SIMILAR
MATERIAL FOR BODY ONE = NUMBER 39
MATERIAL FOR BODY TWO = NUMBER 15
MATERIAL FOR BODY THREE = NUMBER 45
MINIMUM SIZE OF BODY THREE = .240 INCH
MAXIMUM SIZE OF BODY THREE = .250 INCH
THICKNESS OF BODY ONE = .250 INCH
THICKNESS OF BODY TWO = .500 INCH
BOTH PARTS MANUFACTURED TO SAME TOLERANCES

FIGURE 8. BOLTED SHEAR JOINT EXAMPLE

Solution:

A. After inputting the material properties, geometry, and manufacturing tolerances on the constituent parts, the algorithm will calculate the maximum allowable shear force in a single bolt-hole combination of that joint. Results would be as follows:

$$P(1) = 106 \text{ lb.}$$

$$P(2) = 22 \text{ lb.}$$

$$P = 22 \text{ lb.}$$

For the given joint design, we will not optimize P and proceed to calculate the expected value and standard deviation of the number of load-carrying fasteners. This would be accomplished by using the t-distribution for N less than thirty. The results are shown below:

B12MU = 1

B12SD = 0

B. Following the same methodology as Part A, we assume the geometry and the manufacturing tolerances are fixed, but we allow the material for Body Two to vary. By substituting different types of materials in for Body Two, we can optimize P. When the allowable shear force in Body One is approximately that of Body Two, the shear force P will have been optimized.

Following this procedure, we find that by making Body Two out of material number 5, the results are as follows:

P(1) = 106 lb.

P(2) = 84 lb.

P = 84 lb.

B12MU = 1

B12SD = 0

One could then vary the "true position tolerance" of the joint. The user must be knowledgeable in the use of "dimensioning and tolerancing" in that any change in the "true position tolerance" would be accompanied by an equivalent increased minimum hole size in each body to insure interchangeablity. In practice, hole sizes in designed joints are determined by knowing the required true position tolerance and then calculating the minimum size hole required at "maximum material condition." The next standard size drill and associated tolerance are then used in the design of the detail parts. Other combinations of the tolerance, materials and geometry could be devised. The combinations are only limited by the joint specifications and the manufacturing tolerances.

CONCLUSION

A method by which to calculate the number of load-carrying fasteners in a given design of a shear joint has been proposed. It is based on the geometry of the shear joint, the manufacturing tolerances on the constituent parts and the material properties of the joint itself. The analysis assumes that the strain in all constituent parts of the joint remain within the elastic range upon application of the shear load. The results show that the constituent materials will yield locally at a very low applied shear force due to the Hertzian Contact Stresses. From a practical point of view, this suggests that yielding does occur in all classically designed shear joints which are subjected to their design loads. Therefore, the analysis was based upon a bad assumption and the ensuing results are not representative of what actually occurs in a shear joint.

Although the results are in error, the analysis has suggested a method by which the manufacturing tolerances can be included in the stress analysis of a shear joint. The analysis could be greatly improved upon by first deciding upon an acceptable amount of plastic deformation in a shear joint. Knowing this quantity, a finite element model of a shear joint with one bolt in shear could then be established. This finite element model would be representative of the first bolt-hole combination in any shear joint which equilibrates the shear load. If one can obtain the actual total deformation in the bolt-hole combination of the shear joint at the acceptable level of plastic deformation, this quantity could then be applied to the manufacturing tolerances of the constituent parts of the shear joint as was demonstrated in this paper. This total deformation would have to include the plastic deformation in the constituent parts of the joint as well as the deflection due to the shear and bending moment in the bolt. The principle of superposition could not be used in this case because it is not applicable to plastic problems (2). For future research, this finite element model would need to be established and integrated into the statistical model presented in this work.

It would also be desireable to obtain from the finite element model, a function which relates the applied shear force to its respective deformation. Assuming the force from this function is normally distributed, this analysis could be extened to estimate the approximate stiffness of a joint. Having the statistics of the number of load-carrying fasteners in the joint and the statistics of the deformation, one could obtain statistical statements as to the shear force carried by each bolt. By applying the mathematics of statistics to the number of load-carrying fasteners, the force carried by each fastener, and the deformation statistics of the bolt-hole combination, an approximate stiffness of the joint could be obtained.

APPENDIX I

FORMULATION OF DEFORMATION EQUATIONS DUE TO HERTZIAN CONTACT STRESS

All equations in this appendix referenced with a (19.XX) type of designation are taken from Appendix 19.III of "Theory of Roller-Bearing Lubrication and Deformation (6)." This article should be referred to as needed to follow the derivation of the displacement equations. The derivation follows:

From equation before (19.21) on pg.226, the pressure distribution is given by P(Y) shown below:

P(Y)=((2*PL)/(PI*(SO^2))*((SO^2-Y^2)^0.5) (I-1)

Consult Figure 4 for explanation of SO,Y. The maximum pressure will be located at the center of the pressure distribution where Y = zero. This implies the maximum pressure is given by:

PMAX =(2*PL)/(PI*SO) (I-2)

From equation (19.21):

SO=(PL/B1)^0.5 (I-3)

B1 is defined by equation 19.20:

B1=GA(1)/(2*R*K(1)) (I-4)

Substituting B1 into equation (I-3):

SO=((PL*2*R*K(1))/GA(1))^0.5 (I-5)

Combining equations (I-2) and (I-5) and rearranging results in the following equation for PL:

PL=((PMAX^2)*(PI^2)*R*K(1))/(2*GA(1)) (I-6)

GA(X) is defined by the equation in the article before equation (19.18):

$$GA(1)=K(3)/(K(1)+K(3)) \quad (I-7)$$

Substituting for GA into (I-6):

$$PL=((PMAX^2)*(PI^2)*R*(K(1)+K(3)))/2 \quad (I-8)$$

Equation (I-8) will then be multiplied by the bearing length to determine the total force. In our case, the bearing length will take on the value of the thickness of the plate (e.g., T(1) or T(2)). The yield strength of the joint will be controlled by the weakest material in the joint. For the case at hand, we must calculate the maximum load P that Body One and Body Two can withstand. For Body One, P(1) will be given by the following equation:

$$P=((PMAX^2)*(PI^2)*R*(K(1)+K(3))*T(1))/2 \quad (I-9)$$

This is where PMAX is set equal to the "compressive yield strength" of Body One. The maximum force that Body One can support within its elastic limit would then be given by the following equation:

$$P(1)=((Y(1)^2)*(PI^2)*R*(K(1)+K(3))*T(1))/2 \quad (I-10)$$

P(1) is equal to the force which would just start to yield Body One. Following the same type of equation formulation, P(2) will be given by the following:

$$P(2)=((Y(2)^2)*(PI^2)*R*(K(2)+K(3))*T(2))/2 \quad (I-11)$$

Having the maximum load that Body One and Body Two can support within their elastic limits, the maximum shear load

P allowed in the bolt-hole combination will then be the smaller of these two values. The deformation equation for the reduction of the radius of the roller, which is analogous to the bolt in our case is given by equation (19.23). Multiplying (19.23) through by (P*K1) gives us an expression for the reduction in the bolt radius=D(1). D(1) is given by the following equation:

D(1)=PL*K(3)*((0.5*(Ln(R/(PL*K(3)))) (I-12)
+.193 +(0.5*Ln(2*GA(1)))

D(2) is given by equation (19.25). Multiplying (19.25) through by (P*K2) and reducing results in the following equation:

D(2)=PL*K(3)*(0.5*Ln(R/(PL*K(1))) (I-13)
+0.5*Ln(2*GA(1)) -.693 +
((1-2*NU(3))/(2*(1-NU(3))

The total deformation in Body (X) due to the Hertzian Contact Stresses is given by the following equation:

DEFH(X)= D(1) + D(2) (I-14)

APPENDIX II

FORMULATION OF DEFORMATION EQUATIONS DUE TO THE SHEAR AND BENDING MOMENT IN THE BOLT

Assume the bolt is modeled as a cantilevered beam and loaded as shown in Figure 9. Point A is the origin of our coordinate system with X,Y as shown. The slope at the end of the beam (Point C) is assumed to be zero. This enables us to calculate the moment under the nut which is analogous to Point C by applying "elementary beam theory." First, the slope at Point C due to each of the loads will be calculated and then set equal to zero.

Reference: Advanced Mechanics of Materials (2)

Theta(1) =(-P *((T(1)/2)^2))/(2*E*I) (II-1)

Theta(2) =(-P *((T(1)+(T(2)/2))^2)/(2*E*I) (II-2)

Theta(M) =(-M * (T(1)+ T(2)))/(E*I) (II-3)

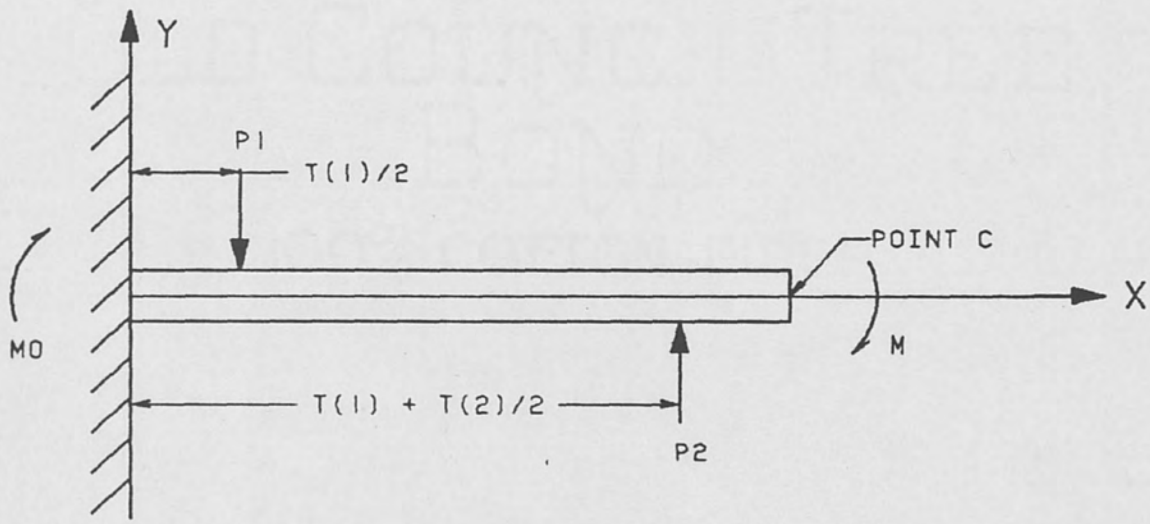
Using the method of superposition, the sum of the slopes is assumed to be zero at point c. This results in the following equation:

Theta(1) + Theta(2) + Theta(M) = 0.0 (II-4)

The above equation can also be written in the following form:

- Theta(M) = Theta(1) + Theta(2) (II-4)

Substituting the values for theta(1) and theta(2) into Equation (II-4) allows us to solve for the moment M under the nut of the bolt to maintain zero slope at the end. The value of M is given by the following equation:



