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Determining Functional Reliability of Pyrotechnic Mechanical Devices

Laurence J. Bement*
NASA Langley Research Center, Hampton, Virginia 23681-2199
and
Herbert A. Multhaup†
New England, North Dakota 58647

A new approach is presented for predicting the mechanical functional reliability of pyrotechnic devices. The currently accepted approach for predicting the reliability of a particular device requires hundreds or thousands of consecutive, successful tests of very similar components. Furthermore, because no performance measurements are made in go/no-go testing, the physics of failure for the device are routinely ignored. The presented approach logically begins with measuring, understanding, and controlling mechanical performance variables within a device. Then the energy required to accomplish the desired function is compared to that delivered by the pyrotechnic energy source to determine a mechanical functional margin. Finally, the data collected in establishing this functional margin are analyzed to predict functional reliability, using small-sample statistics. A careful application of this approach can provide considerable cost savings and an improved understanding of component and system performance over that of go/no-go statistics. Evaluating 20 or fewer units can define performance and provide reliability predictions. The application of this approach to a pin puller used on a successful NASA mission is offered as an example.

Introduction

ALTHOUGH pyrotechnics are required to perform critical aerospace mechanical functions, currently accepted reliability predictions are not based on functional performance, nor are reliability analyses statistically rigorous.

Few guidelines exist for defining the functional performance of pyrotechnics.[1] The current approach is to treat these explosive- and propellant-actuated mechanisms as black boxes without the ability to measure and quantify performance. The only quantifiable performance attribute used for statistical analyses is go or no-go; it either did or did not function as required. Thus, this type of statistical attribute testing is blind to any and all design variables (as well as tolerances on these variables), which actually control functional failures; indeed, these tests are blind to the very existence of any and all physics of failure. Furthermore, the generally accepted approach for pyrotechnic functional margin demonstrations (imposed over 30 years ago on the Gemini program) contributes nothing toward quantifying reliability predictions. This approach, which requires test firings with ±15% pyrotechnic loads, was introduced to provide a qualitative assurance that devices would function properly. If the device still functioned with an 85% load, some functional margin is implied. Or if it functioned without bursting with a 115% load, some structural containment margin is implied. As described in Refs. 2 and 3, the ±15% testing does not quantitatively define either the relative effects of system parameters or actual mechanical functional margins. Consequently, when failures occurred[4] in pyrotechnic subsystems, the most frequently cited cause was a lack of understanding of pyrotechnic component and system functional mechanisms.

The statistical approach widely used in evaluating the reliability and confidence levels of pyrotechnically actuated mechanisms uses only go/no-go functional data. The basis for this approach is simply the number of tests conducted on sample components; no functional measurements or evaluations are made. Table 1 (Ref. 5) shows the number of consecutively successful tests required for achieving two specific reliability levels at three specific confidence levels (reliability of the desired reliability) no matter what statistical distribution exists. Clearly, a requirement to increase either reliability or confidence level with this approach demands the testing of larger and larger quantities. Even at the lower reliability and confidence levels, such numbers are normally cost prohibitive.

When reliability and confidence-level requirements are made in specifications, suppliers often first contend that the device they are offering has been qualified on another similar application. Then they justify their ability to meet the reliability/confidence specification by referring to the number of successful tests they propose to accomplish on the units to be manufactured for this particular application and on history. The number of units manufactured in a single, controlled group (lot) of expensive aerospace hardware often number fewer than 100 units and, therefore, contributes little to realistic predictions of go/no-go functional reliability. Lists of previous manufactured lots and applications of this device or similar, qualified devices are provided, which implies that all previous hardware contributes toward the determination of reliability at some confidence level. Unfortunately, the statistical objective of using the same units as those to be used in the desired application has been violated: 1) The historical samples tested are not from the same manufacturing lot, 2) previous designs often do not use the same materials, and 3) previous designs often do not meet the same form, fit, and function.

As an aside, statistical test methods, such as the Bruceton,[6] are used to determine the reliability of initiating pyrotechnic devices. The reliability predictions from these tests are frequently and erroneously used to imply the ability of the devices to accomplish intended mechanical functions. The capabilities to initiate and to accomplish a mechanical function are separate entities in the understanding of pyrotechnic performance. Only mechanical functional evaluations and reliability are addressed in this paper.

The quandary for the potential user of pyrotechnics is that there is no currently accepted, standard procedure that provides a functional understanding of pyrotechnic mechanisms while providing predictions of reliability for specific manufacturing lots to be used. Also, the cost of pyrotechnic devices prevents the use of large numbers for the accepted statistical standard of go/no-go testing for reliability predictions. Manufacturing lots often number fewer than 100 units,

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*Senior Pyrotechnic Engineer, Test and Development Branch, Mail Stop 431. Associate Fellow AIAA.
†Reliability Engineer, Consultant, P.O. Box 402.

