DO A DUANE

BY

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Introduction

The Duane Model was first postulated in 1962 as a practical method for quantifying the rate of reliability growth in development. Attention was drawn to Duane's Model in a paper at the 1968 I.E.E.E. Symposium on Reliability(1) and since then it has been described in papers by J. E. Green of the Royal Radar Establishment(2)(3).

Work at R.N.E.C. Manadon following a lecture by J. E. Green to the Engineering Management Course suggests that Duane's Model provides a simple and powerful method of analysing in-service failure data and presenting reliability information to management.

The Duane Model

J. T. Duane of the General Electric Company, U.S.A., discovered an empirical relationship between the failure rate and the testing time for development testing programmes during which a continuous effort was made to improve reliability by the introduction of modifications following the experience and diagnosis of failures. If these conditions apply it is commonly found that successive values of cumulative mean time between failures (MTBF) plotted against cumulative testing time on log-log paper yield a straight line. The slope of this line (α) may be used to derive the instantaneous value of MTBF achieved after a given period of testing. FIG. 1 shows the typical form of a Duane Plot and its use for reliability prediction.

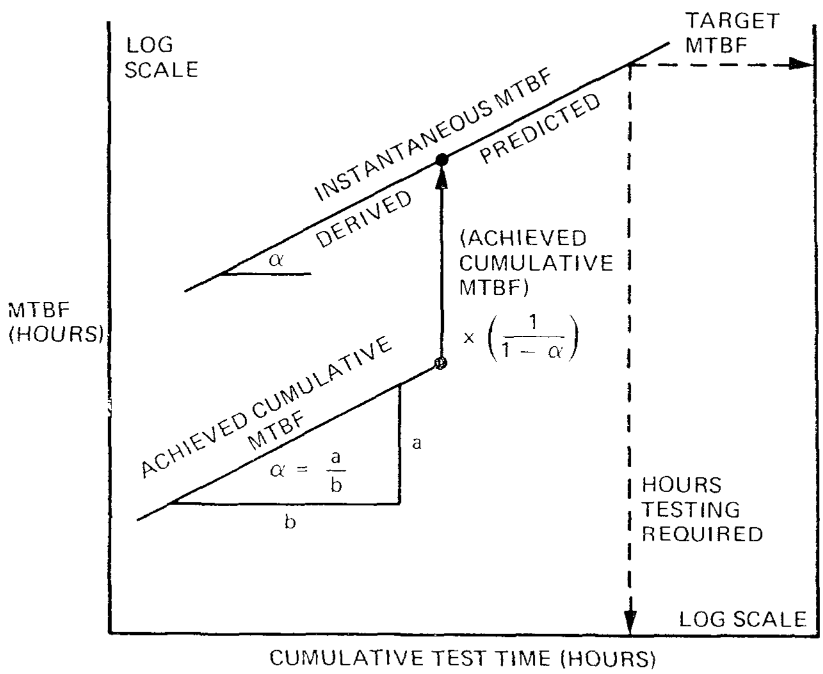

FIG. 1—TYPICAL DUANE PLOT AND ITS USE FOR RELIABILITY PREDICTION

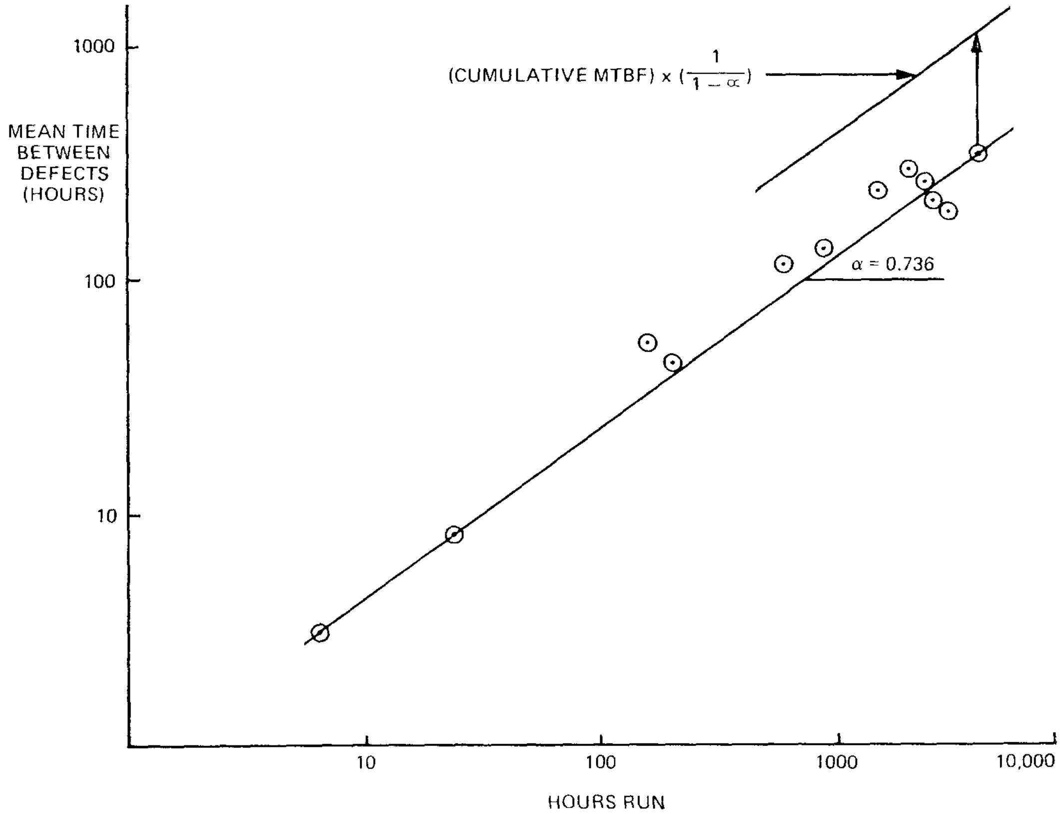

Fig. 2—Duane chart for prototype diesel generator tested at AMEE

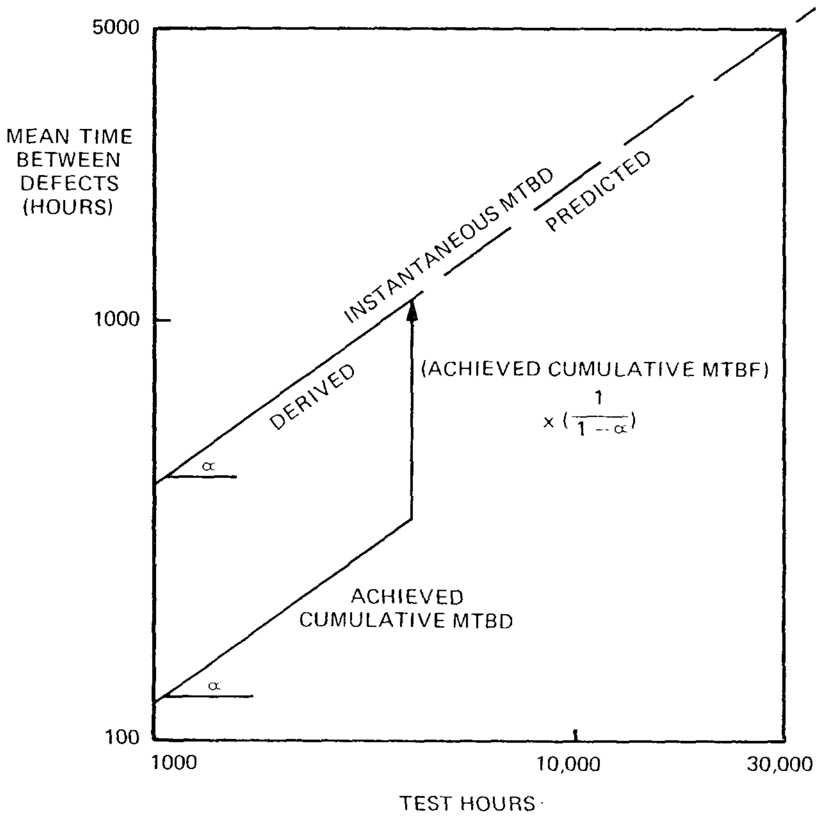

Fig. 3—Plot as Fig. 2 showing instantaneous MTBF derived line

How to Plot a Duane Chart

(*a*) The following data are required:

(*i*) The running time in successive testing periods

(*ii*) The number of failures in successive testing periods

(*b*) At the end of each testing period, the length of which may be arbitrarily chosen, calculate:

$$\text{Cumulative MTBF} = \frac{\text{Total running time to date}}{\text{Total No. of failures to date}}$$

(*c*) Then plot Cumulative MTBF versus Total running time to date on log-log paper.

(*d*) If a continuous effort to improve reliability by the introduction of modifications has been sustained the successive points will lie generally on a straight line whose slope (α) is a measure of reliability growth. Values of instantaneous achieved MTBF are given by:

$$\text{Instantaneous achieved MTBF} = \text{Cumulative MTBF} \times \frac{1}{1-\alpha}$$

(*e*) These values form a straight line parallel to that formed by cumulative values. Extrapolation of this instantaneous MTBF line then allows prediction of, for instance, the period of development testing that is required in order to achieve a specified target MTBF.

