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A DESCRIPTION OF EXPECTED FAILURE RATES OF NEWLY ACQUIRED COMPONENTS PRIOR TO STEADY STATE

Richard F. Erickson, et al

Air Force Institute of Technology
Wright-Patterson Air Force Base

January 1974

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Constant Failure Rate						
Decreasing Failure Rate						
Increasing Failure Rate						
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A study of the effects on the population failure rate of component failures during the period of transition to steady state is presented. Comparisons between the simulated failure rates and the system failure rate predicted under the present Air Force assumption of an underlying Poisson process are accomplished for various MTBF's and parameters of the Weibull distribution. The decreasing hazard, constant hazard, and increasing hazard functions are studied and presented.

This study was performed as a simulation of the transition period using the GASP II package developed by Pritsker and Kiviat. Such a simulation package greatly simplifies the required programs necessary to be written. The computer program used in this study is included as part of this paper.

The results of the study indicate there are significant differences between the present Air Force methods of predicting failure rates and the simulated failure rate distribution during the transition period. Plots of the simulated results compared to the present Air Force methods indicate these differences could reach 100% of the Air Force estimated failure rate when the Weibull shape parameter is greater than 3 and the components MTBF exceeds 1000 hours.

The study indicates that component failure rates, which can be described by a Weibull density function, will result in oscillations about the present Air Force computed rate at steady state.

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A DESCRIPTION OF EXPECTED FAILURE RATES OF NEWLY ACQUIRED COMPONENTS PRIOR TO STEADY STATE

A Thesis

Presented to the Faculty of the School of Systems and Logistics

of the Air Force Institute of Technology

Air University

In Partial Fulfillment of the Requirements for the

Degree of Master of Science in Logistics Management

By

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January 1974

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This thesis, written by

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and

Captain Donald H. Hammond

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CHAPTER I

INTRODUCTION

Structure

For the convenience of the reader, we have structured the following report so that Chapters III and IV are not required for an intuitive understanding of the background and results of our investigation. A reader with little time or desire for mathematical background material may wish to omit Chapters III and IV in the interest of brevity. In addition, we offer our definitions of the following commonly used terms.

Component--The general term for any part, subassembly, line replaceable unit, system, or piece of equipment whose failure and replacement must be considered in logistics plans.

Component Population--The total number of a component type in the Air Force operating inventory.

Failure--The opposite of "operating normally." Thus, for our purposes, a component has only two states of nature; either it is serviceable, or it has failed.

Failure Rate--The rate of failure in a population of identical components. This measures applies when components are repaired (to new condition) or replaced (by new components) and thus continue to operate. It is computed by dividing the total number of observed failures in a time period by the accumulated operating time during the period.

Mean Time Between Failures (MTBF)--The average operating time expected between failures in a population of identical components. This measure has meaning only when we are discussing a population where there is repair or replacement.

Hazard Rate--The instantaneous failure rate of the components under consideration; or, the expected failure rate during the next time interval.

Mean Time To Failure (MTTF)--The average operating time expected before failure of a component which is not repaired or replaced. This is simply the average time to failure of "n" units, i.e., the sum of "n" individual unit times to failure divided by "n" units.

Statement of the Problem

One of the basic factors associated with the logistical support of a weapons system, or a group of weapons systems, is the determination of future requirements. Specifically, we need to know how often parts and/or equipment will fail. In practice, the occurrence of a component failure is so basic to the support function that its importance is sometimes overlooked. Yet, the frequency and distribution of component

failures determine how many spare parts are to be purchased, how many support manhours are to be scheduled, what base and depot support facilities are to be made available, and even how many aircraft are to be required to perform the mission.

In the established procedures for determining support requirements (5), the Air Force makes an implicit assumption as to the underlying distribution of failures. We assume each component population has a constant failure rate with respect to time. Under such an assumption, we ignore the reality of the situation where components actually deteriorate over time and that the probability of failure may increase as the components accrue larger and larger operating times. Thus, under such an assumption of a constant failure rate, we may unintentionally introduce serious errors into our logistics planning to meet future support requirements.

Objective

The objective of this research is to investigate, through digital computer simulation, the distribution of failure rates during the transition period from the initial acquisition of new weapons systems to the attainment of a "steady state" condition, resulting from the incremental introduction of a fleet of aircraft. For simplification we assume each aircraft consists of a self-contained, independent component whose probability of failure can be approximated by a Weibull distribution. Specifically, we were interested in the change of the component

population's failure rate with respect to time. In reliability terms, we wanted to investigate the pooled output of N superpositioned renewal processes where N(t) = f(t).[1]

Hypothesis

The fleet wide distribution of failures for any replaceable equipment/component is at all times a Poisson process; therefore, the assumption of a constant failure rate is always valid in estimating future expected failures.

---

[1]We are interested in the system average failure rate at a point in time. This failure rate is the sum of the individual failure rates divided by the number of failures, i.e.,

$$N(t) = \frac{\sum_{i=1}^{n} N_i(t)}{n} = f(t)$$

CHAPTER II

BACKGROUND

The Air Force Method for Estimating Part Failures

If each part, subassembly, or line replaceable unit (LRU) in our supply inventory came with a "service life" stamped next to the part number, logistics plans for future requirements could be made by anyone with a desk calculator. Components could be replaced before failure, stocked exactly in the right amounts, and always reordered in the most economical quantities. Unfortunately, this is not the case, since individual component times to failure occur randomly and are not exactly predictable. To overcome this problem and prepare meaningful quantitative support plans, the Air Force has adopted a method for estimating the service time of components by averaging service times. This paper is concerned with the accuracy of such an estimation method during the initial provisioning process, and the early life of a weapon system.

The established Air Force procedures for predicting component failures are so basic that we seldom realize we are using a "method,"

and that there are requirements which must be met before applying it. The following is a rough description of present Air Force procedures (for mathematical derivations and references see Chapter III).

In order to sensibly deal with random failures, we first must make a few assumptions. One of the most helpful assumptions is to assume that while individual components fail at random, the total parent population is in a steady state condition. For our purposes, a component's supply system would be in steady state if the average Air Force-wide demand for the component remained constant year after year.[2] Where the parent population is in steady state, or sufficiently close so that we could assume steady state, then we can use the population's long run average demand as an estimator for a future period of time. For example, we might predict 1125 F-4 tire failures next year because we have averaged 1125 failures for the last five years. Such a quantitative measure belongs to a parent population in steady state and identifies the average number of failures experienced during the prior time period.

Next, we assume that component failures are distributed uniformly over the entire interval. If we have a homogeneous system which is not subject to large seasonal demands, then this assumption

---

[2]We would not expect a particular F-4E aircraft to use exactly the same number of right main tires every year; however, if the yearly F-4 flying program did not change, we could expect the fleetwide demand for F-4 tires to be approximately constant.

will be valid.[3] We can now calculate an estimate of the population failure rate for any desired small time interval. Thus, if we averaged 1125 F-4 tire failures each year while logging 225,000 flying hours, we can assume we experience .005 failures per flying hour, or an average of 200 flying hours between failures. Since the component population is in steady state, is homogeneous, and composed of identical items, we can assume the above estimate applies uniformly to the individual components. Thus, each component's failure rate and time between failures would be identical to the population failure rate and time between failures. In our example, we would assume each F-4 tire had a failure rate of .005 failures per flying hour, or an average service life (MTBF) of 200 flying hours.

The procedure is complete; a quantitative measure has been determined which can be used in estimating future requirements. However, this method provides quantitative estimates only for the steady state conditions. Thus, future requirements may be estimated from current supply demand rates. As the component and its parent population age, these estimates can be refined as more data is collected.

Identical or Similar Components

When we begin the planning process for a new weapons system,

---

[3]Seasonal demands for items by their very nature do not exhibit a uniform distribution throughout the time interval. However, where the seasonal demands are relatively small in comparison to total demands, then such demands would not significantly affect this assumption.

we do not have to start over for every new component. Many items on a new aircraft are identical or quite similar to components used before. If we have collected data on similar systems, we may be able to accurately predict future requirements and provision for the new components using our past demand data. However, if the basic assumptions we made while applying the previous "method" are not valid for the new component population, sizable errors may be introduced into provisioning plans.

If the new aircraft are to be acquired in large numbers, say, 100, 500, or 700 in the total fleet, it is unlikely that all the aircraft will be placed into operation immediately. They will probably be introduced into the active inventory over a period of months, or even years. Does our first assumption of a steady state system still hold? If the components we are buying are not yet members of a steady state population, can we attribute to each of them the old system failure rate and mean time between failures? In some cases yes; in some cases no.

To illustrate this point, we will use a hypothetical situation. Consider a "specialist" shop in a maintenance squadron that supports ten aircraft. This shop repairs a photographic system that has two components: a power supply unit and a camera unit. Assume that the system has been in the Air Force inventory for a few years and that it is in steady state. The specialist repairman is new and eager. On his first day in the shop he erects a four-month wall chart for each component, complete with aircraft tail numbers and the date. For four

months he religiously records each failure as a large "X" on the chart until, at the end of April, the charts appear as in Figure 1. The charts appear quite similar with five failures each month. Knowing that each aircraft flies 100 hours a month, our camera specialist calculates each component's failure rate

$$\frac{5 \text{ failures}}{1000 \text{ flying hours}} = .005 \text{ failures per hour}$$

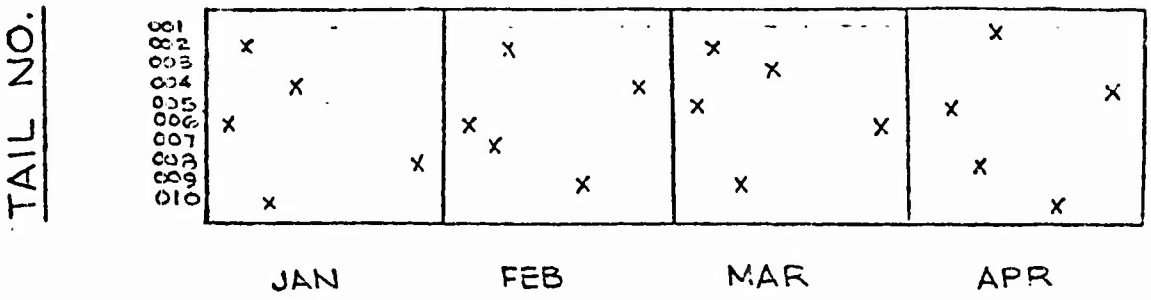
and mean time between failures

$$\frac{1000 \text{ hours}}{5 \text{ failures}} = 200 \text{ hours.}$$

While the results from the charts appeared equal for the power supply units and the cameras, they disagreed with the repairman's intuition. He knew the components were entirely different; and therefore, he guessed that they should possess different failure patterns. The power supply unit was a solid state, fully electronic assembly that appeared to fail at random. Conversely, the camera unit was composed of small gears, bearings, and sprockets which became clogged with dust-like film emulsion and thus failed at regular intervals. To test his conjecture, the repairman went back to his charts and connected the "X"s for each aircraft with a solid line. The lines represent the operating time prior to failure for each individual component (Figure 2).

For the power supply components, the service time lines were

POWER SUPPLY UNIT



CAMERA UNIT

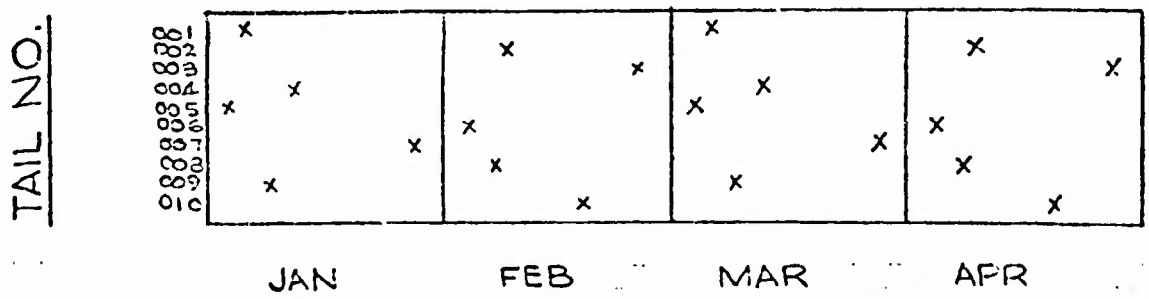
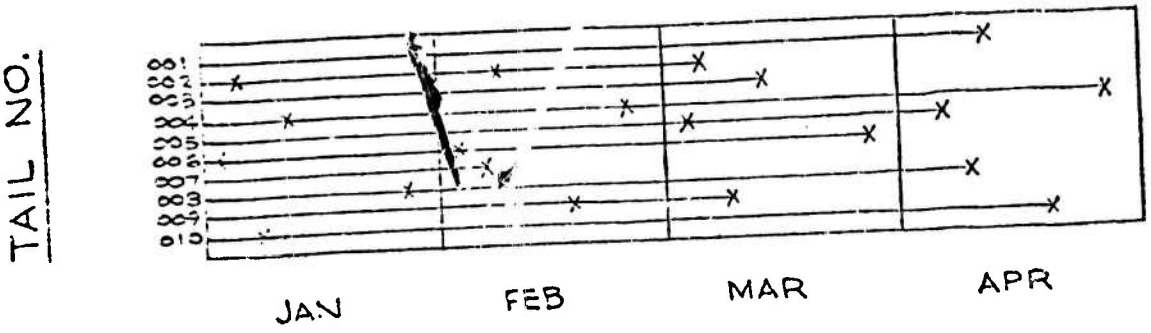


FIGURE 1

COMPONENT FAILURES - EXAMPLE
FAILURE DENOTED BY "X"
SYSTEM IN STEADY STATE

POWER SUPPLY UNIT



CAMERA UNIT

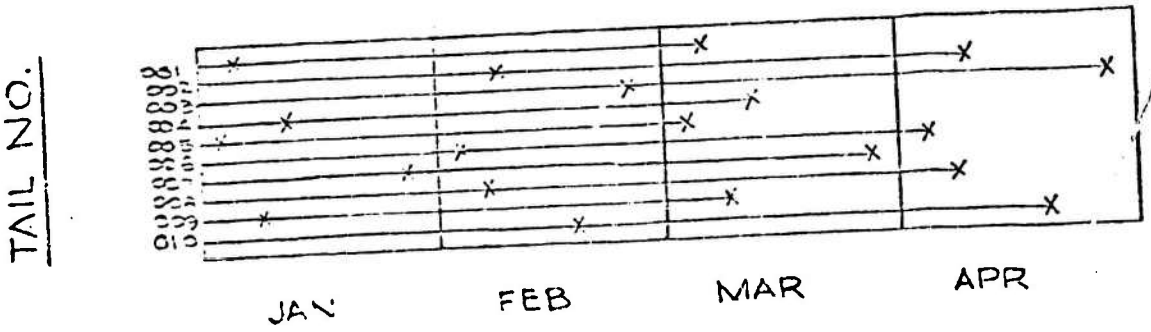


FIGURE 2

COMPONENT FAILURES - EXAMPLE
FAILURE DENOTED BY "X"
SYSTEM IN STEADY STATE

many different lengths; but, the average length was, as computed, 200 hours. The probability that they will fail in the next moment is not a function of operating age. Because of this property the length of service varies randomly from very short to very long. The service times for the camera units appear very consistent, varying only over a small range of times around 200 hours.

Now that we have accumulated failure data in our hypothetical shop, suppose we go one step further and attempt to provision for an entirely new camera system. Assume the squadron acquires ten aircraft from the production line equipped with the new camera system and expects to fly each aircraft an average of 100 hours a month beginning 1 January. We use our hypothetical (steady state) failure rates and stock parts/equipment based upon the prediction of five power supply and five camera failures each month. Figure 3 shows the hypothetical results experienced on the basis of our earlier assumptions.

The power components appear in steady state immediately, however, the camera components experience no failures for the first two months. Then they begin a two month failure cycle which continues until the small variations in service time smooth the distribution to the steady state condition shown in Figure 1. We have over stocked parts/equipment for the camera unit during the months of January and February since no failures were experienced. However, during the month of March, we discover that we do not have enough parts/

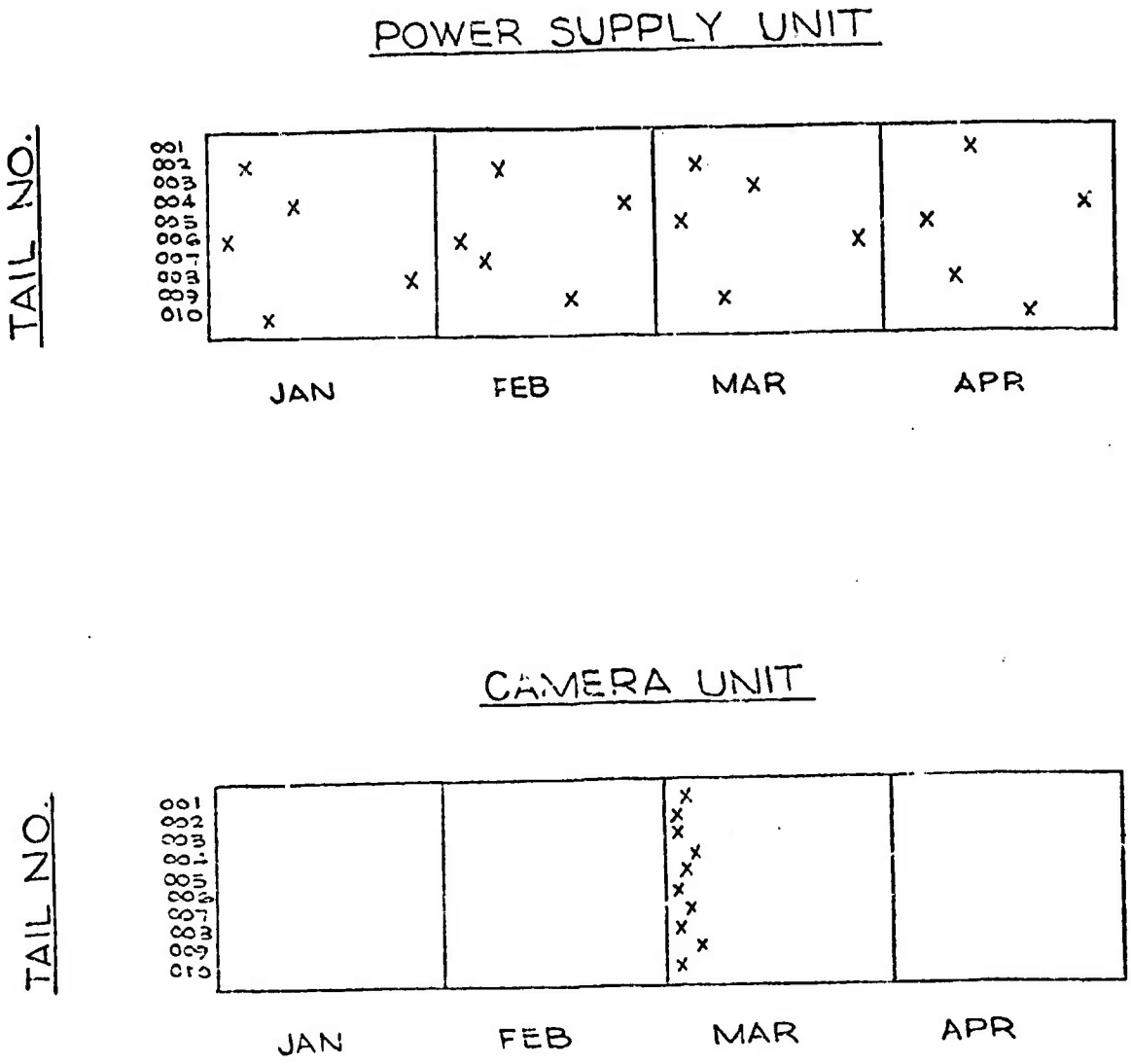


FIGURE 3

COMPONENT FAILURES - EXAMPLE
FAILURE DENOTED BY "X"
SYSTEM IN TRANSITION

equipment on hand to satisfy all failures and the mission is affected due to lack of parts. The stockage requirements for repair support of the camera system may be increased to insure sufficient spares are available to meet future requirements. When the system eventually reaches steady state, we find that we now have excess spares on hand to meet the system repair requirements; i.e., five failures per month.

Although the new power supply and camera units were similar to the old system, both had not achieved steady state. Therefore, assuming that our previous estimates of failure rates and service times were applicable to the new systems caused us to acquire erroneous stocks of parts/equipment for the camera unit.

Totally New or Dissimilar Components

When the Air Force procures a new weapons system, a large number of new items of supply are also received. Since the Air Force may not have prior supply experience for these new units, it must depend upon the contract engineering estimates for component failure rates and service times. A problem arises in that Air Force estimation methods may not be the same as those used by the contract engineers. To understand this problem, we need to define a few key terms.

If we are discussing a population of components that operate together as a system in steady state, and if each component is repaired or replaced upon failure, we use the term Mean Time Between

Failures (MTBF). (18:197) "MTBF may be determined by testing several equipments through several failure incidents and averaging the total operating time for the number of failures." (17:15-5) If we discuss the failure or service time of one component, we use its Mean Time To Failure (MTTF). We could life-test several of these units until they failed, and then average their service lives (time to failure) to find the unit's MTTF.

> It is often convenient to characterize a failure model or set of failure data by a single parameter. One generally uses the mean time to failure or the mean time between failures for this purpose.... Unfortunately these two quantities are sometimes wrongly thought of as equivalent, probably because for certain simple constant-hazard cases they are equal. In a single-parameter distribution, specification of the MTTF fixes the parameter. (18:197)

In Figures 1, 2, and 3 the power supply was of this simple type where the MTBF calculated by our steady state method was always equal to the individual unit's MTTF. This was not true of the camera unit.

When procuring a new system, we tell the contractor exactly what we want. We want a component that will have a given MTBF (calculated by our methods) regardless of when and how we use it.

> In many instances military contracts for complex systems express quantitative reliability requirements in terms of mean time between failures (MTBF). In fact, more than one MTBF may be specified. No matter how many MTBF's are specified, there should be a definition of what MTBF means. One of the pitfalls in current contracts is that a MTBF is required but what it stands for is not explained....
>
> 1. Is this MTBF the design, minimum acceptable hardware, or the operational requirement?
> 2. When is this MTBF to be attained?
> 3. What definition of failure is to be used in calculating MTBF?

> .....
> The second question above, regarding "when", is of paramount interest. The...MTBF may be attainable at some future date, but not in the first operational system. Usually, the best approach is to make this MTBF the average of systems, for instance, the first squadron or wing of delivered systems for a military contract.... (12:14-12)

The Air Force contracts for a given MTBF and the contractor designs for a steady state failure rate. But how long will it take before our actual failure rate reaches the steady state failure rate? The answer to this may be different for each component population. However, present Air Force initial provisioning procedures consider only the steady state MTBF. Air Force planners must also consider the transition period prior to steady state. To do this we must know something about the behavior of failure rates during the transition period.

Burn-in Phase

There is another problem associated with the present "method." Many complex electronic systems go through an infant mortality or "burn-in" phase. During this phase, many systems exhibit a decreasing failure rate with respect to time. Their initial failure rate is high, but after the first few repairs the system failure rate settles down to a constant low level. (17:15-14) This condition is often encountered in the real world, however we have not analyzed this type of phenomenon in this study. A long run average or an engineer's steady state estimate may suppress indications of a burn-in phase. Unless we are

forewarned, the sudden appearance of a high failure rate may cause undue alarm during the first few operational months.

Summary

In this chapter we have attempted to show that the procedures used by the Air Force to estimate future logistics requirements have necessary underlying assumptions. The most basic of these is the assumption of a steady state condition. If a component has a constant failure rate, its component population will immediately appear in steady state. However, if a component has an increasing or a decreasing failure rate with respect to time, or if we receive a steady state engineering estimate, the component's population may pass through a transition period prior to reaching the steady state failure rate. The objective of this research is to investigate failure rates to be expected during this transition period.

CHAPTER III

MATHEMATICS

General

In published procedures for determining quantitative requirements for initial spare parts, the Air Force assumes that the occurrence of component failures can be approximated by a Poisson probability distribution. (5) While this assumption is not explicitly stated, it is implicit in Air Force tables which suggest that every spare part has a unique mean time between failure (MTBF) and a constant failure rate. A constant failure rate implies an exponential density function (18:185) and, therefore, that failures are generated by a Poisson process. (8:111)

In the following discussion we will show that there are two procedures which lead to a Poisson process. The first procedure requires each component to have a constant hazard function, but does not require steady state. The second procedure requires a steady state, but not a constant hazard function.

Constant Hazard Model

If we are discussing one component and we can assume its time to failure (TTF) follows an exponential distribution, then,

(1) $f(t) = \lambda e^{-\lambda t}$, $0 < t \leq \infty$ (exponential density function)

(2) $F(t) = \int_0^t f(x)dx = 1 - e^{-\lambda t}$, $0 < t \leq \infty$ (cumulative density function)

where λ is a constant and is defined as the hazard rate. (18:48) and t is operating time. We can also find the mean time to failure, MTTF, by

(3) $MTTF = E[TTF] = \int_0^\infty t\, f(t)dt = \frac{1}{\lambda}$ (7:165)

However, if we are discussing a population of identical independent components, we can discuss the fractional portion of the original population which fail prior to a time t by

(4) $P(x \leq t) = \int_0^t f(x)dx = \int_0^t e^{-\lambda x}dx = F(t)$, $0 < t \leq \infty$.

Which is identical to the cumulative function above, equation (3). Thus, $1 - F(t)$ represents the fraction of the population surviving to time t (7:164), defined as the reliability function as follows,

(5) $R(t) = 1 - F(t) = e^{-\lambda t}$ (Reliability function)

We can define the population hazard rate or the distribution hazard function as the rate at which the survivors fail. (7:165) Then,

$$(6) \qquad Z(t) = \frac{f(t)}{R(t)} = \frac{\lambda e^{-\lambda t}}{e^{-\lambda t}} = \lambda, \; 0 < t \leq \infty \text{ (hazard function)}$$

which is constant for all values of t. For this distribution it has been proven that the reciprocal of the hazard function is the mean time between failures, (MTBF) (14:4-43), or,

$$(7) \qquad \text{MTBF} = \frac{1}{Z(t)} = \frac{1}{\lambda}$$

Thus, for the constant hazard model a component's hazard rate equals the population hazard rate and the MTTF = MTBF, and the MTBF is independent of the value of t.

The Renewal Model

If we are discussing the failure of one component, but, this time, we replace the failure with an identical new component (or an old component which has been repaired to new condition), we have a renewal process. (3) Furthermore, if we assume time to be component operating time and that we can replace a failed component instantaneously, the system's operating time becomes:

$$(8) \qquad T_{sys} = t_1 + t_2 + t_3 \ldots + t_n$$

Where t_n = the operating time for the nth renewal. The density function

(9) $f(T_{sys}) = f(t_1, t_2, t_3, \ldots, t_n)$

may be found by the use of Laplace transforms, which simplify the function to

(10) $f^*_{Tsys}(S) = f^*_1(S)\, f^*_2(S)\, f^*_3(S) \ldots f^*_n(S)$

where $f^*_n(S)$ is the Laplace transform of $f_n(t)$ such that

(11) $f^*_n(S) = \int_0^\infty e^{-st_n} f_n(t_n)dt$

or, finally, where all units are identical:[4]

(12) $f^*_{Tsys}(S) = [f^*(S)]^n$ (18:351-352)

Up to this point we have been discussing the renewal (or repair) of <u>one</u> component. A population of components, all operating, failing, and being instantaneously renewed, is referred to as a superposition of renewal processes. In order to analyze a pool of individual component processes, it is helpful to visualize each component's renewal process as an <u>independent distribution of failure times</u>, and then refer to the following basic reliability references.

---

[4]In the special case where the components are constant hazard we obtain:

$$f_{Tsys}(t) = \frac{\lambda(\lambda t)^{n-1}}{(n-1)!}\, e^{-\lambda t} \quad \text{(the special Erlangian function)}$$

Which is called the Poisson process.

> One of the first areas of reliability to be approached with any mathematical sophistication was the area of machine maintenance (Khintchine, 1932, and C. Palm, 1947). The techniques used to solve these problems grew out of the successful experiences of A. K. Erlang, C. Palm and others in solving telephone trunking problems. (2:1)

As Erlang and Palm demonstrated, the Poisson distribution was a very good approximation to the actual behavior of their "simple stream" of phone calls. (11:12) However, Palm, and later, Khintchine realized that groups of telephone calls did not always satisfy the strict assumptions of the Poisson distribution. This was especially true of the requirement that the distribution be memoryless or in their words, "without after-effects." (11:12) In the introduction to his mathematical proof of Palm's theorem, Khintchine wrote:

> Thus, although an investigator, when applying the theory to experimental data, usually has the task of explaining the causes of deviation of the actual processes from the course theoretically predicted for them, the situation is in fact the wrong way round--experimental data agree with the deductions from the constructed theory, as a rule, better than could have been expected on the principal considerations, and it is precisely this 'much better' agreement which requires explanation. Palm has made a noteworthy attempt to explain facts of this kind by the assumption that a given process represents a simple sum (superposition) of a large number of mutually independent processes of small intensity, in which each of these processes is stationary and orderly <u>and can be either with or without after-effects.</u> [author's underlining] In this it is shown that under broad assumptions the summary stream must be very near to a simple one. Such a statement of the problem is, on the face of it, very near to the real situation. So, if a large number of subscribers are attached to the given exchange, a general stream of calls is composed of streams (of a comparatively small intensity) arising from different subscribers, in which the component streams can in the first instance be regarded as stationary, orderly, and mutually independent. (11:49)

Khintchine then presents a chapter-long proof of Palm's proposal.

While this particular proof is too lengthy to reproduce in this report, two other authors have interpreted the meaning for us. In his text on renewal theory, Cox discusses Khintchine's proof in relation to the pooled output from superpositioned renewal processes.

> Khintchine...has proved that in the limit the numbers of renewals in non-overlapping intervals follow independent Poisson distributions, thus showing that in the limit the pooled output is a Poisson process. His proof does not require the component process to have identical distributions of failure time. (3:78)

And in his text on reliability, Shooman writes:

> Since we are now dealing with the superposition of sums of random variables, the arguments for using the central-limit theorem and obtaining limiting forms are even stronger. Specifically one can state that for K superposed (pooled) processes:
>
> 1. If each process is Poisson with parameter λ, the pooled process is Poisson with parameter $K\lambda$.
> 2. For arbitrary processes, if a large number is pooled, the output approaches a Poisson process.
> 3. As K becomes large, the time between renewals approaches an exponential distribution with parameter $K\lambda$... (18:356-357)

If each component of a population operates, fails, and is renewed; we have a population of independent renewal processes. If such a population were in the Air Force inventory, the Air Force would pool the outputs from these processes into a maintenance report. Khintchine's and Shooman's proofs show that this procedure would, in the limit, produce a Poisson process.

Summary

We have attempted to demonstrate in this chapter that there are two methods which produce a Poisson process. First, if a component has a constant failure rate, it can be described by the constant hazard model. This model is independent of time and number in the population. Second, if a component has an increasing or decreasing failure rate with time, the constant hazard model does not apply. However, the Poisson process still applies, at steady state, if the component is part of a pooled renewal process.

CHAPTER IV

MATHEMATICAL TOOLS

The Weibull Distribution

The Poisson and exponential distributions enjoyed wide acceptance in the 1950's due to their good results and appealing simplicity.

> A comprehensive analysis of failure distributions was done [in the early 1950's] at [the] RAND [Corporation] by D. J. Davis, who found that the exponential distribution. . . accurately described the failure characteristics of a wide variety of devices. As examples, he cited. . . commercial aircraft radio tubes, radar set components, tubes, resistors, . . . and combinations of various components. (9:209)

Many other investigators added items to the growing list. Yet, there were intuitive and theoretical arguments against the universal use of these distributions.

> The exponential law is reasonably appropriate where chance alone dictates failure occurrence. If it is known, for example, that failure is consistently due to deterioration, wear-out, degradation, fatigue, or any repetitive mechanism, almost certain nonexponentiality is implied. . . . To be truly random, failure cannot be due to design deficiencies or manufacturing errors. Being assignable as to cause, failure distributions associated with early life of a product usually are not exponential in that they are not random. (13:394)

We were cautioned--

> It is to be emphasized that considerable care is required in the selection of the appropriate underlying distribution for reliability testing. The validity of the test results depends to a large degree upon how well the selected probability distribution represents the actual distribution of the time to failure upon which observations are being made.... This point is emphasized because the widespread (perhaps indiscriminate) use of the exponential distribution as a model of failure patterns may lead one to believe that failure times in general may be adequately represented by such a distribution.... The use of other distributions introduced complications into the testing procedures; however, if one is to draw reasonable conclusions from the tests, he must be willing to face these other problems. (4:3-6)

Professor Weibull was willing to face the problems. He "... suggested it [the Weibull distribution] as the distribution for a variety of problems.... The agreement he found between his observations and those predicted with the fitted Weibull was very impressive...." (1:1)

The Weibull Mathematical functions are:

Weibull density function:

$$(13) \qquad f(t) = \frac{K}{\theta^k} (t-c)^{k-1} \text{ EXP} \left[- \left(\frac{t-c}{\theta} \right)^k \right], \; K > 0, \theta > 0, 0 < t \leq \infty.$$

Weibull cumulative function:

$$(14) \qquad F(t) = \int_0^t f(t)dt = 1 - \text{EXP} \left[- \left(\frac{t-c}{\theta} \right)^k \right], \; K > 0, \theta > 0, 0 < t \leq \infty.$$

Weibull reliability function:

$$(15) \qquad R(t) = \text{EXP} \left[- \left(\frac{t-c}{\theta} \right)^k \right], \; K > 0, \theta > 0, 0 < t \leq \infty.$$

Where C is the location parameter (for purposes of this research

$C = 0$ and time begins at the origin); K is the shape parameter; and, θ is the scale parameter.

> Since this distribution includes the... exponential as a special case, the Weibull is sometimes thought of as a generalization of the exponential distribution. Its use would then be considered by anyone who has been using the exponential distribution but felt a more flexible model was needed. Indeed, the popularity of the exponential distribution as the model for many experimenters in the fifties was challenged by the popularity of the Weibull in the sixties. (1:1ff)

The Weibull distribution, with its generality, has indeed given the model builder a powerful tool. By the appropriate choice of the parameter, K, we can change the distribution from the decreasing hazard model--a model sometimes used to show the "infant mortality" or break-in period, to the constant hazard exponential model, to the increasing hazard model--models characterized by the Rayleigh and normal distribution where a unit wears-out with time. By proper choice of the scaling factor θ, we can adjust the amplitude of the distribution much like we do when choosing the appropriate λ for the exponential. Therefore, by adjusting K and θ we may model a great number of hazard distributions. (18:190)

To properly define the failure rate characteristics of a system of equipment/components, it is necessary to describe the instantaneous failure rate function associated with the underlying failure generating distribution. This instantaneous failure rate function has been generally described by many authors as the hazard rate function, $Z(x)$, as follows:

(16) $$Z(x) = \frac{f(x)}{R(x)}$$ (10:2-5)

Where f(x) is the failure density function and R(x) is the reliability function.

The failure density function has been defined as:

(17) $$f(x) = Z(x)\ \mathrm{EXP}\left[-\int_0^t Z(x)dx\right]$$ (10:2-5)

Thus given an instantaneous failure rate function, we can easily obtain the failure density function by simple integration based upon the exponential law of growth or decay.

Many failure distributions can therefore be determined by integration of their characteristic instantaneous failure rate function. For example:

If: $$Z(t) = \frac{1}{\theta},\ \theta > 0$$

Then: $$f(t) = \frac{1}{\theta}\ \mathrm{EXP}\left[-\int_0^t \frac{1}{\theta}\ dx\right]$$

$$= \frac{1}{\theta}\ \mathrm{EXP}\left[-\frac{t}{\theta}\right]$$

which is the well known exponential function.

Other instantaneous failure rate functions may be integrated to obtain the required failure density functions in the same manner.

The instantaneous failure rate function used in this simulation is as follows:

(18) $Z(t) = \frac{K}{\theta^k} t^{k-1}, \theta > 0, K > 0, 0 < t \leq \infty.$

Then: $f(t) = Z(t) \text{ EXP} \left[- \int_0^t Z(t)dt \right]$

(19) $f(t) = \frac{K}{\theta^k} t^{k-1} \text{ EXP} \left[- \left(\frac{t}{\theta} \right)^k \right], \theta > 0, K > 0, 0 < t \leq \infty.$

This is one form of the Weibull function and it is interesting to note that the exponential distribution is a special case of the Weibull distribution when K = 1. Other authors have indicated that when K is approximately 3, the Weibull approximates the shape of the Normal distribution. (19:21) Other failure distribution shapes can be approximated by the Weibull model. Decreasing failure rate models have a $0 < K < 1$ and increasing failure rate models have a $K > 1$.