NOTE: FOR EQUILIBRIUM, P1=P2=P=ALLOWABLE SHEAR LOAD

MO = MOMENT UNDER HEAD OF BOLT

M = MOMENT UNDER THE NUT

T(1) = THICKNESS OF BODY ONE

T(2) = THICKNESS OF BODY TWO

FIGURE 9. BOLT MODELED AS CANTILEVERED BEAM

```
M=(.75*(T(1)^2)+.25*(T(2)^2)                 (II-5)
+(T(2)*T(1)))*P)/(2*(T(1)+T(2)))
```

To calculate the deflection due to the shear and bending moment on the bolt, we must again use superposition. We will first calculate the deflection in the middle of Body One. The total deflection in the middle of Body One will be the superpostion of the deflections from the combined loading. In equation form this can be written as follows:

```
DEFB(1)= DEF1-1 + DEF1-2 + DEF1-M            (II-6)
```

These quantities will be given by the following equations

```
DEF1-1 =(-P * (T(1)^3))/(24*E*I)             (II-7)
DEF1-2=((P *((T(1)/2)^2))/(24*E*I))*         (II-8)
((-2.5 * T(1))-(1.5 * T(2)))
DEF1-M =((M* T(1)/2)^2)/(2*E*I)              (II-9)
```

Where M is defined by Equation (II-5). The Deflection at Body Two is calculated in the same fashion. The total deflection due to the shear and moment load on the bolt at the centroid of Body Two is given by the following equation:

```
DEFB(2)= DEF2-1 + DEF2-2 + DEF2-M            (II-10)
```

These quantities will be given by the following equations:

```
DEF2-1=((P*((T(1)/2)^2))/(24*E*I))*          (II-11)
((-2.5 * T(1))-(1.5 * T(2)))
DEF2-2 =(P *(4*(T(1)^2)+ T(1)+T(2)))))/      (II-12)
(24*E* I*((-2 * T(1))-( T(2))
```

DEF2-M=(M*(4*(T(1)^2)+T(1)+T(2))))/(8*E*I) (II-13)

The total deformation in Body One due to bending will be referred to as DEFB(1) and will be computed by equation (II-6). The total deformation in Body Two due to bending will be referred to as DEFB(2) and will be computed by equation (II-10).

APPENDIX III

CALCULATION OF THE NUMBER OF LOAD BEARING FASTENERS FOR GREATER THAN OR EQUAL TO THIRTY DEGREES OF FREEDOM (NORMAL DISTRIBUTION)

Calculation of the most probable number of bolts which would come into bearing due to the bolt-hole elongating will be calculated for any "Body" in general. Using the statistics of the effective hole size and the statistics of the bolt population, we calculate the probabability of the clearance between the bolt and the effective hole size to be less than zero. This results in a calculation of Zeff(x).

Before we can do this, we first must calclulate the statistics of the effective hole size. This requires that we determine the statistics(MU,SD) of the deformation. The total deformation due to the applied load is given by the below equation:

$$DEFT(X) = DEFH(X) +[(DEFB(X)] \quad (III-1)$$

DELMAX and DELMIN are calculated by substituting the maximum diameter of the bolt and the minimum diameter of the bolt in the general expression for the total deformation due to the applied load. DSD is calculated by the below equation:

$$DSD=((DELMAX-DELMIN)/6) \quad (III-2)$$

DMU is calculated by the equation below:

$$DMU=((DMAX -DMIN)/2) + DMIN \quad (III-3)$$

Having T=(TMU,TSD)

D=(DMU,DSD)

H=(HMU,HSD)

We calculate the statistics of S= Shift of the Hole Pattern from its theoretical centerline. S= (SMU,SSD) These quantities are calculated by use of the following equations.

$$SMU=TMU+DMU \quad (III-4)$$

$$SSD=((DSD^2 + TSD^2)^{0.5}) \quad (III-5)$$

Next, we calculate the statistics of the effective hole size (EMU,ESD). These are defined by the following equations:

$$EMU=(HMU-SMU) \quad (III-6)$$

$$ESD = (SSD^2 + HSD^2)^{0.5} \quad (III-7)$$

We then want to calculate the statistics of the clearance of the effective hole size relative to the theoretical centerline C=(CMU,CSD).

$$CMU= (EMU - BMU) \quad (III-8)$$

$$CSD=(ESD^2 + BSD^2)^{0.5} \quad (III-9)$$

Now, having the statistics of the clearance, we calculate the probability that the clearance is less than zero. This results in the following equation.

$$Zeff(0)=(0 - CMU)/CSD \quad (III-10)$$

Using the value of Zeff(0), we calculate the area under the Normal Curve which is equal to the probability that the clearance is less than zero. This results in the calculation of PZeff(1) and PZeff(2). We then calculate all of the following quantities.

$$BBMU(1)= PZeff(1) * N \quad (III-11)$$

$$BBMU(2)= PZeff(2) * N \quad (III-12)$$

BBSD(1)= CSD(1) * N (III-13)

BBSD(2)= CSD(2) * N (III-14)

B12MU= (PZeff(1)*PZeff(2)*N) + K (III-15)

Here K is a constant that is numerically to the number of degrees of freedom of motion between the two bodies before the initial shift.

K = 1 for Concentric Cylinders

K = 2 for joint comprised of two plates

It is also possible to design a shear joint comprised of two flat plates which physically have only one degree of freedom of motion with respect to one another. For this case, the concentric cylinder model should be utilized to calculate the number of load-carrying fasteners in the joint. The standard deviation of the bolts bearing on both bodies is also calculated = B12SD.

B12SD = (((BMU(1)^2)*(BBSD(2)^2)) (III-16)

+ ((BBMU(2)^2)* (BBSD(1)^2))

+ ((BBSD(1)^2)* (BBSD(2)^2)))^0.5

APPENDIX IV

CALCULATION OF THE NUMBER OF LOAD BEARING FASTENERS FOR LESS THAN THIRTY DEGREES OF FREEDOM (T-DISTRIBUTION)

We follow the same basic methodology in calculating the statistics of the parts as explained for greater than thirty "Degrees of Freedom".(See Appendix III)

Assume the statistics: T= (TMU,TSD)

D= (DMU,DSD)

H= (HMU,HSD)

Due to the manner in which the t-distribution is tabulated, instead of calculating the clearance statistic, we will calculate the interference statistics I= (IMU,ISD)

IMU =(BMU-EMU) (IV-1)

ISD= (ESD^2 + BSD^2) (IV-2)

Having the interference statistics, we calculate the probability that the interference is greater than zero. This results in the following equation:

teff(0)= (0-IMU)/((ISD/(N^0.5))) (IV-3)

Using the value of teff(0), we calculate the probability that the interference is greater than zero. We calculate Pteff(1) and Pteff(2). All other quantities can than be calculated as follows:

BBMU(1)= Pteff(1) * N (IV-4)

BBMU(2)= Pteff(2) * N (IV-5)

BBSD(1)= ISD(1) * N (IV-6)

BBSD(2)= ISD(2) * N (IV-7)

B12MU= (Pteff(1)*Pteff(2)*N) + K (IV-8)

Here K is a constant that is numerically to the number of degrees of freedom of motion between the two bodies before the intial shift.

K = 1 for Concentric Cylinders

K = 2 for joint comprised of two plates

It is also possible to design a shear joint comprised of two flat plates which physically have only one degree of freedom with respect to one another. For this case, the concentric cylinder model should be used. The standard deviation of the bolts bearing on both bodies is also calculated = B12SD.

B12SD = (((BMU(1)^2)*(BBSD(2)^2)) (III-14)

+ ((BBMU(2)^2)* (BBSD(1)^2))

+ ((BBSD(1)^2)* (BBSD(2)^2)))^0.5

APPENDIX V

USER'S MANUAL AND INSTRUCTIONS

In order to use the program, one must insert the diskette into drive a on a personal computer which has the software for the basic computer language. Then, one must type the following and then hit the "return" key:

```
basica
```

This will allow you to use the basic computer language. One must then load the algorithm into the computer. This is accomplished by typing the following information into the computer:

```
Load"a:shear.bas"
```

The computer will come back with the statement: OK. The program is now ready to use. One must then type:

```
Run
```

The program will then ask you to input the following joint parameters into its memory.

MN(X)	Material Number for Body X.	X=1,2,3
T(X)	Thickness of Body X.	X=1,2
GEO	Geometry Factor	
NT	Total number of fasteners in joint.	
TP(X)	True position tolerance for Body X.	X=1,2
HMAX(X)	Maximum hole size for Body X.	X=1,2
HMIN(X)	Minimum hole size for Body X.	X=1,2
DMAX	Maximum diameter of bolt.	
DMIN	Minimum diameter of bolt.	

The Materials List should be consulted for the appropriate material number for each body. In the event you want to use a different material other than what is tabulated in the Materials List, the algorithm will ask you to input the following information:

E(X)	Young's Modulus for Body X.	X=1,2,3
NU(X)	Poisson's Ratio for Body X.	X=1,2,3
Y(X)	Compressive yield strength for Body X.	X=1,2,3

After all the previous information is input into the program, the algorithm will calculate the maximum allowable shear load in a single bolt-hole combination of the shear joint for each body. At that time, a decision must be made as to whether or not the user wants to optimize the load P. If one does not want to optimize P, the algorithm will then display the results, at which time, a copy of the output could be obtained. If changes are desired to the Joint Design, the desired changes would have to be input into the program.

MATERIALS LIST

MATERIALS SHALL BE LISTED ACCORDING TO
THE FORMAT SHOWN BELOW

Material
no.