Table 1 Consecutive successes needed to achieve reliability[5]

Confidence level, %	Reliability 99.9%	Reliability 99.99%
50	700	7,000
90	2,300	23,000
95	3,000	30,000

sometimes fewer than 20. The purpose of this paper is to provide a methodology for predicting the reliability of pyrotechnically actuated mechanical functions. The following are specific objectives:

1) Use performance-based evaluation logic to provide an understanding of functional mechanisms, variables, and margins and to determine the most influential failure-controlling performance variable for analysis of reliability.

2) Use 2–20 functional tests from a manufacturing lot for demonstration of mechanical functional reliability.

This paper shows how these purposes and objectives were accomplished through the following experience at the NASA Langley Research Center: Personnel in the Halogen Occultation Experiment (HALOE) Project Office at NASA Langley Research Center were faced with the quandary of how to treat failures[2] experienced by a second user. Two failures to properly stroke occurred in a newly manufactured lot of pin pullers in a design that the project had selected for use on their mission. This lot of pin pullers was being manufactured by the same source, using the same drawings, as the units planned for use on HALOE. An investigation was conducted, and a decision was made to redesign the HALOE pin puller, conduct another qualification, determine functional margin, and predict the functional reliability of the redesigned pin puller.

The approach to predict functional reliability for the HALOE pin puller was to 1) experimentally measure functional performance of the pin puller during development, environmental qualification, and final system demonstration to determine the most influential failure-inducing variable (variation in the output of the pyrotechnic energy source); 2) determine the functional margin of the pin puller in its flight configuration; and 3) develop a method to predict the functional reliability of the pin puller, based on the demonstrated functional margin.

Hardware Tested

The two components evaluated in this program were the HALOE pin puller and the NASA Standard Initiator (NSI).

Pin Puller Description

The purpose of the redesigned HALOE pin puller, shown in Fig. 1 and reported in Ref. 2, was to withdraw the 0.635-cm- (0.25-in.-) diam steel pin into its steel body a distance of at least 1.613 cm (0.563 in.) to release a mechanical interface. Electrically initiating either of the NSIs, installed in the ports shown, drove the piston/pin from left to right. The hot gases from the NSI passed through a 0.254-cm- (0.10-in.-) diam opening in the bottom of the NSI port to the back side of the piston to provide the force to stroke the piston. A 0.140-cm- (0.055-in.-) diam 2024-T4 aluminum shear pin [356-N (80-lbf) static strength] held the pin in the extended position until the NSI was fired. A deep-drawn, energy-absorbing, crushable steel cup was attached to the backside of the piston to stop the piston at the limit of its stroke. The cup, which had a 0.025-cm (0.010-in.) wall thickness and was 0.635 cm (0.25 in.) deep, not only absorbs the excess energy of the moving piston/pin but prevents piston impact to reduce pyrotechnic shock. Also, deformation of this cup locks the piston/pin in the withdrawn position, ensuring no rebound.

NSI

The NSI, shown in cross section in Fig. 2 and described in Refs. 7 and 8, is an electrically initiated cartridge, which was designed to produce heat, light, gas, and burning particles. Three different manufacturing lots were tested: the Viking Standard Initiator (VSI), NSI lot XPJ, and NSI lot XDB; the VSI and lot XPJ were from one supplier, and lot XDB was from another. The major physical difference among the three lots was the $KClO_4$ oxidizer; two different manufacturing processes were employed, yielding different particle sizes and shapes. The $KClO_4$ used in the Viking lot and NSI lot XDB was manufactured using a hammer mill process. That is, the $KClO_4$ powder was pulverized by repeated impacts of steel hammers attached to the sides within a rotating cylinder. This process produced an irregularly shaped particle. The average particle size for lot XDB was 10 μm; the particle size for the VSI lot was much smaller. The $KClO_4$ for NSI lot XPJ was produced by a fluid mill process, which sprayed and dried a fluid mixture in an inert gas environment. This process produced highly uniform, cylindrical particles with an average particle size of 3 μm.

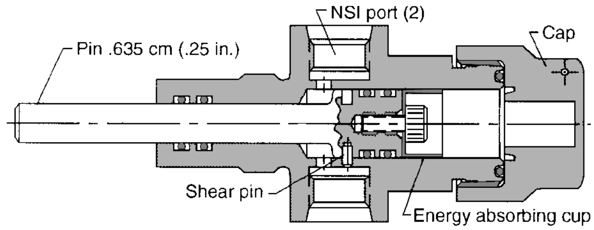

Fig. 1 Cross-sectional view of redesigned HALOE pin puller.