The parameter θ of the Weibull model determines the variance or dispersion of the model. The variance of the Weibull model is given as:

(20) Variance Weibull $= \theta^2 \left\{ \Gamma(1 + 2/k) - (\Gamma(1 + 1/k))^2 \right\}$

Thus by changing the θ value we can set the variance of the failure density function and in conjunction with the K value approximate many failure distributions.

Mathematics of the Model

Using equations 16, 17, and 18 of the previous section, we can derive the following mathematical tools used in this study.

Hazard function:

(21) $$Z(t) = \frac{K}{\theta^k} t^{k-1}, \quad K > 0, \theta > 0, \; 0 < t \leq \infty.$$

Failure density function:

(22) $$f(t) = Z(t) \; \mathrm{EXP}\left[-\int_0^t Z(t)dt\right]$$

$$= \frac{K}{\theta^k} t^{k-1} \; \mathrm{EXP}\left[-\left(\frac{t}{\theta}\right)^k\right], \quad K > 0, \theta > 0, \; 0 < t \leq \infty.$$

Cumulative density function:

(23) $$F(t) = \int_0^t f(t)dt, \quad 0 < t \leq \infty.$$

$$= 1 - \mathrm{EXP}\left[-(t/\theta)^k\right], \quad K > 0, \theta > 0, \; 0 < t \leq \infty.$$

Reliability function:

(24) $$R(t) = 1 - F(t)$$

$$= \mathrm{EXP}\left[-(t/\theta)^k\right], \quad K > 0, \theta > 0, \; 0 < t \leq \infty.$$

where K is the shape parameter and θ is the scale parameter. (15:94) From equation 3 and 22 we can then determine the expected value of the density function, MTTF, as follows:

$$\text{MTTF} = \int_0^\infty t\, f(t)dt$$

$$= \int_0^\infty t \left(\frac{K}{\theta^k}\, t^{k-1}\, \text{EXP}\left[-(t/\theta)^k \right] \right) dt$$

$$= \theta\, \Gamma(1 + 1/k),\ \theta > 0,\ K > 0$$

As shown earlier, this relationship yields the steady state failure rate for a pooled output of renewal processes, where each component's density function is described by a Weibull density function with parameters K and θ, and if the number of processes is large. Under such conditions, we can equate the MTTF of the individual components to the MTBF of the component population as follows:

(25) $\text{MTBF} = \theta\, \Gamma\, (1 + 1/k)$

We used equation 25 to compute our simulation model scale parameter, θ. When the shape parameters, $0.5 \leq K \leq 5.0$, were then chosen, we demonstrated that an appropriate choice of the scale parameter, θ, caused the pooled output of the renewal processes to approach the MTBF predicted by the constant hazard function of the exponential, i.e.,

$$\text{MTBF}_{exp} = \frac{1}{\text{Constant Failure Rate}}\ .$$

And therefore, at steady state, the MTTF for any individual component would equal the MTBF for the component population--a condition which

exists only in a Poisson process. (18:197)

Random Numbers

To generate random numbers to compute individual times to failure for components, we used the inverse transform method as follows: (20:511)

$$v = 1 - \mathrm{EXP}\left[-(t/\theta)^k\right]$$

$$\mathrm{EXP}\left[-(t/\theta)^k\right] = 1 - v = u$$

$$-(t/\theta)^k = \ln u$$

$$t^k = \theta^k(-\ln u)$$

$$t = \theta\,(-\ln u)^{1/k}$$

where v is a uniformly distributed pseudo-random number, $0 \leq v \leq 1$, and thus, $(1 - v) = u$ is also a uniformly distributed pseudo-random number, $0 \leq u \leq 1$.

Therefore, by this inverse transform procedure, we can generate a stream of values for t which follow the Weibull distribution.

CHAPTER V

PROCEDURES

The Computer Model

We developed a computer model for this investigation to simulate the renewal processes underlying a portion of the Air Force maintenance system.

The time frame of our model covers approximately four years. We selected a 30 day month as our reporting interval so that our 4 year period contained 48 monthly reporting points. We assumed a 4 hour daily utilization rate per component and, thus, each component in the inventory operated 120 hours each month. The required inputs for each simulation were the total fleet size, the introduction rate, and the desired shape parameter.

The computer model introduced a percentage of the total fleet into our inventory at the beginning of each month. As each unit entered, a service time was selected from a random Weibull distribution and then added to the present computer time to form the unit's future failure time. The model then stored the unit with its failure

time in a future events file. When the computer clock reached a scheduled failure time, the model removed the associated unit from the events file; recorded the failure; selected a new future failure time; and refiled the unit and time in the events file. Once started, this cycle continued independently for each unit in the inventory.

At the end of each computer month, the model stored the total number of failures which occurred in a memory array. We repeated each 4 year simulation 40 times for each set of input parameters. After the 40th run, the model calculated an average number of failures for each monthly period, and then divided this value by each month's operating time. The results were 48 average monthly failure rates. For a more detailed description of the simulation model see Appendix A.

Scope

General. --The research for this paper was limited to a literature search and digital computer simulation techniques. We have not attempted to evaluate our simulated data against actual failure data. However, we have attempted to select our model parameters so that they would present a reasonable approximation to actual conditions.

Fleet Size. --The total size of a fleet of aircraft may depend on many variables, e.g., planned mission, projected costs, actual cost, adaptability to alternate missions, world conditions, etc. Therefore, we set a range of fleet sizes, 20 to 1000 aircraft, and tested increments of this range in our preliminary simulations. Our preliminary

results indicated that the total number in the fleet had little effect on our prime performance variable, failure rate, as long as a constant percentage of that total were introduced each month. For this reason we chose a fleet size, 100 aircraft, that was well within the feasible range, and one that would simplify later extrapolation.

Introduction Rate. --As with fleet size, the introduction rate of a fleet of aircraft is subject to political and economic pressures and, therefore, highly variable. In addition, this rate is limited by the physical problems of "tooling up" for production. Therefore, we selected as an average figure the monthly introduction rate at 5%. We used percentage values, as stated before, to simplify extrapolation to actual introduction phases.

Average Operating Period. --The number of hours an aircraft flies each day again depends on the type of aircraft and the mission. However, when we are discussing components on an aircraft, the problem becomes more complex. A C-5A may use a system for the full mission, a B-52 may use the same type system only on take off and landing, and an F-106 may use the same system for special missions only. In our model, all component failures are a function of operating time; thus, all results are directly related to the utilization rate. For this reason we chose the "ball park" value of four hours per unit per day for our utilization rate.

Mean Time Between Failures. --We selected the values for this variable to cover a feasible range for Air Force repair or replacement

parts. We conjectured that a major system with less than 50 hours MTBF would be unacceptable for reliability reasons, and that a system with failure intervals greater than 2000 hours (nearly 17 months in our model) would cause few logistics problems. We then investigated the values of 50, 100, 500, 1000, and 2000 hours to cover our assumed range.

Shape Parameters.--We investigated the effects of this parameter through the values of 0.5, 1.0, 1.5, 2.0, 3.0, 4.0, and 5.0; and we conjecture that the properties of our performance variable, failure rate, are continuous within this range. These values take us from a rapidly decreasing failure rate (infant mortality phase) through a constant failure rate (random failures) to a rapidly increasing failure rate (wear-out phase).

Scale Parameters.--The scale parameter, θ, was determined as previously indicated from equation 25. Equation 25 allowed us to transform the MTBF desired or indicated to an appropriate scale parameter of our simulation model. Thus, we were able to track the experienced failure rates through the transition period until the component population steady state failure rate was achieved.

CHAPTER VI

SIMULATION RESULTS

General

The simulation results have been divided into decreasing hazard rate, constant hazard rate and increasing hazard rate categories to more easily discuss and analyze the simulation output. The discussion and analysis will be based upon frequency plots of the output data. The actual tabulated output data is included in Appendix B for readers wishing to perform a more extensive analysis than presented in this study.

As indicated earlier, our objective is to investigate the distribution of failures per hour during the transition period from initial acquisition of weapons systems to the attainment of steady state; and we want to compare such failure rates to the constant failure rate predictions presently in use by the Air Force. (5) Thus, our main interest is the magnitude of the difference between the simulation results and the Air Force prediction methods.

Definitions

The analysis has been performed in terms of the average absolute deviation between the present prediction methods and the simulation results prior to the achievement of the system steady state condition. For purposes of analysis, system steady state is "broadly" defined as relatively minor absolute deviations of the simulation results from the current predicted constant failure rate.

The following definitions are necessary to the analysis.

Constant Hazard Rate (CHR)--the constant failure rate predicted by present Air Force methods

$$\text{CHR} = \frac{1}{\text{MTBF}} .$$

Constant Failure Rate--the condition of the Weibull failure generating function where the shape parameter, K, is equal to 1.

Decreasing Failure Rate--the condition of the Weibull failure generating function where the shape parameter, K, is $0 < K < 1$.

Increasing Failure Rate--the condition of the Weibull failure generating function where the shape parameter, K, is greater than 1.

Mean Time Between Failure (MTBF)--the time between failures predicted by the present Air Force method

$$\text{MTBF} = \frac{1}{\text{Constant Failure Rate}} .$$

Period Failure Rate (PFR)--the monthly simulation produced failure rate.

Per Cent Average Absolute Deviation (AD)--the per cent of

average absolute deviation between the simulation results and the CHR computed as follows:

$$AD = \frac{\sum_{i=1}^{48} |PFR_i - CHR|}{48\ (CHR)} \times 100\% .$$

Per Cent Maximum Absolute Deviation (MD)--the per cent of maximum absolute deviation between the simulation results and the CHR computed as follows:

$$MD = \frac{MAX\,|PFR_i - CHR|}{CHR} \times 100\%,\ i = 1, 2, 3, \ldots, 48.$$

Per Cent In Range (IR)--the number of individual PFR's within the range CHR $\pm$ AD computed as follows:

$$IR = \frac{\sum_{i=1}^{48} Oi}{48} \times 100\%$$

where:

$$Oi = \begin{cases} 1, & \text{when } (CHR - AD) \leq PFR_i \leq (CHR + AD) \\ 0, & \text{otherwise} \end{cases}$$

The Decreasing Failure Rate Case

The Decreasing Failure Rate Case is defined as the condition where the hazard function of the components is inversely related to time, i.e., the function decreases over time. In this case, the simulation program assigned to each component of the population such a

decreasing failure rate, and we were interested in observing what effect such a failure rate would have on the total population failure rate.

Figures 6, 7, and 8 of Appendix B are plots of the system failure rates produced by the simulation program. (The simulation output may be found in Appendix B of this study.) The plots of the system failure rates indicate relatively large failure rates during the initial months of introduction. However, these large failure rates rapidly reduced in magnitude in a relatively short period of time. The rate of change of the system failure rate is negative and decreases at a decreasing rate eventually approaching the CHR asymptotically from above.

Each plot indicates that deviations from the CHR may be 10% or higher for the first 24-28 months of operation. Such deviations appear to be directly related to the size of the MTBF as can be seen from the plots. Figure 6 indicates that with a MTBF of 500 hours, the system of components enters steady state (our broad definition) in approximately 36 months. However Figures7 and 8 with MTBF's of 1000 hours and 2000 hours are not to be considered in steady state throughout the entire simulation period of 48 months.

The simulation results indicate that components of a given population characterized by a decreasing hazard function affect the population failure rate distribution. Much higher population rates than predicted by the present Air Force methods should be experienced

during the initial months of the transition period to steady state. It appears that the population failure rate will eventually achieve steady state conditions, however, the transition period may be quite lengthy, and for large MTBF's may not actually be attainable. Table 1 indicates the simulated maximum % deviations (MD) and the average % deviations (AD) from such a CHR prediction method.

TABLE 1

THE DECREASING FAILURE RATE CASE

MTBF	Shape Parameter	MD	AD	% OBS. (1/MTBF) (1±AD)
500	.5	272.9%	36.57%	68.75%
1000	.5	412.5%	59.89%	60.41%
2000	.5	591.6%	95.58%	62.50%

Under such conditions, the Air Force planners may decide to approximate the expected failure rate by averaging several period failure rates. However, since the population failure rate distribution is continuously decreasing, such a procedure would result in the acquisition of replacement/spare parts in quantities larger than actually necessary. If the MTBF supplied by the contractor is used as the basis for logistical support planning, the simulation results indicate that fewer items would be planned for than would actually be required.

The Constant Failure Rate Case

The Constant Failure Rate Case is defined as the condition where the hazard rate function of the components is a constant over time. The simulation program assigned to each component of the population such a failure rate. Again, the effect of such a component characteristic on the total population failure rate is our main interest.

Figures 9, 10, 11, 12, and 13 of Appendix B are plots of the system failure rates produced by the simulation program. All plots indicate that the system failure rates immediately tend to oscillate around the CHR predicted by the present Air Force method. A transition period does not appear to be present and according to our "broad" definition of steady state, we conjecture the system of components to be immediately in steady state. The oscillations around the predicted CHR tend to increase proportionally with increases in the MTBF used. Table 2 indicates the simulated maximum % deviations (MD) and the average % deviations (AD) from the CHR.

TABLE 2

THE CONSTANT FAILURE RATE CASE

MTBF	Shape Parameter	MD	AD	% OBS (1/MTBF) (1±AD)
50	1.0	8.33%	1.78%	56.25%
100	1.0	10.83%	2.06%	62.50%
500	1.0	10.95%	3.14%	64.58%
1000	1.0	17.40%	4.79%	58.33%
2000	1.0	20.80%	5.48%	60.41%

Under such conditions it appears that the present Air Force procedures for predicting expected failures for new weapons systems would produce "satisfactory" results since the system would immediately be in a steady state condition.

The Increasing Failure Rate Case

The Increasing Failure Rate Case is defined as the condition where the hazard function of the components is directly proportional to time, i.e., the function increases over time. As with the other cases, we are still interested in the effect such component failure rates have upon the population failure rate. We conjecture that component failures which possess this characteristic are more representative of the real world situation than either the decreasing or constant failure rate cases. Intuitively, it is more reasonable to expect larger probabilities of failure as items age than either constant or decreasing probabilities of failure with increasing age.

Figures 14 through 36 of Appendix B are plots of the simulation results for varying MTBF's and shape parameters for this case. (The simulation data may be found in Appendix B of this study.) The plots of the simulated failure rates have been categorized into groups on the basis of MTBF's and will be discussed in this order.

MTBF = 50.--For shape parameters, $2 \leq k \leq 5$, the plots indicate a minimum of 5% deviation between the predicted failure rate and the simulation results for the first few months during transition to

steady state. The magnitude of these deviations appears to increase with increases in the shape parameter. Such a condition is to be expected with the Weibull distribution, since shape parameters less than, or greater than approximately 3 generate skewed distributions, right and left respectively, with a symetrical distribution occurring when the shape parameter equals 3. The length of the transition period appears to be in the 16-24 month range for MTBF's of 50, and the variation around the predicted CHR during steady state is small. The rate of change in the population failure rate distribution is positive and approaches the predicted CHR asymptotically from below. See Figures 14 through 17, Appendix B.

MTBF = 100.--Again the same general observations can be made of these plots. The rate of change of the failure rate is positive, increasing at a decreasing rate and approaching the predicted CHR asymptotically from below. The system failure rate appears to achieve steady state in about 20 months. The simulated results deviate from the predicted CHR by at least 10% during the first few months of the transition period. The maximum deviation of the simulated failure rate from the predicted CHR is approximately 31% during the first month. See Figures 18 through 21, Appendix B.

MTBF = 500. --The same general observations made above are again observed. However, the maximum deviation of the simulated failure rates from the predicted CHR has increased considerably. For shape parameters of 4 and 5 the maximum deviation is 100%. The

system appears to achieve steady state in approximately 24-28 months. The rate of change in the failure rate also appears to have decreased with increasing scale parameters. See Figures 22 through 26, Appendix B.

MTBF = 1000. The same general observations made above also apply here. Steady state appears to be achieved in approximately 24-28 months, however, the relative deviations around the predicted CHR at steady state has increased. The rate of change of the failure rate has again decreased. See Figures 27 through 31, Appendix B.

MTBF = 2000. The same general observations are applicable to this group also. There is a marked difference in the rate of change of the system failure rate. Steady state appears to be reached in the 26-28 month period. The relative fluctuations in the failure rate have also increased markedly. During the first 12 months, the minimum deviation between the simulation results and the predicted CHR is at least 40%. See Figures 32 through 36, Appendix B.

In all of the plots, there appears to be a change to the shape of the failure distribution during the transition period resulting from increasing MTBF's. The relative fluctuation of simulated failure rates also appears to increase as the MTBF is increased. All the failure distributions approach the predicted CHR asymptotically from below. Tables 3 and 4 summarize the results of the simulation for the parameters and ranges tested. Table 3 indicates that for increases in MTBF for a given shape parameter, the MD and AD (as defined before)

TABLE 3

INCREASING FAILURE RATE CONDITION WITH CONSTANT SHAPE

MTBF	Shape Parameter	MD	AD	% OBS (1/MTBF) (1±AD)
50	2.0	12.71%	1.43%	77.08%
100	2.0	25.42%	2.73%	75.00%
500	2.0	77.10%	10.63%	70.80%
1000	2.0	85.40%	18.35%	60.41%
2000	2.0	100.00%	28.74%	60.41%
50	3.0	15.83%	1.54%	79.16%
100	3.0	31.67%	2.94%	79.16%
500	3.0	93.75%	13.96%	72.91%
1000	3.0	100.00%	21.71%	62.50%
2000	3.0	100.00%	34.46%	62.50%
50	4.0	16.66%	1.56%	75.00%
100	4.0	31.67%	2.94%	72.91%
500	4.0	100.00%	14.47%	70.83%
1000	4.0	100.00%	23.09%	64.58%
2000	4.0	100.00%	36.44%	62.50%
50	5.0	17.5%	1.58%	77.08%
100	5.0	30.00%	2.99%	72.91%
500	5.0	100.00%	14.51%	72.91%
1000	5.0	100.00%	24.06%	64.58%
2000	5.0	100.00%	37.70%	62.50%

have increased. Table 4 indicates that for increases in the shape parameter for a given MTBF that the MD and AD have increased. Thus for large MTBF's or large shape parameters, we can expect larger deviations from the predicted CHR.

TABLE 4

INCREASING FAILURE RATE CASE WITH CONSTANT MTBF

MTBF	Shape Parameter	MD	AD	% OBS (1/MTBF) (1±AD)
50	2.0	12.71%	1.43%	77.08%
50	3.0	15.83%	1.54%	79.16%
50	4.0	16.66%	1.56%	75.00%
50	5.0	17.50%	1.58%	77.08%
100	2.0	25.42%	2.74%	75.00%
100	3.0	31.67%	2.95%	79.16%
100	4.0	31.67%	2.94%	72.91%
100	5.0	30.00%	2.99%	72.91%
500	2.0	77.10%	10.63%	70.80%
500	3.0	93.75%	13.96%	72.91%
500	4.0	100.00%	14.47%	70.83%
500	5.0	100.00%	14.51%	72.91%
1000	2.0	85.40%	18.35%	60.41%
1000	3.0	100.00%	21.71%	62.50%
1000	4.0	100.00%	23.09%	64.58%
1000	5.0	100.00%	24.06%	64.58%
2000	2.0	100.00%	28.74%	60.41%
2000	3.0	100.00%	34.46%	62.50%
2000	4.0	100.00%	36.44%	62.50%
2000	5.0	100.00%	37.70%	62.50%

Standardized Table for Steady State

The following is the development of a standard table, Table 5, and curve, Graph 1, which was used to estimate the required MTTF or scale parameter, θ, of the failure generating function for this simulation. Once the shape and scale parameters have been estimated for a given equipment/component failure distribution, then the MTTF can be estimated by using the table. For example

The time to failure P.D.F. is:

$$f(t) = \frac{K}{\theta^k} t^{k-1} e^{-\left(\frac{t}{\theta}\right)^k}, \quad K > 0, \theta > 0, 0 < t \leq \infty .$$

$$E(t) = MTTF = \int_0^\infty t\, f(t)\, dt$$

$$= \int_0^\infty t \left\{ \frac{K}{\theta^k} t^{k-1} e^{-\left(\frac{t}{\theta}\right)^k} \right\} dt$$

$$= \theta \cdot \Gamma (1 + 1/K)$$

$$\text{Mean Failures Per Hr} = \frac{1}{E(t)} = \frac{1}{\theta \cdot \Gamma(1+1/K)} = \frac{1}{MTTF}$$

From the above, given the MFPH and K, the scale parameter can be estimated from:

$$\theta = \frac{1}{MFPH \cdot \Gamma(1+1/K)} = \frac{MTTF}{\Gamma(1+1/K)}$$

Thus, by estimating the shape parameter, K, and determining one of the other two parameters θ or MFPH, we can derive an estimate for the remaining variable when the failure distribution is of the Weibull form:

$$f(t) = \frac{K}{\theta^k} t^{k-1} e^{-\left(\frac{t}{\theta}\right)^k}$$

The table is constructed with $\theta = 1$ and the K parameter is varied from 0 to 10 in increments of .25. All that is necessary to determine the MFPH or θ value is to obtain the tabulated mean value,

TABLE 5

STANDARDIZED TABLE TO DETERMINE THE STEADY STATE MFPH OF COMPONENTS WHICH HAVE A WEIBULL TIME TO FAILURE DISTRIBUTION

STANDARDIZED TABLE	
SHAPE	EXPECTED MEAN
0.250	0.04166667
0.500	0.50000000
0.750	0.83988503
1.000	1.00000000
1.250	1.07367142
1.500	1.10773224
1.750	1.12281597
2.000	1.12837909
2.250	1.12901184
2.500	1.12706082
2.750	1.12377663
3.000	1.11984669
3.250	1.11565629
3.500	1.11142324
3.750	1.10726975
4.000	1.10326244
4.250	1.09943514
4.500	1.09580223
4.750	1.09236656
5.000	1.08912425
5.250	1.08606765
5.500	1.08318715
5.750	1.08047223
6.000	1.07791221
6.250	1.07549660
6.500	1.07321534
6.750	1.07105894
7.000	1.06901857
7.250	1.06708595
7.500	1.06525347
7.750	1.06351410
8.000	1.06186141
8.250	1.06028937
8.500	1.05879261
8.750	1.05736604
9.000	1.05600511
9.250	1.05470550
9.500	1.05346334

TABLE 5 (Continued)

SHAPE	EXPECTED MEAN
9.750	1.05227505
10.000	1.05113725

given the estimated K parameter and then divide the value by the predetermined scale parameter, or MFPH respectively.

Examples:

(1) Given K = 3.5

and, $\theta = 950.$

Obtaining from the table, MEAN = 1.11142324

the MFPH = $\frac{\text{MEAN}}{950}$ = .0011699

(2) Given K = 2

and, MTTF = 1500

or, MFPH = $(1500)^{-1}$

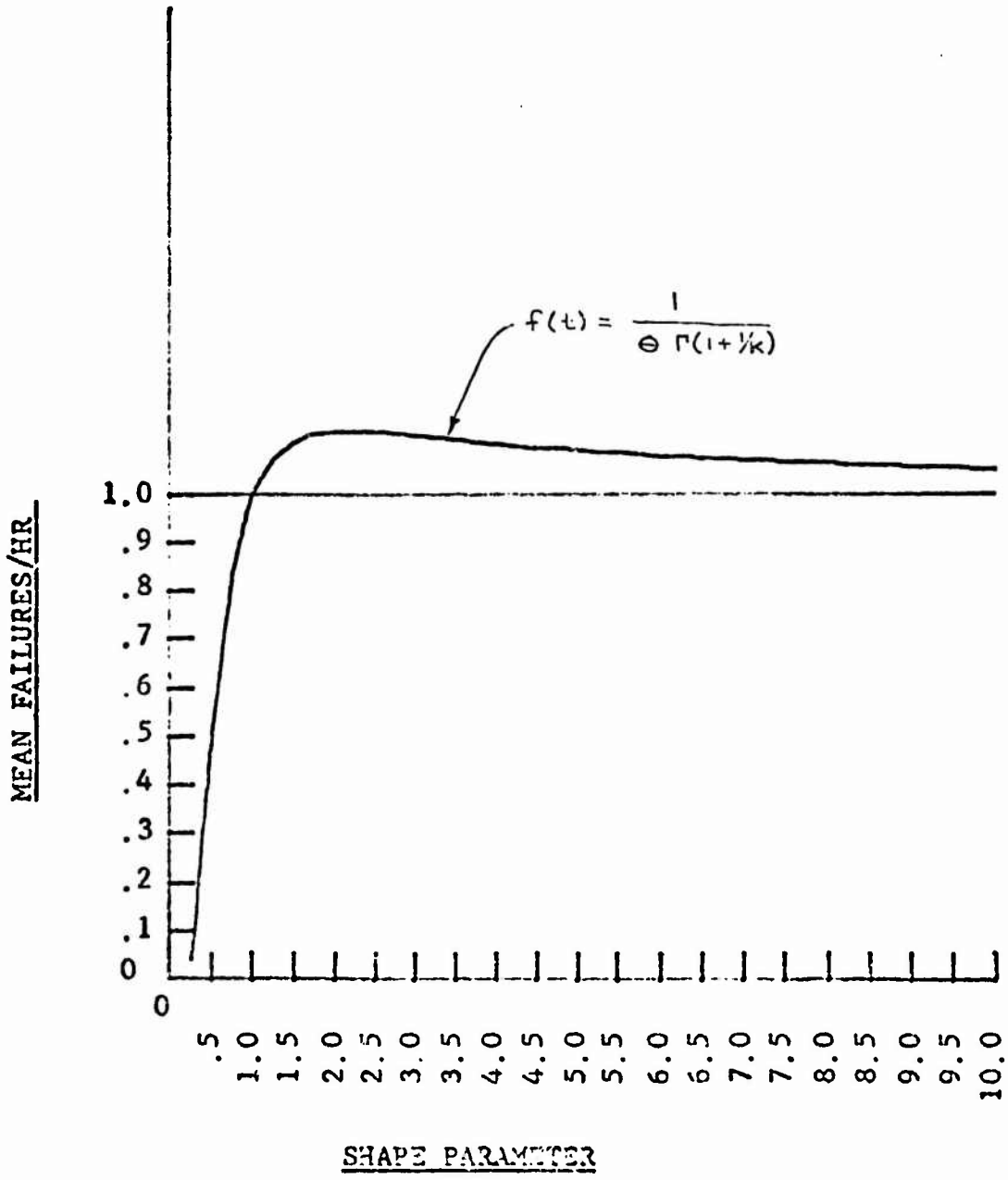
Obtaining from the table, MEAN = 1.12837909

$$\theta = \frac{\text{MEAN}}{(1500)^{-1}} = 1692.5685$$

In the case of the constant failure rate, the shape parameter, k, for the Weibull cumulative density function is 1 and the scale parameter, θ, is directly proportional to the MTBF as follows:

$$\text{MTTF} = \int_0^\infty t\, f(t)\, dt$$

$$= \int_0^\infty t\, \frac{K}{\theta^k}\, t^{k-1}\, e^{-\left(\frac{t}{\theta}\right)^k} dt, \quad K>0, \theta>0$$



GRAPH 1

STANDARD CURVE FOR MFPH

$= \theta\Gamma\ (1 + 1/K)$

With K = 1, MTTF becomes:

$MTTF = \theta\Gamma\ (1 + 1/1)$

or

$MTTF = \theta\Gamma(2)$

But $\Gamma(2)$ is equal to 1, therefore

$MTTF = \theta \cdot 1 = \theta$

and,

$$MFPH = \frac{1}{MTBF} = \frac{1}{\theta}$$

Thus, when the underlying failure distribution follows the exponential distribution, we can equate the scale parameter to the reciprocal of the MFPH, or equate the scale parameter directly to the MTTF. Under these conditions, we can predict the steady state MFPH by computing the reciprocal of the MTTF or of θ.

Summary

Of the three cases investigated, only the constant failure rate case appeared to be in steady state immediately. The decreasing (DFR) and increasing (IFR) failure rate cases result in significant deviations from the failure rates predicted by the present Air Force methods which may lead to supply difficulties in supporting weapons systems during the transition period.

The transition period prior to the attainment of steady state

conditions for the DFR and IFR exceeds 12 months for the MTBF's and parameters tested and may actually be longer than 24 months for large MTBF's. Systems in transition tend to approach steady state more rapidly for lower MTBF values, and the random relative fluctuations appear to be less erratic than those for larger MTBF values.

The plots of the system failure rates indicate that upon attainment of steady state, the expected future failure rates for the system can be approximated or predicted by the present Air Force methods quite satisfactorily. In the limit, the population failure distributions appear to exhibit the random oscillations around the steady state failure rate characteristic of the constant failure rate case.

CHAPTER VII

CONCLUSION

Our original hypothesis that the fleetwide distributions of failures for any replaceable equipment/component is at all times a Poisson process and that the assumption of a constant failure rate is always valid in the estimation of future expected failures is not supported by the simulation results and we reject the hypothesis.

The simulation results using the Weibull failure generating function as the underlying failure distribution for the population of equipments/components indicate that a deviation between the simulated failures and those failures predicted by a Poisson process is to be expected when aircraft components are introduced incrementally into the Air Force inventory. The transition period between the initial level of failures and the steady state level of failures is related to the MTTF of the introduced components and the characteristic shape parameter of the underlying failure distribution.

Since the shape parameter of the Weibull failure distribution determines the general "shape" of the distribution, we can approximate

the exponential distribution and the normal distributions which are the basic statistical forms assumed to describe the failure characteristics of components. As the shape parameter is increased above the value 1, the Weibull tends to approach a normal distribution. The larger the K parameter becomes the smaller the deviation from the predicted failure rate becomes, until in the limit, i.e., $K \to \infty$, the distribution has no deviation and the failures, MFPH, can be approximated by $\frac{1}{MTTF}$. This can be seen from the following:

$$MFPH = \frac{1}{MTTF} = \frac{1}{\theta \Gamma (1 + 1/k)}$$

$$\lim_{K \to \infty} \Gamma (1 + 1/K) = \Gamma (1) = 1$$

therefore,

$$\lim_{K \to \infty} MFPH = \lim_{K \to \infty} \frac{1}{\theta \Gamma (1 + 1/K)} = \frac{1}{\theta} = \frac{1}{MTTF}$$

As can be seen from the Standardized Table (Table 5) and graph (Graph 1) the maximum average deviation from the predicted exponential MFPH is the range $2. \leq K \leq 2.25$. The maximum deviation occurs at approximately $K = 2.17$. Such a K value is quite possible in actual experience with equipment/component failure rates, since such a K value places the underlying failure distribution "between" the exponential, i.e., $K = 1$, and an approximation to the shape of the normal distribution, i.e., $K = 3$. Thus, when the Air Force acquires equipments/components incrementally and the actual underlying failure distribution is of the increasing failure rate type, we should not be surprised to

observe increasing failure rates during the transition period to steady state.

When we have equipments/components which are characterized by decreasing failure rates, the Weibull failure generating function has a shape parameter $0 < K < 1$. Such a case has been explored in this simulation and the results have been indicated in the Analysis Section of this report as the Decreasing Failure Rate Case. Simulation results indicate that a shape parameter value of .5 causes the experienced failure rate to approach the predicted failure rate asymptotically from above. The deviation from the predicted failure rate and the simulated failure rate increasing directly with the MTBF. In such a situation, we should expect to see larger initial failure rates which decrease throughout the introduction period and eventually settling down when steady state is reached.

In the case of constant failure rates, i.e., a shape parameter $K = 1$, the simulation results indicate that failures will be randomly distributed about the predicted failure rate increasing in absolute deviation from the predicted failure rate as the MTBF increases. We should not be surprised nor concerned with apparent increases or decreases in the number of failures observed when the components have an underlying exponential failure distribution, since such deviations from the expected or predicted failure rate are due to random fluctuations.

The simulation results also indicate that after steady state has

been attained for a system of equipments/components the observed distribution of failures resembles the random fluctuations of the constant failure rate case. This is the result proved by Khintchine as previously indicated in Chapter III. Thus, it appears that upon the attainment of steady state, the expected failures can be estimated by assuming a Poisson process, regardless of the underlying failure generating distribution; and, in steady state the MTBF should equal the MTTF.

APPENDIX A

COMPUTER SIMULATION PROGRAM

The program developed for this research is shown in Figure 4 and a simplified logic chart is shown in Figure 5. This program is a FORTRAN language program using the GASP2B simulation package developed by A. Alan B. Pritsker and Philip J. Kiviat. (16) The use of GASP2B simulation package greatly simplifies the programming required to be written for this study.

Basically the program is composed of a Main Program and six Subroutines as shown in Figure 4. The Main Program is used to initialize non-GASP variables and to call the GASP2B program package. When the GASP package is called, the internal GASP executive routines control all further simulation events until simulation termination is reached.

The GASP executive routines call Subroutine EVNTS which in turn selects the appropriate INTRO, FAILR, REPORT, or ENDSM subroutines based upon the currently processed event.

The INTRO subroutine is primarily used to introduce the

Preceding page blank

aircraft into the inventory incrementally until the total fleet size has been attained. Each unit introduced incrementally to the system is assigned a time to failure (service time) and internally filed in a future events file.

The FAILR subroutine is called by the GASP routine whenever a failure event occurs. To simulate the instantaneous repair/replacement of failed components, this subroutine immediately computes a new time to failure and then refiles this new time to failure in the future events file. Statistics are collected on the service time of each failure.

The REPORT subroutine schedules the next monthly reporting, and records the total period failures and service times which have been experienced. A check is made against the total simulation time for each run and the simulation run is terminated if required.

The ENDSM subroutine sets specific GASP variables for the termination of the current simulation run. A check is made to determine if the total number of simulation runs has been completed and the OUTPUT subroutine is called as required.

