[9]Fox, R.L., *Optimization Methods for Engineering Designs,* 1st Ed., Addison-Wesley, Reading, Mass., 1971, pp. 137-150.

[10]Meyer, R.R., "Buckling of 45° Eccentric-Stiffened Waffle Cylinders," *Journal of Royal Aeronautical Society,* Vol. 71, July 1967, pp. 516-520.

[11]Karmakar, R., "Buckling of Waffle Cylinders," *Aeronautical Journal,* Vol. 83, July 1979, pp. 274-278.

[12]Wittrick, W.H., "Symmetrical Buckling of Right-Angled Isosceles Triangular Plates," *Aeronautical Quarterly,* Vol. 5, 1954.

[13]Schmit, L.A., Kicher, T.P., and Morrow, W.M., "Structural Synthesis Capability for Integrally Stiffened Waffle Plates," *AIAA Journal,* Vol. 1, Dec. 1963, pp. 2820-2836.

A80-084

Impact of the Space Environment on Spacecraft Lifetimes

30015 70032

J. C. Baker*
Analytic Services Inc., Arlington, Va.
and
G. A. Baker Sr.†
University of California, Davis, Calif.

Introduction

THIS paper examines whether space is a benign environment insofar as spacecraft life is concerned. This topic should be of concern to planners who must assure that adequate numbers of satellites are available on orbit to perform specific missions, yet not at the expense of gross over-procurement of satellites. Taylor[1] has stated that the environment is benign and thus spacecraft lifetimes, once faulty satellites are weeded out by early failures, are very long.

We have examined data compiled by the NASA[2,3] on 57 typical satellites, both at the black box and total spacecraft levels. The data, analysis, and conclusions are presented below.

Data

Data[2] relating to spacecraft failures as a function of time in orbit are given in Fig. 1. A failure is defined as the loss of operation of any spacecraft function, part, component, or subsystem irrespective of its effect on total spacecraft mission performance, which is monitored by telemetry. Infant failures,[3] that is, failures occurring at or near initial spacecraft activation, have been removed from the raw data since these failures represent malfunctions introduced by the harsh launch environment and are not indicative of the effects of the space environment on spacecraft. Of the 57 spacecraft sampled, 54 survived launch.

The data were fit with a Weibull cumulative failure distribution[4]

$$W(t) = A[1 - \exp(-t^{\beta}/\alpha)] \tag{1}$$

by a least-squares fit. The estimated values of the parameters are

$$A = 2.1 \times 10^2 \qquad \alpha = 1.9 \times 10 \qquad \beta = 5.4 \times 10^{-1} \tag{2}$$

and the fitted line is shown in Fig. 1. This differs from the standard Weibull distribution by the factor A which must be included here because it is unknown *a priori* how many failures could occur. The derived value of A indicates approximately 4.0 malfunctions per spacecraft for the 54 spacecraft. The rms difference between the Weibull distribution and the data is 2.0 which indicates a very good fit.

Figure 2 shows the number of spacecraft surviving as a function of time. A spacecraft failure is defined as problems of sufficient nature as to cause operation of the spacecraft to be discontinued. These data are fitted with a Weibull distribution of the form

$$F(t) = 54\exp(-t^{\beta}/\alpha) \tag{3}$$

with the results

$$\alpha = 7.0 \times 10^2 \qquad \beta = 8.7 \times 10^{-1} \tag{4}$$

The fitting curve is shown in the figure, and the rms error is 1.2 indicating a good fit.

Discussion

The mean life for an object following the Weibull failure distribution is given by

$$\mu = \alpha^{1/\beta}\Gamma(1/\beta + 1) \tag{5}$$

For $\beta = 1$, $\mu = \alpha$. Based on this sample, the mean lifetime for components in space is 410 days and the mean lifetime for spacecraft is 2000 days.