XX. Material Name

Youngs Modulus X(10^6)psi	Poisson's Ratio	Yield Strength X (10^3)psi

1. Al. Alloy -A356-T6 per QQ-A-601

10.3	.33	40

2. Al. Alloy -A356-T6 per QQ-A-596

10.3	.33	40

3. Al. Alloy -A356-T61 per MIL-A-21180

10.3	.33	40

4. Al. Alloy -2024-T3 per QQ-A-250/4

10.5	.33	88

5. Al. Alloy -2024-T42 per QQ-A-250/4

10.5	.33	61

6. Al. Alloy -2024-T3 per QQ-A-250/5

10.5	.33	82

7. Al. Alloy -2024-T62 per QQ-A-250/5

10.5	.33	78

8. Al. Alloy -5052-H32 per QQ-A-250/8

10.1	.33	37

9.	Al. Alloy -5052-H34 per QQ-A-250/8 10.1	.33	41
10.	Al. Alloy -5052-H36 per QQ-A-250/8 10.1	.33	46
11.	Al. Alloy -5052-H38 per QQ-A-250/8 10.1	.33	51
12.	Al. Alloy -5086-0 per QQ-A-250/7 10.2	.33	28
13.	Al. Alloy -5086-H32 per QQ-A-250/7 10.2	.33	48
14.	Al. Alloy -5086-H34 per QQ-A-250/7 10.2	.33	58
15.	Al. Alloy -5086-H112 per QQ-A-250/7 10.2	.33	31
16.	Al. Alloy -6061-T4 per QQ-A-250/11 10.1	.33	26
17.	Al. Alloy -6061-T451 per QQ-A-250/11 10.1	.33	26
18.	Al. Alloy -6061-T6 per QQ-A-250/11 10.1	.33	58
19.	Al. Alloy -6061-T4 per QQ-A-225/8 10.1	.33	26
20.	Al. Alloy -6061-T6 per QQ-A-225/8 10.1	.33	56

21.	Al. Alloy -6061-T6 per QQ-A-367 and MIL-A-22771			
	9.9	.33	61
22.	Al. Alloy -6061-T4 per QQ-A-200/8		
	9.9	.33	26
23.	Al. Alloy -6061-T6 per QQ-A-200/8		
	9.9	.33	60
24.	Al. Alloy -7075-T6 per QQ-A-250/12		
	10.3	.33	117
25.	Al. Alloy -7075-T651 per QQ-A-250/12		
	10.3	.33	114
26.	Al. Alloy -7075-T651 per QQ-A-250/13		
	10.3	.33	111
27.	Al. Alloy -7075-T6 per QQ-A-250/26		
	10.3	.33	101
28.	Al. Alloy -7075-T6 per QQ-A-225/9		
	10.3	.33	92
29.	Al. Alloy -7075-T6 per QQ-A-200/11		
	10.4	.33	110
30.	Al. Alloy -7075-T6 per QQ-A-200/15		
	10.4	.33	98
31.	Al. Bronze per AMS 4631		
	16.0	.30	54
32.	Beryllium Copper per QQ-C-530-AT		
	18.5	.27	143

33.	Beryllium Copper per QQ-C-530-HT		
	18.5	.27	170
34.	Beryllium Copper per QQ-C-533-AT		
	18.5	.27	143
35.	Beryllium Copper per QQ-C-533		
	18.5	.27	143
36.	Steel, Carbon per MIL-S-7952,1025		
	29.0	.32	90
37.	Steel, Carbon per MIL-S-7097,COMP.3		
	29.0	.32	90
38.	Steel, Stainless per MIL-S-5059;ANNEALED		
	28.0	.12	50
39.	Steel, Stainless per MIL-S-5059;.25 HARD		
	26.0	.083	125
40.	Steel, Stainless per MIL-S-5059;.50 HARD		
	26.0	.13	167
41.	Steel, Stainless per MIL-S-5059;.75 HARD		
	26.0	.18	200
42.	Steel, Stainless per MIL-S-5059;FULL HARD		
	26.0	.18	241
43.	Steel, Stainless 17-4PH; H900 PER AMS 5643		
	28.5	.27	280
44.	Steel, Stainless 17-4PH; H1025 PER AMS 5643		
	28.5	.27	250