The OUTPUT subroutine has been written to provide the total simulation output when the total number of simulation runs has been completed. In this research, a simulation run is approximately 4 years long and each simulation run is performed 40 times. The OUTPUT subroutine then takes an average of all statistics collected over the 40 runs before the output is printed. In this manner, we minimize the effect of extreme values in our output data. The printed output format and data are shown in the simulation output in Appendix B.

```
C MAIN PROGRAM HANDLE WITHOUT SIMULATION
 DIMENSION JSLI(10,120)
C  ***********DIMENSION AND COMMON CARDS FOR GASP2B*************
 COMMON SLIB
 DOUBLE PRECISION SLIB
 COMMON IO,IO,INTI,JEVNT,JMNTI,NCA,NSTOP,NX,NXC,NCLCT,NHIST,NOQ,
XNORPT,IOT,IPRNS,NRUN,NRUNS,NSTAT,OUT,SCALE,ISEED,TNOW,TBEG,TFIN,
XOXX,SPRCT,DEF,SPPRJ,HOM,NDAY,NYR,JCLK
 COMMON ATRIB(10),TNO(20),TNN(20),JCELS(10,22),KRANK(20),MAXNQ(20),
XMFL(20),NLS(20),NLI(20),NCELS(10),NQ(20),PARAM(20,4),OTIME(20),
XSSOLA(26,5),SUMA(20,5),NAME(6),VNQ(20),FAIL(48),CTIME(48),FPH(48)
 COMMON FPH2(48)
 COMMON XNFIRIT,XINRATE,XNINTRD,THEDA,AK,KPIPERD,SIMTIME,L,ANTOTAL
X,ALASTPD
 I=1.0
 ANTOTAL=0.0
 ALASTPD=0.0
 DO 1 I=1,48
 FAIL(I)=0.0
 FPH2(I)=0.0
 CTIME(I)=0.0
1 FPH(I)=0.0
 CALL GASP2B(NSET)
 STOP
 END
```

Figure 4. --Computer Program

```
10-11-75    16.825    SUBROUTINE EVENTS HAMRIC WEIBULL ***

C **** SUBROUTINE EVENTS HAMRIC WEIBULL ***
 SUBROUTINE EVNTS(IK,NSET)
 DIMENSION ISET(10,1)
C  ****DIMENSION AND COMMON CARDS FOR GASP20************
 COMMON SET
 DOUBLE PRECISION SETD
 COMMON IB,IN,IOUT,JEVNT,JMNIT,MFA,MSTOP,MX,MXC,NCLCT,NHIST,NOQ,
&NORPT,NPT,NPRMS,NRUN,NRUNS,NSTAT,OUT,SCALE,ISEED,TNOW,TBEG,TFIN,
&MXX,NPRNT,NCP,NPROJ,MON,NDAY,NYR,JCLR
 COMMON ATRIB(10),ENQ(20),TNN(20),JCELS(10,22),KRANK(20),MAXNQ(20),
&MFL(20),MLC(20),MLE(20),NCELS(10),NQ(20),PARAM(20,4),DTIME(20),
&SSUM(20,5),SUMA(20,5),NAME(6),VNQ(20),FAIL(48),CTIME(48),FPH(48)
 COMMON FPH2(48)
 COMMON XNFIFET,XINRATE,XNINTRO,THEDA,AK,RPIPERD,SIMTIME,..,ANTOTAL
&,ALASTPD
 GO TO(1,2,3,4),IX
 1 CALL INTRO(NSET)
 RETURN
 2 CALL FAILR(NSET)
 RETURN
 3 CALL REPORT(NSET)
 RETURN
 4 CALL FNDSH(NSET)
 RETURN
 END
```

Figure 4 continued

```
C ***** SUBROUTINE INITRO-HAMRIC WEIBULL **
      SUBROUTINE INITRO(NSET)
      DIMENSION NSET(10,1)
C     *****DIMENSION AND COMMON CARDS FOR GASP2D************
      COMMON SEED
      DOUBLE PRECISION SEED
      COMMON IP,IB,IFIL,JEVNT,JANIT,MFA,NSTOP,MX,MXC,NCLCT,NHIST,NOQ,
&NSTPRT,NOT,NPRMS,NRUN,NRUNS,NSTAT,OUT,SCALE,ISEED,TNOW,TBEG,TFIN,
&NX,NPRNT,NTP,NPROJ,NDN,NDAY,NYR,JCLK
      COMMON ATRIB(10),TNN(20),TNN(20),JCELS(10,22),KRANK(20),MAXNQ(20),
&NNT(20),NLE(20),NCL(20),NCELS(10),NQ(20),PARAM(20,4),UTIME(20),
&SSUMA(20,5),SUMA(20,5),NAME(6),VNQ(20),FAIL(48),CTIME(48),FPH(48)
      COMMON TPH2(48)
      COMMON XNFLFLT,XINRATE,XNINTRO,THEDA,AK,RPIPERD,SIMTIME,I,ANTOTAL
&,ALASTPD
      XNFLFLT=PARAM(1,1)
      XINRATE=PARAM(1,2)
      XNINTRO=PARAM(1,3)
      RPIPERD=PARAM(1,4)
      THEDA=PARAM(2,1)
      AK=PARAM(2,2)
      SIMTIME=PARAM(2,3)
      CALL INST(ANTOTAL,INOW,1,NSET)
      ANTOTAL=ANTOTAL+XNINTRO
      IF(XNFLFLT-ANTOTAL)1,1,2
    2 ATRIB(1)=TNOW+XINRATE
      ATRIB(2)=1.0
      CALL FILEM(1,NSET)
    1 NTRO=XNINTRO
      DO 10 I=1,NTRO
      Y=1.0/AK
      ATRIB(1)= INOW +(THEDA*(EXP(Y*ALOG(-ALOG(DRAND(SEED))))))
      ATRIB(2)=2.0
      CALL FILEM(1,NSET)
      SERVIN= ATRIB(1)-TNOW
   10 CALL HISTO(SERVIN,100.0,100.0,1)
      RETURN
      END
```

Figure 4 continued

```
C ****SUBROUTINE FAILURE HANDIC WEIBULL**
 SUBROUTINE FAIR(NSFI)
 DIMENSION NSFI(10,1)
C   ****DIMENSION AND COMMON CARDS FOR GASP2B************
 COMMON SEED
 DOUBLE PRECISION SEED
 COMMON IO,IN,IBUF,JEVNT,IHMIT,NFA,MSIDP,MX,MXC,NCLCT,NHIST,NOQ,
&NORPT,IDT,NPKCS,NRUN,NRUNS,NSTAT,OUT,SCALE,ISEED,TNOW,TBEG,TFIN,
&MXX,NPRNT,TFP,NPROJ,MON,MDAY,NYR,JCLR
 COMMON AIRIB(10),FRQ(20),IWN(20),JCELS(10,22),KRANK(20),MAXNQ(20),
&MFI(20),MLC(20),MLI(20),NCELS(10),NQ(20),PARAM(20,4),QTIME(20),
&SSUMA(20,5),SUMA(20,5),NAME(6),VNQ(20),FAIL(48),CTIME(48),FPH(48)
 COMMON FPH2(48)
 COMMON XNFIRST,XINRATE,XNINTRO,THEDA,AK,RPTPERD,SIMTIME,L,ANTOTAL
&,ALASTPD
 Y=1.0/AK
 AIRIB(1)=TNOW+(THEDA*(EXP(Y*ALOG(-ALOG(DRAND(SEED))))))
 AIRIB(2)=2.0
 CALL FILEM(1,NSFI)
 SERVTM=AIRIB(1)-TNOW
 CALL HISTO(SERVTM,100.0,100.0,1)
 CALL COLCT(1.0,1,NSFI)
 RETURN
 END
```

Figure 4 continued

```
C ****SUBROUTINE REPORT HAMRIC WEIBULL **
 SUBROUTINE REPORT(NSET)
 DIMENSION NSET(10,1)
C   *****DIMENSION AND COMMON CARDS FOR GASP2B************
 COMMON SEED
 DOUBLE PRECISION SEED
 COMMON IB,IM,INIT,JEVNT,JMNIT,NFA,MSTOP,MX,MXC,NCLCT,NHIST,NOO,
&NORPT,NOT,NPRMS,NRUN,NRUNS,NSTAT,NUT,SCALE,ISEED,TNOW,TBEG,TFIN,
&XXX,LPRNT,NEP,NPROG,MON,NDAY,NYR,JCLR
 COMMON ATRIB(10),TNU(20),TNN(20),JCELS(10,22),KRANK(20),MAXNQ(20),
&NFE(20),NC(20),NLL(20),NCELS(10),NO(20),PARAM(20,4),QTIME(20),
&SSUMA(20,5),SUMA(20,5),NAME(6),VNQ(20),TAIL(40),CTIME(40),FPH(40)
 COMMON FPH2(40)
 COMMON XNFTFIT,XINRATE,XNINTRO,THETA,AK,RPIPERD,SIMTIME,L,ANTOTAL
&,ALASTPD
 ATRIB(1)=TNOW + RPIPERD
 ATRIB(2)=3.0
 CALL FILEM (1,NSET)
 CALL TEST(ANTOTAL,TNOW,1,NSET)
 CTIME(L)=CTIME(L)+ (SSUMA(1,2)-ALASTPD)
 FPH(L)=FPH(L)+(SUMA(1,1)/(SSUMA(1,2)-ALASTPD))
 FPH2(L)=FPH2(L)+(FPH(L)**2)
 TAIL(L)=TAIL(L)+SUMA(1,1)
 ALASTPD=SSUMA(1,2)
 L=L+1.
 DO 1 J=1,5
 1 SUMA(1,J)=0
 IF(SIMTIME.GE.L) GO TO 2
 ATRIB(1)=TNOW
 ATRIB(2)=4.0
 CALL FILEM(1,NSET)
 2 RETURN
 END
```

Figure 4 continued

```
C **** SUBROUTINE FOR DF SIM HAMRIC WEIBULL **
 SUBROUTINE FNDSM(NSFI)
 DIMENSION NSFI(19,1)
C  ****DIMENSION AND COMMON CARDS FOR GASP2B************
 COMMON SELO
 DOUBLE PRECISION SELO
 COMMON IB,IC,INFI,JEVNT,JMNIT,MFA,MSTOP,MX,NXC,NCLCT,NHIST,NOQ,
&NOPRT,NOT,NPRNS,NRUN,NRUNS,NSTAT,OUT,SCALE,ISEED,TNOW,TBEG,TFIN,
&MXX,TPRNT,HEP,GPROD,MON,NDAY,NYR,JCLR
 COMMON ATRIB(10),TNH(20),INH(20),JCELS(10,22),KRANK(20),MAXNQ(20),
&NFI(20),NLP(20),NFI(20),NCELS(10),NQ(20),PARAM(20,4),DTIME(20),
&SSUM(20,5),SUMA(20,5),NAME(6),VNQ(20),TAIL(40),CTIME(48),FPH(48)
 COMMON TPH,(48)
 COMMON XNEXELT,XINRATE,XNTOTRD,THEDA,AK,RPTPERD,SINTIME,L,ANTOTAL
&,ZLASTPB
 NSTOP=-1
 IF(NEVN.-40)1,2,2
 1 NOKPI=1
 L=1.0
 ANTOTAL=0.0
 ALASTPB = 0.0
 RETURN
 2 NOKPI=0
 RETURN
 END
```

Figure 4 continued

```
      SUBROUTINE DIPDI(NSET)
      DIMENSION ISET(10,1)
C     ****DIMENSION AND COMMON CARDS FOR GASP2B************
      COMMON SLEP
      DOUBLE PRECISION SEED
      COMMON ID,ID,IFIT,JEVNT,JMBIT,MFA,MSTOP,MX,MXC,NCLCT,NHIST,NOQ,
&NORPT,NOT,NPRMS,NRUNS,NRUNS,NSTAT,OUT,SCALE,ISEED,TNOW,TOFG,TFIN,
&XXX,JPRBT,SEP,NPROJ,NDN,NDAY,NYR,JCLR
      COMMON AIRTH(14),LBO(20),INN(20),JCELS(10,22),XRANK(20),MAXNO(20),
&REF(20),MLE(20),NLE(20),NCELS(10),NO(20),PARAM(20,4),QTIME(20),
&SSQDA(20,5),SUMA(20,5),NAME(6),VNO(20),FAIL(40),CTIME(40),FPH(40)
      COMMON FPH2(40)
      COMMON XNFLEET,XINRATE,XNINTRO,THEDA,AK,RPTPERD,SIMTIME,L,ANTDIAL
&,ALASTPD
      PRINT 99
      99 FORMAT(1H1,//,27X,"AVG",8X,"FLY",6X,"FAIL PER")
      PRINT 104
      104 FORMAT(" ",15X,"PERIOD",4X,"FAIL",7X,"HOURS",5X,"FLY HOUR",
&6X,"STD.DEV")
      PRINT 98
      98 FORMAT(1H )
      DO 1 IJ=1,13
      AVFAIL=FAIL(IJ)/40.0
      AVCTME=CTIME(IJ)/40.0
      AVFPH=FPH(IJ)/40.0
      AFPH2=FPH2(IJ)/40.0
      STD=AFPH2-(AVFPH**2)
      PRINT 101,IJ,AVFAIL,AVCTME,AVFPH,STD
      101 FORMAT(" ",15X,I3,F10.1,3X,F10.1,5X,F8.6,5X,F8.6)
      1 CONTINUE
      PRINT 102,XNFLEET,XINRATE
      102 FORMAT(///,15X,"NUMBER IN FLEET =",F5.1,5X,"INTRO INTERVAL =",
&F6.1)
      PRINT 103,RPTPERD,THEDA,AK
      103 FORMAT(/,15X,"REPORT INTERVAL =",F6.1,5X,"THETA =",F6.1,
&3X,"SHAPE =",F3.1)
      PRINT 107,SIMTIME,XNINTRO
      107 FORMAT(15X,"SIM PERIODS =",F5.1,3X,"NUMBER INTRO / PERIOD =",
&F5.1)
      RETURN
      END
```

Figure 4 continued

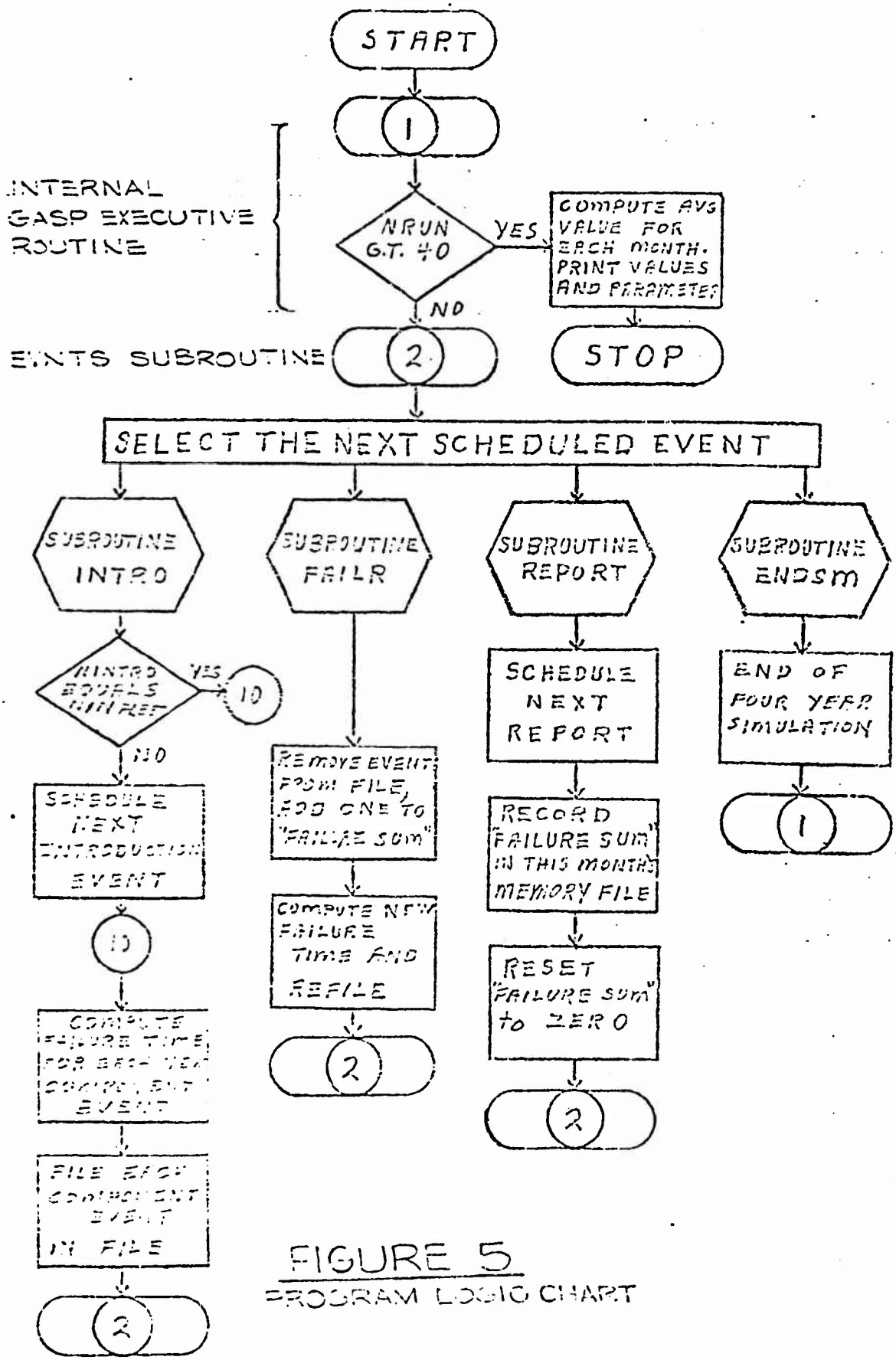


FIGURE 5
PROGRAM LOGIC CHART

APPENDIX B

SIMULATION OUTPUT DATA

This appendix contains the final simulation output listings and plots for the various parameters investigated in this study. Each listing contains the average number of failures per period, the period operating hours, the average number of failures per operating hour per period and the period standard deviation of failures per operating hour. The legend at the bottom of each listing describes the conditions for which the data was generated. Definitions of these conditions are as follows:

NUMBER IN FLEET--the maximum size of the fleet to be in the inventory.

INTRO INTERVAL--the time interval between increments of the fleet in hours. (120 hrs. equals 1 Report Interval).

REPORT INTERVAL--the time length of each reporting period in hours.

SCALE--a parameter of the Weibull distribution determined by the equation

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$$\theta = \frac{\text{MTBF}}{\Gamma(1+1/k)} \quad .$$

SHAPE--the other parameter, K, of the Weibull distribution tested in this study.

MTBF--the Mean Time Between Failures under the assumption of an exponential time to failure distribution.

NUMBER INTRO/PERIOD--the number of items introduced to the simulation until the total fleet size is attained.

The failures per ops hour have been plotted for each listing and are included in Chapter VI of this report.

The listings are presented as follows:

TABLE NO.	MTBF	SHAPE
B-1	500	.5
B-2	1000	.5
B-3	2000	.5
B-4	50	1.0
B-5	100	1.0
B-6	500	1.0
B-7	1000	1.0
B-8	2000	1.0
B-9	50	2.0
B-10	50	3.0
B-11	50	4.0
B-12	50	5.0
B-13	100	2.0
B-14	100	3.0
B-15	100	4.0
B-16	100	5.0
B-17	500	1.5
B-18	500	2.0
B-19	500	3.0
B-20	500	4.0
B-21	500	5.0
B-22	1000	1.5
B-23	1000	2.0

TABLE NO.	MTBF	SHAPE
B-24	1000	3.0
B-25	1000	4.0
B-26	1000	5.0
B-27	2000	1.5
B-28	2000	2.0
B-29	2000	3.0
B-30	2000	4.0
B-31	2000	5.0

PERIOD	AVG FAIL	OPS HOURS	FAIL PER OPS HOUR	STD.DEV
1	4.5	600.0	0.007458	0.026953
2	7.2	1200.0	0.005979	0.018714
3	9.5	1800.0	0.005250	0.012758
4	9.6	2400.0	0.004000	0.008490
5	11.2	3000.0	0.003725	0.008012
6	12.9	3600.0	0.003583	0.006766
7	14.8	4200.0	0.003518	0.006663
8	15.5	4800.0	0.003219	0.005650
9	17.2	5400.0	0.003185	0.005657
10	18.6	6000.0	0.003096	0.005493
11	19.8	6600.0	0.003004	0.004918
12	22.9	7200.0	0.003184	0.005430
13	24.7	7800.0	0.003160	0.005543
14	22.4	8400.0	0.002670	0.003885
15	25.5	9000.0	0.002833	0.004234
16	25.4	9600.0	0.002646	0.004064
17	27.2	10200.0	0.002662	0.004018
18	29.7	10799.9	0.002750	0.004139
19	30.0	11399.9	0.002636	0.003729
20	31.4	11999.9	0.002617	0.003852
21	29.2	12000.0	0.002431	0.003146
22	26.0	12000.0	0.002165	0.002679
23	27.8	12000.0	0.002317	0.002978
24	26.5	12000.0	0.002208	0.002678
25	25.8	12000.0	0.002154	0.002470
26	26.8	12000.0	0.002238	0.002715
27	26.5	12000.0	0.002206	0.002666
28	26.9	12000.0	0.002240	0.002627
29	26.2	12000.0	0.002183	0.002485
30	27.5	12000.0	0.002290	0.002646
31	26.1	12000.0	0.002177	0.002570
32	25.5	12000.0	0.002129	0.002520
33	26.5	12000.0	0.002204	0.002665
34	26.5	12000.0	0.002210	0.002651
35	25.5	12000.0	0.002123	0.002264
36	25.2	12000.0	0.002102	0.002426
37	24.3	12000.0	0.002021	0.002233
38	25.2	12000.0	0.002096	0.002446
39	24.1	12000.0	0.002010	0.002250
40	23.4	12000.0	0.001948	0.002139
41	24.0	12000.0	0.002002	0.002235
42	25.0	12000.0	0.002081	0.002461
43	24.6	12000.0	0.002052	0.002434
44	23.7	12000.0	0.001973	0.002095
45	22.7	12000.0	0.001894	0.002034
46	24.7	12000.0	0.002054	0.002377
47	24.5	12000.0	0.002044	0.002340
48	24.1	12000.0	0.002006	0.002229

TABLE B-1

NUMBER IN FLEET = 100.0 INTPO INTERVAL = 120.0
REPORT INTERVAL = 120.0 SCALE = 250.0 SHAPE =0.50
MTBF = 500.0 NUMBER INTPO / PERIOD = 5.0

PERIOD	AVG FAIL	OPS HOURS	FAIL PER OPS HOUR	STD.DEV
1	3.1	600.0	0.005125	0.014348
2	4.4	1200.0	0.003708	0.006944
3	5.3	1800.0	0.003514	0.005805
4	5.9	2400.0	0.002865	0.004052
5	7.5	3000.0	0.002492	0.003549
6	7.8	3600.0	0.002167	0.002503
7	9.4	4200.0	0.002232	0.002806
8	10.1	4800.0	0.002109	0.002464
9	9.4	5400.0	0.001741	0.001572
10	10.8	6000.0	0.001804	0.001669
11	12.4	6600.0	0.001883	0.001849
12	12.5	7200.0	0.001740	0.001744
13	13.5	7800.0	0.001740	0.001789
14	14.4	8400.0	0.001717	0.001534
15	15.0	9000.0	0.001783	0.001710
16	17.5	9600.0	0.001820	0.001876
17	16.8	10200.0	0.001645	0.001482
18	17.8	10799.9	0.001646	0.001537
19	18.0	11399.9	0.001579	0.001365
20	19.3	11999.9	0.001608	0.001479
21	15.0	12000.0	0.001250	0.000889
22	15.8	12000.0	0.001400	0.001080
23	15.0	12000.0	0.001252	0.000854
24	14.8	12000.0	0.001235	0.000833
25	14.9	12000.0	0.001240	0.000841
26	13.5	12000.0	0.001133	0.000714
27	13.8	12000.0	0.001148	0.000696
28	14.3	12000.0	0.001194	0.000764
29	13.6	12000.0	0.001131	0.000707
30	13.8	12000.0	0.001152	0.000734
31	15.0	12000.0	0.001252	0.000804
32	12.9	12000.0	0.001077	0.000658
33	12.3	12000.0	0.001021	0.000600
34	14.0	12000.0	0.001167	0.000781
35	13.1	12000.0	0.001094	0.000653
36	14.4	12000.0	0.001198	0.000784
37	12.5	12000.0	0.001042	0.000596
38	13.1	12000.0	0.001094	0.000684
39	12.5	12000.0	0.001040	0.000554
40	12.9	12000.0	0.001071	0.000625
41	12.5	12000.0	0.001044	0.000588
42	13.1	12000.0	0.001096	0.000698
43	13.3	12000.0	0.001108	0.000672
44	13.1	12000.0	0.001096	0.000745
45	13.5	12000.0	0.001123	0.000708
46	13.1	12000.0	0.001090	0.000663
47	12.7	12000.0	0.001056	0.000549
48	12.8	12000.0	0.001029	0.000557

TABLE 5-2

NUMBER IN FLEET = 100.0 INTRO INTERVAL = 120.0
REPORT INTERVAL = 120.0 SCALE = 500.0 SHAPE =0.50
MTBF =1000.0 NUMBER INTRO / PERIOD = 5.0

PERIOD	AVG FAIL	OPS HOURS	FAIL PER OPS HOUR	STD.DEV
1	2.1	600.0	0.003458	0.006739
2	2.9	1200.0	0.002438	0.003095
3	3.8	1800.0	0.002097	0.001987
4	4.9	2400.0	0.002021	0.001831
5	5.5	3000.0	0.001825	0.001879
6	4.9	3600.0	0.001375	0.001038
7	5.9	4200.0	0.001417	0.001096
8	6.4	4800.0	0.001339	0.001063
9	7.5	5400.0	.001389	0.001040
10	7.7	6000.0	0.001288	0.000942
11	7.0	6600.0	0.001061	0.000535
12	7.5	7200.0	0.001038	0.000646
13	7.5	7800.0	0.000962	0.000489
14	8.9	8400.0	0.001060	0.000556
15	9.3	9000.0	0.001031	0.000613
16	9.8	9600.0	0.001023	0.000534
17	9.9	10200.0	0.000968	0.000492
18	10.8	10799.9	0.000998	0.000508
19	11.8	11399.9	0.001033	0.000573
20	12.5	11999.9	0.001038	0.000626
21	9.9	12000.0	0.000823	0.000382
22	9.8	12000.0	0.000815	0.000373
23	9.0	12000.0	0.000752	0.000315
24	9.0	12000.0	0.000748	0.000325
25	7.8	12000.0	0.000652	0.000249
26	9.2	12000.0	0.000767	0.000310
27	8.8	12000.0	0.000735	0.000320
28	9.0	12000.0	0.000754	0.000304
29	7.2	12000.0	0.000602	0.000223
30	7.6	12000.0	0.000637	0.000226
31	7.7	12000.0	0.000644	0.000218
32	7.8	12000.0	0.000650	0.000253
33	8.0	12000.0	0.000665	0.000252
34	7.6	12000.0	0.000629	0.000212
35	7.1	12000.0	0.000594	0.000191
36	7.6	12000.0	0.000629	0.000221
37	7.5	12000.0	0.000623	0.000220
38	7.5	12000.0	0.000625	0.000195
39	7.4	12000.0	0.000617	0.000221
40	7.0	12000.0	0.000581	0.000190
41	7.1	12000.0	0.000588	0.000178
42	6.6	12000.0	0.000548	0.000158
43	7.1	12000.0	0.000596	0.000199
44	6.6	12000.0	0.000552	0.000161
45	7.2	12000.0	0.000598	0.000187
46	6.9	12000.0	0.000577	0.000194
47	6.1	12000.0	0.000505	0.000137
48	6.9	12000.0	0.000577	0.000179

TABLE B-3

NUMBER IN FLEET = 100.0 INTRO INTERVAL = 120.0
REPORT INTERVAL = 120.0 SCALE =1000.0 SHAPE =0.50
MTBF =2000.0 NUMBER INTRO / PERIOD = 5.0

PERIOD	AVG FAIL	OPS HOURS	FAIL PER OPS HOUR	STD.DEV
1	13.0	600.0	0.021667	0.244795
2	25.0	1200.0	0.020875	0.227015
3	34.6	1800.0	0.019222	0.205380
4	48.4	2400.0	0.020188	0.221661
5	57.6	3000.0	0.019283	0.201221
6	69.8	3600.0	0.019389	0.208494
7	82.6	4200.0	0.019673	0.216171
8	95.7	4800.0	0.019932	0.222196
9	107.9	5400.0	0.019977	0.218236
10	120.4	6000.0	0.020075	0.222688
11	134.2	6600.0	0.020439	0.226803
12	143.4	7200.0	0.019913	0.219229
13	154.1	7800.0	0.019753	0.218330
14	173.6	8400.0	0.020673	0.235528
15	184.6	9000.0	0.020403	0.231080
16	196.2	9600.0	0.020435	0.226882
17	207.3	10200.0	0.020324	0.223536
18	222.7	10799.9	0.020618	0.233327
19	225.7	11399.9	0.019796	0.216921
20	247.3	11999.9	0.020611	0.233564
21	238.	12000.0	0.019860	0.216788
22	237	12000.0	0.019810	0.214436
23	238.7	12000.0	0.019890	0.219047
24	241.0	12000.0	0.020083	0.223878
25	237.9	12000.0	0.01[illegible]	0.218736
26	234.6	12000.0	0.019548	0.215024
27	245.7	12000.0	0.020475	0.233321
28	247.1	12000.0	0.020596	0.233856
29	245.3	12000.0	0.020444	0.229164
30	240.7	12000.0	0.020058	0.221789
31	245.9	12000.0	0.020490	0.231067
32	242.6	12000.0	0.020219	0.225421
33	242.[illegible]	12000.0	0.020177	0.226727
34	241.4	12000.0	0.020119	0.221331
35	236.1	12000.0	0.019675	0.215930
36	235.5	12000.0	0.019625	0.211694
37	236.0	12000.0	0.019669	0.213025
38	238.0	12000.0	0.019829	0.218186
39	242.9	12000.0	0.020240	0.225078
40	245.0	12000.0	0.020421	0.227945
41	235.6	12000.0	0.019635	0.214527
42	231.9	12000.0	0.019321	0.208287
43	239.3	12000.0	0.019944	0.217497
44	245.0	12000.0	0.020421	0.228055
45	236.7	12000.0	0.019725	0.217550
46	242.8	12000.0	0.020233	0.225827
47	241.[illegible]	12000.0	0.020106	0.221023
48	239.4	12000.0	0.019945	0.219304

NUMBER IN REPORT = 100.0 INTRO INTERVAL = 12 .0
REPORT INTERVAL = 120.0 SCALE = 50.0 SHAPE =1.00
MTBF = 50.0 NUMBER INTRO / PERIOD = 5.0

TABLE B-4

PERIOD	AVG FAIL	OPS HOURS	FAIL PER OPS HOUR	STD.DEV
1	6.5	600.0	0.011083	0.064460
2	12.9	1200.0	0.010708	0.056275
3	18.1	1800.0	0.010070	0.055324
4	23.2	2400.0	0.009646	0.051510
5	29.0	3000.0	0.009933	0.054463
6	35.7	3600.0	0.009917	0.054594
7	41.3	4200.0	0.009827	0.051356
8	49.0	4800.0	0.010208	0.057469
9	49.5	5400.0	0.009162	0.045966
10	59.8	6000.0	0.009963	0.056754
11	65.0	6600.0	0.009849	0.054562
12	72.1	7200.0	0.010010	0.054408
13	78.1	7800.0	0.010010	0.055395
14	84.0	8400.0	0.010003	0.055628
15	91.5	9000.0	0.010167	0.055525
16	97.7	9600.0	0.010180	0.056901
17	103.3	10200.0	0.010130	0.056830
18	103.8	10799.9	0.009607	0.051694
19	115.7	11399.9	0.010151	0.057671
20	124.3	11999.9	0.010358	0.058873
21	121.9	12000.0	0.010163	0.057388
22	123.0	12000.0	0.010250	0.057078
23	123.2	12000.0	0.010269	0.057637
24	121.7	12000.0	0.010144	0.055546
25	121.6	12000.0	0.010131	0.054884
26	124.6	12000.0	0.010385	0.060052
27	120.0	12000.0	0.010002	0.054844
28	121.7	12000.0	0.010140	0.057201
29	120.6	12000.0	0.010052	0.055584
30	122.2	12000.0	0.010348	0.059103
31	119.1	12000.0	0.009929	0.054085
32	119.8	12000.0	0.009983	0.054559
33	119.9	12000.0	0.009990	0.055097
34	119.4	12000.0	0.009946	0.054316
35	117.2	12000.0	0.009765	0.051733
36	118.8	12000.0	0.009990	0.055065
37	122.6	12000.0	0.010221	0.057604
38	118.9	12000.0	0.009904	0.054286
39	119.8	12000.0	0.009985	0.055599
40	117.1	12000.0	0.009763	0.052513
41	118.5	12000.0	0.009877	0.054683
42	119.1	12000.0	0.009927	0.055543
43	116.3	12000.0	0.009854	0.051610
44	124.1	12000.0	0.010340	0.059083
45	126.3	12000.0	0.010527	0.062465
46	120.9	12000.0	0.010079	0.055933
47	122.5	12000.0	0.010235	0.058353
48	123.1	12000.0	0.010256	0.057484

NUMBER IN FLEET = 100.0 INTRO INTERVAL = 120.0
REPORT INTERVAL = 120.0 SCALE = 100.0 SHAPE =1.00
MTBF = 100.0 NUMBER INTRO / PERIOD = 5.0

TABLE B- 5

PERIOD	AVG FAIL	OPS HOURS	FAIL PER OPS HOUR	STD.DEV
1	1.2	600.0	0.001958	0.002259
2	2.6	1200.0	0.002167	0.002464
3	3.9	1800.0	0.002139	0.002171
4	5.3	2400.0	0.002219	0.002433
5	6.5	3000.0	0.002175	0.002435
6	7.4	3600.0	0.002069	0.002270
7	8.1	4200.0	0.001929	0.002026
8	10.0	4800.0	0.002094	0.002519
9	11.1	5400.0	0.002056	0.002386
10	11.5	6000.0	0.001917	0.001982
11	12.5	6600.0	0.001898	0.002004
12	13.1	7200.0	0.001826	0.001827
13	15.8	7800.0	0.002026	0.002248
14	15.4	8400.0	0.001949	0.002165
15	18.0	9000.0	0.002003	0.002097
16	20.2	9600.0	0.002099	0.002347
17	21.0	10200.0	0.002061	0.002395
18	22.0	10799.9	0.002039	0.002290
19	22.2	11399.9	0.001945	0.002002
20	23.2	11999.9	0.001935	0.002138
21	22.5	12000.0	0.001879	0.002000
22	22.9	12000.0	0.001908	0.002020
23	23.9	12000.0	0.001992	0.002137
24	24.0	12000.0	0.002002	0.002279
25	23.3	12000.0	0.001944	0.002126
26	23.9	12000.0	0.001994	0.002138
27	23.3	12000.0	0.001946	0.002064
28	24.2	12000.0	0.002015	0.002225
29	23.7	12000.0	0.001971	0.002112
30	24.0	12000.0	0.002002	0.002229
31	22.8	12000.0	0.001900	0.002040
32	24.7	12000.0	0.002060	0.002309
33	23.5	12000.0	0.001962	0.002302
34	24.5	12000.0	0.002045	0.002308
35	23.5	12000.0	0.001954	0.002113
36	24.2	12000.0	0.002017	0.002269
37	25.8	12000.0	0.002150	0.002370
38	24.5	12000.0	0.002042	0.002312
39	24.8	12000.0	0.002065	0.002314
40	23.4	12000.0	0.001948	0.002096
41	24.9	12000.0	0.002077	0.002366
42	24.1	12000.0	0.002008	0.002117
43	23.8	12000.0	0.001983	0.002145
44	24.0	12000.0	0.002000	0.002148
45	24.5	12000.0	0.002037	0.002327
46	23.5	12000.0	0.001957	0.002175
47	24.5	12000.0	0.002040	0.002305
48	24.2	12000.0	0.002012	0.002218

TABLE B-6

NUMBER IN FLEET = 100.0 INTRO INTERVAL = 120.0
REPORT INTERVAL = 120.0 SCALE = 500.0 SHAPE =1.00
MTBF = 500.0 NUMBER INTRO / PERIOD = 5.0

PERIOD	AVG FAIL	OPS HOURS	FAIL PER OPS HOUR	STD.DEV
1	0.6	600,0	0,001000	0,000547
2	1.4	1200,0	0,001146	0,000750
3	1,9	1800,0	0,001042	0,000560
4	2,7	2400,0	0,001135	0,000582
5	2,7	3000,0	0,000900	0,000373
6	4,2	3600,0	0,001174	0,000744
7	4,3	4200,0	0,001012	0,000506
8	5,1	4800,0	0,001052	0,000673
9	5,7	5400,0	0,001056	0,000641
10	6,2	6000,0	0,001033	0,000575
11	7,2	6600,0	0,001087	0,000634
12	7,3	7200,0	0,001010	0,000572
13	7,7	7800,0	0,000987	0,000542
14	7,7	8400,0	0,000914	0,000427
15	7,6	9000,0	0,000850	0,000478
16	9,1	9600,0	0,000951	0,000475
17	10,5	10200,0	0,001025	0,000595
18	10,5	10799,9	0,000975	0,000525
19	11,0	11399,9	0,000963	0,000494
20	11,9	11999,9	0,000994	0,000527
21	12,0	12000,0	0,000996	0,000537
22	13,5	12000,0	0,001125	0,000685
23	12,0	12000,0	0,000996	0,000556
24	12,5	12000,0	0,001044	0,000608
25	11,6	12000,0	0,000969	0,000542
26	13,0	12000,0	0,001081	0,000628
27	11,5	12000,0	0,000985	0,000523
28	11,4	12000,0	0,000948	0,000475
29	11,9	12000,0	0,000995	0,000554
30	11,7	12000,0	0,000977	0,000540
31	11,2	12000,0	0,000935	0,000509
32	11,3	12000,0	0,000940	0,000483
33	11,3	12000,0	0,000940	0,000480
34	11,1	12000,0	0,000925	0,000502
35	12,5	12000,0	0,001034	0,000641
36	12,1	12000,0	0,001006	0,000544
37	12,3	12000,0	0,001023	0,000578
38	12,0	12000,0	0,001002	0,000554
39	11,4	12000,0	0,000950	0,000500
40	11,5	12000,0	0,000954	0,000515
41	11,8	12000,0	0,000983	0,000497
42	12,0	12000,0	0,001000	0,000539
43	11,9	12000,0	0,000992	0,000525
44	11,3	12000,0	0,000938	0,000480
45	11,5	12000,0	0,000958	0,000503
46	12,1	12000,0	0,001004	0,000563
47	11,1	12000,0	0,000925	0,000475
48	12,4	12000,0	0,001035	0,000560

NUMBER IN FLEET = 100,0 INTRO INTERVAL = 120,0
REPORT INTERVAL = 120,0 SCALE =1000,0 SHAPE =1,00
MTBF =1000,0 NUMBER INTRO / PERIOD = 5,0