Of considerable interest is the hazard rate, the instantaneous failure rate as a function of time $z(t)$,

$$z(t) = f(t)/R(t) \tag{6}$$

where $f(t)$ is the failure distribution function and $R(t)$ is the reliability function, or $F(t)/N$ where N is the number of cases in the notation of Eq. (3). Furthermore, $f(t) = -R'(t)$, so that for Weibull distributions

$$z(t) = (\beta/\alpha)t^{\beta-1} \tag{7}$$

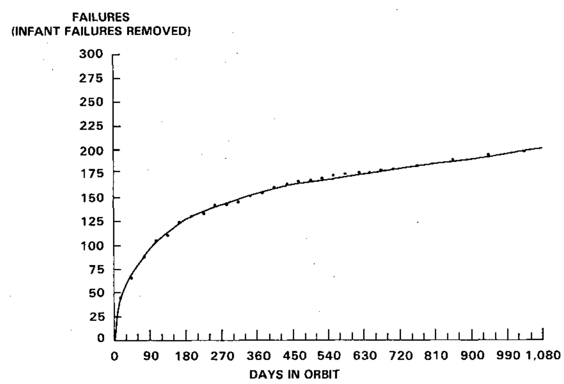

Fig. 1 Spacecraft failures in orbit.

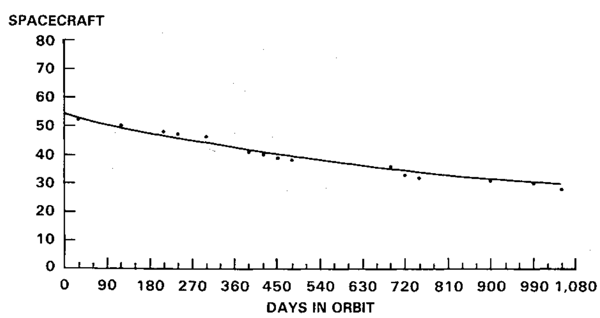

Fig. 2 Number of spacecraft still operating.

Received March 12, 1980; revision received May 19, 1980.

Index categories: Reliability, Maintainability, and Logistics Support; Spacecraft Testing, Flight and Ground.

*Deputy Division Manager, Space Division.

†Professor of Mathematics and Statistician, Experiment Station, Emeritus.

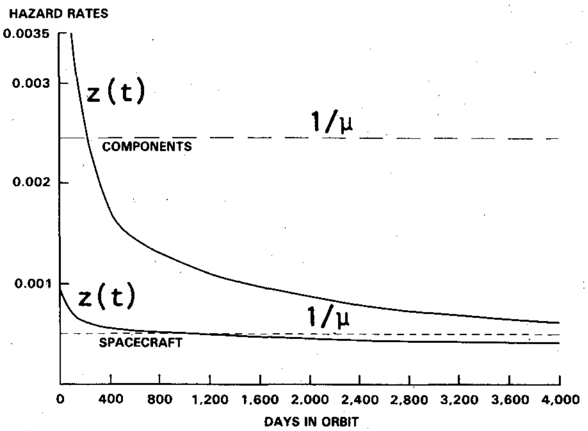

Fig. 3 Hazard rates for spacecraft and components.

The cases of interest are plotted in Fig. 3. The upper pair of curves is the hazard rate for components (solid line) and the constant component hazard rate based on the mean life of 410 days (dashed line) for comparison. The lower pair of curves is the same for spacecraft failures with the dashed line based on the derived 2000 day mean satellite lifetime. Both hazard rates decrease with time which means the longer a spacecraft or component exists in space, the longer it is likely to live. For example, the mean remaining life expected ($1/z(t)$) for components after 100 days is only 294 days, but rises to 833 days after 1000 days in space and 1600 days after 4000 days in space. Spacecraft after 100 days in space have a mean remaining life expectancy of 1470 days which rises to 1980 after 1000 days and 2370 after 4000 days.

Concluding Remarks

Thus, those spacecraft that last, last on and on. This means that space itself is not a harsh environment for spacecraft; for if it were, the hazard rate would increase as a function of time as cumulative exposure precipitates failures. There is the prospect, then, that adequate prelaunch testing could weed out low quality components so that satellite lifetime could be greatly extended.

References

[1]Taylor, E.C., private communication, Rand Corp., Santa Monica, Calif., 1978.

[2]Timmins, A.R., "A Study of Total Space Life Performance of GSFC Spacecraft," NASA TND-8, July 17, 1975.

[3]Timmins, A.R. and Heuser, R.E., "A Study of First-Day Space Malfunctions," NASA TND-6474, Sept. 1971.

[4]von Alven, W.H. (ed.), *Reliability Engineering*, Prentice-Hall Inc., Englewood Cliffs, N.J., 1964, pp. 161-168.