45. Steel, Stainless 17-4PH; H1150 PER AMS 5643
28.5 .27 181

46. Steel, Stainless 17-4PH; H1000 PER AMS 5343
28.5 .27 222

47. Steel, Stainless 17-4PH; H1000 PER AMS 5355
28.5 .27 222

48. Steel, AISI 4130,8630 and 8735
29.0 .32 120

49. Steel,Low Alloy per AMS 6418
29.0 .32 286

50. Steel,Low Alloy; 4330 Si 4330 V
29.0 .32 296

51. Steel,Low Alloy; D6AC 4335 V
29.0 .32 302

52. Steel,Low Alloy; per AISI 4340 D6AC
29.0 .32 343

53. Steel,Low Alloy; per AISI 4340
29.0 .32 343

54. Steel,Low Alloy; 300 M
29.0 .32 396

APPENDIX VI

PROGRAM LISTING

```
1       REM SHEAR.BAS                                    VERSION 1.0
2       REM COPYRIGHT 1987 (C) MARTIN MARIETTA CORPORATION, ALL RIGHTS RESERVED
3       REM
4       REM
5       REM THIS PROGRAM IS ONE ELEMENT OF A THESIS: EFFECT OF MANUFACTURING
6       REM TOLERANCES ON THE NUMBER OF LOAD-CARRYING FASTENERS IN A JOINT
7       REM SUBJECTED TO A SHEAR LOAD -- A STATISTICAL APPROACH
8       REM
9       REM CONCEIVED AND DEVELOPED BY L.J. BORKOWSKI, EMPLOYEE OF MARTIN MARIETTA
10      REM CORPORATION AND GRADUATE STUDENT AT THE UNIVERSITY OF CENTRAL FLORIDA,
11      REM UNDER THE INDUSTRIAL ASSOCIATES PROGRAM SPONSORED BY MARTIN MARIETTA.
12      REM
13      REM FOR INFORMATION: CALL L.J. BORKOWSKI 305-356-8120
14      REM
15      REM THIS PROGRAM (WORK) IS LICENSED TO THE UNIVERSITY OF CENTRAL FLORIDA
16      REM FOR ACADEMIC PURPOSES AND THESIS PUBLICATION.  THIS LICENSE ALSO
17      REM EXTENDS TO THESIS, USER MANUAL AND RELATED SOFTWARE PROGRAMS.
18      REM
20      REM PROGRAM DETAIL: BASIC LANGUAGE, OPERATES ON MOST PERSONAL COMPUTERS
22      REM                 IBM AND IBM COMPATIBLE
23      REM
24      REM A COPY OF THIS PROGRAM IS AVAILABLE AT THE LIBRARY AT THE UNIVERSITY
25      REM OF CENTRAL FLORIDA WITH THE THESIS MATERIAL.  A COPY OF THE THESIS
26      REM MATERIAL IS AVAILABLE AT THE TECHNICAL INFORMATION CENTER, MARTIN
27      REM INFORMATION CENTER, MARTIN MARIETTA CORP., ORLANDO, FLORIDA
28      REM ATTENTION: DR. M. MELTZER , (305)-356-4151/2051
30      REM
35      REM
40      REM
97      REM SHEAR JOINT DESIGN AND ANALYSIS PROGRAM
98      REM THIS PROGRAM CAN BE USED AS A DESIGN OR ANALYSIS TOOL
99      REM CONSULT USERS MANUAL FOR PROGRAM USAGE AND DEFINITIONS
100     DIM A(2), BBMU(2), BBSD(2), CMU(2), CSD(2), CVX(2), D(5), DEFB(2)
110     DIM DEFH(2), DEFT(2), DELMAX(2), DELMIN(2), DMU(2), DSD(2), E(54)
120     DIM EMU(2), ESD(2), HMU(2), GA(2), FZ(2), HMAX(2), HMIN(2), HSD(2)
130     DIM IMU(2), ISD(2), K(3), MN(54), NU(54), P(2), PTEFF(2), PZEFF(2)
140     DIM SMU(2), SSD(2), TMU(2), TSD(2), T(2), TP(2), Q(2), QZ(3)
150     DIM Y(54), X(2), Z(2),TSN(29,10), AR(29,10),B(3),DOF(29),TEFF(2)
200     C=0!
399     CLS
400     LOCATE 1,1:PRINT "THIS PROGRAM CAN BE USED TO OPTIMIZE THE MAXIMUM"
405     LOCATE 2,1:PRINT "SHEAR FORCE IN A JOINT AND THE NUMBER OF LOAD CARRYING"
410     LOCATE 3,1:PRINT "FASTENERS IN A INTERCHANGEABLE JOINT SUBJECTED TO A "
415     LOCATE 4,1:PRINT "SHEAR LOAD UP TO THE ELASTIC LIMIT."
419     LOCATE 6,1:PRINT "THE ANALYSIS IS BASED ON SIMPLIFYING ASSUMPTIONS."
420     LOCATE 7,1:PRINT "FIRST TIME USERS SHOULD REFER TO THE TEXT FROM WHICH"
425     LOCATE 8,1:PRINT "THIS CAME IN ORDER TO MAKE SURE THEY ARE NOT VIOLATING"
430     LOCATE 9,1:PRINT "SOME OF THE ASSUMPTIONS UPON WHICH THIS ANALYSIS IS"
440     LOCATE 10,1:PRINT "BASED."
450     LOCATE 24,1:INPUT "HIT ENTER WHEN DONE READING",Y
500     CLS
990     REM INTIALIZE ALL STARTING VALUES
1000    FOR I=1 TO 2
1005       B(I)=0!
1010       BBMU(I)=0!
1020       BBSD(I)=0!
1030       CMU(I)=0!
1040       CSD(I)=0!
1050       CVX(I)=0!
1060       D(I)=0!
1070       DEFB(I)=0!
1080       DEFH(I)=0!
1090       DEFT(I)=0!
1100       DMU(I)=0!
```

```
1110      DSD(I)=0!
1120      EMU(I)=0!
1130      FZ(I)=0!
1140      ESD(I)=0!
1150      GA(I)=0!
1160      HMU(I)=0!
1180      HSD(I)=0!
1190      HMAX(I)=0!
1200      HMIN(I)=0!
1210      IMU(I)=0!
1220      ISD(I)=0!
1230      K(I)=0!
1235      PL(I)=0!
1236      P(I)=0!
1240      PTEFF(I)=0!
1250      PZEFF(I)=0!
1260      SMU(I)=0!
1270      SSD(I)=0!
1280      TMU(I)=0!
1290      T(I)=0!
1300      TP(I)=0!
1310      Z(I)=0!
1320      Q(I)=0!
1330      QZ(I)=0!
1340      X(I)=0!
1350      MN(I)=0!
1360      A(I)=0!
1400      NEXT I
1410  FOR J=1 TO 29
1412    FOR K=1 TO 10
1414      TSN(J,K)=0!
1416      AR(J,K)=0!
1418      NEXT K
1420    NEXT J
2000  REM INITIALIZE ALL OTHER STARTING VALUES
2010  ANS=0!
2050  B(3)=0!
2100  B12SD=0!
2110  B12MU=0!
2120  BMU=0!
2130  BSD=0!
2140  DMAX=0!
2141  DMIN =0!
2150  DELMAX=0!
2160  DELMIN=0!
2162  DT=0!
2170  GEO=0!
2180  II=0!
2182  IT=0!
2190  M=0!
2191  MN(3)=0
2192  M1=0!
2194  M2=0!
2196  M3=0!
2198  M4=0!
2200  MO=0!
2300  P=0!
2302  PERC=0!
2303  K(3)=0!
2304  JK=0!
2310  PL=0!
2350  PI=3.1415927#
2360  B1=.31938153#
2370  B2=-.356563782#
2380  B3= 1.781477937#
2390  B4=-1.821255978#
2391  D(3)=0!
2392  D(4)=0!
2393  D(5)=0!
2395  D12=0!
2397  D22=0!
2398  ROB=0!
```

```
2399  PRT=0!
2400  REM C IS THE COUNTER TO SEE IF THEY WANT TO CHANGE MATERIAL OR THICKNESS
2410  PP=.2316419
2500  REM MUST DETERMINE IF THE USER WANTS TO USE A MATERIAL THAT IS NOT
2510  REM ON THE MATERIALS LIST
2520  REM THIS IS WHERE I INPUT THE MATERIAL PROPERTIES
2530  FOR I=1 TO 54
2531    MN(I)=0!
2532    E(I)=0!
2533    Y(I)=0!
2534    NU(I)=0!
2535    NEXT I
2537  IF C>0 THEN 2549
2538  GOTO 2550
2549  RESTORE
2550  FOR I=1 TO 54
2555    READ MN(I), E(I),NU(I),Y(I)
2560    NEXT I
2600  REM THIS IS THE MATERIAL DATA
2610  DATA  1,10.3,0.33,40,     2,10.3,0.33,40
2612  DATA  3,10.3,0.33,40,     4,10.5,0.33,88
2614  DATA  5,10.5,0.33,61,     6,10.5,0.33,82
2616  DATA  7,10.5,0.33,78,     8,10.1,0.33,37
2618  DATA  9,10.1,0.33,41,    10,10.1,0.33,46
2620  DATA  11,10.1,0.33,51,   12,10.2,0.33,28
2622  DATA  13,10.2,0.33,48,   14,10.2,0.33,58
2624  DATA  15,10.2,0.33,31,   16,10.1,0.33,26
2626  DATA  17,10.1,0.33,26,   18,10.1,0.33,58
2628  DATA  19,10.1,0.33,26,   20,10.1,0.33,56
2630  DATA  21, 9.9,0.33,61,   22, 9.9,0.33,26
2632  DATA  23, 9.9,0.33,60,   24,10.3,0.33,117
2634  DATA  25,10.3,0.33,114,  26,10.3,0.33,111
2636  DATA  27,10.3,0.33,101,  28,10.3,0.33, 92
2638  DATA  29,10.4,0.33,110,  30,10.4,0.33, 98
2640  DATA  31,16.0,0.30, 54,  32,18.5,0.27,143
2642  DATA  33,18.5,0.27,170,  34,18.5,0.27,143
2644  DATA  35,18.5,0.27,143,  36,29.0,0.32, 90
2646  DATA  37,29.0,0.32, 90,  38,28.0,0.12, 50
2648  DATA  39,26.0,.083,125,  40,26.0,0.13,167
2650  DATA  41,26.0,0.18,200,  42,26.0,0.18 ,241
2652  DATA  43,28.5,0.27,280,  44,28.5,0.27 ,250
2654  DATA  45,28.5,0.27,181,  46,28.5,0.27 ,222
2656  DATA  47,28.5,0.27,222,  48,29.0,0.32 ,120
2658  DATA  49,29.0,0.32,286,  50,29.0,0.32 ,296
2660  DATA  51,29.0,0.32,302,  52,29.0,0.32 ,343
2662  DATA  53,29.0,0.32,343,  54,29.0,0.32 ,396
2800  REM THIS IS WHERE THE MATERIAL PROPERTIES GET MULTIPLIED BY THE
2802  REM APPROPRIATE CONSTANTS
2810  FOR I = 1 TO 54
2820    E(I)=E(I)*(10^6)
2830    Y(I)=Y(I)*(10^3)
2840    NEXT I
3000  CLS
3005  REM IF THE MATERIAL PROPERTIES WERE INPUT BY THE USER, WE WANT TO SKIP
3006  REM INPUTTING THE MATERIAL AND START INPUTTING THE THICKNESS.
3007  REM THIS WILL BE DETERMINED BY THE VALUE OF ANS
3008  IF ANS>0 THEN 3300
3010  LOCATE 1,1:PRINT "THE MATERIAL FOR BODY ONE, BODY TWO AND BODY THREE WILL"
3020  LOCATE 2,1:PRINT "BE INPUT FIRST."
3030  LOCATE 5,1:PRINT "THE MATERIAL PROPERTIES SHALL BE INPUT INTO THE DATA"
3040  LOCATE 6,1:PRINT "FOR EACH BODY.  IN ORDER TO SPECIFY THE MATERIAL PROPERT
IES."
3050  LOCATE 7,1:PRINT "FOR ANY OF THE BODIES, YOU ONLY NEED TO INPUT THE MATERI
ALS"
3060  LOCATE 8,1:PRINT "NUMBER IN THE SPACE PROVIDED."
3070  LOCATE 10,1:PRINT "AFTER INPUTTING EACH MATERIAL NUMBER, HIT ENTER AFTER E
ACH DATA POINT"
3080  LOCATE 15,1:PRINT "TO INPUT ALL DATA, ONE MUST HIT THE ENTER KEY AFTER EAC
H DATA POINT."
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3100  LOCATE 24,1:INPUT "HIT ENTER WHEN DONE READING",Y
3110  CLS
3112  LOCATE 1,1:PRINT "YOU CAN USE DIFFERENT MATERIALS IN THE DESIGN OF A JOINT
"