TABLE B-7

PERIOD	AVG FAIL	OPS HOURS	FAIL PER OPS HOUR	STD.DEV
1	[illegible]	600,0	0,000583	0,000194
2	0,6	1200,0	0,000500	0,000125
3	0,9	1800,0	0,000500	0,000148
4	1,5	2400,0	0,000604	0,000169
5	1,7	3000,0	0,000550	0,000126
6	1,8	3600,0	0,000507	0,000116
7	2,1	4200,0	0,000500	0,000132
8	2,4	4800,0	0,000510	0,000139
9	2,9	5400,0	0,000528	0,000160
10	2,9	6000,0	0,000488	0,000124
11	3,3	6600,0	0,000500	0,000149
12	4,3	7200,0	0,000594	0,000206
13	4,1	7800,0	0,000529	0,000150
14	4,9	8400,0	0,000583	0,000192
15	4,5	9000,0	0,000508	0,000135
16	4,5	9600,0	0,000482	0,000130
17	5,4	10200,0	0,000532	0,000151
18	5,1	10799,9	0,000477	0,000126
19	5,3	11399,9	0,000463	0,000115
20	5,5	11999,9	0,000456	0,000105
21	5,4	12000,0	0,000450	0,000113
22	5,4	12000,0	0,000446	0,000112
23	5,[illegible]	12000,0	0,000502	0,000139
24	5,4	12000,0	0,000446	0,000105
25	5,7	12000,0	0,000477	0,000118
26	6,3	12000,0	0,000523	0,000138
27	6,0	12000,0	0,000502	0,000133
28	5,8	12000,0	0,000481	0,000120
29	6,[illegible]	12000,0	0,000498	0,000126
30	6,2	12000,0	0,000519	0,000146
31	6,2	12000,0	0,000517	0,000154
32	6,0	12000,0	0,000500	0,000135
33	6,2	12000,0	0,000515	0,000140
34	6,3	12000,0	0,000525	0,000150
35	6,0	12000,0	0,000502	0,000138
36	6,5	12000,0	0,000540	0,000175
37	6,3	12000,0	0,000525	0,000155
38	6,6	12000,0	0,000554	0,000169
39	5,9	12000,0	0,000490	0,000126
40	6,1	12000,0	0,000506	0,000158
41	6,0	12000,0	0,000498	0,000131
42	6,0	12000,0	0,000498	0,000132
43	6,9	12000,0	0,000573	0,000171
44	5,3	12000,0	0,000444	0,000103
45	5,8	12000,0	0,000471	0,000125
46	5,8	12000,0	0,000483	0,000123
47	6,1	12000,0	0,000508	0,000126
48	5,6	12000,0	0,000471	0,000121

NUMBER IN FLEET = 100,0 INTRO INTERVAL = 120,0
[illegible] INTERVAL = 120,0 SCALE =2000,0 SHAPE =1,00
MTBF =20[illegible],0 NUMBER INTRO / PERIOD = 5,0

TABLE B-8

PERIOD	AVG FAIL	OPS HOURS	FAIL PER OPS HOUR	STD.DEV
1	10,5	600,0	0,017458	0,165011
2	22,8	1200,0	0,019021	0,188774
3	33,5	1800,0	0,018611	0,193972
4	47,1	2400,0	0,019604	0,212547
5	56,6	3000,0	0,018875	0,195905
6	69,8	3600,0	0,019389	0,205766
7	81,3	4200,0	0,019345	0,208306
8	95,1	4800,0	0,019807	0,218622
9	105,9	5400,0	0,019602	0,210512
10	118,1	6000,0	0,019679	0,214462
11	132,2	6600,0	0,020030	0,219911
12	143,2	7200,0	0,019885	0,216582
13	152,8	7800,0	0,019590	0,214023
14	169,0	8400,0	0,020113	0,222405
15	179,4	9000,0	0,019936	0,221164
16	191,3	9600,0	0,019930	0,218879
17	204,6	10200,0	0,020064	0,220596
18	216,6	10799,9	0,020058	0,220934
19	225,6	11399,9	0,019875	0,217891
20	239,4	11999,9	0,019952	0,219556
21	239,0	12000,0	0,019912	0,218956
22	239,8	12000,0	0,019983	0,220382
23	238,1	12000,0	0,019844	0,218390
24	241,5	12000,0	0,020123	0,223539
25	238,9	12000,0	0,019903	0,219446
26	236,5	12000,0	0,019706	0,216265
27	242,7	12000,0	0,020227	0,226430
28	242,3	12000,0	0,020192	0,226937
29	241,5	12000,0	0,020133	0,223789
30	243,0	12000,0	0,020248	0,224845
31	240,4	12000,0	0,020031	0,222207
32	243,3	12000,0	0,020275	0,227731
33	241,8	12000,0	0,020146	0,225780
34	240,8	12000,0	0,020063	0,221999
35	237,5	12000,0	0,019790	0,216635
36	237,4	12000,0	0,019779	0,215101
37	236,7	12000,0	0,019727	0,215706
38	240,1	12000,0	0,020006	0,221237
39	239,8	12000,0	0,019981	0,219930
40	240,7	12000,0	0,020056	0,222005
41	240,0	12000,0	0,020000	0,220062
42	236,6	12000,0	0,019721	0,218458
43	239,2	12000,0	0,019931	0,219560
44	244,3	12000,0	0,020358	0,225699
45	238,0	12000,0	0,019837	0,217822
46	240,5	12000,0	0,020044	0,221420
47	236,5	12000,0	0,019885	0,218412
48	242,3	12000,0	0,020192	0,224737

NUMBER OF PERIOD = 100.0 INTRO INTERVAL = 120,0
REPORT INTERVAL = 120,0 SCALE = 56,4 SHAPE =2,00
MTBF = 50,0 NUMBER INTRO / PERIOD = 5,0

TABLE B-1

PERIOD	ACC FAIL	OPS HOURS	FAIL PER OPS HOUR	STD.DEV
1	10.1	600.0	0.016833	0.155651
2	22.4	1200.0	0.018646	0.185025
3	32.8	1800.0	0.018208	0.185432
4	46.6	2400.0	0.019427	0.208211
5	57.3	3000.0	0.019100	0.204975
6	69.3	3600.0	0.019243	0.203652
7	81.8	4200.0	0.019476	0.210895
8	93.9	4800.0	0.019552	0.211547
9	105.9	5400.0	0.019611	0.211821
10	116.4	6000.0	0.019733	0.214629
11	131.5	6600.0	0.019932	0.214565
12	142.8	7200.0	0.019715	0.213366
13	152.9	7800.0	0.019599	0.212570
14	167.3	8400.0	0.019914	0.219609
15	176.8	9000.0	0.019867	0.218224
16	190.2	9600.0	0.019813	0.216003
17	203.4	10200.0	0.019939	0.217753
18	216.3	10799.9	0.020023	0.221443
19	224.8	11399.9	0.019717	0.214370
20	239.4	11999.9	0.019950	0.219393
21	237.8	12000.0	0.019812	0.217062
22	239.9	12000.0	0.019990	0.221455
23	240.6	12000.0	0.020048	0.222070
24	241.6	12000.0	0.020138	0.223140
25	237.2	12000.0	0.019765	0.216828
26	238.5	12000.0	0.019873	0.218773
27	241.7	12000.0	0.020140	0.223868
28	241.0	12000.0	0.020083	0.223732
29	241.0	12000.0	0.020083	0.223861
30	240.5	12000.0	0.020127	0.223420
31	241.3	12000.0	0.020106	0.223401
32	243.0	12000.0	0.020243	0.226354
33	239.6	12000.0	0.019967	0.221997
34	241.1	12000.0	0.020092	0.222179
35	238.0	12000.0	0.019838	0.217861
36	237.9	12000.0	0.019821	0.216712
37	236.9	12000.0	0.019906	0.219327
38	239.7	12000.0	0.019977	0.220876
39	239.1	12000.0	0.019925	0.219316
40	240.5	12000.0	0.020054	0.221212
41	240.6	12000.0	0.020054	0.221900
42	237.5	12000.0	0.019788	0.216571
43	237.5	12000.0	0.019956	0.219897
44	243.1	12000.0	0.020263	0.225909
45	237.8	12000.0	0.019813	0.216990
46	240.2	12000.0	0.020015	0.221604
47	[illegible]	12000.0	0.020029	0.221419
48	240.6	12000.0	0.020050	0.221223

NUMBER IN FLEET = 100.0 INTRO INTERVAL = 120.0
REPORT INTERVAL = 120.0 SCALE = 56.0 SHAPE =3.00
MTBF = 50.0 NUMBER INTRO / PERIOD = 5.0

TABLE B-10

PERIOD	AVG FAIL	OPS HOURS	FAIL PER OPS HOUR	STD.DEV
1	10.0	600.0	0.016667	0.151928
2	22.3	1200.0	0.018563	0.185382
3	32.8	1800.0	0.018236	0.186163
4	46.1	2400.0	0.019188	0.201955
5	57.5	3000.0	0.019192	0.203409
6	69.2	3600.0	0.019229	0.203896
7	81.9	4200.0	0.019512	0.211115
8	93.4	4800.0	0.019453	0.210389
9	105.4	5400.0	0.019520	0.209845
10	118.2	6000.0	0.019700	0.214449
11	131.5	6600.0	0.019936	0.217981
12	141.4	7200.0	0.019639	0.212071
13	153.2	7800.0	0.019641	0.213288
14	167.0	8400.0	0.019881	0.219036
15	178.4	9000.0	0.019820	0.216608
16	190.2	9600.0	0.019510	0.215882
17	203.2	10200.0	0.019919	0.218550
18	218.7	10799.9	0.019880	0.217546
19	224.5	11399.9	0.019693	0.214323
20	239.9	11999.9	0.019908	0.218676
21	239.8	12000.0	0.019921	0.219319
22	239.9	12000.0	0.019992	0.221675
23	239.7	12000.0	0.019975	0.220249
24	241.4	12000.0	0.020113	0.222586
25	238.1	12000.0	0.019842	0.218676
26	238.4	12000.0	0.019865	0.218097
27	241.6	12000.0	0.020131	0.223740
28	248.6	12000.0	0.020048	0.223210
29	241.1	12000.0	0.020087	0.223178
30	241.3	12000.0	0.020106	0.223156
31	243.4	12000.0	0.020031	0.222437
32	242.1	12000.0	0.020175	0.223801
33	239.9	12000.0	0.019990	0.222457
34	241.2	12000.0	0.020098	0.222899
35	239.2	12000.0	0.019935	0.219364
36	238.6	12000.0	0.019721	0.214833
37	241.5	12000.0	0.020042	0.222018
38	239.1	12000.0	0.019925	0.220744
39	239.2	12000.0	0.019935	0.219281
40	241.0	12000.0	0.020083	0.222186
41	240.0	12000.0	0.020000	0.219835
42	238.2	12000.0	0.019848	0.218126
43	239.7	12000.0	0.019977	0.220427
44	242.4	12000.0	0.020200	0.224497
45	238.4	12000.0	0.019863	0.216160
46	239.8	12000.1	0.019996	0.221549
47	241.3	12000.0	0.020027	0.220979
48	216.6	12000.0	0.020052	0.221940

NUMBER IN FLEET = 100.0 INTRO INTERVAL = 120.0
REPORT INTERVAL = 120.0 SCALE = 55.2 SHAPE =4.00
MTBF = 50.0 NUMBER INTRO / PERIOD = 5.0

TABLE B-11

PERIOD	AVG FAIL	OPS HOURS	FAIL PER OPS HOUR	STD.DEV
1	9.9	600.0	0.016500	0.149551
2	22.3	1200.0	0.018625	0.187072
3	32.8	1800.0	0.018195	0.184488
4	46.0	2400.0	0.019156	0.201517
5	57.7	3000.0	0.019242	0.204961
6	69.0	3600.0	0.019160	0.202984
7	82.2	4200.0	0.019571	0.211688
8	93.0	4800.0	0.019375	0.209249
9	105.6	5400.0	0.019565	0.209706
10	116.4	6000.0	0.019725	0.215396
11	130.9	6600.0	0.019837	0.215536
12	141.5	7200.0	0.019653	0.213251
13	153.1	7800.0	0.019631	0.212681
14	166.2	8400.0	0.019783	0.216602
15	176.1	9000.0	0.019795	0.216252
16	189.0	9600.0	0.019768	0.215315
17	203.6	10200.0	0.019961	0.219767
18	213.9	10799.9	0.019803	0.216045
19	225.2	11399.9	0.019752	0.215721
20	238.6	11999.9	0.019888	0.218102
21	238.4	12000.0	0.019865	0.217909
22	239.7	12000.0	0.019975	0.220819
23	240.6	12000.0	0.020048	0.222200
24	241.5	12000.0	0.020129	0.223251
25	238.1	12000.0	0.019844	0.218973
26	238.8	12000.0	0.019902	0.217375
27	240.7	12000.0	0.020060	0.222943
28	240.9	12000.0	0.020077	0.222797
29	241.1	12000.0	0.020092	0.223919
30	240.1	12000.0	0.020010	0.221973
31	240.4	12000.0	0.020029	0.222270
32	241.8	12000.0	0.020152	0.223624
33	239.3	12000.0	0.019940	0.220892
34	241.8	12000.0	0.020152	0.224379
35	239.1	12000.0	0.019927	0.218944
36	237.2	12000.0	0.019769	0.216102
37	240.1	12000.0	0.020008	0.221102
38	240.0	12000.0	0.019998	0.221850
39	239.4	12000.0	0.019952	0.220249
40	240.3	12000.0	0.020069	0.221128
41	239.7	12000.0	0.019975	0.219916
42	239.1	12000.0	0.019925	0.219993
43	238.5	12000.0	0.019902	0.219920
44	242.0	12000.0	0.020167	0.224191
45	238.7	12000.0	0.019894	0.218231
46	240.3	12000.0	0.020021	0.221927
47	240.1	12000.0	0.020013	0.221065
48	240.7	12000.0	0.020060	0.222118

NUMBER IN FIRST = 100.0 INTRO INTERVAL = 120.0
REPORT INTERVAL = 120.0 SCALE = 54.5 SHAPE =5.00
MTBF 50.0 NUMBER INTRO / PERIOD = 5.0

TABLE B-12

PERIOD	AVG FAIL	OPS HOURS	FAIL PER OPS HOUR	STD.DEV
1	4.5	600.0	0.007458	0.039403
2	10.6	1200.0	0.008854	0.041436
3	16.3	1800.0	0.009069	0.042967
4	21.9	2400.0	0.009125	0.046916
5	28.7	3000.0	0.009558	0.050650
6	33.7	3600.0	0.009354	0.047943
7	38.7	4200.0	0.009220	0.047265
8	47.2	4800.0	0.009839	0.052399
9	54.7	5400.0	0.009394	0.048685
10	58.1	6000.0	0.009683	0.052825
11	64.1	6600.0	0.009708	0.052138
12	76.2	7200.0	0.009750	0.052576
13	77.9	7800.0	0.009872	0.053157
14	81.5	8400.0	0.009699	0.052302
15	89.8	9000.0	0.009975	0.054359
16	94.9	9600.0	0.009891	0.053735
17	100.8	10200.0	0.009882	0.053696
18	105.2	10799.9	0.009738	0.052579
19	112.4	11399.9	0.009858	0.054669
20	120.7	11999.9	0.010056	0.054772
21	120.1	12000.0	0.010008	0.056180
22	120.8	12000.0	0.010069	0.055464
23	120.9	12000.0	0.010075	0. 5916
24	121.9	12000.0	0.010163	0.056211
25	120.8	12000.0	0.010065	0.055859
26	121.9	12000.0	0.010160	0.056318
27	121.4	12000.0	0.010117	0.056246
28	119.0	12000.0	0.009917	0.054338
29	119.2	12000.0	0.009931	0.054772
30	123.4	12000.0	0.010281	0.057561
31	119.9	12000.0	0.009988	0.055577
32	116.6	12000.0	0.009881	0.054097
33	119.1	12000.0	0.009921	0.054427
34	121.4	12000.0	0.010117	0.055964
35	117.4	12000.0	0.009779	0.052322
36	120.8	12000.0	0.010069	0.057584
37	119.5	12000.0	0.009958	0.053841
38	120.6	12000.0	0.010050	0.055690
39	120.0	12000.0	0.010000	0.056293
40	117.8	12000.0	0.009812	0.052734
41	120.3	12000.0	0.010021	0.055163
42	117.5	12000.0	0.009790	0.053799
43	119.1	12000.0	0.009925	0.055359
44	122.9	12000.0	0.010246	0.058371
45	121.3	12000.0	0.010110	0.056570
46	122.2	12000.0	0.010183	0.057497
47	120.6	12000.0	0.010053	0.055575
48	121.6	12000.0	0.010133	0.057565

NUMBER IN FLEET = 100.0 INTRO INTERVAL = 120.0
REPORT INTERVAL = 120.0 SCALE = 112.0 SHAPE =2.00
MTBF = 100.0 NUMBER INTRO / PERIOD = 5.0

TABLE B-13

PERIOD	AVG FAIL	OPS HOURS	FAIL PER OPS HOUR	STD.DEV
1	4.1	600.0	0.006833	0.024860
2	10.2	1200.0	0.008521	0.039618
3	15.8	1800.0	0.008764	0.040143
4	21.5	2400.0	0.008979	0.045444
5	28.5	3000.0	0.009508	0.050326
6	33.5	3600.0	0.009313	0.047444
7	38.5	4200.0	0.009173	0.046687
8	46.3	4800.0	0.009646	0.050990
9	50.7	5400.0	0.009394	0.048937
10	59.2	6000.0	0.009858	0.053714
11	62.2	6600.0	0.009515	0.050647
12	69.9	7200.0	0.009708	0.051781
13	76.1	7800.0	0.009760	0.052077
14	81.6	8400.0	0.009735	0.052661
15	88.9	9000.0	0.009878	0.053206
16	95.0	9600.0	0.009896	0.054186
17	99.6	10200.0	0.009760	0.052663
18	106.1	10799.9	0.009824	0.052677
19	111.6	11399.9	0.009785	0.053496
20	119.6	11999.9	0.009965	0.054875
21	120.3	12000.0	0.010023	0.055304
22	119.9	12000.0	0.009996	0.054746
23	120.6	12000.0	0.010054	0.055400
24	120.9	12000.0	0.010073	0.055698
25	121.1	12000.0	0.010096	0.056465
26	120.7	12000.0	0.010058	0.055214
27	120.5	12000.0	0.010040	0.055637
28	120.1	12000.0	0.010006	0.055272
29	118.9	12000.0	0.009906	0.054255
30	122.4	12000.0	0.010196	0.057096
31	119.5	12000.0	0.009960	0.055567
32	119.1	12000.0	0.009925	0.053939
33	119.7	12000.0	0.009977	0.055400
34	120.6	12000.0	0.010048	0.055416
35	119.1	12000.0	0.009929	0.054023
36	119.8	12000.0	0.009900	0.054997
37	120.2	12000.0	0.010017	0.054887
38	121.0	12000.0	0.010085	0.056197
39	119.7	12000.0	0.009973	0.055386
40	117.9	12000.0	0.009829	0.053476
41	121.2	12000.0	0.010098	0.056041
42	117.9	12000.0	0.009823	0.053914
43	120.6	12000.0	0.010000	0.055648
44	121.3	12000.0	0.010104	0.056659
45	120.9	12000.0	0.010077	0.056348
46	121.1	12000.0	0.010092	0.056096
47	120.1	12000.0	0.010008	0.055354
48	121.4	12000.0	0.010113	0.056492

NUMBER IN FLEET = 100.0 INTRO INTERVAL = 120.0
REPORT INTERVAL = 120.0 SCALE = 112.0 SHAPE =3.00
MTBF 1.0.0 NUMBER INTRO / PERIOD = 5.0

TABLE B-14

PERIOD	AVG FAIL	OPS HOURS	FAIL PER OPS HOUR	STD.DEV
1	4.1	600.0	0.006833	0.025360
2	10.1	1200.0	0.008438	0.036684
3	15.7	1800.0	0.008736	0.040886
4	21.2	2400.0	0.008813	0.043550
5	28.9	3000.0	0.009625	0.050890
6	33.0	3600.0	0.009174	0.046718
7	38.0	4200.0	0.009232	0.047329
8	45.8	4800.0	0.009542	0.049428
9	50.7	5400.0	0.009384	0.048883
10	59.2	6000.0	0.009858	0.053374
11	63.4	6600.0	0.009610	0.051738
12	69.3	7200.0	0.009629	0.051617
13	75.7	7800.0	0.009705	0.051327
14	82.1	8400.0	0.009774	0.052837
15	87.1	9000.0	0.009683	0.051476
16	95.1	9600.0	0.009904	0.054037
17	106.1	10200.0	0.009814	0.053291
18	106.2	10799.9	0.009831	0.053028
19	111.0	11399.9	0.009835	0.053363
20	118.7	11999.9	0.009892	0.054044
21	120.2	12000.0	0.010019	0.055593
22	120.1	12000.0	0.010004	0.055019
23	119.9	12000.0	0.009992	0.054727
24	120.5	12000.0	0.010065	0.055598
25	120.5	12000.0	0.010042	.056143
26	120.4	12000.0	0.010035	0.055307
27	120.3	12000.0	0.010023	0.055315
28	120.1	12000.0	0.010013	0.055132
29	119.5	12000.0	0.009958	.054880
30	121.3	12000.0	0.010108	.056310
31	119.8	12000.0	0.009983	0.055515
32	119.9	12000.0	0.009987	0.054631
33	119.7	12000.0	0.009973	0.055296
34	119.9	12000.0	0.009988	0.054992
35	120.0	12000.0	0.009998	0.055008
36	118.6	12000.0	0.009887	0.054698
37	120.8	12000.0	0.010065	0.055593
38	119.9	12000.0	0.009992	0.054885
39	119.0	12000.0	0.009915	0.054573
40	119.0	12000.0	0.009915	0.054427
41	121.6	12000.0	0.010131	0.056346
42	119.2	12000.0	0.009850	0.054105
43	120.4	12000.0	0.010029	0.055438
44	119.9	12000.0	0.009987	0.055601
45	121.7	12000.0	0.010144	0.057066
46	119.5	12000.0	0.009993	0.054954
47	120.0	12000.0	0.010002	0.055393
48	121.3	12000.0	0.010108	0.056574

NUMBER IN FLEET = 100.0 INTRO INTERVAL = 120.0
REPORT INTERVAL = 120.0 SCALE = 110.0 SHAPE = 1.00
MTBF = 100.0 NUMBER INTRO / PERIOD = 5.0

TABLE B-15

PERIOD	AVG FAIL	OPS HOURS	FAIL PER OPS HOUR	STD.DEV
1	4.2	600.0	0.007000	0.026585
2	10.1	1200.0	0.008396	0.039027
3	15.7	1800.0	0.008736	0.041246
4	21.3	2400.0	0.008875	0.043193
5	28.2	3000.0	0.009408	0.046873
6	33.3	3600.0	0.009264	0.047860
7	39.0	4200.0	0.009280	0.047713
8	45.2	4800.0	0.009411	0.048508
9	51.0	5400.0	0.009440	0.048986
10	56.8	6000.0	0.009800	0.052777
11	63.9	6600.0	0.009682	0.053061
12	69.1	7200.0	0.009597	0.050825
13	75.6	7800.0	0.009692	0.051574
14	82.5	8400.0	0.009824	0.052886
15	86.8	9000.0	0.009639	0.051005
16	94.8	9600.0	0.009870	0.053708
17	99.3	10200.0	0.009738	0.052810
18	106.8	10799.9	0.009887	0.053536
19	111.5	11399.9	0.009783	0.053045
20	118.2	11999.9	0.009850	0.053726
21	119.9	12000.0	0.009992	0.055489
22	119.7	12000.0	0.009975	0.054387
23	120.1	12000.0	0.010013	0.055174
24	121.0	12000.0	0.010083	0.055899
25	120.0	12000.0	0.009998	0.055479
26	120.5	12000.0	0.010044	0.055652
27	119.9	12000.0	0.009994	0.054689
28	119.8	12000.0	0.009979	0.055165
29	120.6	12000.0	0.010050	0.055573
30	120.5	12000.0	0.010048	0.055469
31	120.1	12000.0	0.010013	0.056092
32	118.9	12000.0	0.009906	0.053936
33	121.1	12000.0	0.010096	0.056227
34	119.1	12000.0	0.009921	0.054230
35	120.1	12000.0	0.010006	0.055348
36	119.0	12000.0	0.009917	0.054739
37	121.3	12000.0	0.010108	0.056218
38	119.7	12000.0	0.009973	0.054855
39	118.7	12000.0	0.009892	0.054296
40	119.4	12000.0	0.009946	0.054739
41	121.1	12000.0	0.010092	0.055758
42	118.8	12000.0	0.009898	0.054586
43	120.3	12000.0	0.010021	0.055714
44	120.2	12000.0	0.010017	0.055532
45	121.5	12000.0	0.010123	0.055936
46	119.6	12000.0	0.009965	0.054918
47	119.4	12000.0	0.009946	0.054783
48	121.4	12000.0	0.010113	0.056326

NUMBER IN FLEET = 100.0 INTRO INTERVAL = 120.0
REPORT INTERVAL = 120.0 SCALE = 108.9 SHAPE =5.00
MTBF = 100.0 NUMBER INTRO / PERIOD = 5.0

TABLE B-16

PERIOD	AVG FAIL	OPS HOURS	FAIL PER OPS HOUR	STD.DEV
1	0,8	600,0	0,000833	0,000429
2	1,5	1200,0	0,001271	0,000858
3	2,3	1800,0	0,001306	0,000890
4	3,8	2400,0	0,001563	0,001244
5	5,3	3000,0	0,001750	0,001483
6	6,1	3600,0	0,001708	0,001567
7	7,2	4200,0	0,001720	0,001558
8	8,0	4800,0	0,001677	0,001592
9	9,3	5400,0	0,001727	0,001754
10	11,0	6000,0	0,001829	0,001930
11	10,6	6600,0	0,001765	0,001661
12	12,3	7200,0	0,001705	0,001588
13	13,7	7800,0	0,001753	0,001695
14	14,8	8400,0	0,001765	0,001686
15	17,1	9000,0	0,001900	0,002011
16	17,9	9600,0	0,001862	0,001928
17	19,5	10200,0	0,001907	0,001899
18	21,0	10799,9	0,001947	0,002026
19	21,5	11399,9	0,001890	0,002041
20	22,8	11999,9	0,001902	0,001958
21	21,9	12000,0	0,001823	0,001876
22	22,1	12000,0	0,001844	0,001943
23	23,2	12000,0	0,001935	0,002129
24	24,1	12000,0	0,002010	0,002248
25	24,5	12000,0	0,002044	0,002347
26	24,2	12000,0	0,002015	0,002267
27	23,3	12000,0	0,001940	0,002102
28	24,6	12000,0	0,002048	0,002221
29	24,1	12000,0	0,002008	0,002129
30	23,7	12000,0	0,001977	0,002183
31	24,3	12000,0	0,002027	0,002300
32	23,6	12000,0	0,001967	0,002167
33	24,9	12000,0	0,002085	0,002359
34	23,1	12000,0	0,001927	0,002104
35	23,8	12000,0	0,001981	0,002193
36	24,0	12000,0	0,002000	0,002159
37	24,0	12000,0	0,001995	0,002191
38	25,5	12000,0	0,002125	0,002356
39	25,2	12000,0	0,002098	0,002369
40	23,3	12000,0	0,001940	0,002028
41	24,0	12000,0	0,002004	0,002248
42	23,8	12000,0	0,001983	0,002220
43	24,1	12000,0	0,002000	0,002337
44	23,5	12000,0	0,001958	0,002120
45	24,4	12000,0	0,002019	0,002293
46	24,2	12000,0	0,002012	0,002226
47	24,3	12000,0	0,002025	0,002334
48	24,1	12000,0	0,002010	0,002282

TABLE B-17

NUMBER IN FLEET = 100,0 INTRO INTERVAL = 120,0
REPORT INTERVAL = 120,0 SCALE = 553,9 SHAPE =1,50
MTBF = 5 0,0 NUMBER INTRO / PERIOD = 5,0

PERIOD	AVG FAIL	OPS HOURS	FAIL PER OPS HOUR	STD.DEV
1	0.3	600.0	0.000458	0.000097
2	0.8	1200.0	0.000667	0.000260
3	1.9	1800.0	0.001056	0.000599
4	3.2	2400.0	0.001344	0.000967
5	4.3	3000.0	0.001442	0.000963
6	5.6	3600.0	0.001549	0.001281
7	7.0	4200.0	0.001673	0.001431
8	7.7	4800.0	0.001609	0.001512
9	8.4	5400.0	0.001556	0.001349
10	10.7	6000.0	0.001788	0.001814
11	11.5	6600.0	0.001735	0.001658
12	12.6	7200.0	0.001747	0.001674
13	12.7	7800.0	0.001625	0.001436
14	14.3	8400.0	0.001705	0.001592
15	16.4	9000.0	0.001819	0.001876
16	18.2	9600.0	0.001898	0.002019
17	18.0	10200.0	0.001767	0.001615
18	19.9	10799.9	0.001843	0.001805
19	20.8	11399.9	0.001822	0.001874
20	23.4	11999.9	0.001948	0.002106
21	22.3	12000.0	0.001862	0.001866
22	22.6	12000.0	0.001885	0.002060
23	23.0	12000.0	0.001912	0.002027
24	25.5	12000.0	0.002127	0.002582
25	23.2	12000.0	0.001935	0.002062
26	24.0	12000.0	0.001995	0.002182
27	24.4	12000.0	0.002033	0.002321
28	23.9	12000.0	0.001994	0.002132
29	24.8	12000.0	0.002067	0.002368
30	23.7	12000.0	0.001973	0.002140
31	23.5	12000.0	0.001960	0.002127
32	24.5	12000.0	0.002040	0.002286
33	23.7	12000.0	0.001975	0.002107
34	24.3	12000.0	0.002025	0.002255
35	23.4	12000.0	0.001950	0.002189
36	24.2	12000.0	0.002017	0.002206
37	23.8	12000.0	0.001979	0.002139
38	25.1	12000.0	0.002090	0.002390
39	25.0	12000.0	0.002081	0.002299
40	23.8	12000.0	0.001987	0.002143
41	23.6	12000.0	0.001965	0.002180
42	24.5	12000.0	0.002069	0.002378
43	24.2	12000.0	0.002012	0.002283
44	24.0	12000.0	0.001995	0.002114
45	23.9	12000.0	0.001992	0.002195
46	24.0	12000.0	0.001998	0.002169
47	24.8	12000.0	0.002062	0.002367
48	23.5	12000.0	0.001961	0.002178

TABLE B-18

NUMBER IN FLEET = 100.0 INTRO INTERVAL = 120.0
REPORT INTERVAL = 120.0 SCALE = 564.2 SHAPE =2.00
MTBF = 500.0 NUMBER INTRO / PERIOD = 5.0

PERIOD	AVG FAIL	OPS HOURS	FAIL PER OPS HOUR	STD.DEV
1	0,1	600,0	0,000125	0,000035
2	0,4	1200,0	0,000333	0,000079
3	1,3	1800,0	0,000722	0,000257
4	2,2	2400,0	0,000917	0,000439
5	4,5	3000,0	0,001500	0,001206
6	5,3	3600,0	0,001479	0,001123
7	5,3	4200,0	0,001494	0,001188
8	7,2	4800,0	0,001500	0,001213
9	8,6	5400,0	0,001588	0,001439
10	9,6	6000,0	0,001608	0,001531
11	11,5	6600,0	0,001758	0,001736
12	12,4	7200,0	0,001715	0,001602
13	13,0	7800,0	0,001670	0,001565
14	14,0	8400,0	0,001673	0,001466
15	15,7	9000,0	0,001742	0,001729
16	17,0	9600,0	0,001768	0,001748
17	17,6	10200,0	0,001723	0,001630
18	19,2	10799,9	0,001773	0,001643
19	22,3	11399,9	0,001952	0,002096
20	21,9	11999,9	0,001827	0,001909
21	22,7	12000,0	0,001894	0,001930
22	22,8	12000,0	0,001900	0,001995
23	24,3	12000,0	0,002023	0,002323
24	24,7	12000,0	0,002054	0,002353
25	23,4	12000,0	0,001950	0,002159
26	23,9	12000,0	0,001994	0,002152
27	24,0	12000,0	0,002000	0,002182
28	24,1	12000,0	0,002010	0,002325
29	24,0	12000,0	0,001998	0,002066
30	24,8	12000,0	0,002065	0,002400
31	23,9	12000,0	0,001992	0,002224
32	23,5	12000,0	0,001956	0,002063
33	24,3	12000,0	0,002027	0,002207
34	24,5	12000,0	0,002038	0,002302
35	23,5	12000,0	0,001960	0,002213
36	23,7	12000,0	0,001975	0,002140
37	24,5	12000,0	0,002044	0,002271
38	23,7	12000,0	0,001971	0,002153
39	24,6	12000,0	0,002050	0,002275
40	24,5	12000,0	0,002038	0,002201
41	24,0	12000,0	0,002000	0,002225
42	24,8	12000,0	0,002069	0,002350
43	23,7	12000,0	0,001975	0,002174
44	24,7	12000,0	0,002054	0,002354
45	23,8	12000,0	0,001983	0,002068
46	23,2	12000,0	0,001933	0,002142
47	28,0	12000,0	0,002081	0,002376
48	23,4	12000,0	0,001948	0,002133

NUMBER IN FLEET = 100,0 INTRO INTERVAL = 120,0
REPORT INTERVAL = 120,0 SCALE = 559,0 SHAPE =3,00
MTBF = 500,0 NUMBER INTRO / PERIOD = 5,0

TABLE B-19

PERIOD	AVG FAIL	OPS HOURS	FAIL PER OPS HOUR	STD.DEV
1	0.	600.0	0.	0.
2	0.3	1200.0	0.000229	0.000028
3	0.7	1800.0	0.000403	0.000097
4	2.4	2400.0	0.000990	0.000505
5	4.1	3000.0	0.001383	0.001015
6	5.4	3600.0	0.001507	0.001208
7	5.7	4200.0	0.001357	0.000989
8	7.1	4800.0	0.001469	0.001144
9	8.8	5400.0	0.001620	0.001494
10	9.5	6000.0	0.001608	0.001516
11	11.0	6600.0	0.001670	0.001530
12	13.0	7200.0	0.001799	0.001757
13	12.2	7800.0	0.001561	0.001332
14	14.3	8400.0	0.001705	0.001586
15	15.6	9000.0	0.001736	0.001693
16	17.0	9600.0	0.001766	0.001703
17	17.3	10200.0	0.001696	0.001669
18	19.3	10799.9	0.001785	0.001690
19	21.7	11399.9	0.001904	0.001940
20	22.0	11999.9	0.001835	0.001921
21	22.4	12000.0	0.001867	0.001918
22	22.9	12000.0	0.001906	0.001943
23	24.8	12000.0	0.002065	0.002431
24	24.5	12000.0	0.002046	0.002345
25	24.4	12000.0	0.002031	0.002322
26	22.8	12000.0	0.001898	0.001977
27	24.0	12000.0	0.001998	0.002186
28	24.6	12000.0	0.002065	0.002363
29	24.3	12000.0	0.002023	0.002190
30	23.3	12000.0	0.001944	0.002173
31	24.8	12000.0	0.002065	0.002340
32	23.3	12000.0	0.001946	0.002003
33	24.6	12000.0	0.002050	0.002276
34	23.2	12000.0	0.001935	0.002100
35	25.5	12000.0	0.002127	0.002607
36	22.3	12000.0	0.001855	0.001912
37	25.3	12000.0	0.002110	0.002396
38	22.8	12000.0	0.001900	0.001929
39	25.0	12000.0	0.002079	0.002486
40	24.5	12000.0	0.002037	0.002237
41	23.8	12000.0	0.001981	0.002133
42	25.9	12000.0	0.002156	0.002535
43	23.1	12000.0	0.001925	0.002066
44	23.8	12000.0	0.001987	0.002224
45	23.5	12000.0	0.001943	0.002044
46	24.3	12000.0	0.002029	0.002344
47	23.4	12000.0	0.001948	0.002080
48	24.1	12000.0	0.002008	0.002333

NUMBER IN FLEET = 100.0 INTRO INTERVAL = 120.0
REPORT INTERVAL = 120.0 SCALE = 551.6 SHAPE =4.00
MTBF = 500.0 NUMBER INTRO / PERIOD = 5.0

TABLE B-20

PERIOD	AVG FAIL	OPS HOURS	FAIL PER OPS HOUR	STD.DEV
1	0.	600,0	0.	0.
2	0,2	1200,0	0,000188	0,000016
3	0,5	1800,0	0,000264	0,000045
4	2,1	2400,0	0,000854	0,000395
5	4,5	3000,0	0,001500	0,001193
6	5,2	3600,0	0,001444	0,001118
7	5,8	4200,0	0,001381	0,001015
8	6,9	4800,0	0,001427	0,001092
9	8,5	5400,0	0,001588	0,001398
10	9,6	6000,0	0,001608	0,001527
11	10,5	6600,0	0,001614	0,001481
12	12,8	7200,0	0,001774	0,001713
13	12,7	7800,0	0,001628	0,001437
14	14,8	8400,0	0,001759	0,001719
15	15,9	9000,0	0,001661	0,001522
16	16,5	9600,0	0,001716	0,001645
17	18,0	10200,0	0,001760	0,001747
18	19,4	10799,9	0,001794	0,001716
19	21,0	11399,9	0,001844	0,001838
20	21,8	11999,9	0,001817	0,001855
21	22,5	12000,0	0,001875	0,001935
22	23,1	12000,0	0,001923	0,001993
23	25,3	12000,0	0,002108	0,002521
24	24,6	12000,0	0,002052	0,002364
25	23,2	12000,0	0,001933	0,002102
26	22,8	12000,0	0,001904	0,002017
27	24,6	12000,0	0,002052	0,002298
28	24,6	12000,0	0,002050	0,002329
29	24,5	12000,0	0,002037	0,002266
30	23,5	12000,0	0,001960	0,002143
31	24,3	12000,0	0,002029	0,002278
32	23,7	12000,0	0,001977	0,002145
33	24,0	12000,0	0,001998	0,002157
34	24,2	12000,0	0,002019	0,002219
35	24,5	12000,0	0,002044	0,002453
36	22,7	12000,0	0,001888	0,001953
37	24,8	12000,0	0,002067	0,002256
38	23,7	12000,0	0,001971	0,002114
39	24,5	12000,0	0,002042	0,002383
40	24,0	12000,0	0,002000	0,002158
41	24,3	12000,0	0,002027	0,002226
42	25,4	12000,0	0,002115	0,002443
43	23,5	12000,0	0,001958	0,002157
44	23,1	12000,0	0,001927	0,002091
45	24,6	12000,0	0,002050	0,002241
46	24,7	12000,0	0,002054	0,002340
47	23,2	12000,0	0,001935	0,002055
48	23,3	12000,0	0,001944	0,002219

TABLE B-21

NUMBER IN FLEET = 100,0 INTRO INTERVAL = 120,0
AMORT INTERVAL = 120,0 SCALE = 544,6 SHAPE =5,00
MTBF = 5 0,0 NUMBER INTRO / PERIOD = 5,0

PERIOD	AVG FAIL	OPS HOURS	FAIL PER OPS HOUR	STD.DEV
1	0.3	600.0	0.000417	0.000084
2	0.5	1200.0	0.000375	0.000098
3	0.9	1800.0	0.000514	0.000123
4	1.5	2400.0	0.000635	0.000221
5	1.9	3000.0	0.000625	0.000193
6	2.7	3600.0	0.000743	0.000283
7	2.7	4200.0	0.000643	0.000195
8	3.9	4800.0	0.000802	0.000330
9	4.4	5400.0	0.000810	0.000360
10	4.9	6000.0	0.000808	0.000374
11	5.3	6600.0	0.000799	0.000374
12	6.1	7200.0	0.000851	0.000363
13	7.2	7800.0	0.000920	0.000480
14	7.0	8400.0	0.000835	0.000388
15	7.0	9000.0	0.000778	0.000347
16	7.4	9600.0	0.000768	0.000316
17	8.8	10200.0	0.000863	0.000416
18	8.8	10799.9	0.000813	0.000360
19	9.8	11399.9	0.000857	0.000411
20	10.4	11999.9	0.000863	0.000417
21	11.3	12000.0	0.000940	0.000464
22	11.4	12000.0	0.000948	0.000469
23	11.5	12000.0	0.000960	0.000525
24	12.0	12000.0	0.000996	0.000503
25	12.6	12000.0	0.001052	0.000606
26	11.6	12000.0	0.000969	0.000536
27	12.2	12000.0	0.001019	0.000567
28	12.6	12000.0	0.001054	0.000605
29	12.3	12000.0	0.001021	0.000588
30	12.4	12000.0	0.001031	0.000578
31	10.6	12000.0	0.000885	0.000408
32	11.0	12000.0	0.000912	0.000464
33	11.3	12000.0	0.000940	0.000506
34	12.1	12000.0	0.001006	0.000595
35	11.3	12000.0	0.000942	0.000487
36	11.3	12000.0	0.000940	0.000495
37	11.9	12000.0	0.000990	0.000557
38	12.4	12000.0	0.001031	0.000583
39	11.9	12000.0	0.000990	0.000541
40	12.6	12000.0	0.001052	0.000631
41	11.8	12000.0	0.000981	0.000521
42	12.0	12000.0	0.000993	0.000550
43	12.5	12000.0	0.001044	0.000611
44	11.9	12000.0	0.000988	0.000557
45	11.0	12000.0	0.000913	0.000427
46	12.2	12000.0	0.001019	0.000565
47	12.4	12000.0	0.001035	0.000590
48	12.4	12000.0	0.001033	0.000585

NUMBER IN FLEET = 100.0 INTRO INTERVAL = 120.0
REPORT INTERVAL = 120.0 SCALE =1107.7 SHAPE =1.50
MTBF =1000.0 NUMBER INTRO / PERIOD = 5.0

TABLE B-22

Reproduced from best available copy.