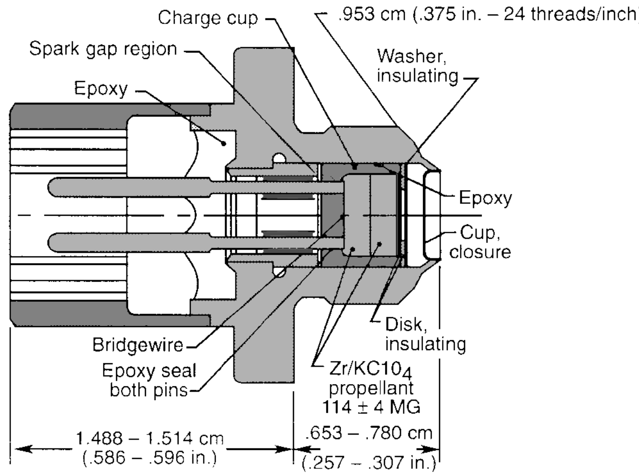

Fig. 2 Cross-sectional view of NSI.

Testing and Analysis Procedures

Tests were conducted to determine how 1) the pin puller operates, 2) the NSI powers the pin puller to accomplish the required function, 3) environments affect the pin puller, and 4) the pin puller functioned in its final application. An analysis used the data collected to determine the functional margin and to predict reliability of the pin puller for the flight.

Several experimental configurations were used to accomplish these tests. To determine how the pin puller operates, weight drop tests were conducted. The output of the NSI to the pin puller was determined by measuring pressure and energy.

Weight Drop Tests

The pin puller mechanical performance was evaluated through measurements of force and energy by dropping 0.454-, 0.908-, or 1.362-kg (1-, 2-, or 3-lb) cylindrical weights onto the vertically oriented pin.[2,3] The impact of the falling weight on the pin simulated the impulsive input from the NSI. The validity of this simulation was based on comparing the function times (at comparable energy levels) that were achieved by the weight impact (1.2 ms) to that achieved in actual firings (0.4 ms); no other method has been found that approaches this similarity while accurately controlling input energy levels. Piezoelectric load cells were positioned under the pin puller to measure the mechanical resistive forces during the actuation of the pin puller. These forces were recorded on a magnetic tape recorder with an overall system frequency response linear to 80 kHz. The weights were guided to impact, using a tube supported by a tripod. This approach provided for highly reproducible energy inputs, measured in joules (inch-pounds) (drop height multiplied by drop weight). The drop height of the weight was reduced to the minimum level required to stroke and lock the piston to determine the energy-required value to function the pin puller. Drop heights were increased to determine the effects of excess energy beyond that needed to function the pin puller. New energy-absorbing cups were installed after each drop, and the amount of crush was measured. Sliding friction, a key performance parameter, was controlled by lubrication.

NSI Output Tests

The performance of the NSI in the pin puller was evaluated by measuring the pressure produced and the energy imparted into the moving piston/pin during the firing. Pressure was measured by installing a piezoelectric pressure transducer in the second NSI port. The data were recorded on the magnetic tape recorder, described earlier. Two different methods were used to measure energy in the moving mass of the piston/pin.

The energy delivered by NSI firings was measured by 1) the energy-absorbing cup in the pin puller and 2) an aluminum honeycomb.[2,3] After each test firing, the pin puller was disassembled, and the amount of cup crush was measured to determine the energy delivered by the NSI in that particular test, using the weight drop test results as the calibration. This method was used as the performance standard for the reliability analysis. The aluminum honeycomb provided a comparison technique for the evaluation of the VSI and two lots of NSIs. The stroke of the piston/pin of the pin puller was transferred through an adapter piston to the precalibrated aluminum honeycomb. The honeycomb resisted the piston/pin throughout its stroke to produce an energy value in joules (inch-pounds or crush distance multiplied by crush strength). A total of 5–10 units of each VSI/NSI lot were test fired in this configuration. Although the honeycomb provided a useful comparative method, the energy values obtained did not represent the functioning of the pin puller in the HALOE instrument and, thus, could not be used for the reliability analyses.

Environmental Effect

There were 10 pin pullers subjected to the HALOE environments expected in the flight. These tests included vibration, constant acceleration, mechanical shock, and thermal/vacuum exposures. The units were x rayed before and after environmental exposures. The units were functioned at laboratory ambient and under thermal/vacuum conditions. The units were disassembled, and the amount of crush of the energy-absorbing cups was measured to determine performance.