3114  LOCATE 2,1:PRINT "OTHER THAN THOSE LISTED IN THE MATERIALS LIST"
3115  GOTO 3118
3116  LOCATE 18,1:PRINT "I BEG YOUR PARDON"
3118  LOCATE 19,1:PRINT "WOULD YOU LIKE TO INPUT YOUR OWN MATERIAL PROPERTIES? "
3122  LOCATE 20,1:PRINT "PLEASE ANSWER YES OR NO"
3123  LOCATE 24,1:INPUT "ENTER 1 FOR YES OR 2 FOR NO:",ANS$
3124  CHOICE = VAL(ANS$)
3126  IF CHOICE<1 OR CHOICE>2 THEN BEEP:LOCATE 18,1: PRINT SPACE$(30):GOTO 3116
3128  ON CHOICE GOTO 3140,3200
3140  CLS
3141  LOCATE 1,1:PRINT "IN ORDER TO SPECIFY YOUR OWN MATERIALS, WE MUST ENTER TH
E"
3142  LOCATE 2,1:PRINT "MATERIAL PROPERTIES IN THE PROGRAM , THEY WILL BE STORED
"
3143  LOCATE 3,1:PRINT "IN ARRAYS"
3145  LOCATE 5,1:PRINT "THE MATERIAL PROPERTIES SHALL BE ENTERED INTO THE ARRAYS
"
3146  LOCATE 6,1:PRINT "IN THE FOLLOWING FORMAT."
3148  LOCATE 10,1:PRINT "FIRST, THE COMPRESSIVE YOUNG'S MODULUS =E FOR BODY 1 SH
ALL BE ENTERED"
3149  LOCATE 12,1:PRINT "THIS SHALL BE FOLLOWED BY POISSON'S RATIO AND THE COMPR
ESSIVE"
3150  LOCATE 13,1:PRINT "YIELD STRENGTH FOR BODY 1."
3151  LOCATE 16,1:PRINT "THE PROCESS WILL THEN BE REPEATED FOR BODY 2 AND 3."
3152  LOCATE 19,1:PRINT "TO ENTER THE DATA VALUES, SIMPLY TYPE THE DATA VALUES"
3153  LOCATE 20,1:PRINT "IN THE SPACE PROVIDED AND HIT ENTER."
3154  LOCATE 24,1:INPUT "HIT ENTER WHEN DONE READING",Y
3157  ANS =1
3158  REM IN THIS PART OF PROGRAM, THE USER HAS CHOSEN TO SPECIFY HIS OWN
3159  REM MATERIAL PROPERTIES.  THE MATERIAL PROPERTIES MUST BE INPUT IN THE
3160  REM PROPER UNITS TO WORK WITH THE PROGRAM. WE WILL TELL THE USER THE
3161  REM CORRECT UNITS AND THEN MULTIPLY BY THE APPROPRIATE CONSTANTS.
3164  CLS
3166  LOCATE 1,1:PRINT "THE MATERIAL PROPERTIES NEED TO BE INPUT INTO THE PROGRA
M"
3168  LOCATE 2,1:PRINT "THE UNITS ON YOUNG'S MODULUS SHOULD BE IN POUNDS PER "
3169  LOCATE 3,1:PRINT "SQUARE INCH MULTIPLIED BY 10 RAISED TO THE -6 POWER "
3170  LOCATE 9,1:PRINT "POISSON'S RATIO IS DIMENSIONLESS"
3172  LOCATE 15,1:PRINT "THE UNITS ON THE COMPRESSIVE YIELD STRENGTH SHOULD BE"
3174  LOCATE 16,1:PRINT "IN POUNDS PER SQUARE INCH MULTIPLIED BY .001"
3177  LOCATE 24,1:INPUT "HIT ENTER WHEN DONE READING",Y
3180  REM NOW WE INPUT THE VALUES.
3181  FOR A = 1 TO 3
3182  CLS
3183    PRINT "THE YOUNG'S MODULUS FOR BODY";A;"=";:INPUT" ";E(A)
3185    PRINT "THE POISSON'S RATIO FOR BODY";A;"=";:INPUT" ";NU(A)
3186    PRINT "THE COMPRESSIVE YIELD STRENGTH FOR BODY";A;"=";:INPUT" ";Y(A)
3187    MN(A)=A
3188    NEXT A
3189    CLS
3198    CLS
3199    GOTO 2800
3200  REM ENTER DATA INTERACTIVELY
3210  CLS
3220  FOR I=1 TO 3
3230    PRINT "MATERIAL NUMBER FOR BODY ";I;"="; : INPUT " ",MN(I)
3240    NEXT I
3300  LOCATE 10,1:PRINT "THE THICKNESS OF BODY ONE AND BODY TWO SHALL BE INPUT N
EXT"
3310  LOCATE 15,1:PRINT "THE THICKNESS DIMENSIONS SHALL BE INPUT IN INCHES."
3320  LOCATE 24,1:INPUT "HIT ENTER WHEN DONE READING",Y
3370  CLS
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3380  FOR I=1 TO 2
3390    PRINT "THE THICKNESS FOR BODY ";I;"="; : INPUT " ",T(I)
3400    NEXT I
3405  CLS
3449  CLS
3450  LOCATE 1,1:PRINT "THE NEXT FACTOR TO BE INPUT INTO THE PROGRAM IS THE"
3460  LOCATE 2,1:PRINT "GEOMETRY FACTOR.  THE GEOMETRY FACTOR IS NUMERICALLY "
3470  LOCATE 3,1:PRINT "EQUAL TO THE NUMBER OF DEGREES OF FREEDOM BETWEEN BODIES
"
3480  LOCATE 4,1:PRINT "PRIOR TO THEIR INITIAL SHIFT.  IF THE SHEAR JOINT IS "
3482  LOCATE 5,1:PRINT "COMPRISED OF TWO CONCENTRIC CYLINDERS, GEO IS EQUAL "
3483  LOCATE 6,1:PRINT "TO ONE."
3484  LOCATE 10,1:PRINT "IF THE SHEAR JOINT IS CONSISTS OF TWO FLAT PLATES,"
3486  LOCATE 11,1:PRINT "GEO IS EQUAL TO TWO."
3500  LOCATE 24,1:INPUT "HIT ENTER WHEN DONE READING",Y
3505  REM ENTER DATA INTERACTIVELY
3507  CLS
3510  PRINT "THE GEOMETRY FACTOR IS EQUAL TO "; : INPUT " " ,GEO
3550  LOCATE 12,1:PRINT "THE TOTAL NUMBER OF BOLTS USED IN THE SHEAR JOINT"
3560  LOCATE 13,1:PRINT "IS "; : INPUT " ",NT
3600  CLS
3610  LOCATE 1,1:PRINT "THE TRUE POSITION TOLERANCE FOR EACH BODY SHALL BE INPUT
 NEXT"
3615  LOCATE 15,1:PRINT "THE TRUE POSITION DIMENSIONS SHALL BE IN INCHES."
3620  LOCATE 24,1:INPUT "HIT ENTER WHEN DONE READING",Y
3700  CLS
3720  FOR I=1 TO 2
3750    PRINT "THE TRUE POSITON TOLERANCE FOR BODY ";I;"="; : INPUT " ",TP(I)
3760    NEXT I
3800  CLS
3810  LOCATE 1,1:PRINT "THE MAXIMUM AND MINIMUM SIZE HOLE FOR EACH BODY"
3820  LOCATE 2,1:PRINT "SHALL BE INPUT NEXT."
3830  LOCATE 15,1:PRINT "THE HOLE SIZE FOR EACH BODY SHALL BE INPUT AS THE DIAME
TER."
3840  LOCATE 16,1:PRINT "OF THE HOLE WITH THE DIMENSIONS IN INCHES."
3841  LOCATE 24,1:INPUT "HIT ENTER WHEN DONE READING",Y
3842  FOR I=1 TO 2
3850  CLS
3860    PRINT "THE MINIMUM HOLE SIZE FOR BODY ";I;"="; : INPUT " ",HMIN(I)
3870  LOCATE 10,1:PRINT "THE MAXIMUM HOLE SIZE IN BODY";I;"="; : INPUT " ", HMAX
 (I)
3890  NEXT I
4000  CLS
4010  LOCATE 1,1:PRINT "THE LAST PORTION OF DATA TO BE ENTERED IS THE MAXIMUM"
4020  LOCATE 2,1:PRINT "AND MINIMUM BOLT DIAMETER THAT IS TO BE USED IN THE "
4030  LOCATE 3,1:PRINT "SHEAR JOINT."
4040  LOCATE 10,1:PRINT "THE MINIMUM BOLT SIZE USED IN THE JOINT IS"; : INPUT "
",DMIN
4050  LOCATE 15,1:PRINT "THE MAXIMUM BOLT SIZE USED IN THE JOINT IS"; : INPUT "
",DMAX
4500  REM THIS SECTION OF THE PROGRAM CALCULATES THE MAXIMUM ALLOWABLE SHEAR
4501  REM SHEAR FORCE IN A SINGLE BOLT-HOLE COMBINATION OF A BOLTED JOINT
4550  I=0
4552  NN=0
4555  FOR I=1 TO 3
4560    NN=MN(I)
4570    K(I)= 2*(1-(NU(NN)^2))/(PI*E(NN))
4572  NEXT I
4583  JK=0!
4584  FOR JK=1 TO 3
4585    IF JK=1 THEN 4588
4586    GOTO 4591
4588    D=((DMAX-DMIN)/2)+DMIN: R=D/2
4589    II=(PI*(D^4))/64 : GOTO 4600
4591    IF JK=2 THEN 4594
4592    GOTO 4597
4594    D=DMAX :R=D/2
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4595    II=(PI*(D^4))/64 : GOTO 4600
4596    REM JK WILL BE EQUAL TO THREE IF THE PROGRAM GETS HERE
4597    D=DMIN :R=D/2
4598    II=(PI*(D^4))/64 : GOTO 4600
4600  FOR I=1 TO 2
4610    NN=MN(I)
4620    P(I)= (((Y(NN)^2)*(PI^2))*R*(K(I) + K(3))*T(I))/2
4630    NEXT I
4650  IF P(1)<P(2) THEN P=P(1)
4660  IF P(2)<P(1) THEN P=P(2)
4670  IF JK>1 THEN 5000
4690  REM NOW WE ARE READY TO DISPLAY THE VALUES OF P(1),P(2) AND P
4700  CLS
4710  LOCATE 1,1:PRINT "THE MAXIMUM ALLOWABLE SHEAR FORCE IN BODY ONE IS";" ";P(
1)
4720  LOCATE 4,1:PRINT "THE MAXIMUM ALLOWABLE SHEAR FORCE IN BODY TWO IS";" ";P(
2)
4722  LOCATE 10,1:PRINT "FOR OPTIMUM JOINT DESIGN, THE MAXIMUM ALLOWABLE SHEAR"
4724  LOCATE 11,1:PRINT "FORCE IN BODY ONE AND BODY TWO SHOULD BE EQUAL.  THE "
4726  LOCATE 12,1:PRINT "MAXIMUM ALLOWABLE SHEAR FORCE IN A SINGLE BOLT-HOLE "
4728  LOCATE 13,1:PRINT "COMBINATION OF THE SHEAR JOINT WITHIN THE ELASTIC "
4730  LOCATE 14,1:PRINT "LIMIT WILL BE EQUAL TO ";P
4735  GOTO 4750
4740  LOCATE 18,1:PRINT "I BEG YOUR PARDON"
4750  LOCATE 19,1:PRINT "WOULD YOU LIKE TO OPTIMIZE P?"
4760  LOCATE 20,1:PRINT "PLEASE ANSWER YES OR NO"
4770  LOCATE 24,1:INPUT "ENTER 1 FOR YES OR 2 FOR NO:",ANS$
4780  CHOICE = VAL(ANS$)
4790  IF CHOICE<1 OR CHOICE>2 THEN BEEP:LOCATE 19,1: PRINT SPACE$(30):GOTO 4740
4800  ON CHOICE GOTO 4900,5000
4900  REM MUST DETERMINE IF THE USER WANTS TO OPTIMIZE P, THIS ROUTE ASSUMES
4905  REM THEY DO.  TO OPTIMIZE P ALL VALUES MUST BE RE-INITIALIZED
4906  C=C+1
4920  GOTO 990
5000  CLS
5010  REM NOW WE MUST CALCULATE THE DEFORMATION DUE TO THE HERTZIAN CONTACT
5012  REM STRESS AND THE SHEAR AND BENDING MOMENT ON THE BOLT.
5015  REM FIRST WE WILL CALCULATE THE DEFORMATION DUE TO THE HERTZIAN CONTACT
5016  REM STRESS IN EACH BODY
5046  REM WE NEED TO DEFINE PL AND GA,  THESE ARE DEPENDENT ON THE MATERIAL
5047  REM PROPERTIES ONLY.
5048    FOR I=1 TO 2
5049      PL(I)=P/(T(I))
5050      GA(I)=K(3)/(K(3)+K(I))
5060      NN=MN(I)
5100      D(1)= PL(I)*K(3)*.5*LOG(R/(PL(I)*K(3)))
5110      D(2)= PL(I)*K(3)*((.5*LOG(2*GA(I)))+.193)
5120      D(3)= PL(I)*K(I)*.5*LOG(R/(PL(I)*K(3)))
5130      D(4)= PL(I)*K(I)*(((.5*LOG(2*GA(I)))-.693))
5140      D(5)= PL(I)*K(I)*(1-(2*NU(NN)))/(2*(1-NU(NN)))
5150      DEFH(I)=D(1)+D(2)+D(3)+D(4)+D(5)
5160      FOR J=1 TO 5
5170        D(J)=0!
5180        NEXT J
5190      NEXT I
5300  REM NOW WE ARE GOING TO CALCULATE THE DEFORMATION DUE TO BENDING