Diesel Generator Example

FIG. 2 shows the Duane plot for a prototype diesel generator tested at the AMEE, Haslar. The cumulative mean time between defects (MTBD) has been calculated at the time of each defect occurrence whereas the Duane method requires only that it be calculated at the end of successive periods of operation (e.g. monthly, every 400 hours, etc.). The plot is also optimistic in that four defects have been neglected. These defects resulted from two causes which were not remedied when they first occurred. The plot therefore shows the reliability growth that would have been achieved if prompt and successful action had been taken.

The plot shows that by the end of 4000 hours testing the engine had achieved an instantaneous MTBD of about 1100 hours. This figure is substantiated by the fact that the final 1500 hours running were achieved without defect. In FIG. 3, the plot has been transferred to a scale which allows the instantaneous MTBD line to be extrapolated. From FIG. 3 it can also be seen that for the MTBD to be extended to, say, 5000 hours it would require testing and development to continue to a total of 30 000 hours

Further applications

One of the most valuable lessons provided by the Duane model is that plotting cumulative MTBF against running time on log-log paper is a simple and expressive way of showing reliability trends. Clearly, if no reliability improvement is effected over a period of operating, successive cumulative MTBF points will lie on a straight horizontal line, while reliability deterioration will cause the plot to droop. This immediately suggests that the simple Duane plotting method could, with advantage, be applied to in-service failure data with a view to maintaining an up-to-date plot of equipment reliability. Where it is known that not all failures are being reported the plot would be labelled 'cumulative mean time between reported defects'. It would not be significant in absolute terms but provided the reporting efficiency remained sensibly constant such a plot would be useful in a relative and comparative sense.

A very natural extension of the method is to plot cumulative mean time to repair (MTTR) against cumulative repair time, or down time. A mathematical analysis analogous to that which yields the Duane model for reliability growth shows that:

$$\text{Instantaneous MTTR} = \text{Cumulative MTTR} \times \frac{1}{1-\alpha}$$

The combination of MTBF and MTTR plots then yields the values necessary to calculate and plot Availability (should this be required) from:

$$\text{Availability} = \frac{\text{MTBF}}{\text{MTBF} + \text{MTTR}}$$

where, MTBF = Instantaneous MTBF from the Duane Model
MTTR = Instantaneous MTTR.

Evaporator Example

The set of failure data provided by Commander Gorst in his article 'Reliability Theory and Practice' (p. 241) provides all the information necessary to explore the potential of the Duane method and its extensions when applied to equipment in service. Total cumulative evaporating hours has been chosen as the time base for the reliability plot, calculated by:

No. of evaps (7) × hours since sailing − down time.

TABLE I — *Data (Columns 2 to 7 are cumulative)*

1	2	3	4	5	6	7
To date	*Total Time (hours) 7 evaps*	*Down Time*	*Up Time*	*Failures*	*MTBF* $\frac{\textit{Col. 4}}{\textit{Col. 5}}$	*MTTR* $\frac{\textit{Col. 3}}{\textit{Col. 5}}$
6/2	283·5	23·5	260	5	52	4·7
10/2	856·5	55·5	801	8	100	6·9
15/2	1696·5	95·5	1601	10	160	9·6
20/2	2536·5	99	2437·5	12	203	8·3
25/2	3376·5	156	3220·5	13	248	12·0
1/3	4216·5	260	3956·5	16	247	16·3
6/3	5056·5	260	4796·5	16	300	16·3
11/3	5896·5	285	5611·5	18	312	15·8
15/3	6736·5	358	6378·5	19	336	18·8
23/3	7924	358	7566	19	398	18·8

The operating time was divided into periods of about five days to give the values presented as TABLE I. The figures give the results of the analysis:

FIG. 4 — Reliability plot. Log-log scale (time base : up time).
FIG. 5 — Maintainability plot. Log-log scale (time base : down time)
FIG. 6 — Availability plot. Log-lin scale (time base : total time).

From these figures it can be seen that the work of the ship's staff in rectifying failures yielded a steady improvement in evaporating system reliability but the mean time to repair tended to increase with time. The resulting availability, derived from the best fit straight line values of MTBF and MTTR, increased over the 47-day operating period.

No general conclusions can be drawn from this example concerning the reliability and maintainability of in-service equipment although many engineers may feel that it generally accords with their experience of operating machinery after a period of dockyard work. The value of this example is that it shows how vividly failure information can be displayed using the very simple methods suggested by the Duane model.