System Tests

Five test firings were conducted with the pin puller assembled with two NSIs and installed in the flight instrument. Only one NSI was fired. Two tests were conducted with the worst-case side loads on the pin in its mating socket. After the firings, the pin pullers were disassembled, and the amount of crush of the energy-absorbing cups was measured to determine how much energy was imparted into the piston/pin.

Mechanical Functional Margin and Reliability Analyses

At this point, following the experimental effort, the most significant failure-inducing variable was clearly the energy delivered by the NSI. Therefore, the analysis focused on comparing the energy required to function the pin puller to the energy delivered by the NSI.

Functional Margin

Because functional margin is the energy that is excess to that needed to accomplish the function, the following definition was used:

$$\text{functional margin} = \frac{\text{mean energy delivered} - \text{energy required}}{\text{energy required}} = \frac{\text{excess energy delivered}}{\text{energy required}}$$

Only the five energy-delivered data points collected in the system test section were used. The energy-required value was obtained from the weight drop tests.

Reliability Prediction

The basis for predicting mechanical functional reliability, or the probability of success, is to analyze the most influential failure-inducing variable, energy. The energy required to accomplish the desired function was compared to the energy produced by the NSI. Figure 3 shows these two parameters as Gaussian distributions, where the frequency of occurrence, or the number of times a particular energy value is obtained, is plotted on the ordinate, with increasing energy on the abscissa. Overlap of the two distributions, as shown in the lower curves, is indicative of a significant probability of failure. The top of Fig. 3 indicates a low probability of failure because there is a wide separation between the two distributions and very little overlap. Clearly, to increase the probability of success, the performance distributions of a device should be as narrow (small amount of performance variation or standard deviation) and as far apart as realistically possible to reduce overlap. For example, with this assumption of Gaussian distributions and known means and standard deviations (σ), there is only a 0.00005 probability that an energy value will occur outside of the tail or 3.89 standard deviations. Only the upper tail of the energy-required plot and the lower tail of the energy-delivered plot affect the probability of failure. Even if the distance between the 3.89 standard deviations on these curves is zero, the product of these two probabilities yields a failure probability of less than 0.00000001. The normal distribution curves plotted here are reasonable assumptions for the functional performance of mechanical devices, but neither the means nor standard deviations are known. The data points collected in functional evaluations contribute to this definition, which can then be used to predict reliability using small-sample statistics. The mean and standard deviation of these data points become the best estimates of the actual values of the distributions. A second assumption simplifies the statistical analysis even further; the energy required to function a mechanism should be so well controlled that the distribution should be very narrow or, in essence, a straight line. That is, it is assumed that the standard deviation of the energy-required value, relative to that of the NSI, is so small that it can be ignored. Therefore, the energy-required value is a single number that can be defined experimentally. Thus, only the lower portion of the energy-delivered distribution is significant, contributing to a one-tail statistical analysis.

As stated in Ref. 9, "Many non-statistical users of statistics are well acquainted with confidence intervals for the population mean and for the population standard deviation and some are also aware of tolerance intervals. However, very few know about prediction intervals, despite their practical importance." The practical importance in this case is that a one-sided prediction interval, based on Student's t distribution, is the simple, objective, reliability prediction wanted if the distribution is normal with unknown mean and standard deviation. That is, Student's t analyses can predict the probability of failure, or that an energy-delivered value will be less than the energy-required value. Figure 4 shows a log/log plot of available t tables, created from Refs. 9–12, extrapolated to a one-in-a-million risk (probability of failure) for several sample sizes. Where n is equal to infinity, e.g., the mean and standard deviation are known, as described earlier. The ordinate, coefficient of σ, a factor that establishes the prediction interval being analyzed (how many energy-delivered standard deviations separate the mean energy delivered from the energy-required failure point) is defined as

$$\text{coefficient of } \sigma = \frac{\text{mean energy delivered} - \text{energy required}}{\text{energy-delivered standard deviation}}$$

The abscissa is the probability of failure; the probability of success (reliability) is plotted on the lower scale. Once the mean and standard deviation of the energy-delivered sample are determined, the coefficient of σ is calculated; the horizontal intercept of that value with the number of functional tests conducted yields the probabilities of failure and success on the abscissa. The desirable result of this analysis is to drive the solution to the left, which can be accomplished in several ways: 1) increasing the interval between the energy-delivered mean and the energy-required value, 2) decreasing the energy-delivered standard deviation, and 3) increasing the number of functional tests. Notice that the sample sizes between