5310  REM FIRST WE CALCULATE M
5320  M1=.75*(T(1)^2)
5322  M2=.25*(T(2)^2)
5324  M3=T(2)*T(1)
5326  M4=M1+M2+M3
5328  M=(M4*P)/(2*(T(1)+T(2)))
5360  NN=MN(3)
5400  DEF11=(-P*(T(1)^3))/(24*E(NN)*II)
5410  D12 = ((-2.5*T(1))-(1.5*T(2)))
5420  DEF12=((P*(T(1)^2))/(24*E(NN)*II))*D12
5430  DEF1M=(M*((T(1)/2)^2))/(2*E(NN)*II)
5440  DEFB(1)=DEF11+DEF12+DEF1M
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5445  DEFB(1) =ABS(DEFB(1))
5450  DEF21=DEF12
5455  D22=(4*((T(1)^2)+(T(1)*T(2))))+(T(2)^2)
5460  DEF22=(P*D22)/(24*E(NN)*II)*((-2*T(1))-T(2))
5470  DEF2M=(M*D22)/(8*E(NN)*II)
5479  DEFB(2)=DEF21+DEF22+DEF2M
5480  DEFB(2) =ABS(DEFB(2))
5550  REM NOW WE ARE READY TO CALCULATE THE TOTAL DEFORMATION
5552  REM THE DEFORMATION CALCULATED HERE WILL DEPEND ON THE DIAMETER OF THE
5554  REM BOLT; THIS DEPENDS ON THE COUNTER JK
5555      FOR I=1 TO 2
5556        DEFT(I)= DEFB(I)+DEFH(I)
5557        IF JK=1 THEN 5560
5558        GOTO 5600
5560        IF I=1 THEN DMU(I)=DEFT(I)
5562        IF I=2 THEN DMU(2)=DEFT(I)
5564        GOTO 5900
5600        IF JK=2 THEN 5620
5610        GOTO 5700
5620        IF I=1 THEN DELMAX(I)=DEFT(I)
5630        IF I=2 THEN DELMAX(I)=DEFT(I)
5640        GOTO 5900
5700  REM AT THIS POINT, JK=3
5710        IF I=1 THEN DELMIN(I)=DEFT(I)
5720        IF I=2 THEN DELMIN(I)=DEFT(I)
5900        NEXT I
5910      NEXT JK
6000  REM WE ARE READY TO CALCULATE THE STATISTICS OF ALL SETS OF DATA
6010  REM WE NEED TO CALCULATE MU,SD FOR ALL DATA SETS
6040  FOR I=1 TO 2
6050    TMU(I)=TP(I)/2
6060    TSD(I)=TP(I)/6
6100    HMU(I)=((HMAX(I)-HMIN(I))/2)+HMIN(I)
6110    HSD(I)=((HMAX(I)-HMIN(I))/6)
6115    DMU(I)=((DELMAX(I)-DELMIN(I))/2)+DELMIN(I)
6120    DSD(I)=((DELMAX(I)-DELMIN(I))/6)
6130    BMU(I)=((DMAX-DMIN)/2)+DMIN
6140    BSD(I)=(DMAX-DMIN)/6
6180  REM  NOW WE ARE COMBINING THE SETS OF DATA USING THE MATHEMATICAL
6190  REM  RELATIONS FOR COMBINING SETS OF DATA
6200    SMU(I)=TMU(I)+DMU(I)
6210    SSD(I)=((DSD(I)^2) +(TSD(I)^2))^.5
6220    EMU(I)=HMU(I)-SMU(I)
6240    ESD(I)=((SSD(I)^2) +(HSD(I)^2))^.5
6250    CMU(I)=EMU(I)-BMU(I)
6260    CSD(I)=((ESD(I)^2) +(BSD(I)^2))^.5
6280    BMU(I)=((DMAX-DMIN)/2)+DMIN
6300    BSD(I)=(DMAX-DMIN)/6
6320    IMU(I)=BMU(I)-EMU(I)
6321    ISD(I)=((ESD(I)^2) +(BSD(I)^2))^.5
6340    NEXT I
6350  REM IF THE PARTS HAVE ZERO TRUE POSITION TOLERANCE AND THE HOLE DIAMETER
6352  REM IS EQUAL TO THE BOLT DIAMETER, THE JOINT WILL NOT BE INTERCHANEABLE,
6354  REM BUT, ALL THE FASTNERS WILL CARRY THE SHEAR LOAD
6357  FOR I=1 TO 2
6359    IF TP(I)=0! THEN 6362
6360    GOTO 6450
6362    NEXT I
6365  IF BMU(1)=HMU(1) THEN 6367
6366    GOTO 6450
6367  IF BMU(2)=HMU(2) THEN 6369
6368    GOTO 6450
6369  IF DMAX= DMIN THEN 6371
6370    GOTO 6450
6371  IF HMAX(2)=HMIN(2) THEN 6375
6372    GOTO 6450
6375  CLS
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6376  LOCATE 1,1:PRINT "BOTH PARTS HAVE ZERO TRUE POSITION TOLERANCE AND THE HOL
E SIZE"
6377 LOCATE 2,1:PRINT"AND THE BOLT SIZE ARE IDENTICAL.  THIS JOINT IS NO LONGER
INTERCHANGEABLE"
6379 LOCATE 4,1:PRINT"        ALL BOLTS WILL CARRY THE  SHEAR LOAD"
6380  B12SD=0!
6386  LOCATE 24,1:INPUT "HIT ENTER WHEN DONE READING",Z
6387  CLS
6388  B12SD=0!
6389  GOTO 9180
6400    NEXT I
6450  REM NOW WE WILL CHECK THE CLEARANCE THE INTERFERENCE
6452  REM STANDARD DEVIATIONS TO SEE IF THEY ARE ZERO.
6454  REM THIS WOULD MAKE TEFF OR ZEFF EQUAL TO INFINITY
6455  REM PHYSICALLY, THIS MEANS THERE IS NO AREA UNDER THE CURVE
6460  REM AT THAT POINT WE DISPLAY THAT RESULT
6465  FOR I=1 TO 2
6467    IF IMU(I)<(10^(-6)) THEN 6480
6469    IF CMU(I)<(10^(-6)) THEN 6480
6471    NEXT I
6473  GOTO 6500
6480  CLS
6482  LOCATE 1,1:PRINT "THE DEFORMATION IN THE BOLT-HOLE COMBINATION IS NOT LARG
E ENOUGH"
6484  LOCATE 2,1:PRINT "TO CAUSE ANY OTHER FASTENERS TO COME INTO BEARING.  THIS
 RESULTS IN "
6486  LOCATE 3,1:PRINT "A NEGLIGIBLE AREA UNDER THE T-CURVE  OR NORMAL CURVE"
6490  LOCATE 24,1:INPUT "HIT ENTER WHEN DONE READING",Z
6491  A(1)=0!
6492  A(2)=0!
6493  ISD=0!
6494  B12SD=0!
6496  B12MU=GEO
6498  GOTO 8942
6500  REM NOW WE ARE READY TO CALCULATE THE AREA UNDER THE NORMAL CURVE
6502  REM OR THE T-CURVE DEPENDING UPON THE NUMBER OF DEGREES OF FREEDOM
6510  N=NT-GEO
6540  IF N<30 THEN 8000
7000  REM THIS PART OF THE PROGRAM CALCULATES THE AREA UNDER THE NORMAL
7002  REM CURVE; THIS IS APPROXIMATED USING A BINOMIAL EXPANSION
7010  REM FIRST, WE MUST CALCULATE Q(Z)
7020  REM TO ACCOMPLISH THIS, WE MUST FIRST CALCULATE THE Z VALULE FOR EACH BODY
7100  FOR I=1 TO 2
7120    Z(I)=(0-CMU(I))/CSD(I)
7130    Z=Z(I)
7140    IF Z < -3! THEN 7314
7150    X= -(Z^2)/2
7160    FZ(I)=(1/((2*PI)^.5))*EXP(X)
7161  PRINT
7162  PRINT
7163  PRINT
7164  PRINT
7165  PRINT
7166  PRINT "THIS IS Z,Z(I),X,FZ(I)"
7167  PRINT
7168  PRINT  Z;Z(I);X;FZ(I)
7200  REM  NOW WE ARE READY TO CALCULATE T
7210    T=1/(1+(PP*ABS(Z)))
7220    QZ(1)=(B1*T)+(B2*(T^2))+(B3*(T^3))
7240    QZ(2)=(B4*(T^4))+(B5*(T^5))
7260    QZ(3)=QZ(1)+QZ(2)
7265    Q(I)=FZ(I)*QZ(3)
7270  IF Z<-3! THEN 7314
7281  IF Z<0 THEN 7294
7282  IF Z>0 THEN 7300
7283  IF Z=0 THEN 7290
7290  A(I)=.5 : GOTO 7307
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7294  A(I)=Q(I) : GOTO 7307
7300  A(I)=1-Q(I) :GOTO 7307
7312  IF A(I)<.01 THEN 7314
7313  GOTO 7320
7314  A(I)=0!
7315  CSD(I)=0!
7316  B12MU=GEO
7317  B12SD=0!
7319  GOTO 8900
7320    NEXT I
7350  REM NOW WE ARE READY TO CALCULATE THE NUMBER OF BOLTS WHICH WOULD COME
7370  REM INTO BEARING AS A RESULT OF THE APPLIED SHEAR FORCE
7372  REM BOTH DISTRIBUTIONS WILL HAVE THE SAME VARIABLE A(I) WHICH IS EQUAL TO
7374  REM THE AREA UNDER THE CURVE
7375  GOTO 8500
8000  REM THIS PART OF THE PROGRAM IS ONLY USED FOR LESS THAN THIRTY DEGREES OF
8010  REM FREEDOM.  FIRST WE MUST FILL THE ARRAYS WITH CRITICAL VALUES OF THE
8020  REM T-DISTRIBUTION.  THE CRITICAL VALUES OF THE T-DISTIBUTION WILL BE
8022  REM LISTED BY THE DEGREES OF FREEDOM AND THE AREA UNDER THE CURVE.
8025  REM THIS IS WHERE THE PROGRAM READS THEM IN
8040  FOR NN=1 TO 29
8041    READ NN
8042    FOR I=1 TO 10
8043      READ TSN(NN,I),AR(NN,I)
8044      NEXT I
8045    NEXT NN
8050  DATA  1, .325,.40,   .727,.30,   1.376,.20,   3.078, .10,   6.314, .050
8052  DATA     12.71,.025, 31.82,.010, 63.66,.005,  318.3,.001,   636.6,.0005
8054  DATA  2, .289,.40,   .617,.30,   1.061,.20,   1.886,.10,    2.920, .050
8056  DATA     4.303,.025, 6.965,.010, 9.925,.005,  22.33,.001,   31.60,.0005
8058  DATA  3, .277,.40,   .584,.30,   .978 ,.20,   1.638, .10,   2.353, .050
8060  DATA     3.182,.025, 4.541,.010, 5.841,.005,  10.22,.001,   12.94,.0005
8062  DATA  4, .271,.40,   .569,.30,   .941 ,.20,   1.533,.10,    2.132, .050
8064  DATA     2.776,.025, 3.747,.010, 4.604,.005,  7.173,.001,   8.610,.0005
8066  DATA  5, .267,.40,   .559,.30,    .920 ,.20,   1.476, .10,   2.015, .050
8068  DATA     2.571,.025, 3.365,.010, 4.032,.005,  5.893,.001,   6.859,.0005
8070  DATA  6, .265,.40,   .553,.30,   .906 ,.20,   1.440,.10,    1.943, .050
8072  DATA     2.447,.025, 3.143,.010, 3.707,.005,  5.208,.001,   5.959,.0005
8074  DATA  7, .263,.40,   .549,.30,   .896 ,.20,   1.415,.10,    1.895, .050
8076  DATA     2.365,.025, 2.998,.010, 3.499,.005,  4.785,.001,   5.405,.0005
8078  DATA  8, .262,.40,   .546,.30,   .889,.20,    1.397,.10,    1.860, .050
8080  DATA     2.306,.025, 2.896,.010, 3.355,.005,  4.501,.001,   5.041,.0005
8081  DATA  9, .261,.40,   .543,.30,   .883,.20,    1.383,.10,    1.833, .050
8082  DATA     2.262,.025, 2.821,.010, 3.250,.005,  4.297,.001,   4.781,.0005
8083  DATA 10, .260,.40,   .542,.30,   .879,.20,    1.372,.10,    1.812, .050
8084  DATA     2.228,.025, 2.764,.010, 3.169,.005,  4.144,.001,   4.587,.0005
8085  DATA 11, .260,.40,   .540,.30,   .876,.20,    1.363,.10,    1.796, .050
8086  DATA     2.201,.025, 2.718,.010, 3.106,.005,  4.025,.001,   4.437,.0005
8087  DATA 12, .259,.40,   .539,.30,   .873,.20,    1.356,.10,    1.782, .050
8088  DATA     2.179,.025, 2.681,.010, 3.055,.005,  3.930,.001,   4.318,.0005
8089  DATA 13, .259,.40,   .538,.30,   .870,.20,    1.350,.10,    1.771, .050
8090  DATA     2.160,.025, 2.650,.010, 3.012,.005,  3.852,.001,   4.221,.0005