PERIOD	AVG FAIL	OPS HOURS	FAIL PER OPS HOUR	STD.DEV
1	3,2	600,0	0,000250	0,000033
2	4,2	1200,0	0,000146	0,000010
3	4,5	1800,0	0,000264	0,000048
4	5,9	2400,0	0,000354	0,000061
5	1,6	3000,0	0,000533	0,000152
6	1,6	3600,0	0,000444	0,000098
7	2,5	4200,0	0,000667	0,000222
8	2,7	4800,0	0,000557	0,000153
9	3,6	5400,0	0,000671	0,000238
10	4,8	6000,0	0,000792	0,000350
11	5,1	6600,0	0,000769	0,000322
12	5,3	7200,0	0,000740	0,000311
13	5,8	7800,0	0,000744	0,000301
14	6,9	8400,0	0,000815	0,000355
15	7,3	9000,0	0,000808	0,000390
16	7,6	9600,0	0,000794	0,000364
17	8,0	10200,0	0,000782	0,000333
18	8,6	10799,9	0,000794	0,000342
19	8,5	11399,9	0,000770	0,000314
20	10,0	11999,9	0,000829	0,000395
21	10,5	12000,0	0,000877	0,000441
22	11,5	12000,0	0,000956	0,000471
23	11,2	12000,0	0,000931	0,000451
24	11,6	12000,0	0,000971	0,000513
25	12,6	12000,0	0,001050	0,000586
26	12,1	12000,0	0,001013	0,000558
27	13,0	12000,0	0,001083	0,000616
28	11,9	12000,0	0,000990	0,000566
29	11,8	12000,0	0,000985	0,000554
30	12,8	12000,0	0,001067	0,000620
31	11,1	12000,0	0,000925	0,000470
32	11,8	12000,0	0,000985	0,000503
33	11,5	12000,0	0,000900	0,000455
34	11,5	12000,0	0,000956	0,000520
35	12,5	12000,0	0,001040	0,000620
36	11,1	12000,0	0,000927	0,000487
37	12,5	12000,0	0,001044	0,000636
38	12,3	12000,0	0,001027	0,000603
39	11,5	12000,0	0,000958	0,000515
40	11,8	12000,0	0,000983	0,000527
41	12,3	12000,0	0,001025	0,000539
42	12,6	12000,0	0,001050	0,000627
43	11,5	12000,0	0,000948	0,000491
44	12,8	12000,0	0,001063	0,000635
45	11,7	12000,0	0,000975	0,000550
46	11,7	12000,0	0,000973	0,000531
47	11,5	12000,0	0,000954	0,000454
48	12,8	12000,0	0,001063	0,000628

TABLE B-23

NUMBER IN FLEET = 100,0 INTRO INTERVAL = 120,0
REPORT INTERVAL = 120,0 SCALE =1128,4 SHAPE =2,00
NTEP =1000,0 NUMBER INTRO / PERIOD = 5,0

PERIOD	AVG FAIL	OPS HOURS	FAIL PER OPS HOUR	STD.DEV
1	0.	600.0	0.	0.
2	0.1	1200.0	0.000063	0.000001
3	0.2	1800.0	0.000111	0.000008
4	0.4	2400.0	0.000156	0.000018
5	0.7	3000.0	0.000225	0.000022
6	1.3	3600.0	0.000361	0.000076
7	1.9	4200.0	0.000458	0.000099
8	2.5	4800.0	0.000526	0.000141
9	3.2	5400.0	0.000597	0.000183
10	4.0	6000.0	0.000663	0.000234
11	4.8	6600.0	0.000720	0.000282
12	5.3	7200.0	0.000736	0.000275
13	5.6	7800.0	0.000721	0.000314
14	6.0	8400.0	0.000711	0.000292
15	7.2	9000.0	0.000803	0.000366
16	7.4	9600.0	0.000768	0.000340
17	8.0	10200.0	0.000782	0.000332
18	8.2	10799.9	0.000759	0.000313
19	9.0	11399.9	0.000789	0.000348
20	10.1	11999.9	0.000844	0.000389
21	8.8	12000.0	0.000735	0.000295
22	10.9	12000.0	0.000910	0.000460
23	12.3	12000.0	0.001021	0.000568
24	12.4	12000.0	0.001033	0.000621
25	11.8	12000.0	0.000981	0.000512
26	12.1	12000.0	0.001006	0.000540
27	11.8	12000.0	0.000985	0.000520
28	12.7	12000.0	0.001058	0.000617
29	12.6	12000.0	0.001050	0.000595
30	11.5	12000.0	0.000958	0.000521
31	13.0	12000.0	0.001085	0.000685
32	11.5	12000.0	0.000965	0.000500
33	11.9	12000.0	0.000990	0.000535
34	11.0	12000.0	0.000915	0.000457
35	11.1	12000.0	0.000923	0.000468
36	12.1	12000.0	0.001013	0.000573
37	12.8	12000.0	0.001067	0.000655
38	11.5	12000.0	0.000981	0.000540
39	12.2	12000.0	0.001019	0.000574
40	11.6	12000.0	0.000967	0.000521
41	12.5	12000.0	0.001038	0.000597
42	11.9	12000.0	0.000994	0.000547
43	11.9	12000.0	0.000986	0.000527
44	12.3	12000.0	0.001023	0.000572
45	11.5	12000.0	0.000960	0.000493
46	11.9	12000.0	0.000994	0.000564
47	12.5	12000.0	0.001038	0.000525
48	12.1	12000.0	0.001013	0.000515

TABLE B-24

NUMBER IN FLEET = 100.0 INTRO INTERVAL = 120.0
REPORT INTERVAL = 120.0 SCALE =1119.6 SHAPE =3.00
MTBF =1000.0 NUMBER INTRO / PERIOD = 5.0

PERIOD	AVG FAIL	OPS HOURS	FAIL PER OPS HOUR	STD.DEV
1	0.	600,0	0,	0,
2	0,	1200,0	0,	0,
3	0,2	1800,0	0,000097	0,000036
4	0,1	2400,0	0,000052	0,000031
5	0,4	3000,0	0,000133	0,000014
6	0,8	3600,0	0,000229	0,000021
7	1,6	4200,0	0,000369	0,000022
8	2,3	4800,0	0,000484	0,000119
9	3,3	5400,0	0,000602	0,000176
10	4,2	6000,0	0,000704	0,000269
11	4,5	6600,0	0,000686	0,000250
12	4,8	7200,0	0,000663	0,000242
13	5,7	7800,0	0,000734	0,000286
14	6,2	8400,0	0,000738	0,000339
15	5,6	9000,0	0,000669	0,000264
16	7,9	9600,0	0,000818	0,000372
17	8,1	10200,0	0,000799	0,000343
18	8,2	10799,9	0,000759	0,000319
19	9,1	11399,9	0,000803	0,000354
20	9,1	11999,9	0,000760	0,000316
21	9,8	12000,0	0,000815	0,000354
22	10,6	12000,0	0,000883	0,000429
23	11,6	12000,0	0,000983	0,000555
24	12,5	12000,0	0,001044	0,000600
25	11,7	12000,0	0,000977	0,000539
26	11,6	12000,0	0,000965	0,000512
27	13,0	12000,0	0,001081	0,000592
28	12,8	12000,0	0,001065	0,000636
29	12,5	12000,0	0,001038	0,000598
30	12,5	12000,0	0,001044	0,000596
31	11,5	12000,0	0,000963	0,000537
32	11,7	12000,0	0,000975	0,000513
33	11,1	12000,0	0,000927	0,000462
34	11,4	12000,0	0,000952	0,000494
35	11,7	12000,0	0,000975	0,000524
36	12,5	12000,0	0,001040	0,000628
37	12,5	12000,0	0,001052	0,000633
38	11,7	12000,0	0,000973	0,000552
39	12,4	12000,0	0,001031	0,000552
40	12,0	12000,0	0,001002	0,000572
41	12,0	12000,0	0,000996	0,000554
42	11,8	12000,0	0,000979	0,000522
43	11,5	12000,0	0,000969	0,000511
44	11,9	12000,0	0,000994	0,000547
45	12,0	12000,0	0,000996	0,000554
46	11,9	12000,0	0,000994	0,000563
47	13,1	12000,0	0,001096	0,000638
48	12,1	12000,0	0,001006	0,000552

TABLE B-25

NUMBER IN FLEET = 100.0 INTRO INTERVAL = 120,0
REPORT INTERVAL = 120,0 SCALE =1103.3 SHAPE =4.00
MTBF =1000,0 NUMBER INTRO / PERIOD = 5,0

PERIOD	AVG FAIL	OPS HOURS	FAIL PER OPS HOUR	STD.DEV
1	0.	600.0	0.	0.
2	0.	1200.0	0.	0.
3	0.0	1800.0	0.000014	0.000000
4	0.2	2400.0	0.000094	0.000005
5	0.1	3000.0	0.000042	0.000001
6	0.6	3600.0	0.000167	0.000018
7	1.4	4200.0	0.000339	0.000055
8	2.0	4800.0	0.000411	0.000095
9	3.5	5400.0	0.000644	0.000209
10	4.1	6000.0	0.000686	0.000246
11	4.9	6600.0	0.000742	0.000289
12	4.4	7200.0	0.000611	0.000212
13	5.8	7800.0	0.000737	0.000298
14	5.9	8400.0	0.000702	0.000280
15	6.3	9000.0	0.000703	0.000303
16	7.2	9600.0	0.000753	0.000311
17	8.0	10200.0	0.000787	0.000339
18	8.6	10799.9	0.000794	0.000353
19	8.5	11399.9	0.000750	0.000304
20	9.9	11999.9	0.000827	0.000371
21	9.5	12000.0	0.000790	0.000331
22	11.2	12000.0	0.000933	0.000486
23	10.6	12000.0	0.000883	0.000457
24	12.5	12000.0	0.001040	0.000594
25	12.0	12000.0	0.000998	0.000569
26	12.3	12000.0	0.001027	0.000563
27	13.1	12000.0	0.001094	0.000636
28	12.9	12000.0	0.001075	0.000625
29	12.5	12000.0	0.001040	0.000585
30	11.3	12000.0	0.000944	0.000511
31	11.6	12000.0	0.000969	0.000528
32	11.8	12000.0	0.000983	0.000542
33	10.6	12000.0	0.000881	0.000424
34	12.4	12000.0	0.001029	0.000562
35	12.0	12000.0	0.000996	0.000561
36	12.2	12000.0	0.001017	0.000594
37	12.4	12000.0	0.001031	0.000566
38	13.0	12000.0	0.001079	0.000563
39	12.1	12000.0	0.001006	0.000564
40	11.3	12000.0	0.000942	0.000490
41	11.9	12000.0	0.000994	0.000557
42	11.7	12000.0	0.000975	0.000530
43	11.9	12000.0	0.000988	0.000533
44	11.7	12000.0	0.000973	0.000516
45	12.9	12000.0	0.001077	0.000548
46	11.5	12000.0	0.000953	0.000506
47	12.8	12000.0	0.001065	0.000613
48	12.0	12000.0	0.001000	0.000555

NUMBER IN FLEET = 100.0 INTRO INTERVAL = 120.0
REPORT INTERVAL = 120.0 SCALE =1089.1 SHAPE =5.00
MTBF =1000.0 NUMBER INTRO / PERIOD = 5.0

TABLE B-26

PERIOD	AVG FAIL	OPS HOURS	FAIL PER OPS HOUR	STD.DEV
1	3,2	6000,0	0,000250	0,000033
2	3,2	12000,0	0,000125	0,000018
3	3,4	18000,0	0,000194	0,000026
4	3,4	24000,0	0,000167	0,000014
5	3,6	30000,0	0,000258	0,000035
6	1,9	36000,0	0,000264	0,000036
7	1,3	42000,0	0,000310	0,000048
8	1,3	48000,0	0,000261	0,000037
9	1,5	54000,0	0,000287	0,000037
10	1,6	60000,0	0,000271	0,000042
11	2,5	66000,0	0,000398	0,000082
12	2,1	72000,0	0,000295	0,000046
13	2,8	78000,0	0,000362	0,000087
14	3,4	84000,0	0,000405	0,000081
15	3,5	90000,0	0,000392	0,000088
16	3,3	96000,0	0,000349	0,000074
17	4,5	102000,0	0,000449	0,000103
18	3,9	107999,9	0,000366	0,000073
19	4,4	113999,9	0,000386	0,000086
20	4,8	119999,9	0,000398	0,000066
21	4,7	120000,0	0,000394	0,000087
22	5,1	120000,0	0,000429	0,000102
23	5,3	120000,0	0,000444	0,000105
24	4,6	120000,0	0,000381	0,000078
25	4,6	120000,0	0,000388	0,000076
26	4,8	120000,0	0,000398	0,000093
27	5,4	120000,0	0,000446	0,000117
28	5,6	120000,0	0,000465	0,000113
29	6,0	120000,0	0,000500	0,000129
30	6,3	120000,0	0,000527	0,000158
31	5,7	120000,0	0,000477	0,000126
32	4,9	120000,0	0,000412	0,000095
33	6,5	120000,0	0,000544	0,000161
34	5,8	120000,0	0,000483	0,000125
35	6,0	120000,0	0,000498	0,000137
36	5,8	120000,0	0,000485	0,000126
37	6,3	120000,0	0,000529	0,000163
38	6,2	120000,0	0,000515	0,000134
39	5,6	120000,0	0,000465	0,000115
40	7,0	120000,0	0,000585	0,000185
41	6,1	120000,0	0,000510	0,000139
42	5,8	120000,0	0,000479	0,000125
43	6,1	120000,0	0,000504	0,000154
44	6,7	120000,0	0,000560	0,000159
45	5,9	120000,0	0,000490	0,000146
46	6,1	120000,0	0,000513	0,000134
47	6,0	120000,0	0,000509	0,000146
48	6,4	120000,0	0,000529	0,000153

TABLE 3-27

NUMBER IN FLEET = 100,0 INTRO INTERVAL = 120,0
REPORT INTERVAL = 120,0 SCALE =2215,5 SHAPE =1,50
MTBF =2000,0 NUMBER INTRO / PERIOD = 5,0

PERIOD	AVG FAIL	OPS HOURS	FAIL PER OPS HOUR	STD.DEV
1	0.	600.0	0.	0.
2	0.2	1200.0	0.000146	0.000013
3	0.1	1800.0	0.000069	0.000012
4	0.2	2400.0	0.000063	0.000004
5	0.4	3000.0	0.000117	0.000008
6	0.5	3600.0	0.000146	0.000009
7	0.6	4200.0	0.000149	0.000012
8	1.0	4800.0	0.000208	0.000023
9	1.2	5400.0	0.000218	0.000020
10	1.3	6000.0	0.000221	0.000026
11	1.6	6600.0	0.000235	0.000025
12	1.5	7200.0	0.000208	0.000026
13	2.5	7800.0	0.000317	0.000049
14	2.1	8400.0	0.000250	0.000036
15	2.8	9000.0	0.000314	0.000052
16	3.6	9600.0	0.000370	0.000069
17	3.2	10200.0	0.000316	0.000054
18	3.8	10799.9	0.000352	0.000078
19	3.9	11399.9	0.000340	0.000062
20	4.8	11999.9	0.000400	0.000086
21	4.1	12000.0	0.000346	0.000067
22	5.0	12000.0	0.000415	0.000087
23	4.6	12000.0	0.000385	0.000086
24	4.8	12000.0	0.000400	0.000092
25	5.4	12000.0	0.000452	0.000116
26	5.0	12000.0	0.000417	0.000094
27	4.9	12000.0	0.000406	0.000087
28	5.5	12000.0	0.000456	0.000118
29	5.1	12000.0	0.000429	0.000102
30	5.9	12000.0	0.000494	0.000132
31	5.7	12000.0	0.000475	0.000136
32	6.8	12000.0	0.000565	0.000168
33	5.7	12000.0	0.000473	0.000122
34	6.1	12000.0	0.000506	0.000145
35	6.2	12000.0	0.000519	0.000145
36	5.9	12000.0	0.000492	0.000135
37	6.1	12000.0	0.000510	0.000148
38	5.9	12000.0	0.000492	0.000129
39	6.3	12000.0	0.000521	0.000136
40	6.3	12000.0	0.000521	0.000157
41	6.1	12000.0	0.000508	0.000137
42	5.2	12000.0	0.000433	0.000092
43	6.9	12000.0	0.000573	0.000179
44	6.7	12000.0	0.000560	0.000170
45	5.9	12000.0	0.000488	0.000129
46	6.4	12000.0	0.000531	0.000153
47	5.5	12000.0	0.000455	0.000120
48	6.4	12000.0	0.000535	0.000168

NUMBER IN FLEET = 100.0 INTRO INTERVAL = 120.0
REPORT INTERVAL = 120.0 SCALE =2256.8 SHAPE =2.00
MTBF =2000.0 NUMBER INTRO / PERIOD = 5.0

TABLE B-28

Reproduced from best available copy.

PERIOD	AVG FAIL	OPS HOURS	FAIL PER OPS HOUR	STD.DEV
1	0.	600.0	0.	0.
2	0.	1200.0	0.	0.
3	0.0	1800.0	0.000014	0.000000
4	0.1	2400.0	0.000031	0.000000
5	0.2	3000.0	0.000067	0.000003
6	0.1	3600.0	0.000021	0.000000
7	0.2	4200.0	0.000042	0.000001
8	0.5	4800.0	0.000094	0.000005
9	0.5	5400.0	0.000097	0.000004
10	0.9	6000.0	0.000154	0.000011
11	1.0	6600.0	0.000144	0.000010
12	1.3	7200.0	0.000181	0.000017
13	1.4	7800.0	0.000179	0.000015
14	1.8	8400.0	0.000208	0.000025
15	2.0	9000.0	0.000219	0.000023
16	2.5	9600.0	0.000260	0.000035
17	3.4	10200.0	0.000331	0.000058
18	3.3	10799.9	0.000308	0.000051
19	3.4	11399.9	0.000303	0.000053
20	4.2	11999.9	0.000348	0.000068
21	4.4	12000.0	0.000363	0.000073
22	4.4	12000.0	0.000369	0.000075
23	4.6	12000.0	0.000387	0.000083
24	5.1	12000.0	0.000427	0.000105
25	5.1	12000.0	0.000429	0.000116
26	5.6	12000.0	0.000469	0.000121
27	5.1	12000.0	0.000429	0.000099
28	5.5	12000.0	0.000456	0.000124
29	5.7	12000.0	0.000477	0.000119
30	6.6	12000.0	0.000550	0.000156
31	6.1	12000.0	0.000508	0.000149
32	5.1	12000.0	0.000429	0.000105
33	5.5	12000.0	0.000460	0.000116
34	6.5	12000.0	0.000544	0.000163
35	6.7	12000.0	0.000558	0.000157
36	5.6	12000.0	0.000550	0.000171
37	5.8	12000.0	0.000483	0.000136
38	6.6	12000.0	0.000546	0.000163
39	6.3	12000.0	0.000527	0.000150
40	5.8	12000.0	0.000481	0.000122
41	6.2	12000.0	0.000519	0.000151
42	5.4	12000.0	0.000454	0.000107
43	5.9	12000.0	0.000496	0.000124
44	5.9	12000.0	0.000488	0.000124
45	5.8	12000.0	0.000485	0.000128
46	6.0	12000.0	0.000498	0.000137
47	6.4	12000.0	0.000529	0.000150
48	6.3	12000.0	0.000523	0.000139

NUMBER IN FLEET = 100.0 INTRO INTERVAL = 120.0
REPORT INTERVAL = 120.0 SCALE =2239.7 SHAPE =3.00
MTBF =2000.0 NUMBER INTRO / PERIOD = 5.0

TABLE B-29

PERIOD	AVG FAIL	OPS HOURS	FAIL PER OPS HOUR	STD.DEV
1	0.	600.0	0.	0.
2	0.	1200.0	0.	0.
3	0.	1800.0	0.	0.
4	0.	2400.0	0.	0.
5	0.1	3000.0	0.000017	0.000000
6	0.1	3600.0	0.000035	0.000001
7	0.2	4200.0	0.000036	0.000001
8	0.1	4800.0	0.000010	0.000000
9	0.3	5400.0	0.000051	0.000002
10	0.5	6000.0	0.000075	0.000002
11	0.7	6600.0	0.000098	0.000005
12	0.9	7200.0	0.000128	0.000009
13	1.3	7800.0	0.000173	0.000016
14	1.1	8400.0	0.000134	0.000009
15	2.2	9000.0	0.000247	0.000020
16	1.9	9600.0	0.000201	0.000022
17	2.9	10200.0	0.000284	0.000043
18	3.0	10799.9	0.000280	0.000042
19	4.2	11399.9	0.000368	0.000078
20	3.9	11999.9	0.000327	0.000059
21	4.4	12000.0	0.000365	0.000077
22	4.1	12000.0	0.000346	0.000066
23	5.1	12000.0	0.000427	0.000091
24	4.8	12000.0	0.000402	0.000102
25	5.5	12000.0	0.000456	0.000118
26	5.6	12000.0	0.000467	0.000138
27	5.6	12000.0	0.000469	0.000121
28	5.3	12000.0	0.000438	0.000106
29	6.1	12000.0	0.000506	0.000128
30	5.6	12000.0	0.000465	0.000121
31	6.5	12000.0	0.000542	0.000168
32	6.2	12000.0	0.000517	0.000133
33	5.5	12000.0	0.000456	0.000118
34	6.3	12000.0	0.000521	0.000146
35	6.4	12000.0	0.000533	0.000155
36	6.9	12000.0	0.000579	0.000189
37	6.6	12000.0	0.000546	0.000175
38	5.9	12000.0	0.000496	0.000137
39	6.1	12000.0	0.000504	0.000135
40	6.0	12000.0	0.000500	0.000152
41	5.6	12000.0	0.000465	0.000120
42	5.1	12000.0	0.000425	0.000089
43	5.5	12000.0	0.000456	0.000115
44	6.0	12000.0	0.000500	0.000131
45	6.1	12000.0	0.000512	0.000138
46	5.9	12000.0	0.000488	0.000133
47	6.6	12000.0	0.000546	0.000153
48	6.3	12000.0	0.000527	0.000147

TABLE B-30

NUMBER IN FLEET = 100.0 INTRO INTERVAL = 120.0
REPORT INTERVAL = 120.0 SCALE =2206.5 SHAPE =4.00
MTBF =2000.0 NUMBER INTRO / PERIOD = 5.0

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TABLE B-31

PERIOD	AVG FAIL	OPS HOURS	FAIL PER OPS HOUR	STD.DEV
1	0.	5[illegible]0.0	0.	0.
2	0.	12[illegible]0.0	0.	0.
3	0.	18[illegible]0.0	0.	0.
4	0.	24[illegible]0.0	0.	0.
5	0.	30[illegible]0.0	0.	0.
6	0.1	3600.0	0.000014	0.000[illegible]
7	0.1	4200.0	0.000012	0.000[illegible]
8	0.2	4800.0	0.000036	0.000[illegible]
9	0.1	5400.0	0.000019	0.000[illegible]
10	0.1	6000.0	0.000021	0.000[illegible]
11	0.5	6600.0	0.000072	0.000[illegible]
12	0.6	7200.0	0.000083	0.000[illegible]
13	1.0	7800.0	0.000122	0.000[illegible]
14	1.7	8400.0	0.000196	0.000019
15	1.3	9000.0	0.000144	0.000011
16	2.3	9600.0	0.000245	0.000028
17	2.3	10200.0	0.000223	0.000027
18	3.2	10799.9	0.000294	0.000047
19	4.2	11399.9	0.000366	0.000074
20	4.1	11999.9	0.000342	0.000064
21	4.4	12000.0	0.000365	0.000074
22	4.7	12000.0	0.000390	0.000090
23	5.0	12000.0	0.000415	0.000097
24	4.8	12000.0	0.000402	0.000094
25	5.3	12000.0	0.000442	0.000115
26	5.6	12000.0	0.000465	0.000118
27	5.4	12000.0	0.000448	0.000115
28	6.0	12000.0	0.000498	0.000139
29	5.4	12000.0	0.000448	0.000124
30	6.4	12000.0	0.000538	0.000169
31	5.9	12000.0	0.000490	0.000130
32	6.1	12000.0	0.000508	0.000125
33	6.1	12000.0	0.000513	0.000147
34	6.3	12000.0	0.000527	0.000147
35	6.9	12000.0	0.000573	0.000181
36	6.4	12000.0	0.000529	0.000161
37	6.6	12000.0	0.000550	0.000168
38	6.3	12000.0	0.000521	0.000156
39	5.8	12000.0	0.000485	0.000135
40	5.5	12000.0	0.000460	0.000116
41	5.3	12000.0	0.000442	0.000111
42	5.6	12000.0	0.000471	0.000123
43	5.3	12000.0	0.000438	0.000097
44	6.4	12000.0	0.000531	0.000167
45	5.6	12000.0	0.000471	0.000119
46	6.1	12000.0	0.000513	0.000134
47	6.3	12000.0	0.000523	0.000143
48	6.4	12000.0	0.000538	0.000150

NUMBER IN FLEET = 100.0 INTRO INTERVAL = 120.0
RETIRE INTERVAL = 120.0 SCALE =2178.2 SHAPE =5.00
MTBF =20 0.0 NUMBER INTRO / PERIOD = 5.0