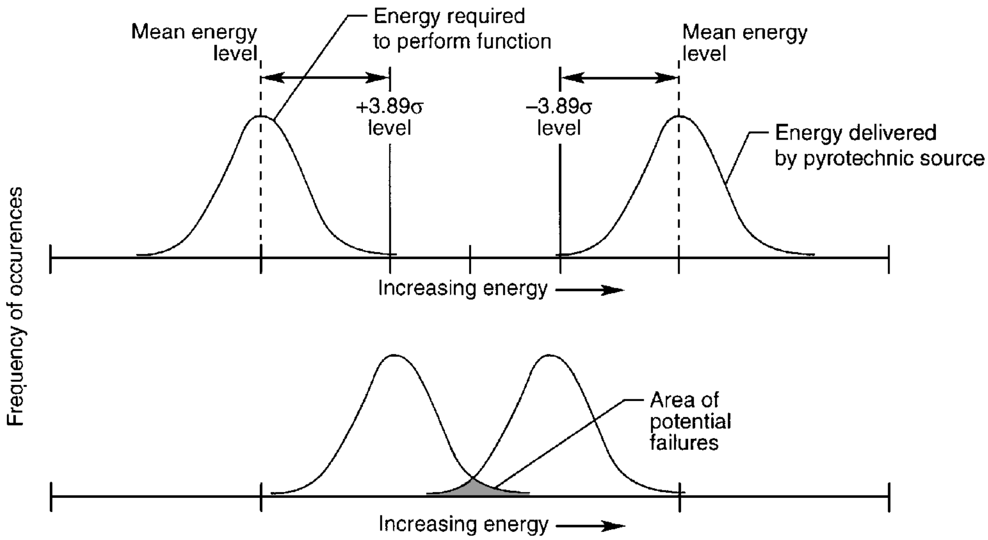

Fig. 3 Statistical presentation of reliability based on comparing the energy delivered to the energy required to accomplish a desired function; the ± 3.89 σ levels for each distribution contain 99.99% of the population.

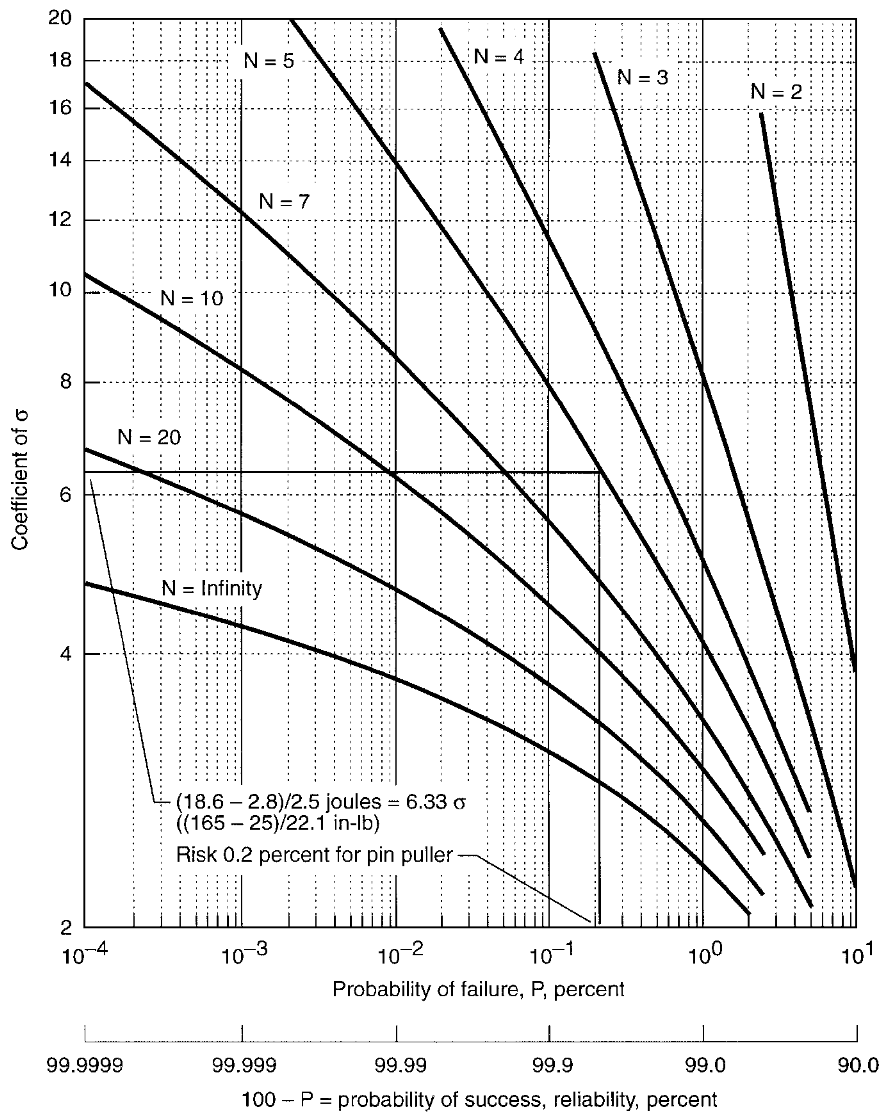

Fig. 4 Statistical presentation of small-sample predictions of the risk of failure and reliability.