8091  DATA 14, .258,.40,   .537,.30,   .868,.20,    1.345,.10,    1.761, .050
8092  DATA     2.145,.025, 2.624,.010, 2.977,.005,  3.787,.001,   4.140,.0005
8093  DATA 15, .258,.40,   .536,.30,   .866,.20,    1.341,.10,    1.753, .050
8094  DATA     2.131,.025, 2.602,.010, 2.947,.005,  3.733,.001,   4.073,.0005
8095  DATA 16, .258,.40,   .535,.30,   .865,.20,    1.337,.10,    1.746, .050
8096  DATA     2.120,.025, 2.583,.010, 2.921,.005,  3.686,.001,   4.015,.0005
8097  DATA 17, .257,.40,   .534,.30,   .863,.20,    1.333, .10,   1.740, .050
8098  DATA     2.110,.025, 2.567,.010, 2.898,.005,  3.646,.001,   3.965,.0005
8099  DATA 18, .257,.40,   .534,.30,   .862,.20,    1.330, .10,   1.734, .050
8100  DATA     2.101,.025, 2.552,.010, 2.878,.005,  3.611,.001,   3.922,.0005
8101  DATA 19, .257,.40,   .533,.30,   .861,.20,    1.328, .10,   1.729, .050
8102  DATA     2.093,.025, 2.539,.010, 2.861,.005,  3.579,.001,   3.883,.0005
8103  DATA 20, .257,.40,   .533,.30,   .860,.20,    1.325, .10,   1.725, .050
8104  DATA     2.086,.025, 2.528,.010, 2.845,.005,  3.552,.001,   3.850,.0005
8105  DATA 21, .257,.40,   .532,.30,   .859,.20,    1.323, .10,   1.721, .050
8106  DATA     2.080,.025, 2.518,.010, 2.831,.005,  3.527,.001,   3.819,.0005
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8107  DATA 22, .256,.40,    .532,.30,    .858,.20,    1.321, .10,   1.717, .050
8108  DATA     2.074,.025, 2.508,.010, 2.819,.005,  3.505,.001,   3.792,.0005
8109  DATA 23, .256,.40,    .532,.30,    .858,.20,    1.319, .10,   1.714, .050
8110  DATA     2.069,.025, 2.500,.010, 2.807,.005,  3.485,.001,   3.767,.0005
8111  DATA 24, .256,.40,    .531,.30,    .857,.20,    1.318, .10,   1.711, .050
8112  DATA     2.064,.025, 2.492,.010, 2.797,.005,  3.467,.001,   3.745,.0005
8113  DATA 25, .256,.40,    .531,.30,    .856,.20,    1.316, .10,   1.708, .050
8114  DATA     2.060,.025, 2.485,.010, 2.787,.005,  3.450,.001,   3.725,.0005
8115  DATA 26, .256,.40,    .531,.30,    .856,.20,    1.315, .10,   1.706, .050
8116  DATA     2.056,.025, 2.479,.010, 2.779,.005,  3.435,.001,   3.707,.0005
8117  DATA 27, .256,.40,    .531,.30,    .855,.20,    1.314, .10,   1.703, .050
8118  DATA     2.052,.025, 2.473,.010, 2.771,.005,  3.421,.001,   3.690,.0005
8119  DATA 28, .256,.40,    .530,.30,    .855,.20,    1.313, .10,   1.701, .050
8120  DATA     2.048,.025, 2.467,.010, 2.763,.005,  3.408,.001,   3.674,.0005
8121  DATA 29, .256,.40,    .530,.30,    .854,.20,    1.311, .10,   1.699, .050
8122  DATA     2.045,.025, 2.462,.010, 2.756,.005,  3.396,.001,   3.659,.0005
8125  RESTORE
8128  FOR N=1 TO 29
8132    FOR I=1 TO 10
8136      NEXT I
8138      NEXT N
8200  REM THE PROGRAM COMES TO HERE WITH A VALUE FOR N
8220  REM FIRST WE HAVE TO CALCULATE A VALUE TEFF FOR BOTH BODIES
8221  N=NT-GEO
8224  FOR J=1 TO 2
8225    TEFF(J)=(0-IMU(J))/((ISD(J)/(N^.5)))
8230    NEXT J
8244  REM NOW WE NEED TO KNOW THE NUMBER OF DEGREES OF FREEDOM N
8245  REM WE FIND THE TWO VALUES OF TSN(I)WHICH TEFF IS BETWEEM FOR BOTH BODIES
8246  REM WE THEN INTERPOLATE USING VALUES OF AR(I) AND TSN(I) TO CALCULATE
8247  REM THE AREA UNDER THE CURVE
8248  REM FIRST WE LOCATE THE CRITICAL VALUES OF THE T-DISTRIBUTION AT
8249  REM THE CORRECT NUMBER OF DEGREES OF FREEDOM THIS IS ACCOMPLISHED
8250  REM BY HAVING TWO DIMENSIONAL ARRAYS.
8252  FOR J=1 TO 2
8260    FOR I=1 TO 10
8261    N=NT-GEO
8270      IF TSN(N,I)>TEFF(J) THEN 8274
8272      GOTO 8295
8274      TMAX=TSN(N,I): TMIN=TSN(N,I-1)
8276      ARMAX=AR(N,I): ARMIN=AR(N,I-1)
8278      GOTO 8310
8295      NEXT I
8296    A(J)=AR
8297    NEXT J
8303  GOTO 8360
8304  REM BETWEEN THAT VALUE AND THE PREVIOUS VALUE.
8305  REM BOTH DISTRIBUTIONS WILL HAVE THE SAME VARIABLE A(I) WHICH IS EQUAL
8306  REM BECAUSE OF THE WAY THE T-DISTRIBUTION IS TABULARIZED, AS SOON AS YOU
8307  REM LOCATE THE VALUE WHICH IS GREATER THAN TEFF, YOU NEED TO INTERPOLATE
8308  REM BETWEEN THAT VALUE AND THE PREVIOUS VALUE
8310  REM NOW WE ARE READY TO INTERPOLATE BETWEEN THE VALUES
8311  DT =TMAX-TMIN
8317  IT=TEFF(J)-TMIN
8318  PERC=IT/DT
8319  REM PERC= THE PERCENTAGE OF SPREAD BETWEEN THE VALUES OF THE
8320  REM T-DISRIBUTION AND HENCE THE AREA
8321  DELA=ARMAX-ARMIN
8322  AR=(PERC*DELA) + ARMIN
8345  REM PERC= THE PERCENTAGE OF SPREAD BETWEEN THE VALUES OF THE T-DISTRIBUTIO
N AND HENCE THE AREA
8350  DELA=0!:TMAX=0!:TMIN=0!:PERC=0!
8352  AR=(PERC*DELA) + ARMIN
8354  DELA=0!:TMAX=0!:TMIN=0!:PERC=0!
8358  END
8360  IF I>10 THEN 8370
8365  GOTO 8499
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8370  CLS
8372  LOCATE 1,1:PRINT "THE DEFORMATION IN THE BOLT-HOLE COMBINATION IS NOT LARG
E ENOUGH"
8374  LOCATE 2,1:PRINT "TO CAUSE ANY OTHER FASTENERS TO COME INTO BEARING.  THIS
 RESULTS IN "
8376  LOCATE 3,1:PRINT "A NEGLIGIBLE AREA UNDER THE T-CURVE."
8380  LOCATE 24,1:INPUT "HIT ENTER WHEN DONE READING",Z
8381  A(1)=0!
8382  A(2)=0!
8384  ISD=0!
8400  GOTO 8728
8499  REM NOW WE ARE READY TO CALCULATE THE NUMBER OF LOAD CARRYING FASTENERS
8500  REM BEFORE WE CAN CALCULATE THE NUMBER OF LOAD CARRYING FASTENERS,
8502  REM WE MUST DETERMINE IF THE SETS OF DATA ARE ROBUST
8505  REM WE NEED TO DO THE NUMERICAL TEST ON DIFFERENT SETS OF DATA
8507  REM DEPENDING ON THE NUMBER OF DEGREES OF FREEDOM
8510  IF N<30 THEN 8600
8520  REM THE PROGRAM WILL COME HERE UNLESS THERE ARE LESS THAN THIRTY
8522  REM DEGREES OF FREEDOM
8530  FOR J=1 TO 2
8531    N=NT-GEO
8532    BBMU(J)=A(J)*N
8534    BBSD(J)=CSD(J)*N
8535    NEXT J
8540  REM HAVING THE TWO SETS OF DATA SE ARE NOW READY TO SEE IF THEY
8542  REM ARE ROBUST
8545  FOR I=1 TO 2
8550    CVX(I)=BBSD(I)/BBMU(I)
8557    NEXT I
8560  IF CVX(1)<.075 THEN 8580
8565  IF CVX(2)<.075 THEN 8580
8570  GOTO 8800
8580    B12MU = (A(1)*A(2)*N) +GEO
8582    B(1)=((BBMU(1)^2) +(BBSD(2)^2))^.5
8584    B(2)=((BBMU(2)^2) +(BBSD(1)^2))^.5
8586    B(3)=((BBSD(1)^2) +(BBSD(2)^2))^.5  --
8590    B12SD = B(1)+B(2)+B(3)
8592  FOR J=1 TO 3
8594    B(J)=0!
8596    NEXT J
8599  GOTO 8900
8600  REM THE PROGRAM WILL COME HERE FOR N<30
8610  FOR J=1 TO 2
8611    N=NT-GEO
8612    BBMU(J)=A(J)*N
8614    BBSD(J)=ISD(J)*N
8630    NEXT J
8690  REM THE NEXT THING YOU WANT TO DO IS TEST THE DATA TO SEE IF ROBUST
8700  REM HAVING THE TWO SETS OF DATA SE ARE NOW READY TO SEE IF THEY
8702  REM ARE ROBUST
8703  IF ROB=1 THEN 8728
8704  FOR I=1 TO 2
8706    CVX(I)=BBSD(I)/BBMU(I)
8720    NEXT I
8722  IF CVX(1)<.075 THEN 8580
8724  IF CVX(2)<.075 THEN 8580
8726  GOTO 8800
8728    B12MU = (A(1)*A(2)*N) +GEO
8732    B(1)=((BBMU(1)^2) +(BBSD(2)^2))^.5
8734    B(2)=((BBMU(2)^2) +(BBSD(1)^2))^.5
8736    B(3)=((BBSD(1)^2) +(BBSD(2)^2))^.5
8740    B12SD = B(1)+B(2)+B(3)
8750  FOR J=1 TO 3
8752    B(J)=0!
8754    NEXT J
8760  GOTO 8900
8800  REM THE PROGRAM WILL ONLY COME HERE IF THE DATA IS NOT ROBUST
8810  CLS
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8812  LOCATE 1,1:PRINT"FROM STATISTICS, THE PRODUCT OF TWO NORMALLY DISTRIBUTED"
8814  LOCATE 2,1:PRINT"RANDOM VARIABLES IS APPROXIMATELY NORMALLY DISTRIBUTED IF
 "
8816  LOCATE 3,1:PRINT"THE SETS OF DATA ARE ROBUST.  THE ANALYSIS ASSUMES THAT "
8818  LOCATE 4,1:PRINT"THE DATA IS ROBUST IN ORDER TO CALCULATE THE NUMBER OF  "
8820  LOCATE 5,1:PRINT"LOAD CARRYING FASTENERS IN THE JOINT"
8822  LOCATE 11,1:PRINT "THE DATA USED IN THE PRECEDING CALCULATIONS IS NOT"
8824  LOCATE 12,1:PRINT "ROBUST.  THEREFORE, THE ASSUMPTIONS IN THE ANALYSIS"
8826  LOCATE 13,1:PRINT "HAVE BEEN VIOLATED AND THE PROGRAM RESULTS WILL BE IN "
8828  LOCATE 14,1:PRINT "ERROR"
8830  LOCATE 24,1:INPUT "HIT ENTER WHEN DONE READING",Y
8835  ROB=1 :GOTO 8728
8900  REM NOW WE ARE READY TO DISPLAY THE RESULTS
8942  CLS
8943  REM IF THE DATA IS NOT ROBUST, THE OUTPUT IS MODIFIED
8944  FOR J=1 TO 2
8945    NN=MN(J)
8946    Y(J)=Y(NN)
8947    NEXT J
8948  CLS
8950  LOCATE 1,1:PRINT "THE NUMBER OF LOAD CARRYING FASTENERS IN THE JOINT IS";"
 ";B12MU
8951  LOCATE 3,1:PRINT "THE STANDARD DEVIATION OF LOAD CARRYING FASTENERS IN THE
 JOINT IS";" ";B12SD
8952  LOCATE 6,1:PRINT "THE TRUE POSTION TOLERANCE OF BODY 1 =";" "TP(1)
8957  LOCATE 7,1:PRINT "THE THICKNESS OF BODY 1=";" ";T(1)