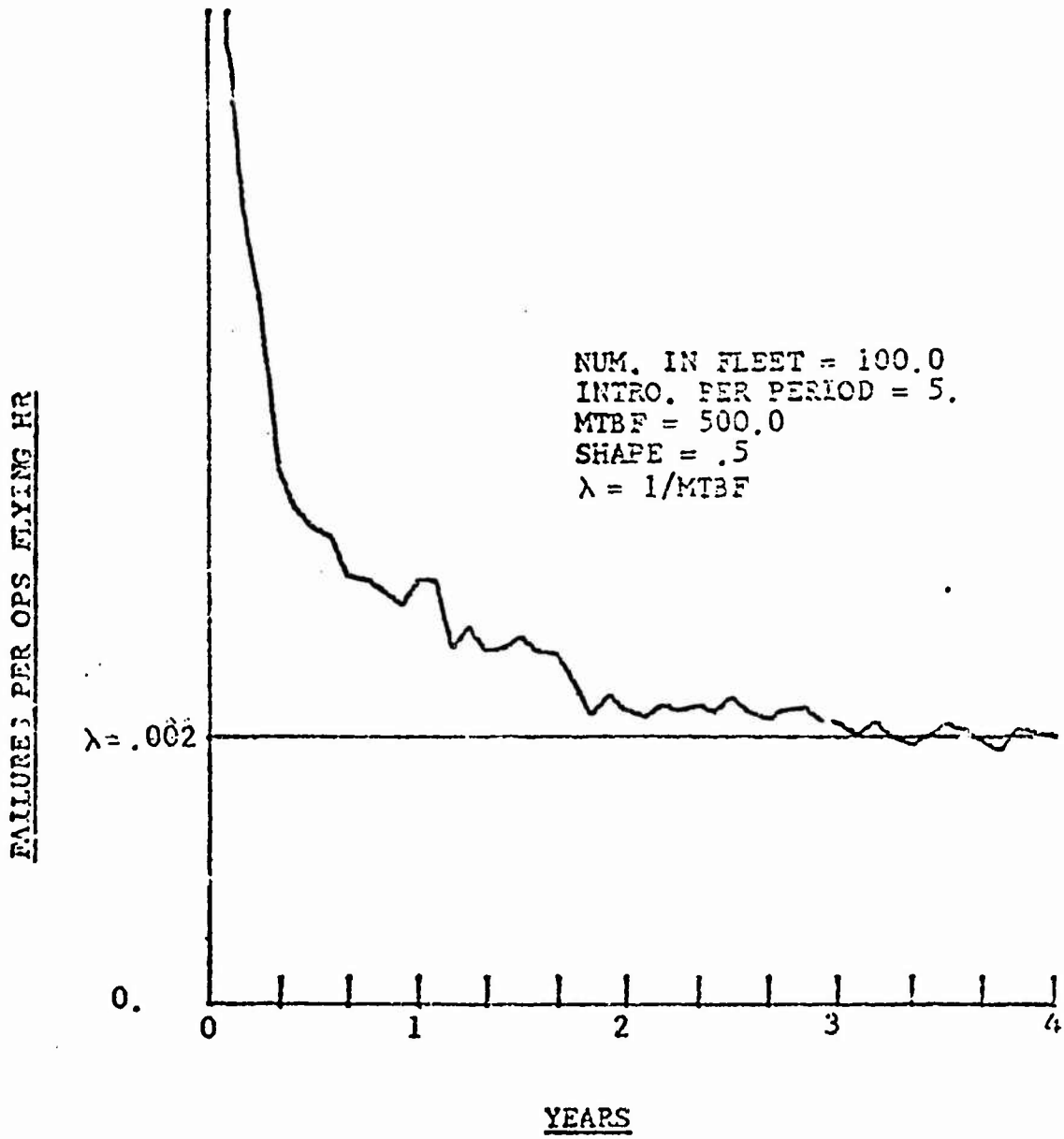

Figure 6

Decreasing Failure Rate

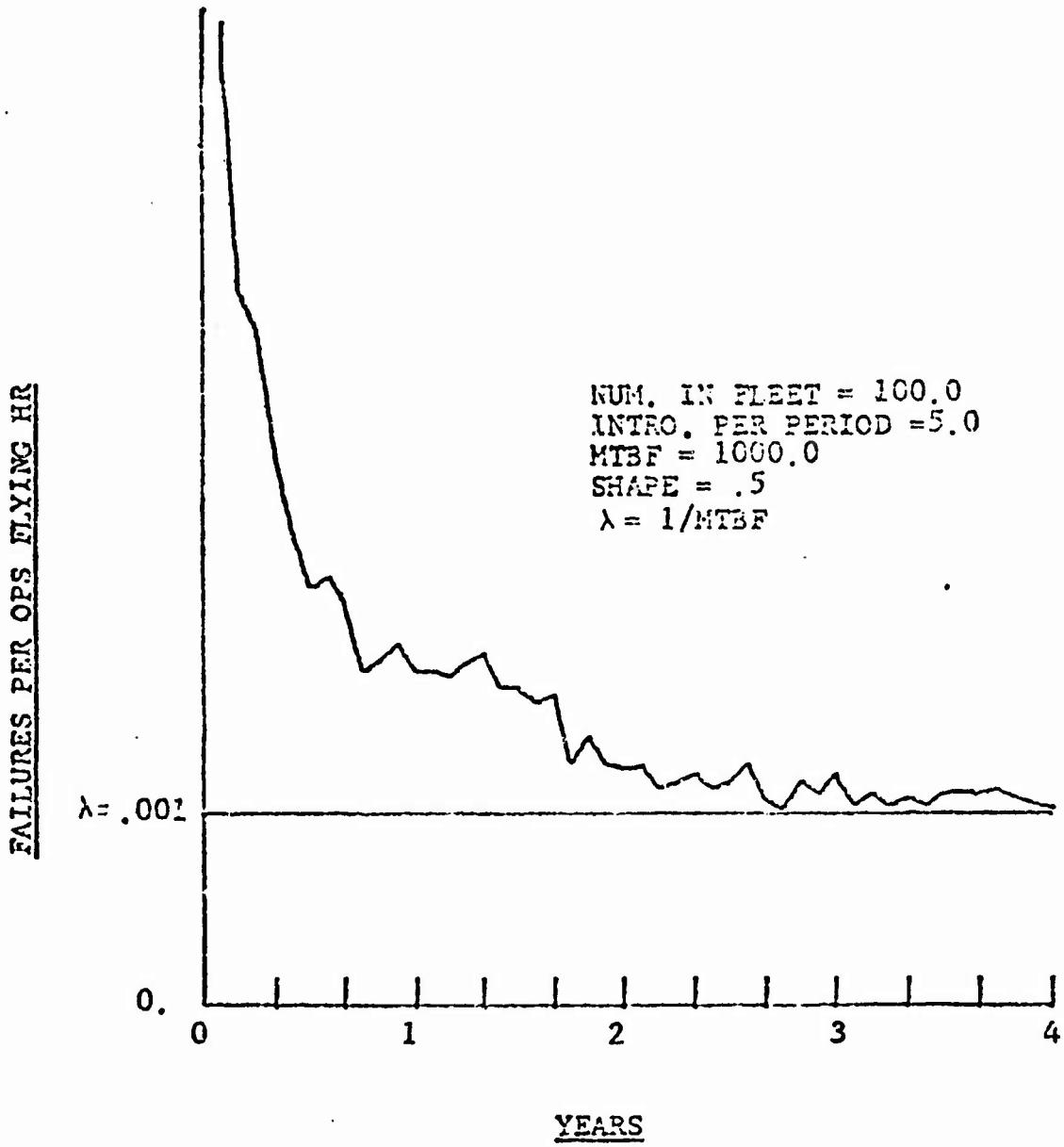

Figure 7

Decreasing Failure Rate

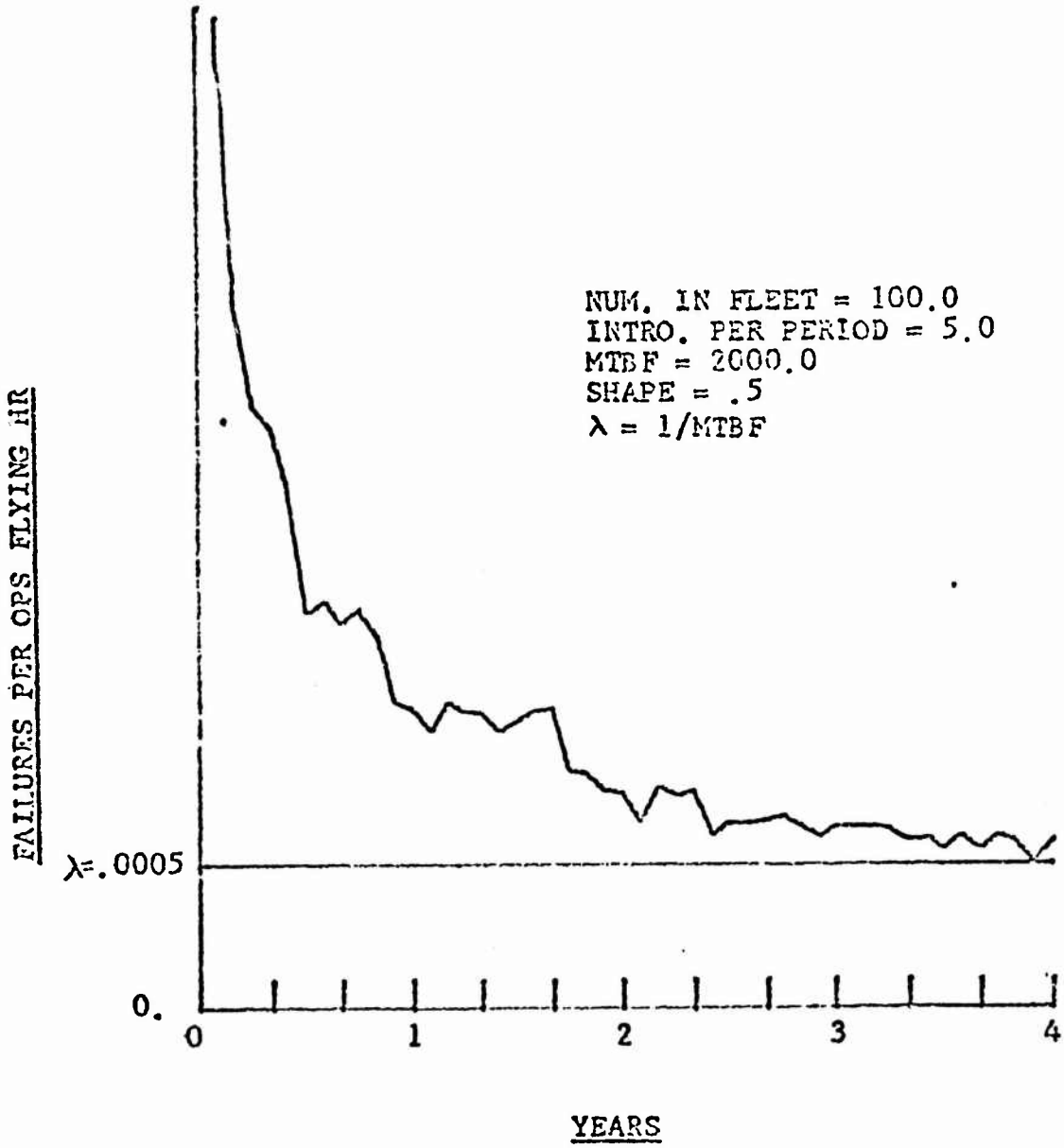

Figure 8

Decreasing Failure Rate

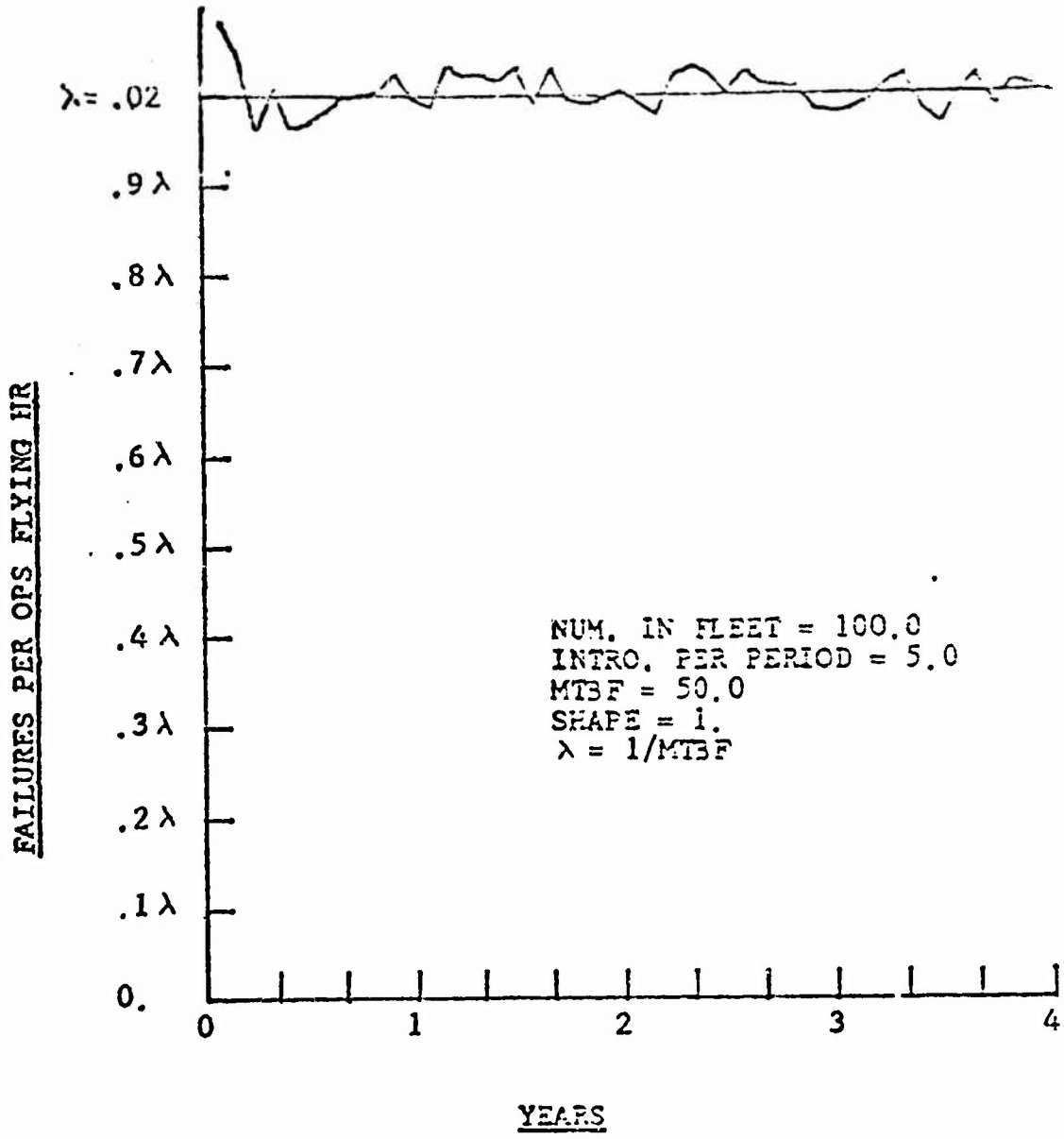

Figure 9

Constant Failure Rate

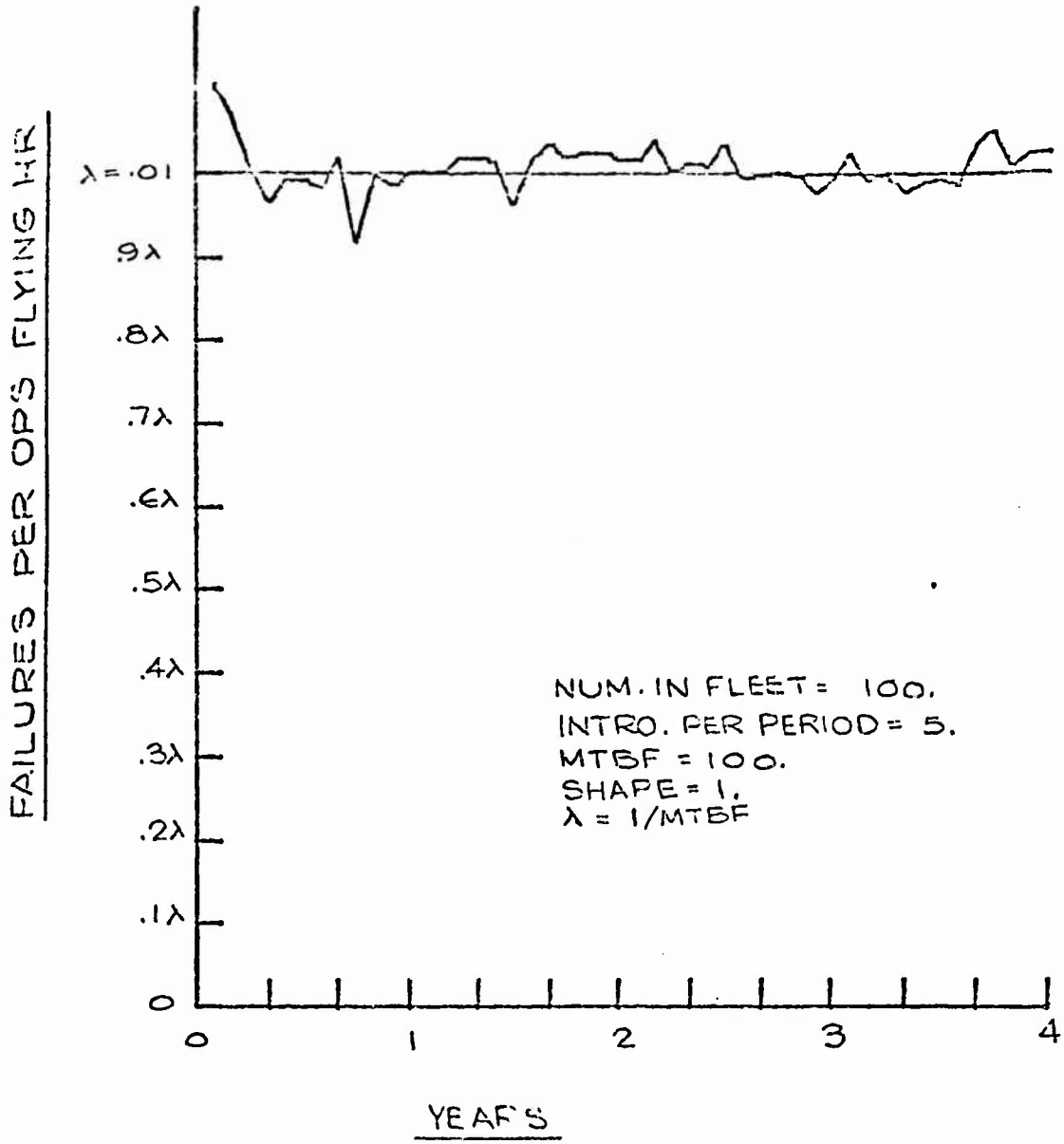

Figure 10

Constant Failure Rate

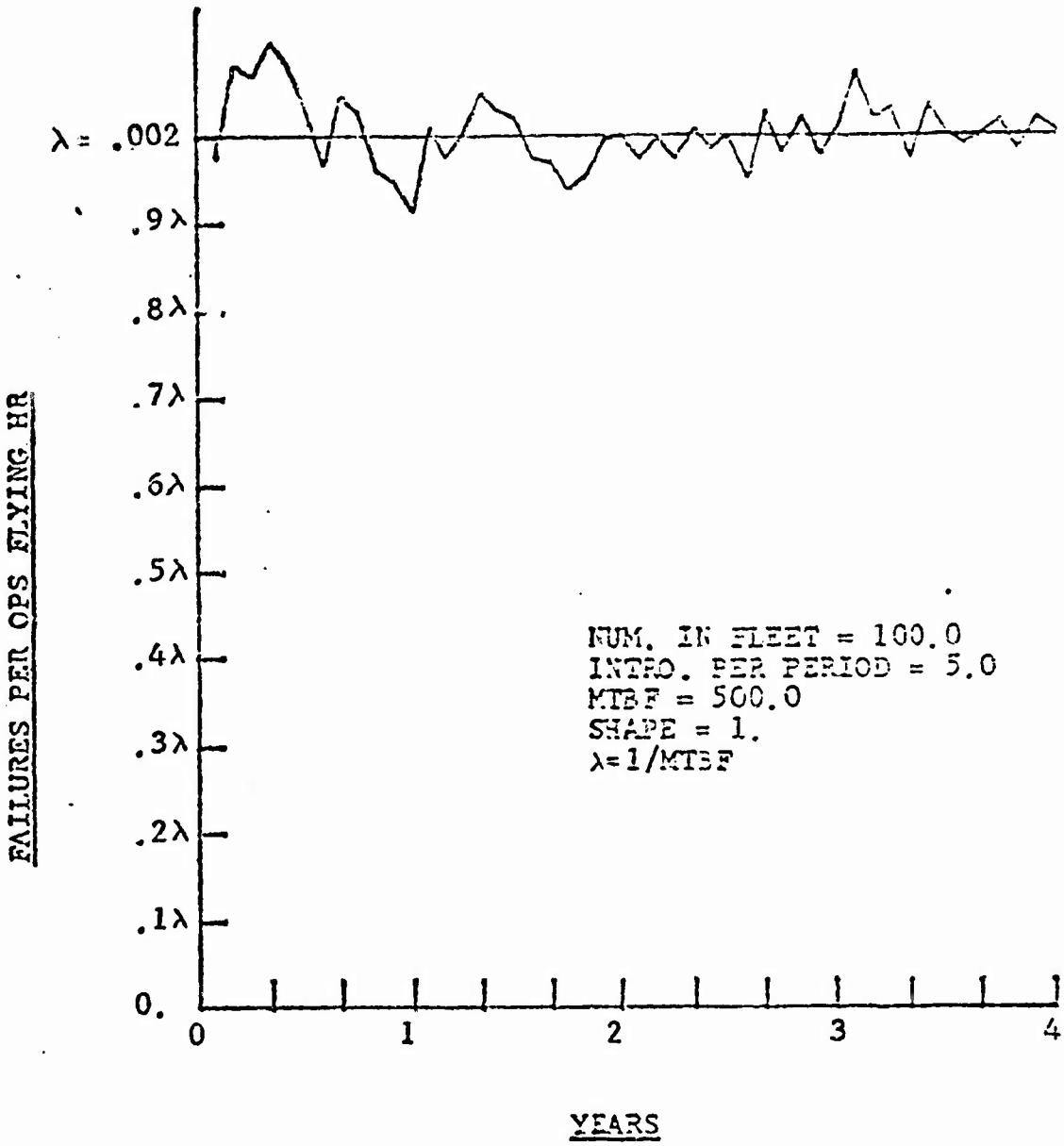

Figure 11

Constant Failure Rate

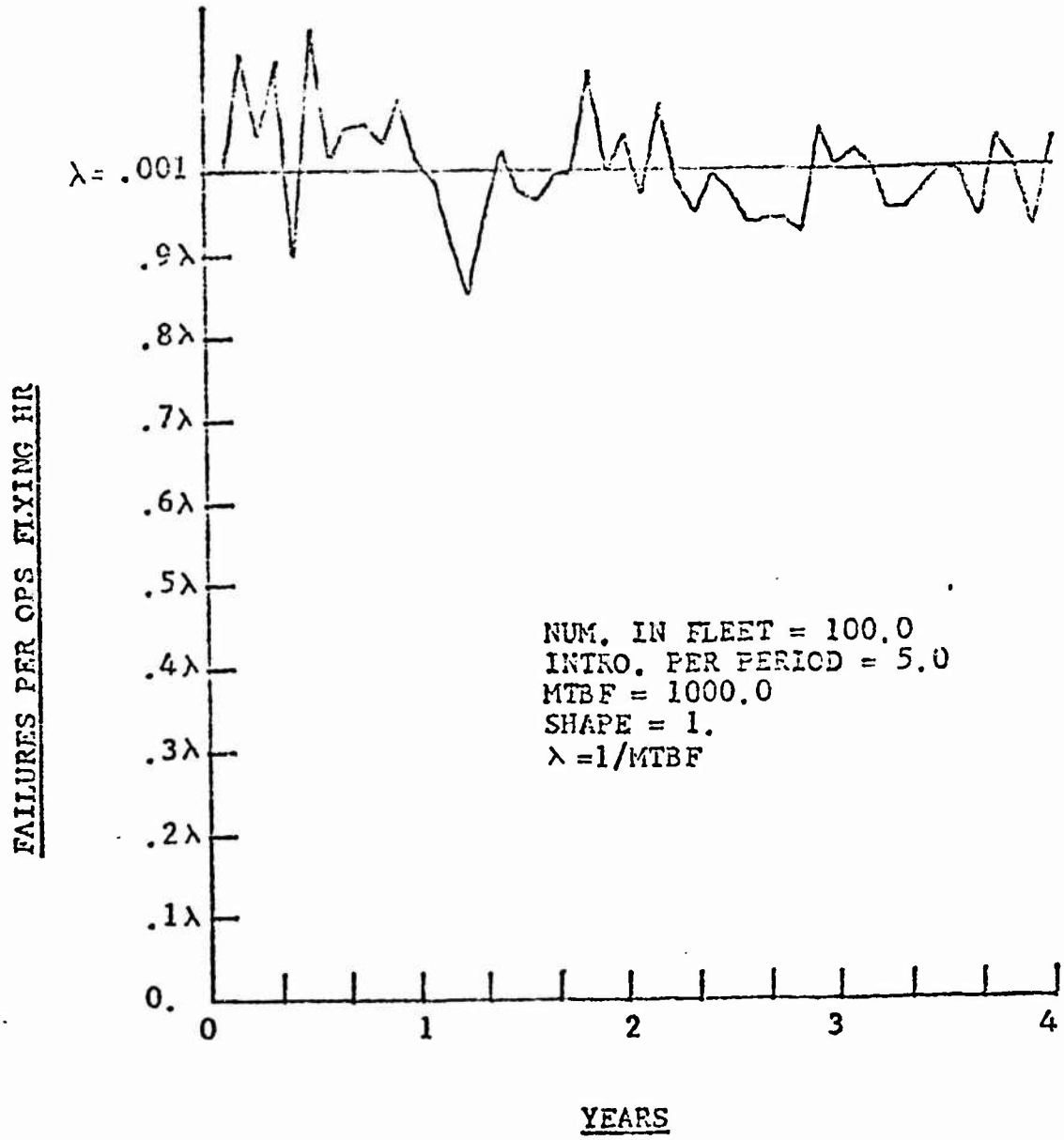

Figure 12

Constant Failure Rate

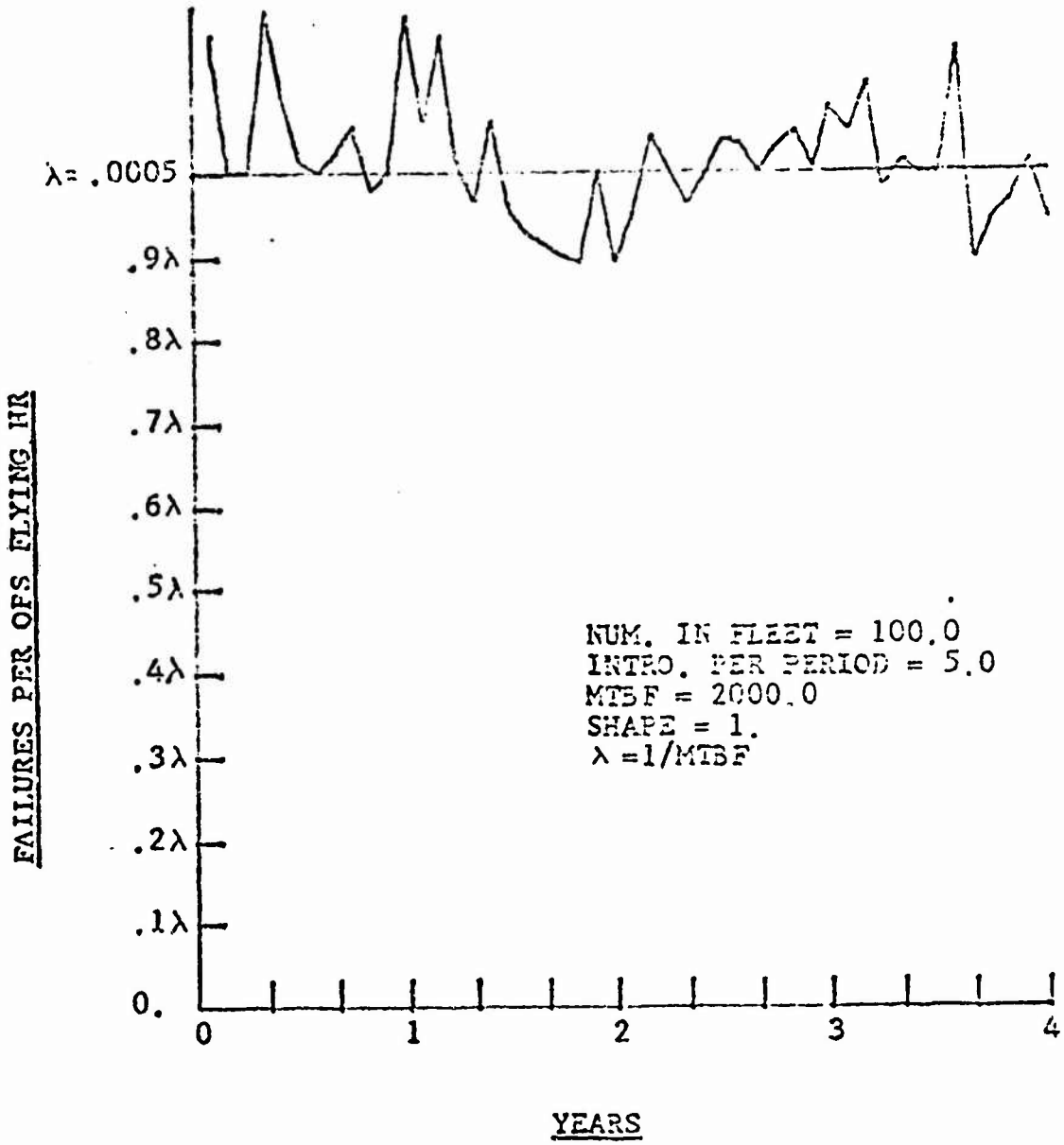

Figure 13

Constant Failure Rate

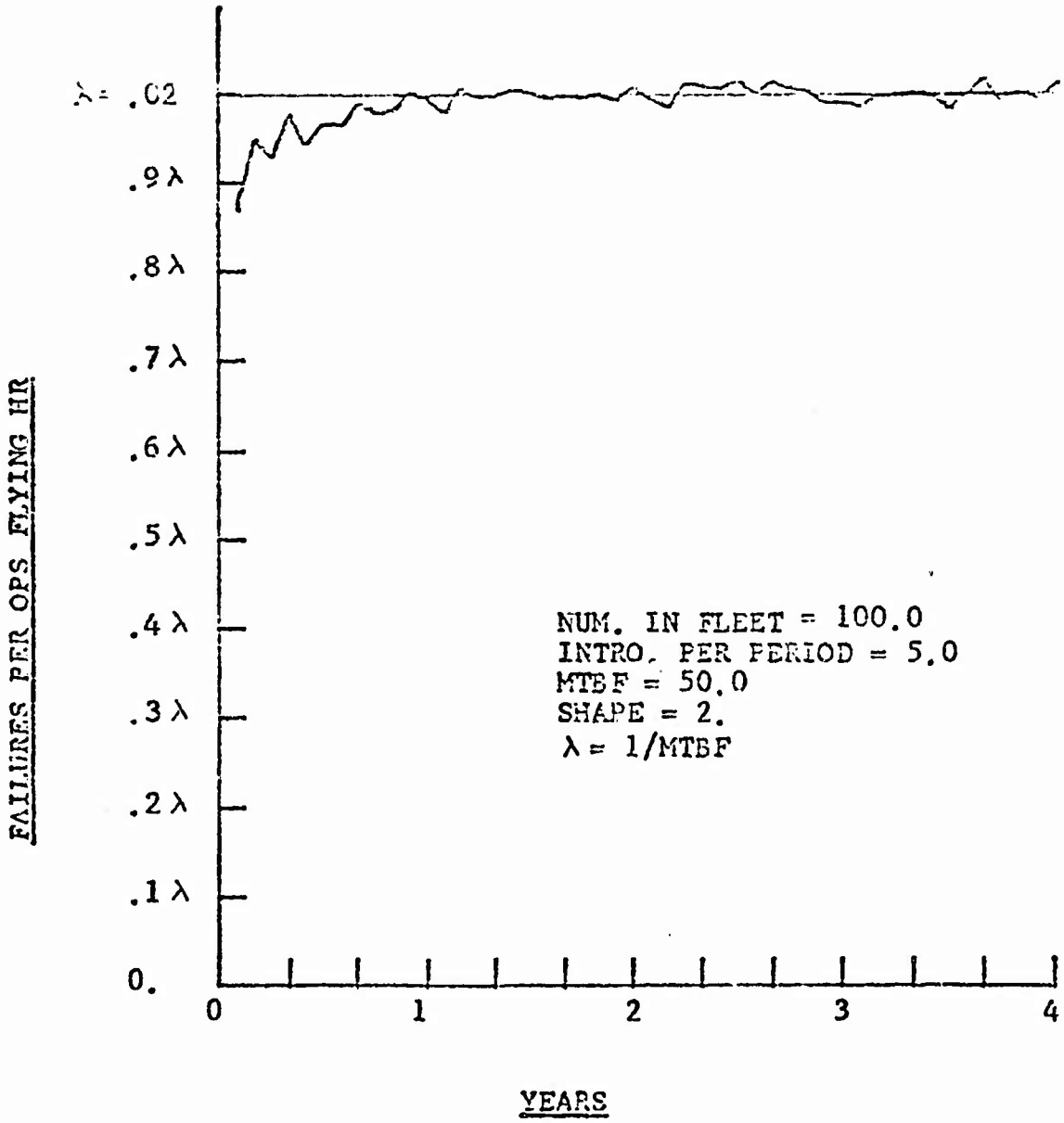

Figure 14

Increasing Failure Rate

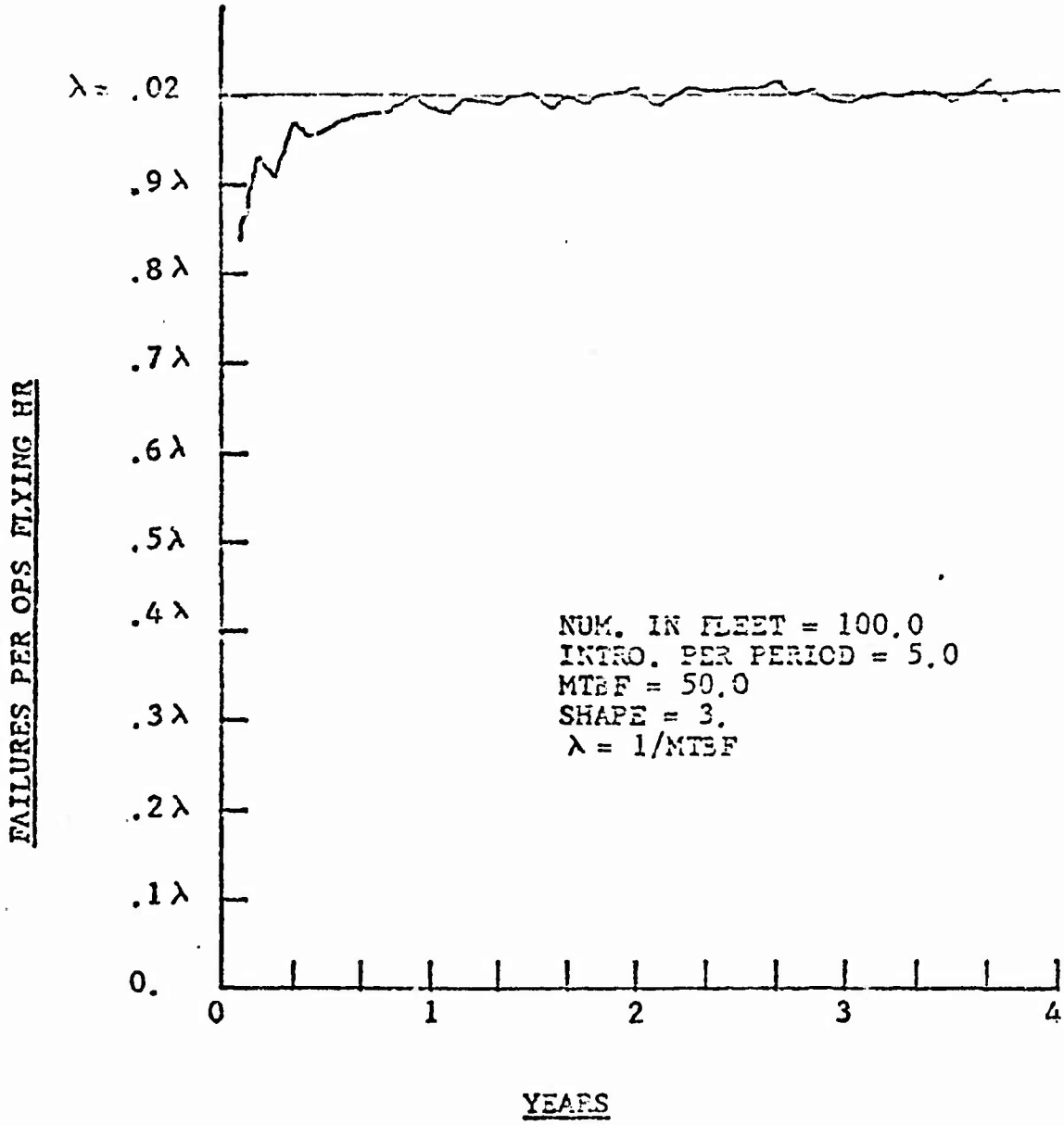

Figure 15

Increasing Failure Rate

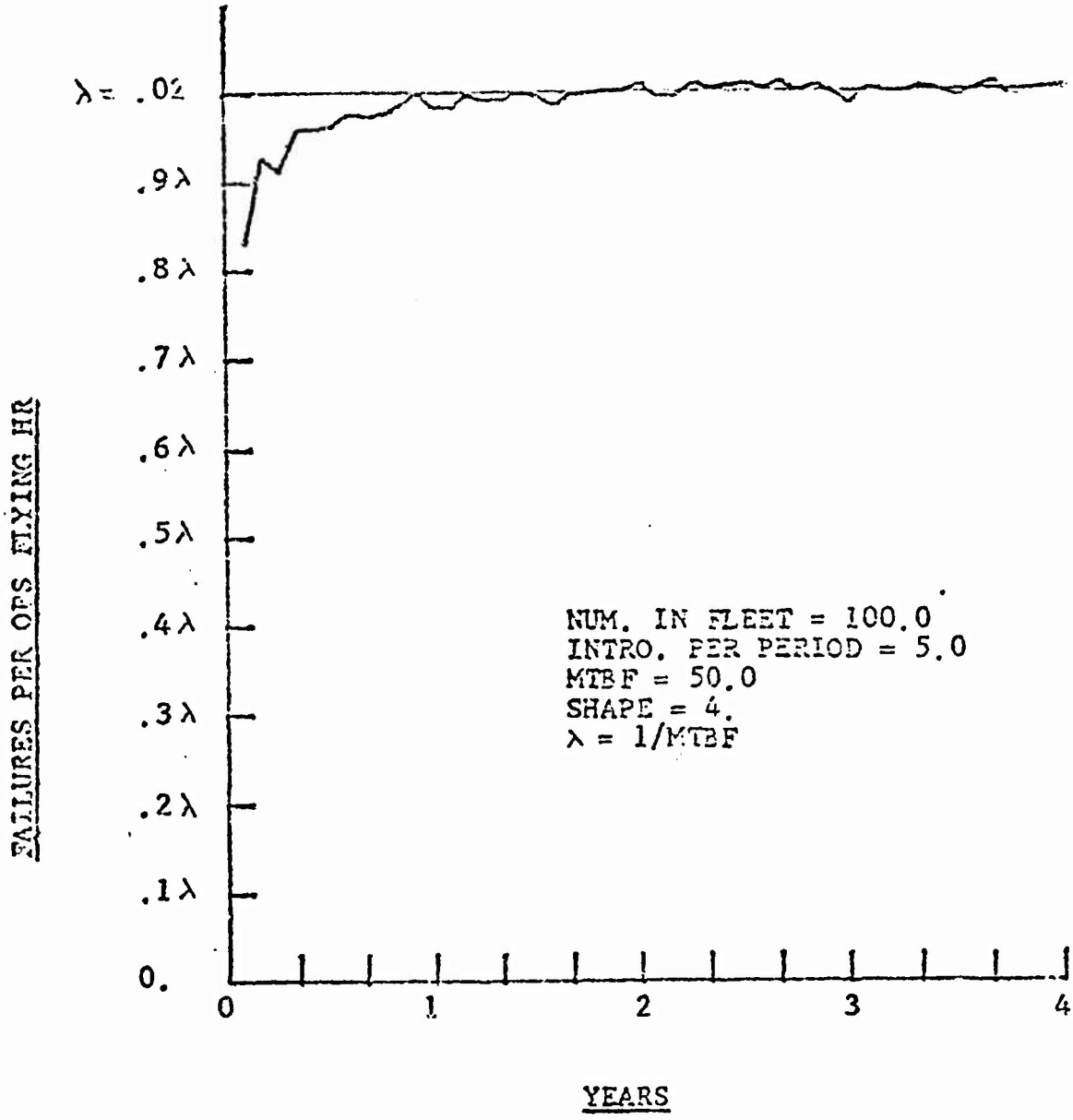

Figure 16