20 and infinity produce a relatively small probability change, which indicates that the collection of a large number of samples is subject to diminishing return. Also note that because this is a prediction of probability (failure/reliability) a confidence level is not needed. Tolerances have confidence levels; predictions do not.[9,10]

Results

This section describes the results of the experimental and analytical efforts to understand performance and predict functional reliability of the pin puller. Detailed results are presented in the same format as the "Testing and Analysis Procedures" section.

Weight Drop Tests

The weight drop tests revealed a considerable difference in performance between unlubricated and lubricated pin pullers. An unlubricated interface required over 11.3 J (100 in.-lb) to accomplish the stroke; the O-rings rolled up on their respective axes, and chunks were torn out during the stroke.

Typical force/time plots of an 8.5-J (75-in.-lb) drop test [a 95.3-cm (37.5-in.) drop of a 0.91-kg mass (2-lb weight) on a well-lubricated pin puller] are shown in Fig. 5. Two plots of the same event are shown; the upper trace has a scale of 222 N (50 lbf), whereas the lower has a scale of 2220 N (500 lbf). The dynamics of the impacting mass induced considerably higher forces as compared with static evaluations. Instead of the static-rated value of 356 N (80 lbf) to fail the 1.4-mm- (0.055-in.-) diam shear pin, an average force of 890 N (200 lb) was required. Instead of the static-rated value of 13 N (3 lb) of sliding friction, the force was oscillatory, averaging 95.6 N (21.5 lb). The last high-level force indication, averaging 7562 N (1700 lb) was induced in crushing the energy-absorbing cup. A reasonable accounting can thus be made of the 8.5-J (75-in.-lb) energy input, as shown in Fig. 5 and Table 2. These weight drop tests provided a conservative result because energy losses due to nonelastic deformations were ignored.

Table 2 Energy consumption in an 8.5-J (75-in.-lb) input to the HALOE pin puller

Energy consumed, J (in.-lb)	Derivation
1.1 (9.8)	Fail the shear pin [1.244-mm (0.049-in.) equivalent square pin × 890 N (200 lbf)]
1.4 (12.6)	Stroke [1.496 cm (0.589-in.) overall stroke × 96.5 N (21.5 lbf)]
5.8 (51.0)	Crush the energy-absorbing cup [0.762 mm (0.030 in.) × 7562 N (1700 lbf)]
0.2 (1.6)	Rebound of the weight [2.0 cm (0.8 in.) × 0.91 kg (2 lb)]
8.5 (75.0)	Total

NSI Energy Output and System Tests

Table 3 shows the results of the performance of three different lots of NSIs using the honeycomb crush tests.

Typical working pressures within the pin puller for one of each of the NSI lots are shown in Fig. 6. The pin reached its full stroke in less than 0.5 ms.

The energy delivered by the five functional tests of the pin puller within the HALOE instrument were 15.4, 16.6, 19.9, 19.9, and 21.5 J (136, 147, 176, 176, and 190 in.-lb). This yielded a mean of 18.6 J (165 in.-lb) and a standard deviation of 2.5 J (22 in.-lb). The mean was significantly less than the functional performance of the unit outside of the instrument, which averaged 20.9 J (185 in.-lb) (Ref. 2).

Environmental Effects

Following the exposure of 10 units from the flight lot to qualification environments, the energies measured in functioning these units were comparable to those obtained in previous tests on untested units.

Mechanical Functional Margin and Reliability Analyses

The most influential failure-inducing performance variable recognized from the experimental effort on the pin puller was energy, which was used for this analysis.

Functional Margin

The functional margin analysis progressed from simple to more complex criteria, as shown in Fig. 7. The first goal of the HALOE

Table 3 Honeycomb crush energy measurements of three lots of NSIs

Lot	Manufacturing date	Average/standard deviation, J (in.-lb)
Viking	1972	11.2/2.4 (99/21)
NSI XPJ	1985	14.3/2.3 (127/20)
NSI XDB	1988	6.0/5.5 (53/49)[a]

[a]Actual energy values collected[2] were 2.9, 2.1, 15.5, 3.5, and 6.1 J (26, 19, 137, 31, and 54 in.-lb).