8958  LOCATE 8,1:PRINT "THE YIELD STRENGTH FOR BODY 1=";" ";Y(1)
8961  LOCATE 11,1:PRINT "THE TRUE POSTION TOLERANCE OF BODY 2 =";" "TP(2)
8963  LOCATE 12,1:PRINT "THE THICKNESS OF BODY 2=";" ";T(2)
8965  LOCATE 13,1:PRINT "THE YIELD STRENGTH FOR BODY 2=";" ";Y(2)
8966  LOCATE 16,1:PRINT "THE TOTAL NUMBER OF FASTENERS USED IN THE JOINT IS";" "
;NT
8967  IF ROB>0 THEN 8969
8968  GOTO 8972
8969  LOCATE 18,1:PRINT "THE DATA SETS ARE NOT ROBUST AND THE ABOVE RESULTS ARE
IN ERROR"
8970  GOTO 8972
8971  LOCATE 20,1:PRINT "I BEG YOUR PARDON"
8972  LOCATE 21,1:PRINT "WOULD YOU LIKE TO CHANGE THE JOINT DESIGN?"
8973  LOCATE 22,1:PRINT "PLEASE ANSWER YES OR NO"
8974  LOCATE 24,1:INPUT "ENTER 1 FOR YES OR 2 FOR NO:",ANS$
8975  CHOICE = VAL(ANS$)
8976  IF CHOICE<1 OR CHOICE>2 THEN BEEP:LOCATE 21,1: PRINT SPACE$(30):GOTO 8972
8982  ON CHOICE GOTO 8985 ,8989
8985  C=C+1:  GOTO 500
8989  CLS
9000  REM  THIS PART OF THE PROGRAM LETS YOU GET A COPY OF THE OUTPUT
9005  CLS
9010  GOTO 9013
9012  LOCATE 19,1:PRINT "I BEG YOUR PARDON"
9013  LOCATE 20,1:PRINT SPACE$(30)
9014  LOCATE 21,1:PRINT "WOULD YOU LIKE A COPY OF THE PREVIOUS RESULTS?"
9016  LOCATE 22,1:PRINT "PLEASE ANSWER YES OR NO"
9017  LOCATE 23,1:PRINT SPACE$(30)
9018  LOCATE 23,1:INPUT "ENTER 1 FOR YES OR 2 FOR NO:",ANS$
9020  CHOICE = VAL(ANS$)
9024  IF CHOICE<1 OR CHOICE>2 THEN BEEP:LOCATE 23,1: PRINT SPACE$(30):GOTO 9012
9050  ON CHOICE GOTO 9100,9300
9100  REM THIS SECTION EXPLAINS HOW TO OBTAIN A PRINT
9110  CLS
9120  LOCATE 1,1:PRINT "TO GET A PRINT OF THE RESULTS, FIRST ADVANCE  "
9124  LOCATE 2,1:PRINT "THE PRINTER TO A FRESH SHEET, THEN PRESS THE SHIFT KEY"
9128  LOCATE 3,1:PRINT "AND THE Prtsc SIMULTANEOUSLY"
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9132  LOCATE 6,1:PRINT "AFTER THE MACHINE IS DONE PRINTING, YOU MUST HIT THE ENT
ER"
9134  LOCATE 7,1:PRINT "KEY TO PROCEED TO EXIT PROGRAM"
9135  PRT=1
9140  LOCATE 24,1:INPUT "HIT ENTER WHEN DONE READING",Z
9150  KEY OFF
9160  CLS
9170  FOR J=1 TO 2
9172    Y(J)=Y(NN)
9174    NEXT J
9175  GOTO 9200
9180  GOTO 9184
9182  LOCATE 20,1:PRINT "I BEG YOUR PARDON"
9184  LOCATE 21,1:PRINT "WOULD YOU LIKE TO CHANGE THE JOINT DESIGN?"
9185  LOCATE 22,1:PRINT "PLEASE ANSWER YES OR NO"
9186  LOCATE 24,1:INPUT "ENTER 1 FOR YES OR 2 FOR NO:",ANS$
9187  CHOICE = VAL(ANS$)
9188  IF CHOICE<1 OR CHOICE>2 THEN BEEP:LOCATE 21,1: PRINT SPACE$(30):GOTO 9182
9189  ON CHOICE GOTO 9190,9300
9190  C=C+1: GOTO 500
9200  LOCATE 1,1:PRINT "THE NUMBER OF LOAD CARRYING FASTENERS IN THE JOINT IS";"
 ";B12MU
9205  LOCATE 3,1:PRINT "THE STANDARD DEVIATION OF LOAD CARRYING FASTENERS IN THE
 JOINT IS";" ";B12SD
9210  LOCATE 6,1:PRINT "THE TRUE POSTION TOLERANCE OF BODY 1 =";" "TP(1)
9212  LOCATE 7,1:PRINT "THE THICKNESS OF BODY 1=";" ";T(1)
9214  LOCATE 8,1:PRINT "THE YIELD STRENGTH FOR BODY 1=";" ";Y(1)
9216  LOCATE 11,1:PRINT "THE TRUE POSTION TOLERANCE OF BODY 2 =";" "TP(2)
9218  LOCATE 12,1:PRINT "THE THICKNESS OF BODY 2=";" ";T(2)
9220  LOCATE 13,1:PRINT "THE YIELD STRENGTH FOR BODY 2=";" ";Y(2)
9222  LOCATE 16,1:PRINT "THE TOTAL NUMBER OF FASTENERS USED IN THE JOINT IS";" "
;NT
9224  IF ROB>0 THEN 9240
9228  GOTO 9245
9240  LOCATE 18,1:PRINT "THE DATA SETS ARE NOT ROBUST AND THE ABOVE RESULTS ARE
IN ERROR"
9242  REM IF PRT=1 THEY ONLY WANT A PRINT OF THE RESULTS AND WE SHOULD EXIT
9244  REM THE PROGRAM
9245  INPUT " ",Y
9300  END
9400  REM SHEAR.BAS                              VERSION 1.0
9500  REM COPYRIGHT 1987 (C) MARTIN MARIETTA CORPORATION, ALL RIGHTS RESERVED
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APPENDIX VII

DEFINTIONS, NOMENCLATURE, SYMBOLS

BBMU(X)	Expected value of bolts bearing on Body X after deformation.
BBSD(X)	Standard deviation of bolts bearing on Body X after deformation.
BMU	Expected value of the bolt size.
BSD	Standard deviation of bolt size.
B12MU	Number of load carrying-fasteners in the joint.
B12SD	Standard deviation of the number of load-carrying fasteners in the joint.
Body 1	Plate or cylinder that the bolt head bears upon.
Body 2	Plate or cylinder that the nut bears upon.
Body 3	Bolt used in shear joint.
CMU(X)	Expected value of clearance in Body X.
CSD(X)	Standard deviation of clearance in Body X.
CVX	"Coefficient of Variation" is defined for a sample population as the ratio of the "standard deviation" to the "expected value" of the population (i.e., CVX=SD/MU).
DEFB(X)	Deflection in bolt due to shear and bending load in centroid of Body X.

DEFH(X)	Deflection in bolt-hole combination due to Hertzian Contact Stress with Body X.
DMAX	Maximum Diameter of Bolt Size.
DMIN	Minimum Diameter of Bolt Size.
DELMAX	Total Deformation of Bolt at maximum bolt size.
DELMIN	Total Deformation of Bolt at minimum bolt size.
DEFT(X)	Total Deformation in Body X bolt-hole combination due to applied shear load.
DEF(X-Y)	Deflection at centroid of Body X due to load P acting at centroid of Body Y due to applied shear load.
DEF(X-M)	Deflection at centroid of Body X due to M.
DMU(X)	Expected Value of Deformation in bolt-hole combination of Body X.
DSD(X)	Standard Deviation of Deformation in bolt-hole combination of Body X.
E(X)	Young's Modulus of Body X.
EMU(X)	Expected Value of effective hole size in Body X.
ESD(X)	Standard Deviation of effective hole size in Body X.
HMU(X)	Expected Value of hole size in Body X.

GA(X)	Stiffness ratio - used in calculation of deformation due to Hertzian Contact Stress.
GEO	Geometry Factor which is numerically equal to the number of "Degrees of Freedom" between bodies prior to their initial shift. In Appendix III and IV , K is numerically equal to GEO.
HMAX(X)	Maximum hole size in Body X.
HMIN(X)	Minimum hole size in Body X.
HSD(X)	Standard Deviation of hole size in Body X.
I	Area Moment of Inertia of the Bolt.
IMU(X)	Expected Value of interference in Body X.
ISD(X)	Standard Deviation of interference in Body X.
K	Geometry Factor which is numerically equal to the number of "Degrees of Freedom" between bodies prior to their initial shift. In Appendix III and IV , K is numerically equal to GEO.
K(X)	Effective Young's Modulus for Body X= 2*(1-(NU(X)^2))/(PI*E(X)).
M	Moment in Bolt under head of nut.
MN(X)	Material Number for Body X.
MO	Moment in Bolt under head of Bolt.
MU	Expected Value or Average of any Population in general.

NT	Total Number of Fasteners used in the joint.
NU(X)	Poissons' ratio of Body X.
P	Applied Shear Load.
PL	Applied Shear Load per unit length.
PI	3.1415927...
PMAX	Maximum allowable pressure in shear joint; This is numerically equal to Y(1) or Y(2).
P(X)	Allowable Shear Load in Body X.
Pteff	Probability that bolt interference is greater than zero ; Numerically equal to the area under the t-curve.
Pzeff	Probability that bolt clearance is less than zero Numerically equal to the area under the normal curve.
R	Radius of Bolt.
SMU(X)	Expected Value of the shift of the hole from its theoretical centerline in Body X.
SMU(X)	Standard Deviation the shift of the hole from its theoretical centerline in Body X.
SD	Standard Deviation of any Population.
TMU(X)	Expected Value of True Position Tolerance in Body X.

TSD(X) Standard Deviation of True Position Tolerance in Body X.

Theta(X) Slope at Point c due to Load X -used in calculating the displacement due to bending.

t(eff) Effective Hole Size after deformation-used with t-Distribution.

T(X) Thickness of Body X.

TP(X) True Position Tolerance in Body X.

X Assumed value of an independent random variable.

[X] Denotes absolute value of variable X.

Y(X) Compressive Yield Strength of Body X.

Z Normalized random variable used in the Standard Normal Distribution.

Z(eff) Effective Hole Size after deformation- used for Standard Normal Distribution.

Z(X) Probability that the random variable takes on a value less than X.

^ Denotes exponentiation.

* Denotes multipulcation.

** Denotes exponentiation.

/	Denotes division.
μ	Expected Value or Average of any population in general.
σ	Standard Deviation of any population in general.

APPENDIX VIII

COPY OF ALGORITHM ON FLOPPY DISK

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