Increasing Failure Rate

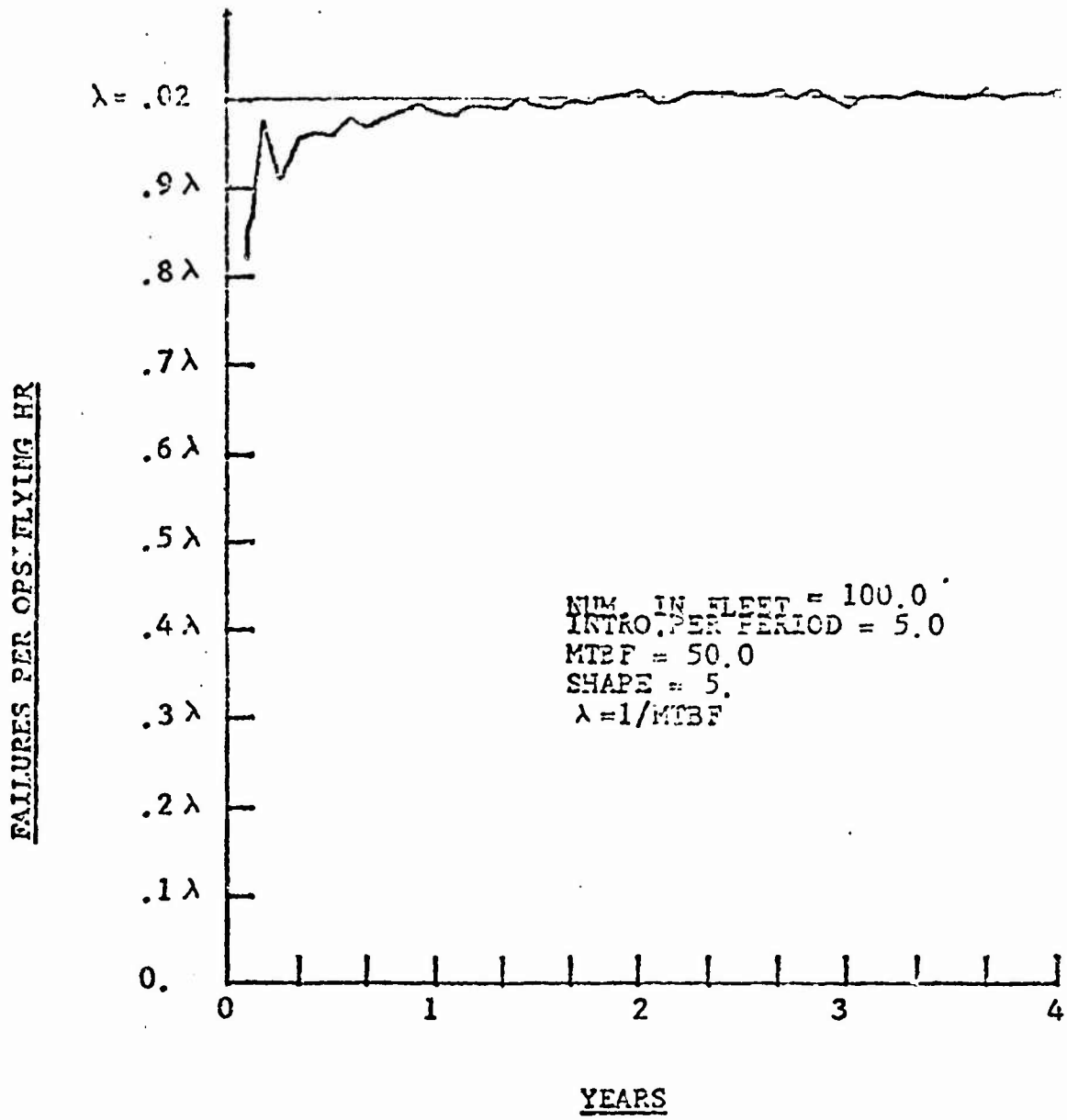

Figure 17

Increasing Failure Rate

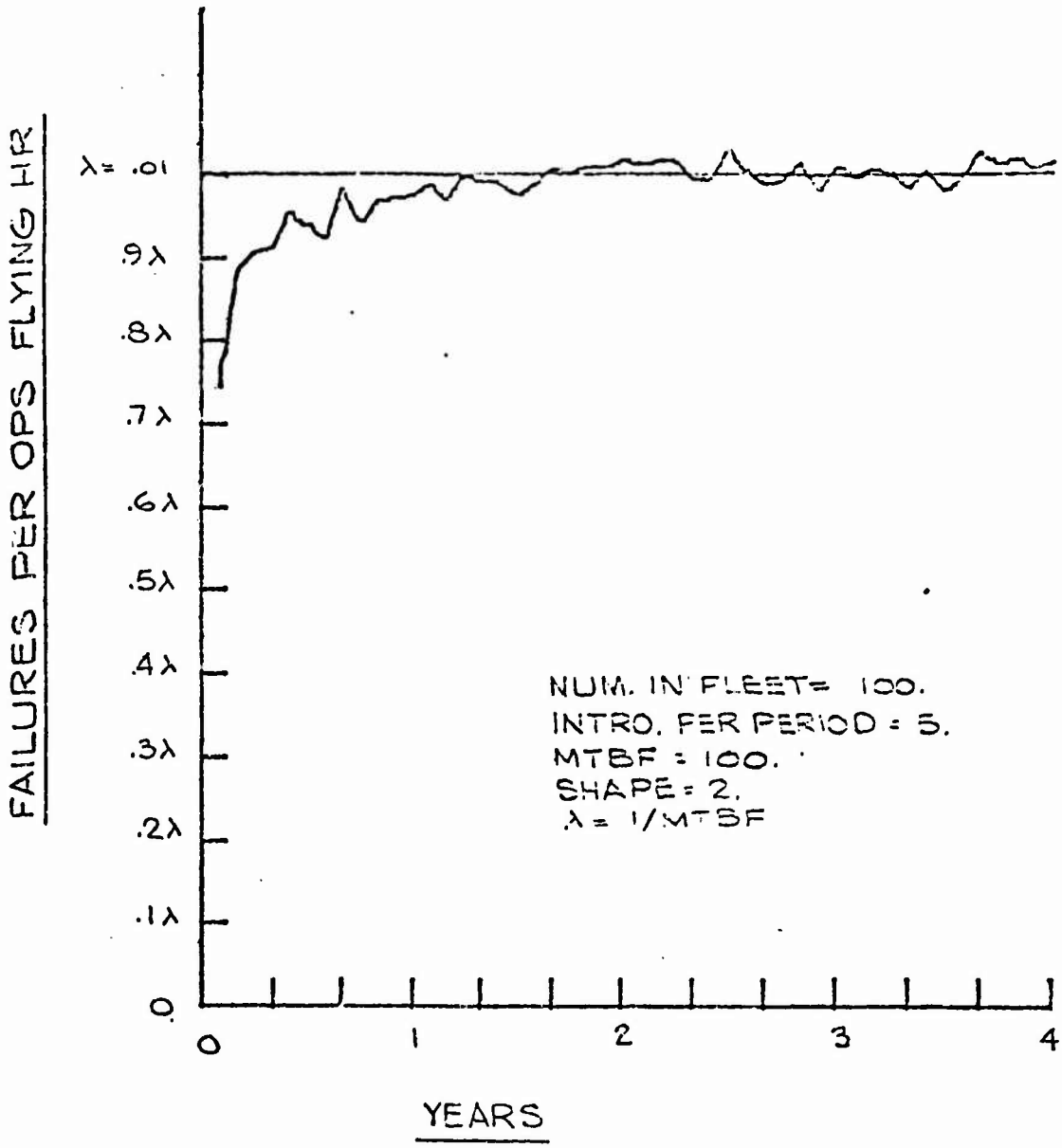

Figure 18

Increasing Failure Rate

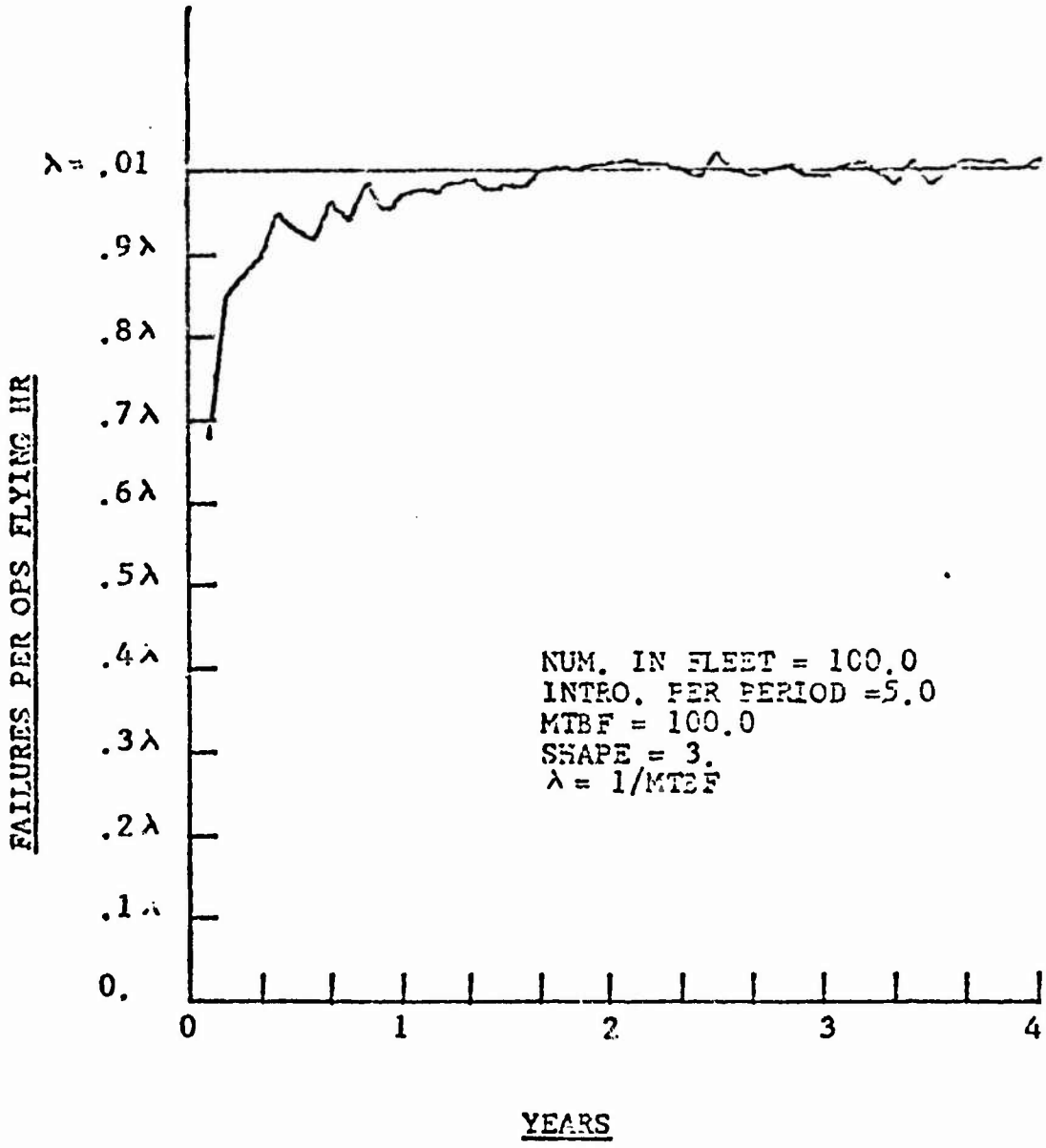

Figure 19

Increasing Failure Rate

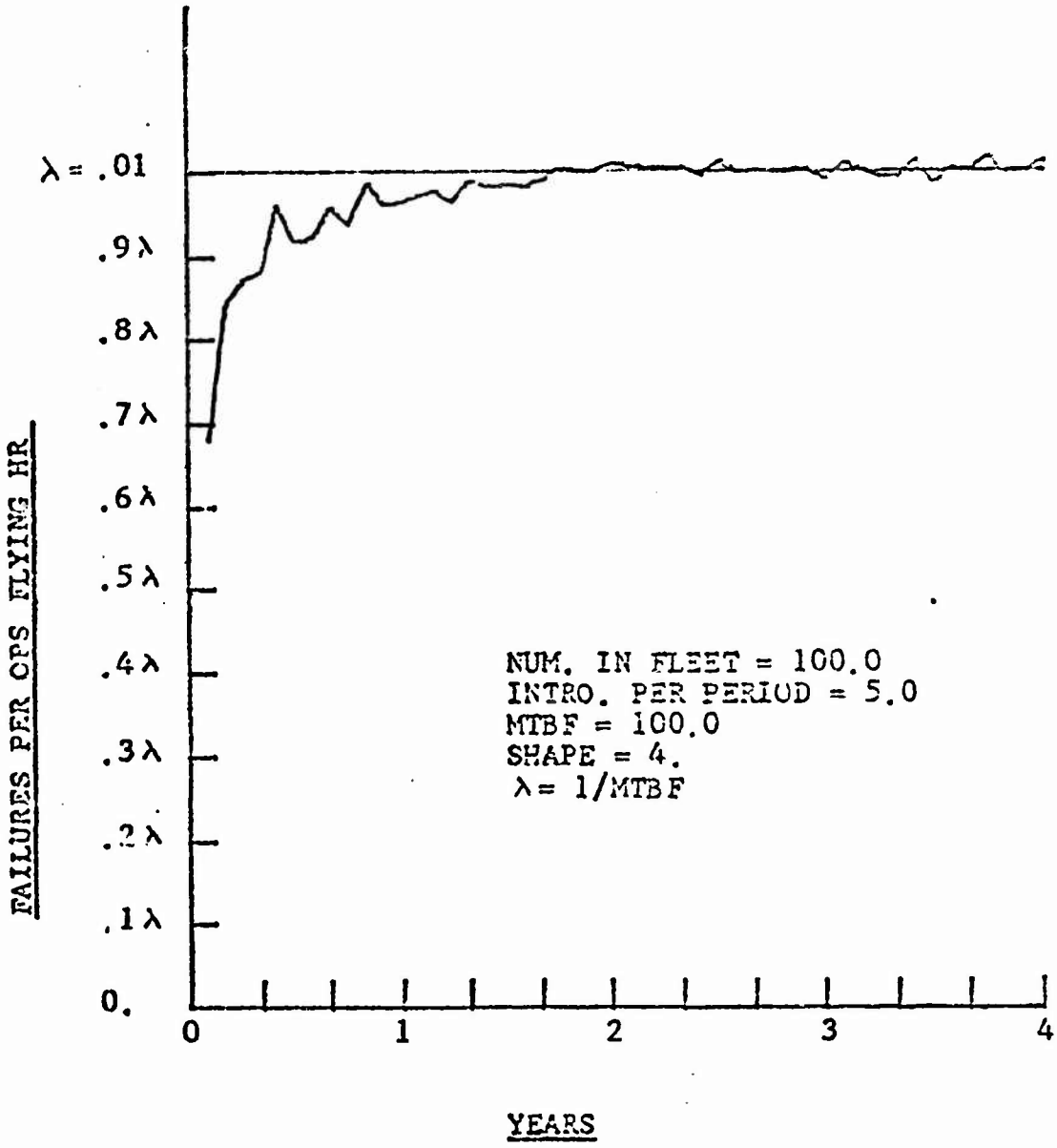

Figure 20

Increasing Failure Rate

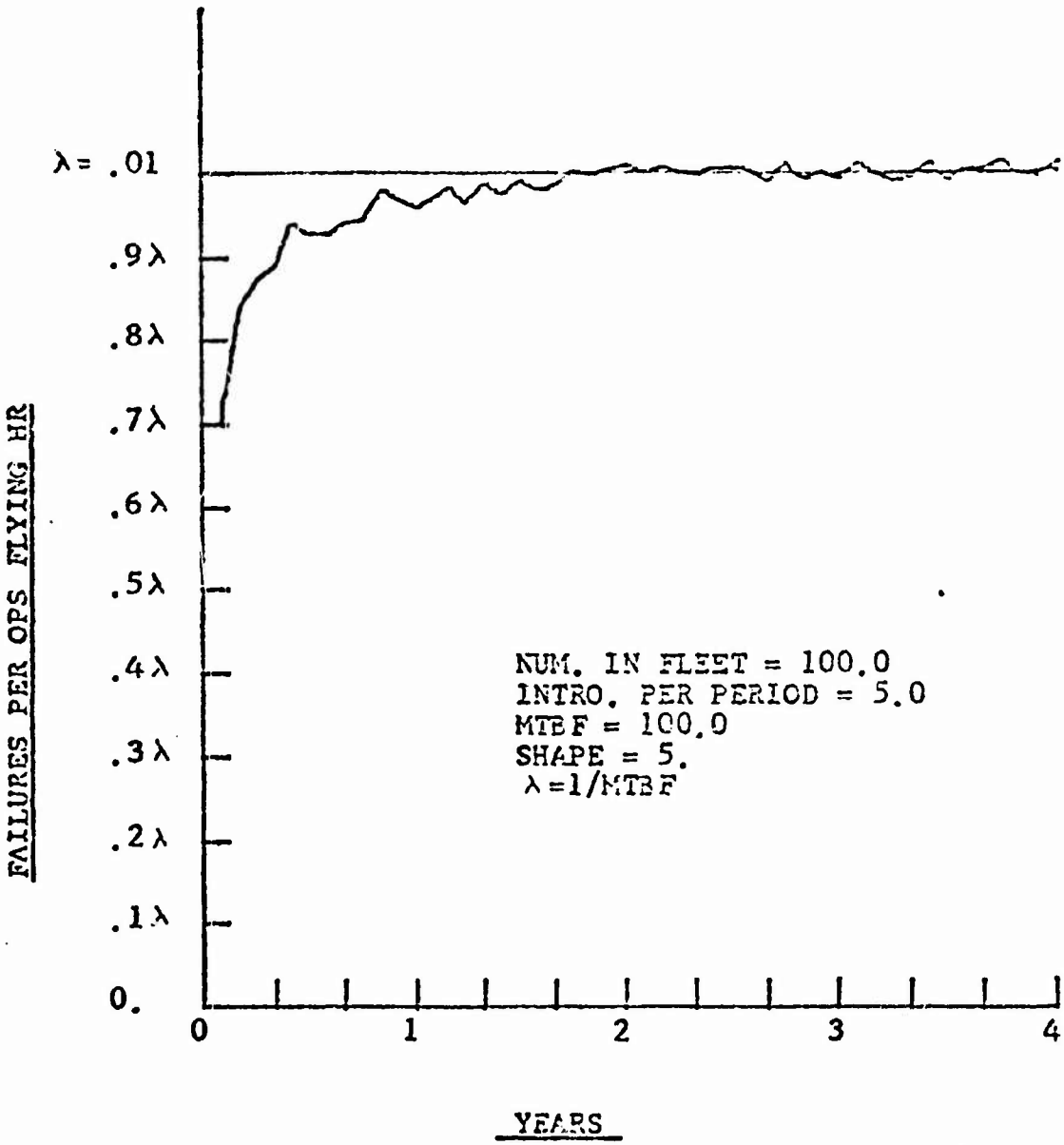

Figure 21

Increasing Failure Rate

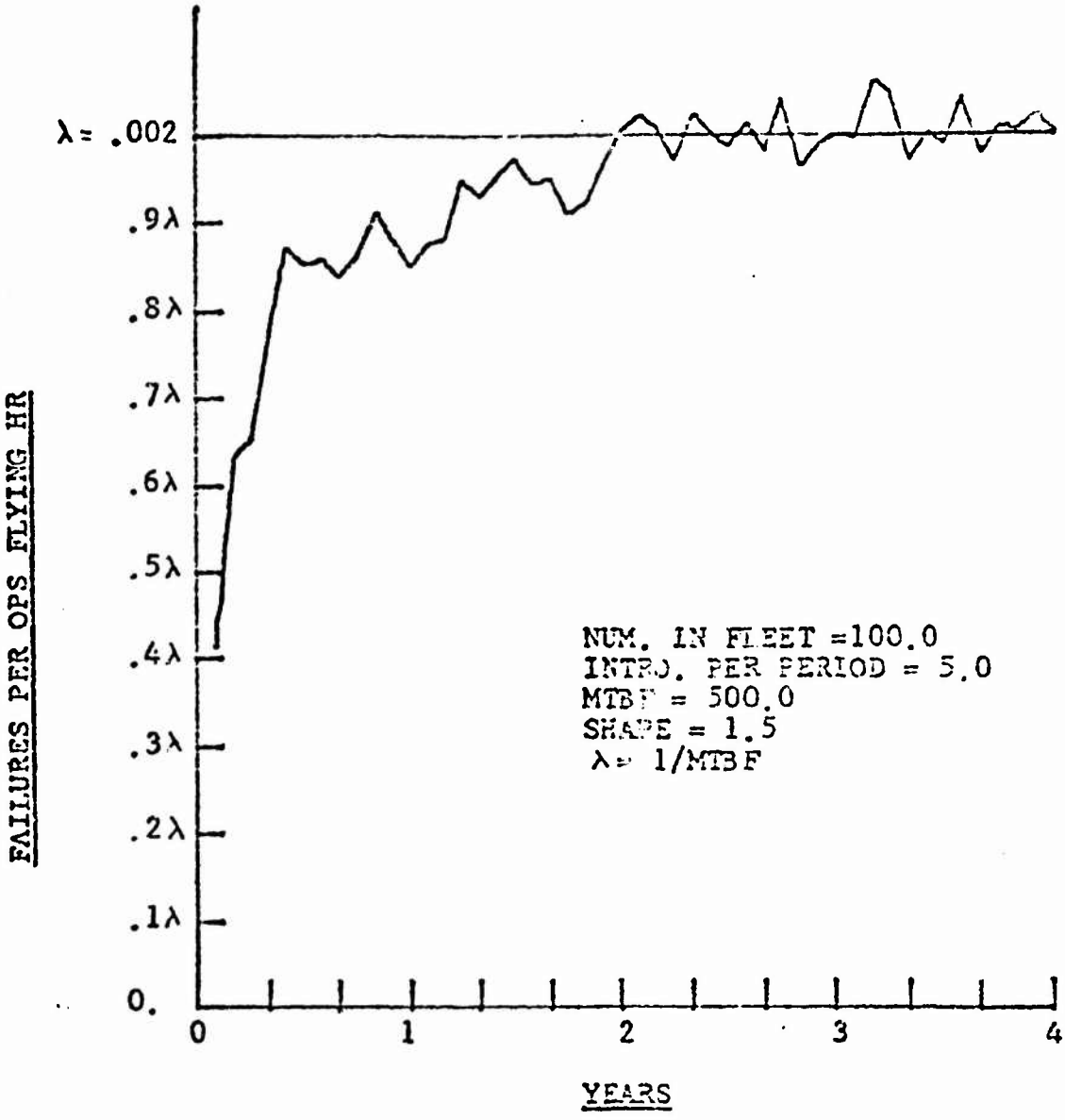

Figure 22

Increasing Failure Rate

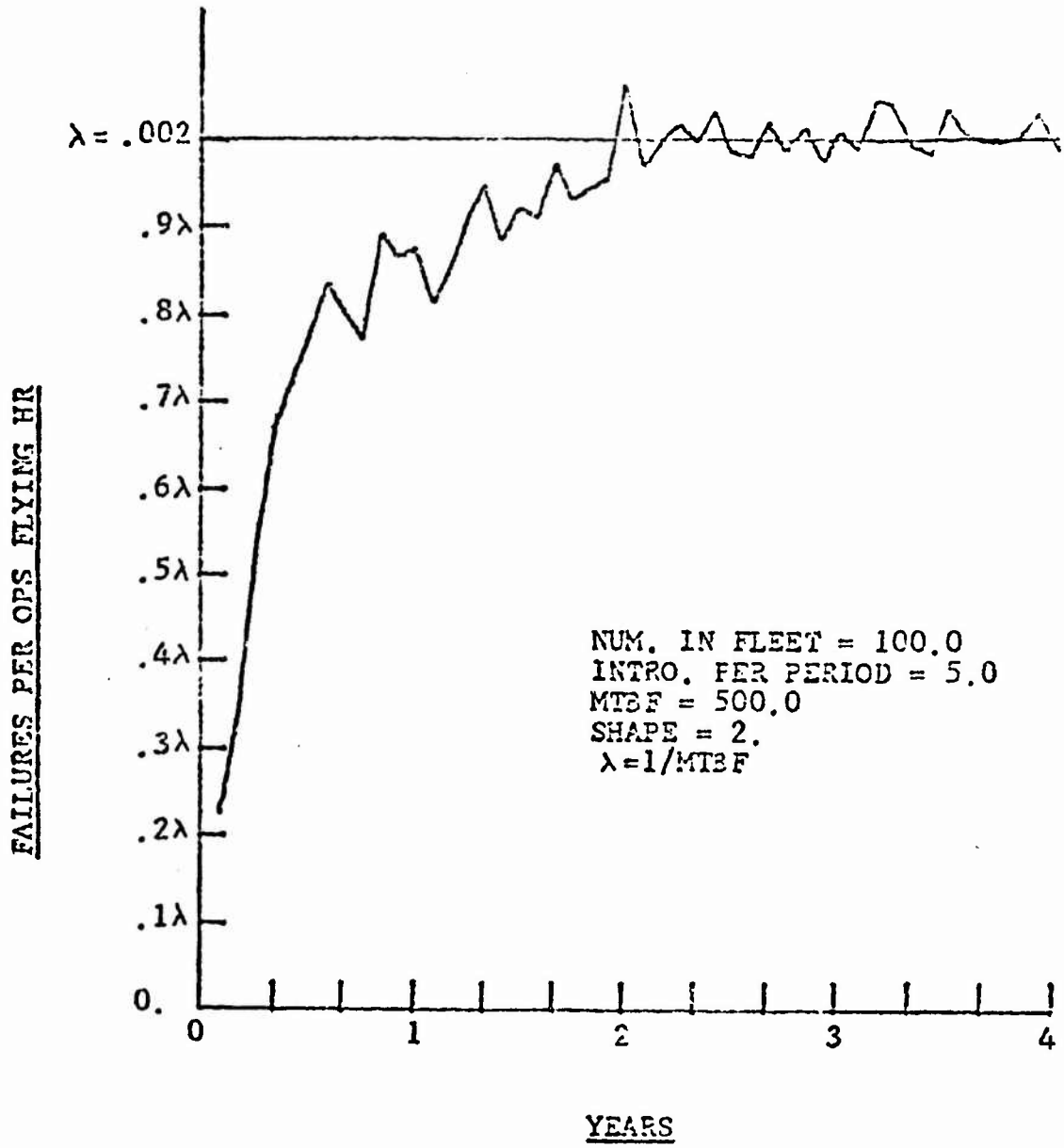

Figure 23

Increasing Failure Rate

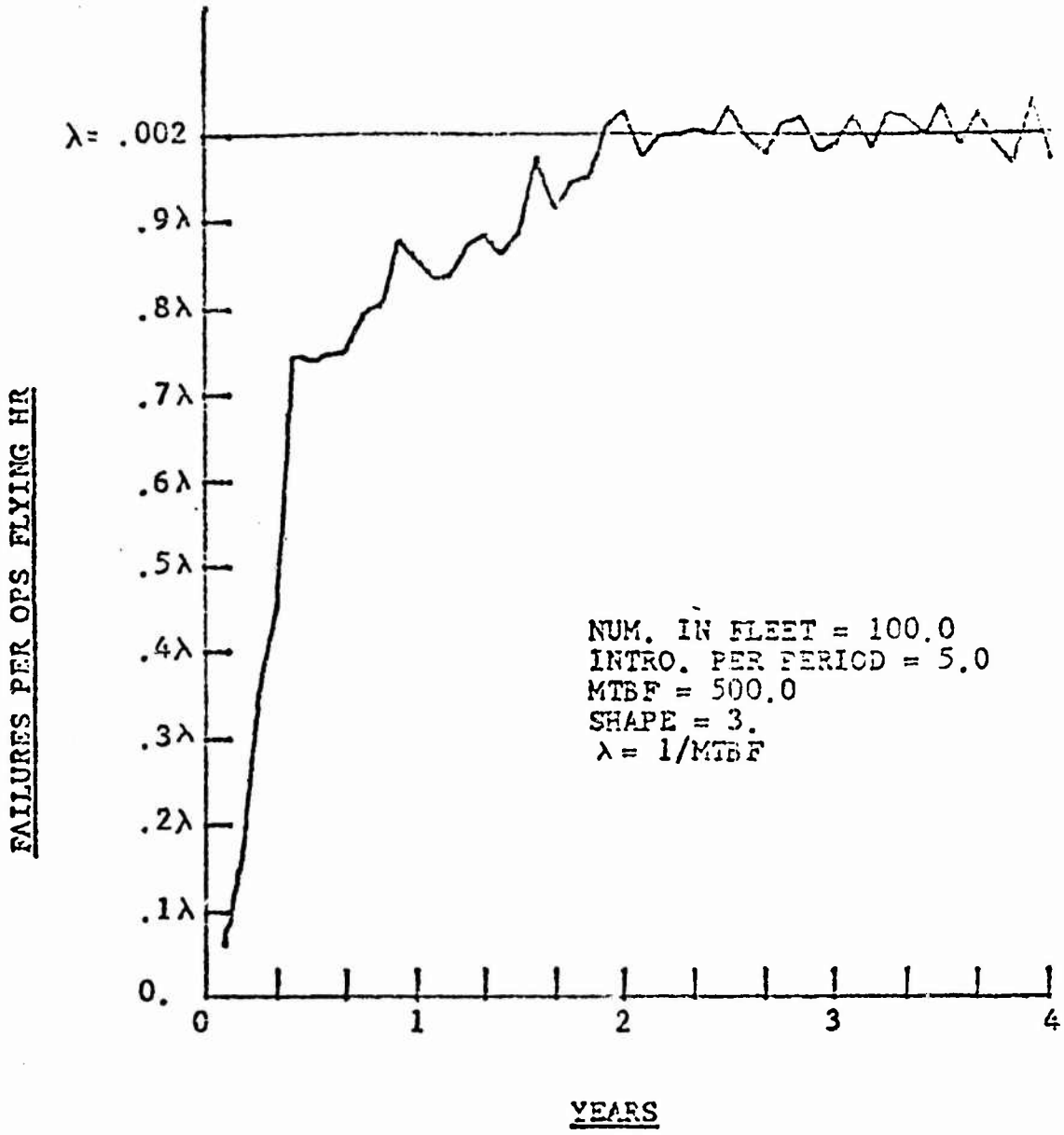

Figure 24

Increasing Failure Rate

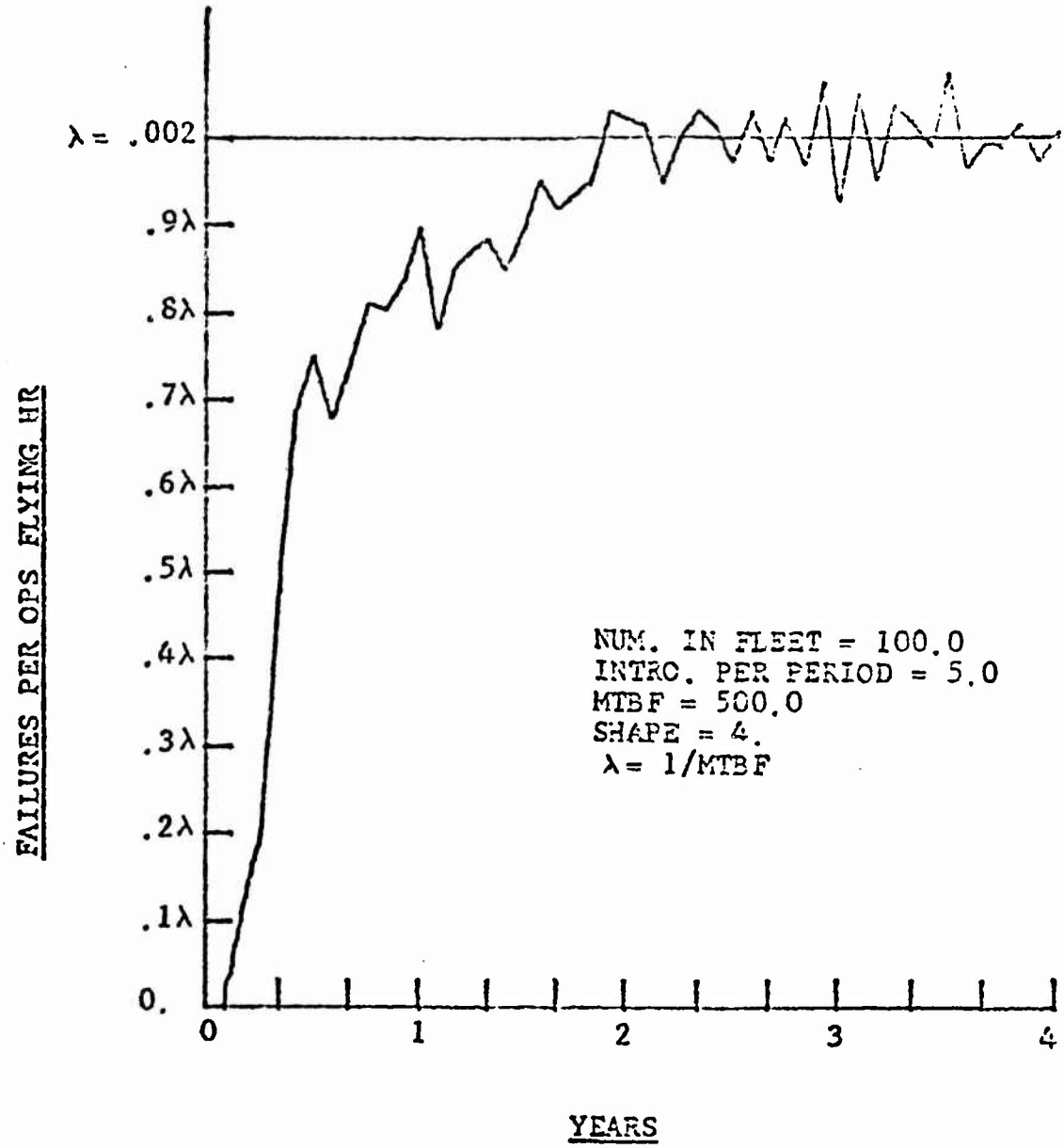

Figure 25

Increasing Failure Rate

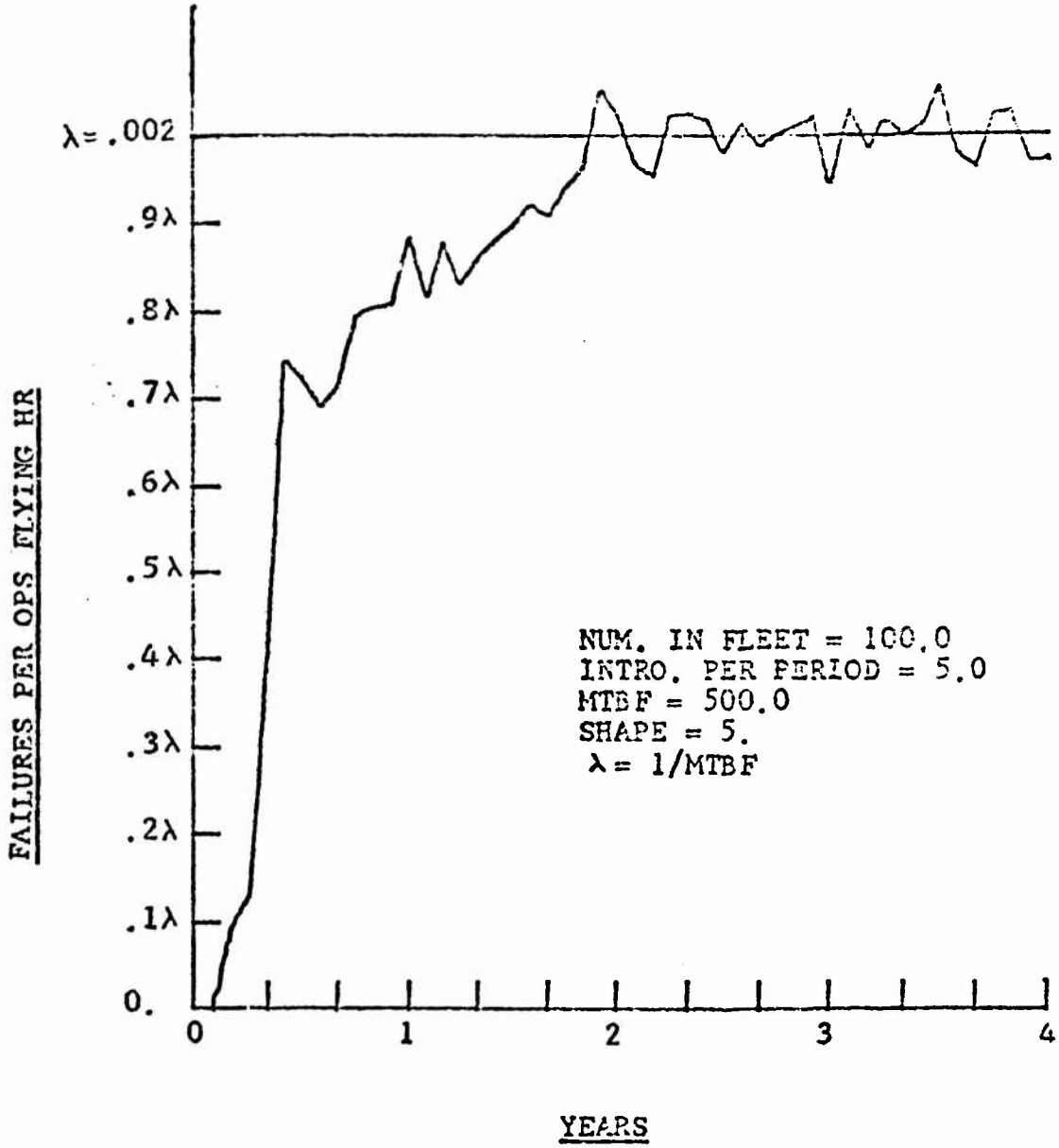

Figure 26

Increasing Failure Rate