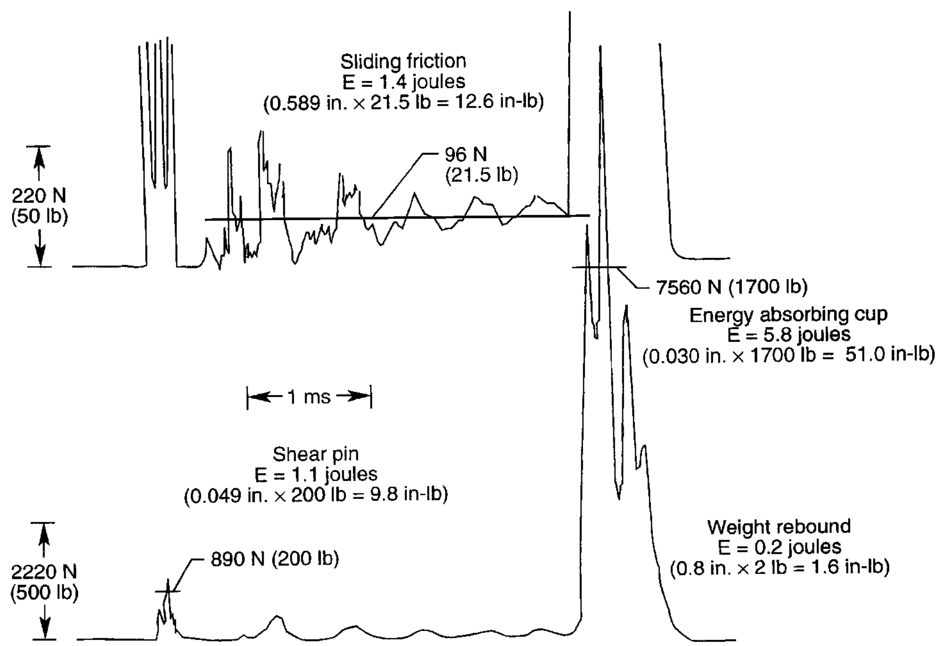

Fig. 5 Force/time history (two scales/same event) of well-lubricated HALOE pin puller with a 8.5-J [75 in.-lb (37.5-in. drop, 2-lb weight)] weight drop test input.

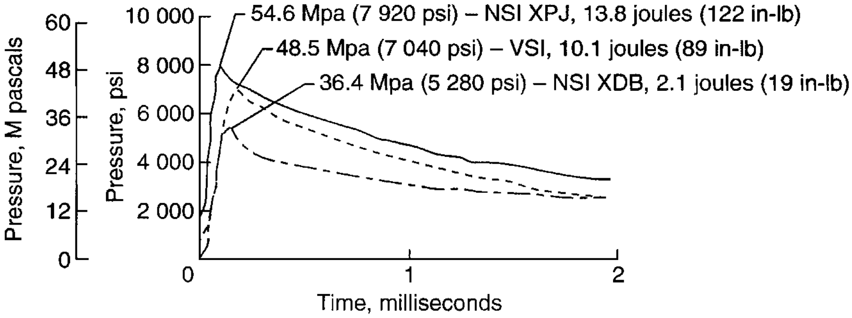

Fig. 6 Typical pressure traces produced during firing of three NSI lots in the HALOE pin puller, indicating the peak pressures and energies delivered.

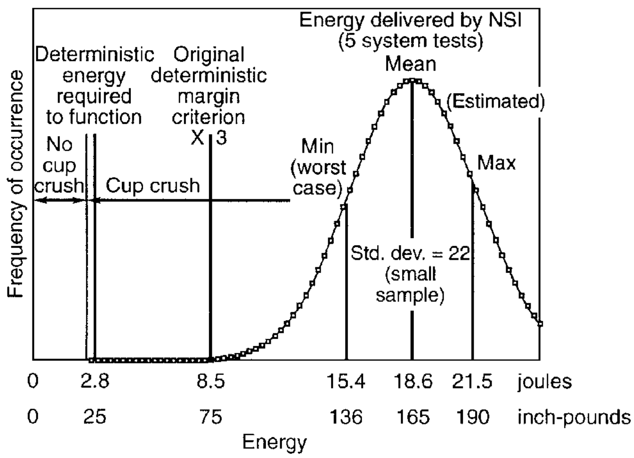

Fig. 7 Statistical presentation of functional margin for the redesigned HALOE pin puller; sample mean is the best estimate of the distribution mean.

program office was to require that the average energy produced by the NSI in the instrument to be at least three times that needed to function the device. The energy required to function the pin puller, as determined experimentally, was a highly reproducible value of 2.8 J (25 in.-lb), which was assumed to be a single-point, deterministic value. The mean energy-delivered value in the instrument was 18.6 J (165 in.-lb). Thus, the functional margin is

$$\frac{\text{mean energy delivered} - \text{energy required}}{\text{energy required}} = \frac{18.6 - 2.8}{2.8} = 5.6$$

Even considering the minimum value of energy delivered observed (a test in which the pin puller had been incorrectly assembled in the instrument and the pin was bound in its retention port), the functional margin is

$$\frac{15.4 - 2.8}{2.8} = 4.4$$

This value is well above the program's minimum energy-delivered goal of 3.