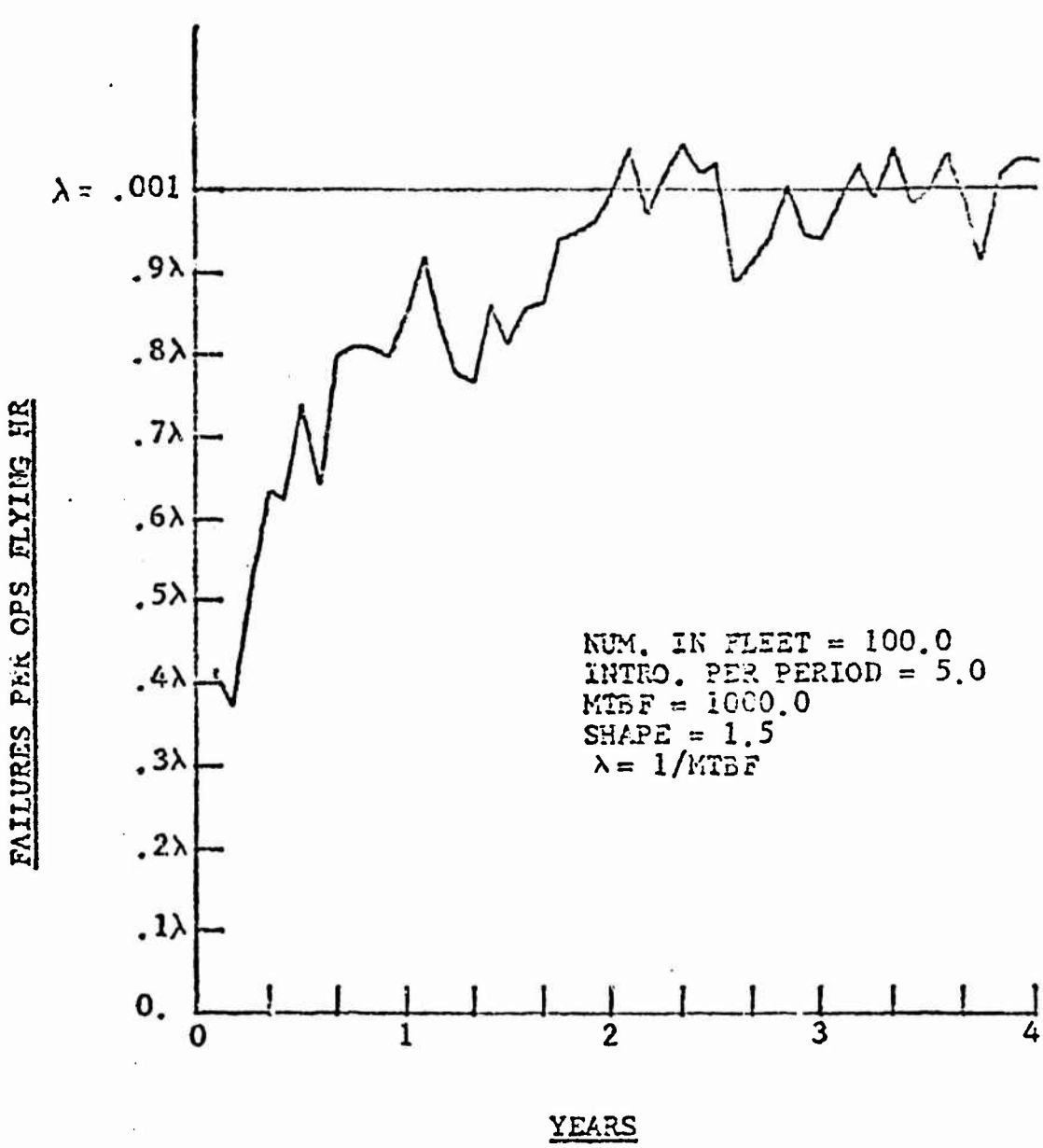

Figure 27

Increasing Failure Rate

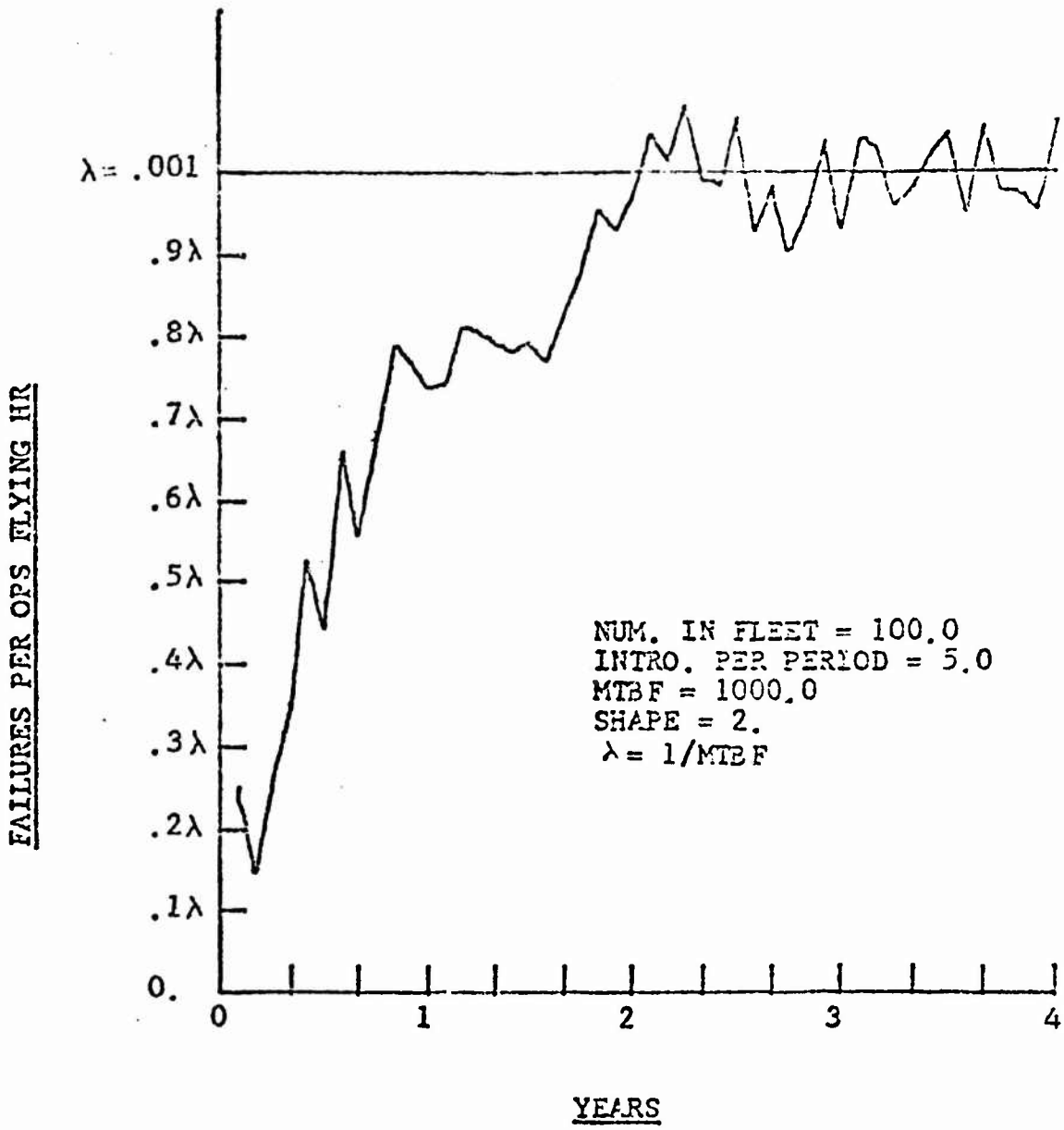

Figure 28

Increasing Failure Rate

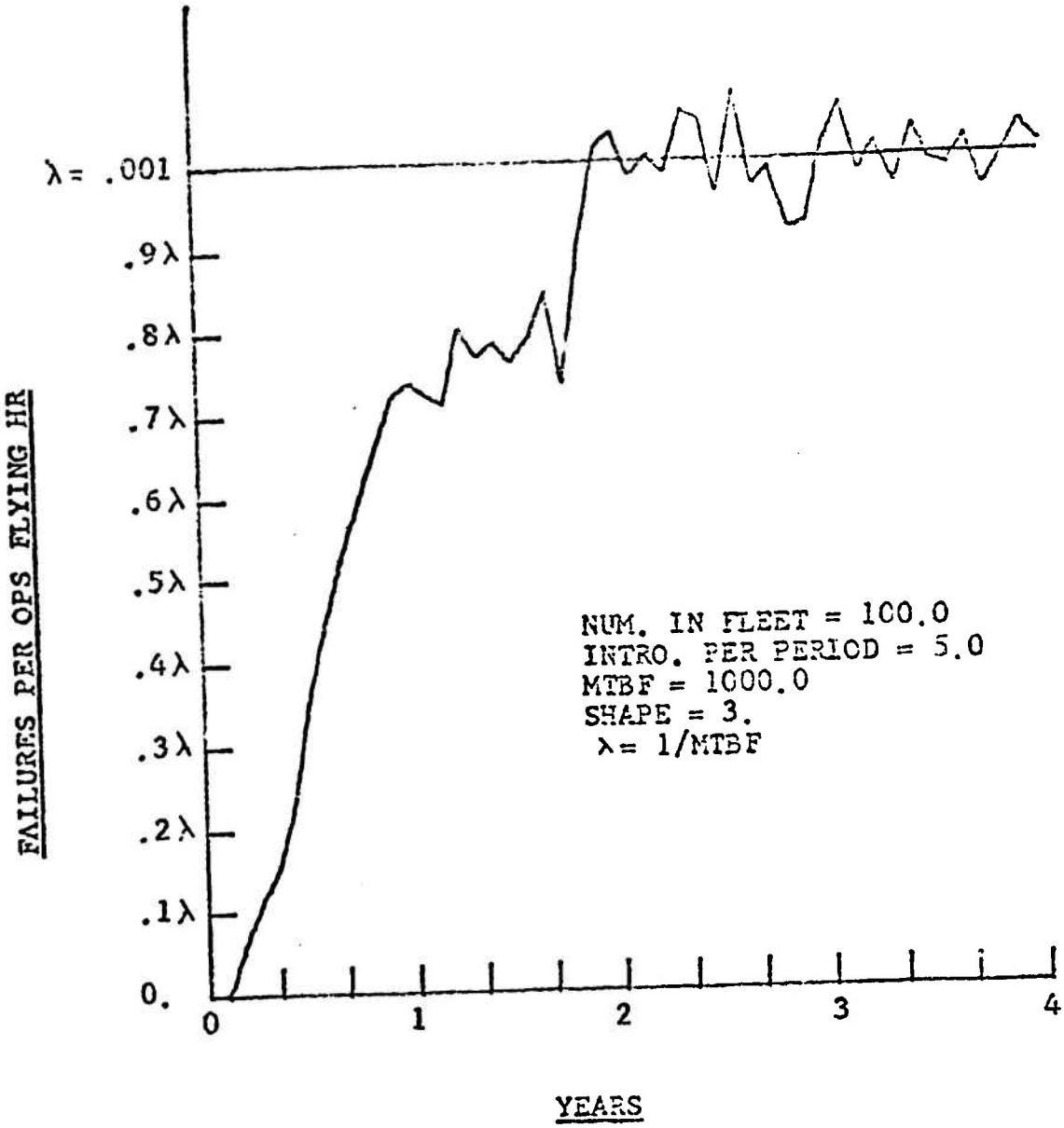

Figure 29

Increasing Failure Rate

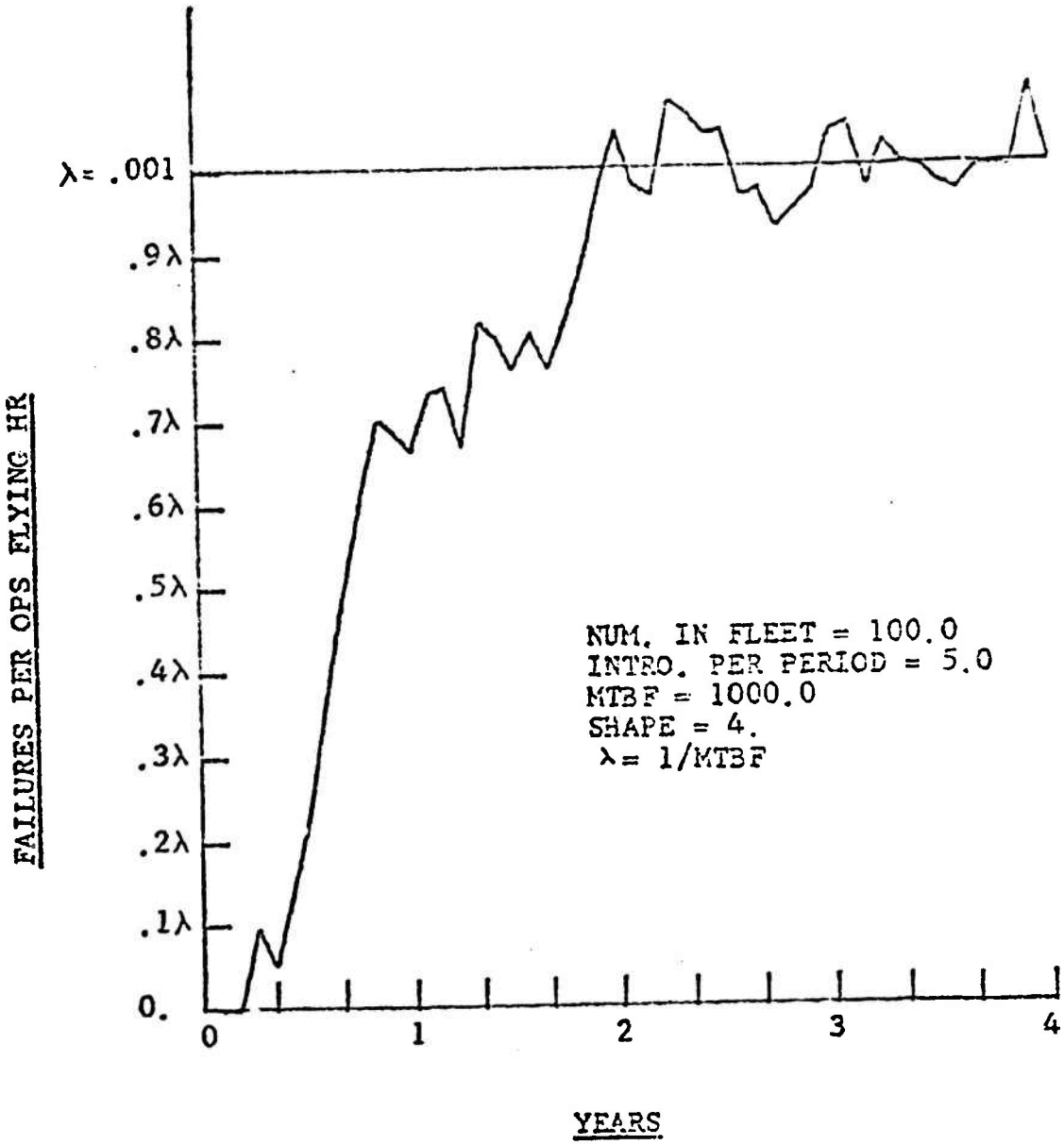

Figure 30

Increasing Failure Rate

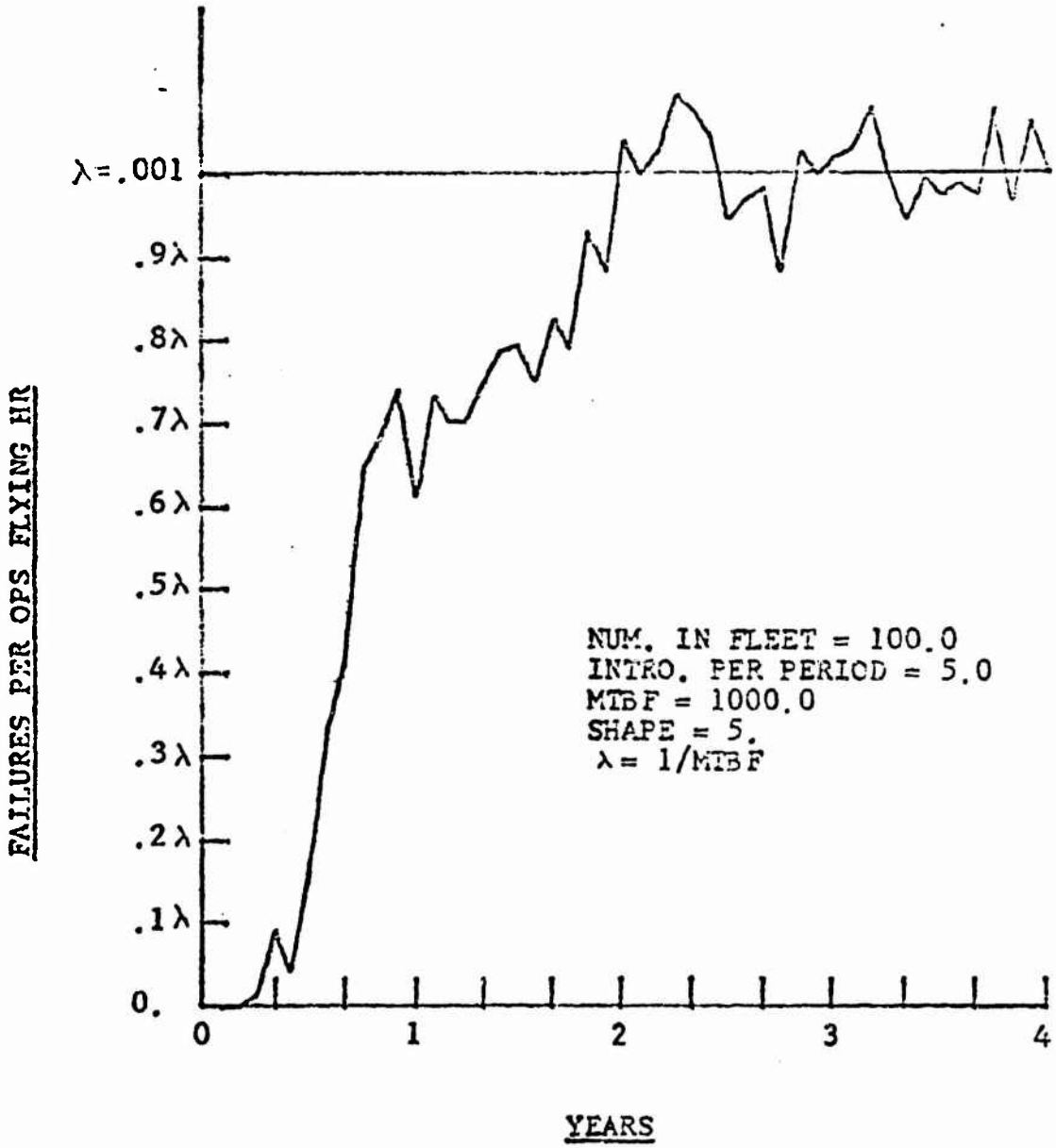

Figure 31

Increasing Failure Rate

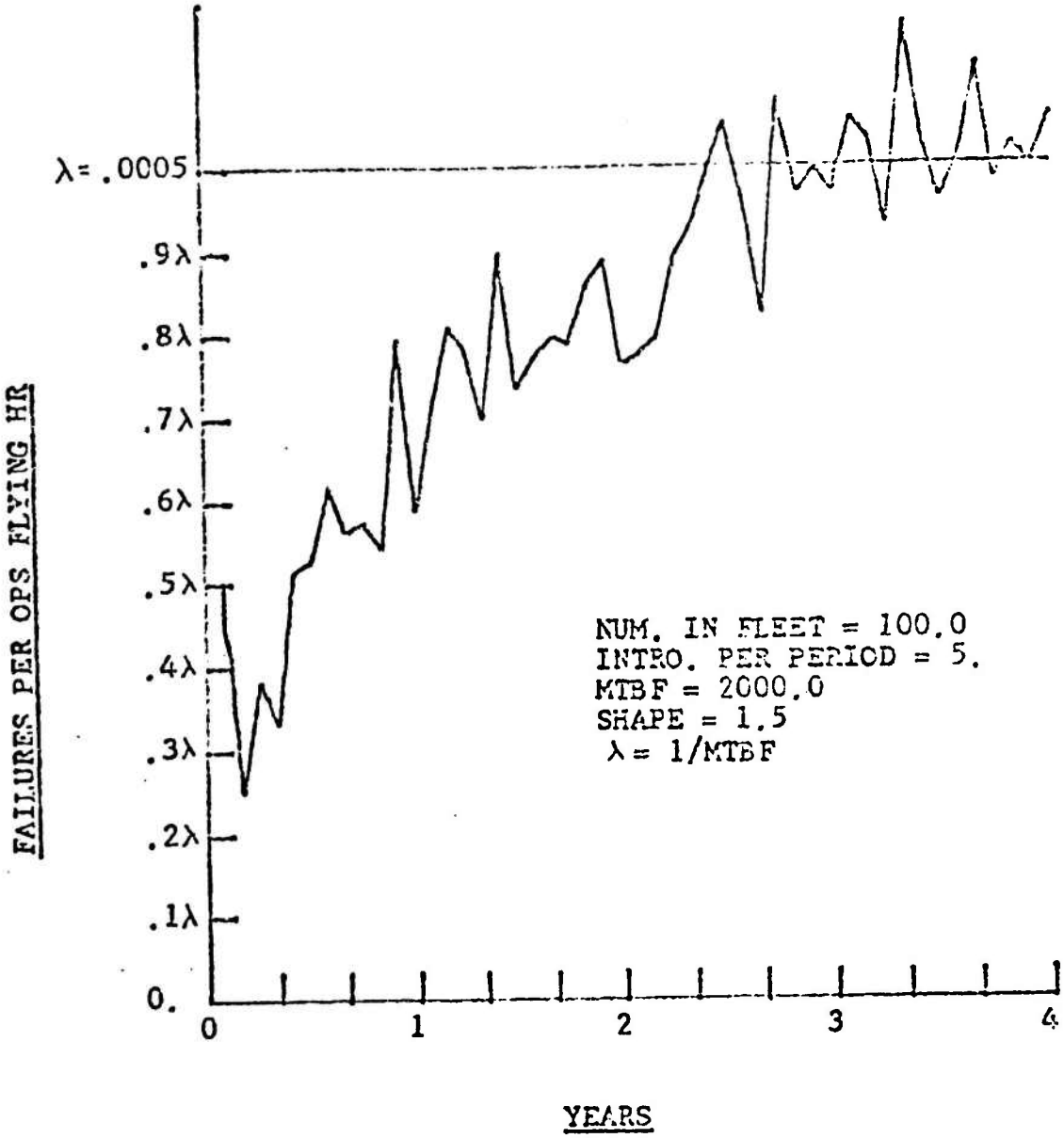

Figure 32

Increasing Failure Rate

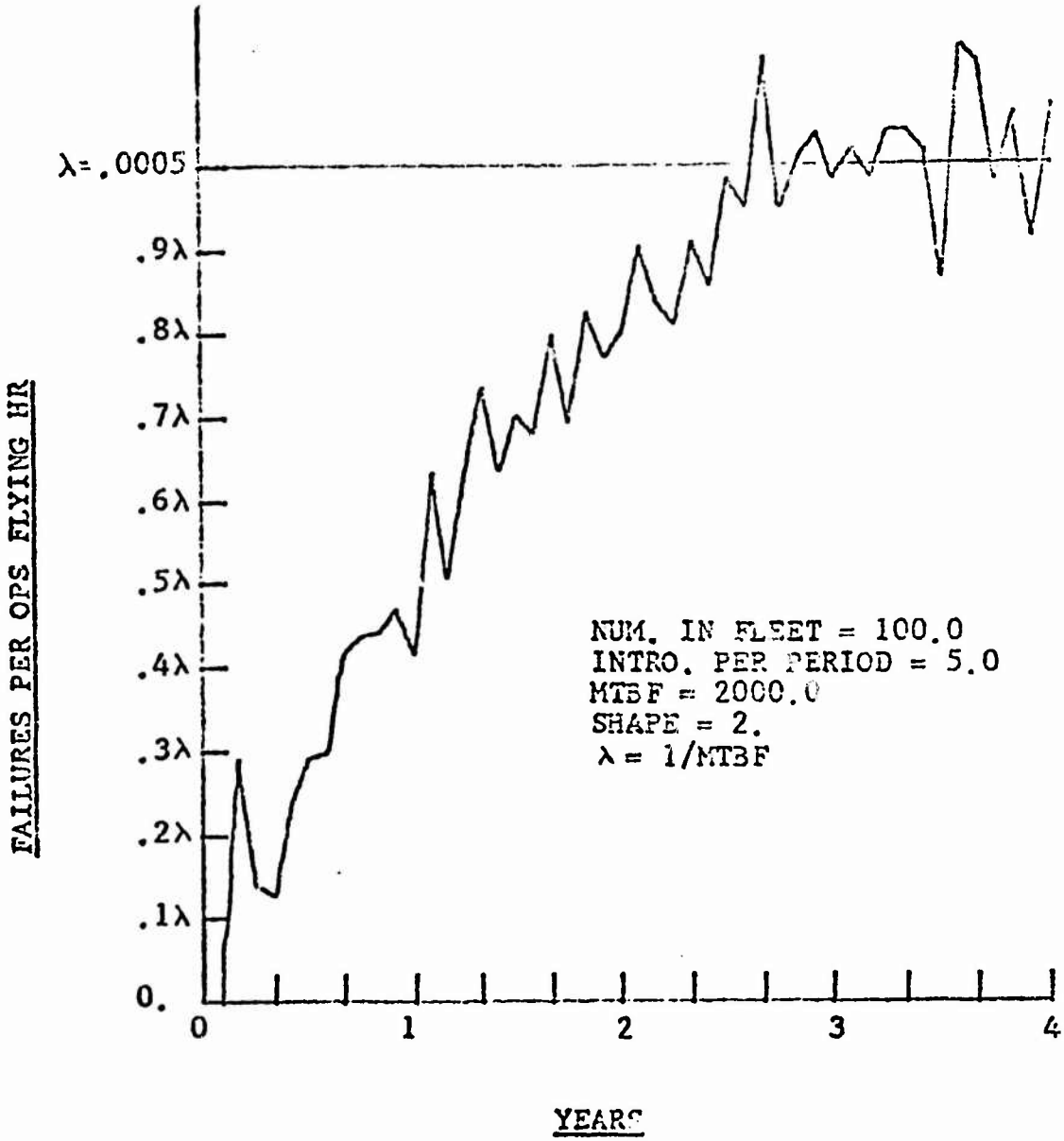

Figure 33

Increasing Failure Rate

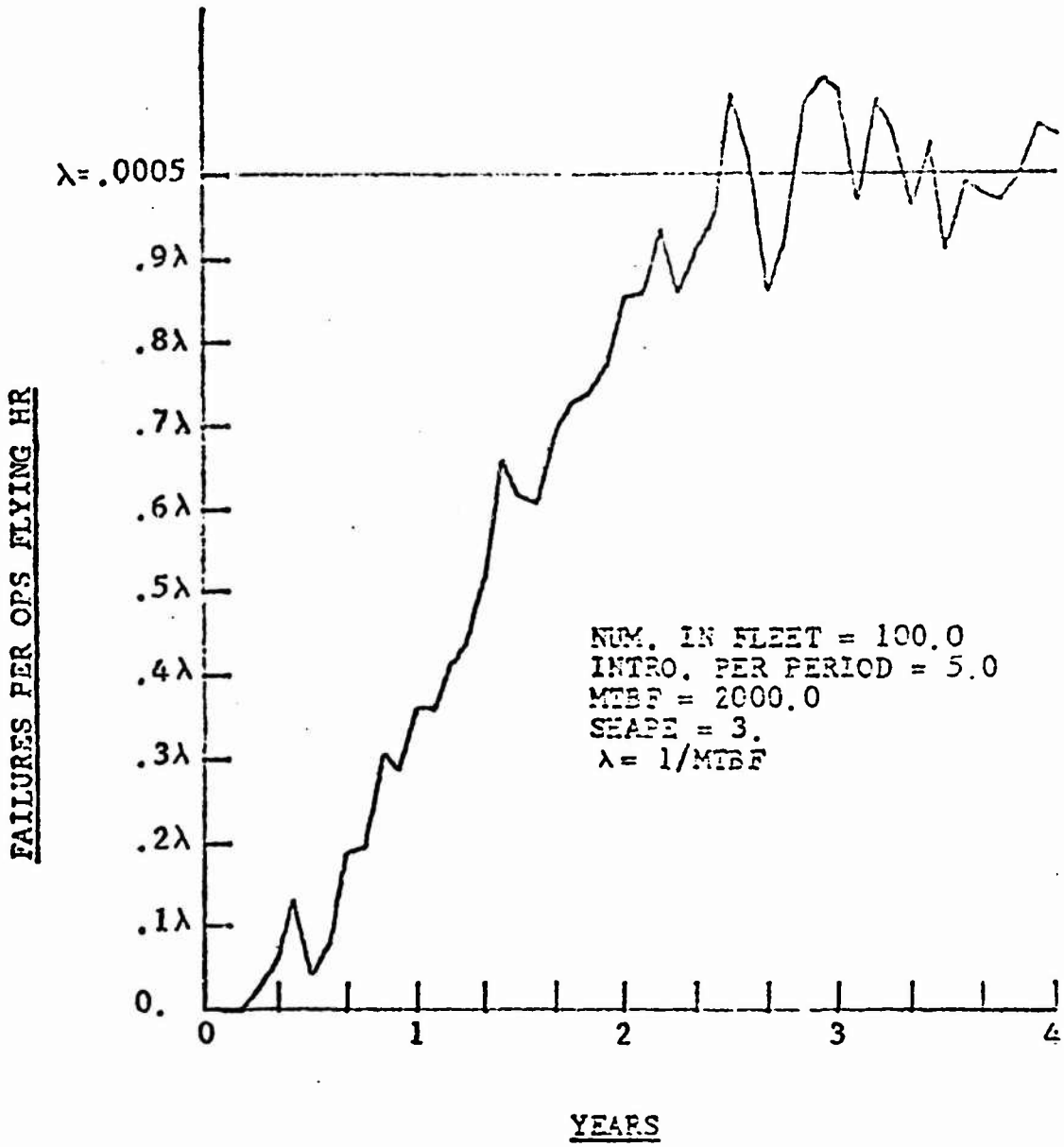

Figure 34

Increasing Failure Rate

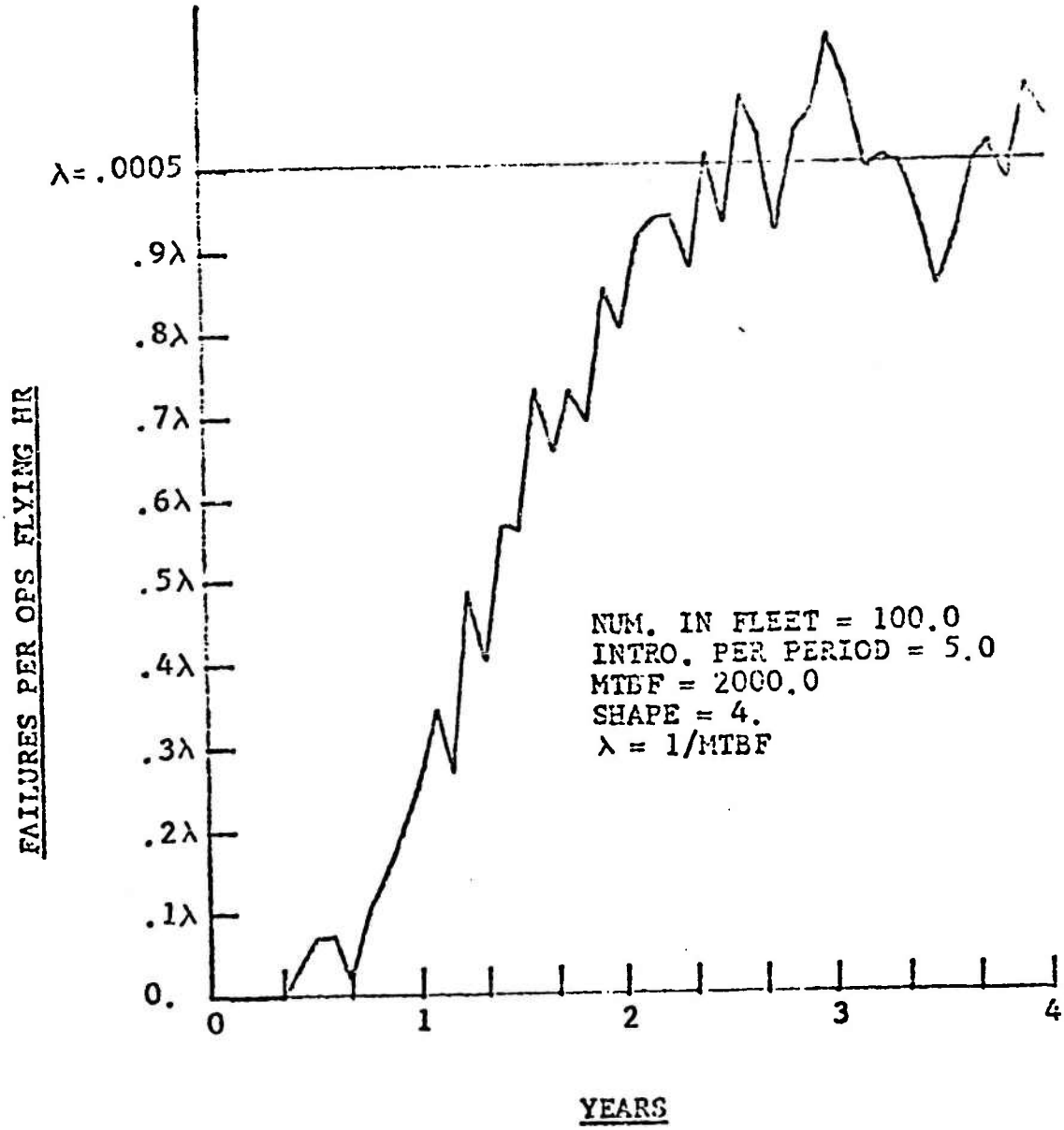

Figure 35

Increasing Failure Rate

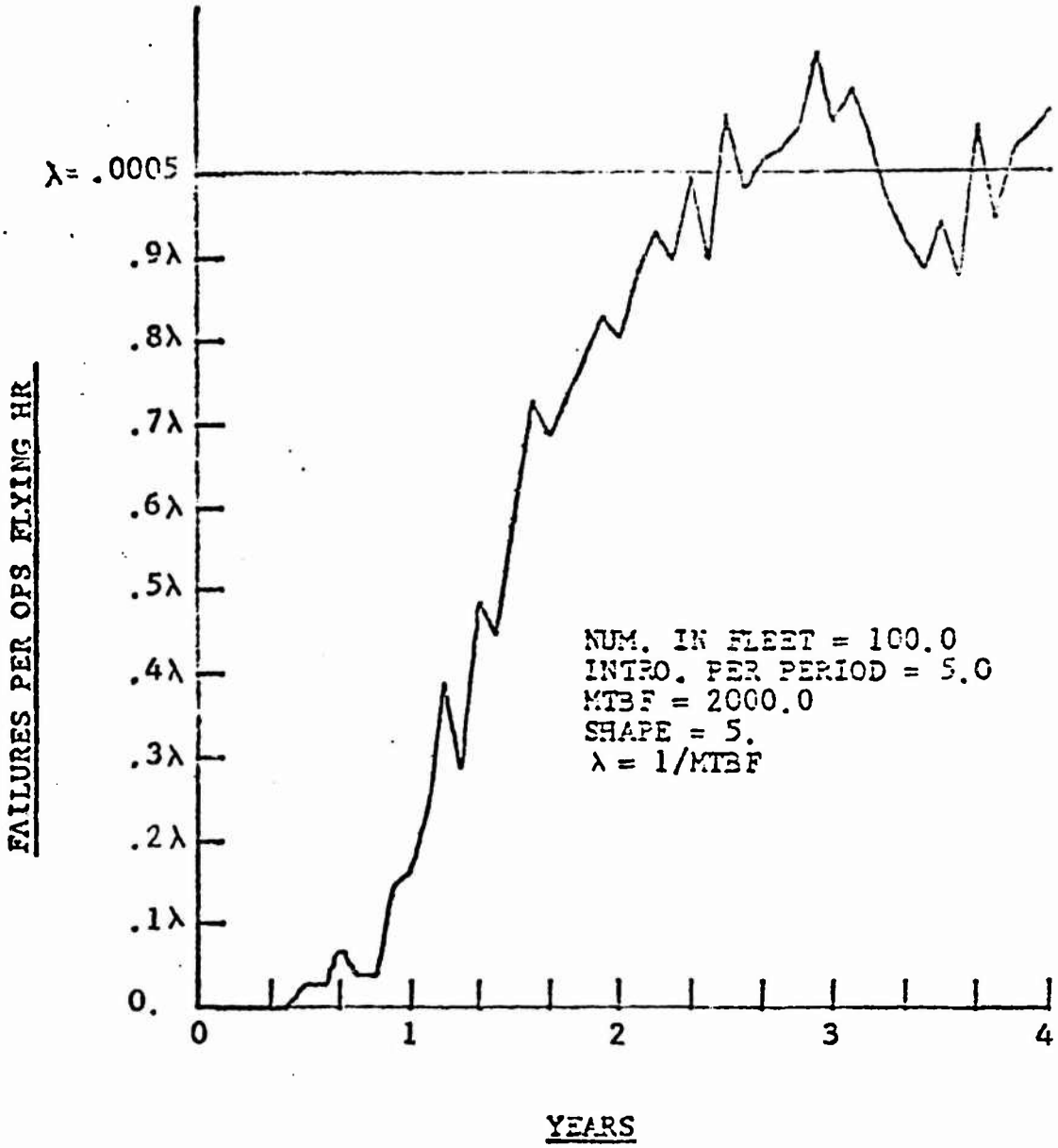

Figure 36

Increasing Failure Rate

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