Reliability Prediction

Figure 7 shows how the data are used. The energy-delivered mean of 18.6 J (165 in.-lb) is assumed to be the mean of the normal distribution indicated. The deterministic failure point is 2.8 J (25 in.-lb). The coefficient of σ for this five-unit sample is

$$\frac{\text{energy-delivered mean} - \text{energy required}}{\text{energy-delivered standard deviation}} = \frac{18.6 - 2.8}{2.5} = 6.33$$

Figure 4 is used to determine the probability of failure, or the probability that the 2.8 J (25 in.-lb) value is contained within the energy delivered normal distribution in Fig. 7. The 6.33 coefficient of σ line intersects the $N = 5$ curve to yield a probability of failure of 0.2 %, or a probability of success (reliability) of 99.8 %.

Conclusions

In response to a request from NASA, an experimental and analytical evaluation was conducted on a pin puller to predict its mechanical functional reliability. The effort logically began with testing to understand how the pin puller worked and how well it worked in the application. The data collected was then used in a statistical analysis to predict a successful operation. The approach is based on 1) understanding and controlling the effects of significant variables, including environments; 2) determining the mechanical functional margin by measuring and comparing the energy delivered by the energy source, in this case the NSI, to the energy required to accomplish the function; and 3) predicting mechanical functional reliability by applying small-sample statistics to the functional margin data.

The experimental effort to understand and control performance variables produced results that were both surprising and expected. Dynamic inputs (impacts from weight drops to simulate the output of the NSI) revealed that considerably more energy was required to achieve the function, compared with what would be expected from static measurements of shear pin strength and sliding friction. The shear pin failed at approximately 890 N (200 lbf) instead of 356 N (80 lbf). Sliding friction in a lubricated pin puller was seven times that expected under static conditions. The lack of lubrication caused a fivefold increase in the energy required to accomplish the function, compared with the well-lubricated interface. Special test methods were required to measure the dynamic, impulsive energy output delivered by the NSI, the most influential failure-inducing or least-controllable variable. In the pin puller, this energy was measured by the amount of crush induced in calibrated energy-absorbing cups at the end of the pin's stroke. Another energy-measuring test series, in which the pin stroked against calibrated aluminum honeycomb, indicated that considerable performance differences existed among three manufacturing lots of NSIs. These differences were most likely caused by variations in the particle size of the $KClO_4$ in NSI manufacturing lots. The lot with the known larger particle size exhibited the poorest combustion performance and most erratic energy delivery. The NSI lot with the highest, most consistent performance was selected for flight. Environmental tests for qualification had no influence on performance. More energy was required to function the pin puller when it was installed in the spacecraft, as compared with an uninhibited firing. This increase in energy was due to increased friction in withdrawing the pin from the spacecraft interface. This experimental evaluation indicated that the energy required to function the pin puller was a highly reproducible 2.8 J (25 in.-lb). The energy delivered by the NSI flight lot in the spacecraft averaged 18.6 J (165 in.-lb) with a standard deviation of 2.5 J (22 in.-lb).

The analysis of these data revealed that the pin puller had a healthy functional margin of 5.6, based on comparing the mean energy delivered by the NSI in a sample of five tests in the spacecraft to the energy required to function the pin puller. A reliability prediction of 99.8% for successful operation of the pin puller was made with these same data, using a small-sample, statistical analysis. It is assumed the energy delivered by the NSI is a normal distribution. Thus, Student's t analysis can be used to predict the probability of failure, or that the value of energy required to function the pin puller will be larger than the energy delivered. This approach provides designers a reasonable reliability analysis with 20 or fewer performance demonstrations in the application, which is within the limits normally applied for qualification of current systems.

The application of this energy-based, small-sample statistical approach for reliability predictions is not a panacea that can be blindly applied to any pyrotechnic mechanism; restrictions must be recognized to ensure its appropriateness. The energy required to accomplish the function must be highly reproducible with a very narrow distribution of performance; if this value is not controlled, a considerably more complex analysis than that offered here must be used. Also, the worst case (largest energy-required value recorded) should be used for the analysis. All energy-delivered measurements should be made in the actual or a very close representation of the mechanical application. Even if the statistical distribution under evaluation is not normal, the approach recommended in this study provides far more information on which to make flight decisions than that obtained from go/no-go statistical analyses.

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G. M. Faeth
Editor-in-Chief