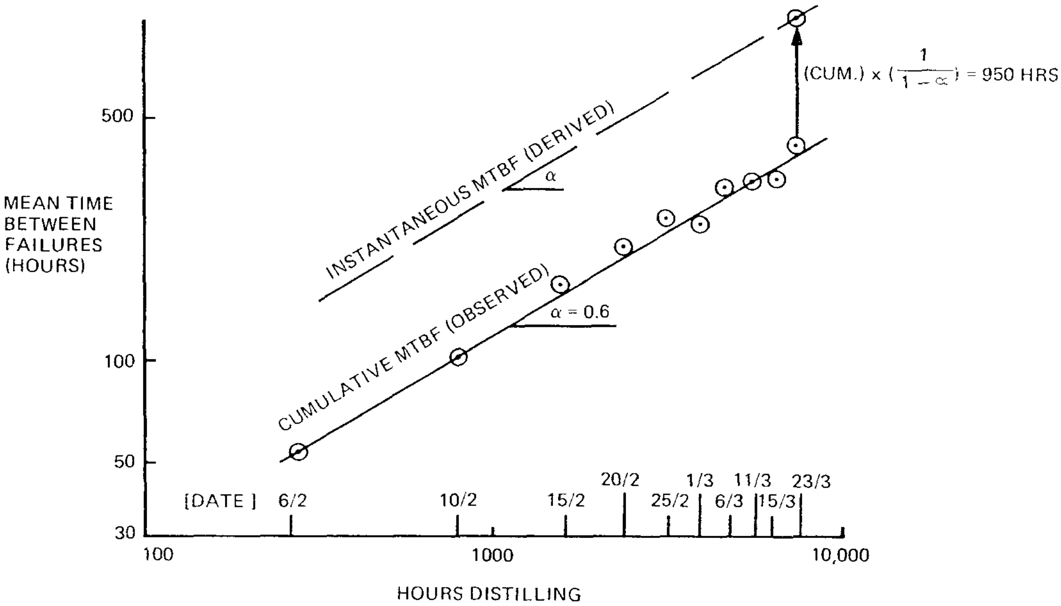

FIG. 4—RELIABILITY PLOT—LOG-LOG SCALE (TIME BASE : UP TIME)

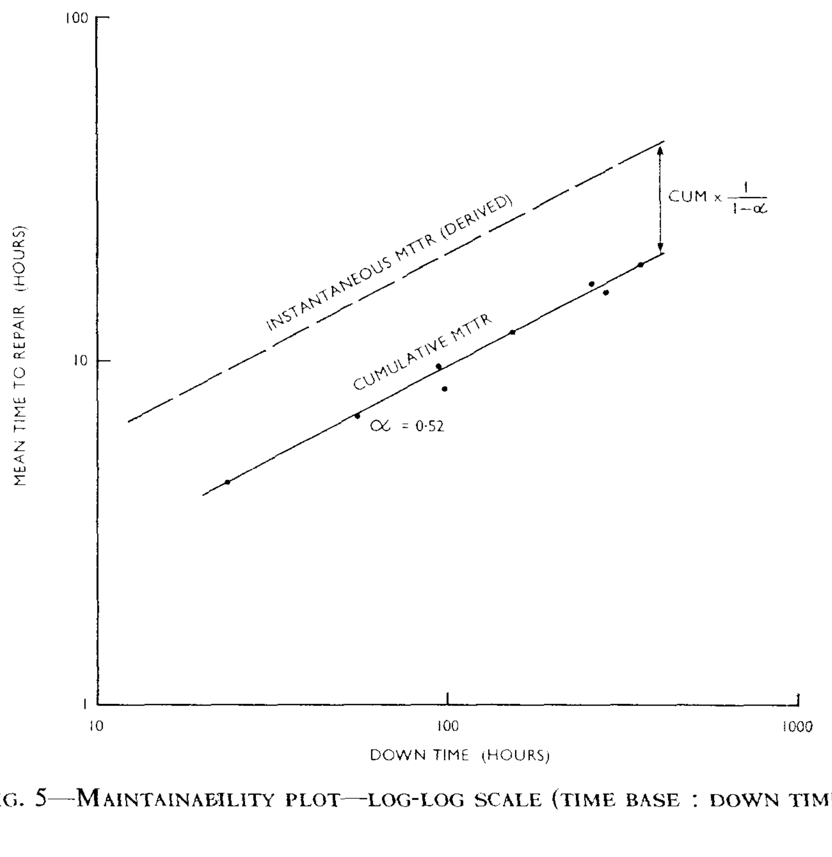

FIG. 5—MAINTAINABILITY PLOT—LOG-LOG SCALE (TIME BASE : DOWN TIME)

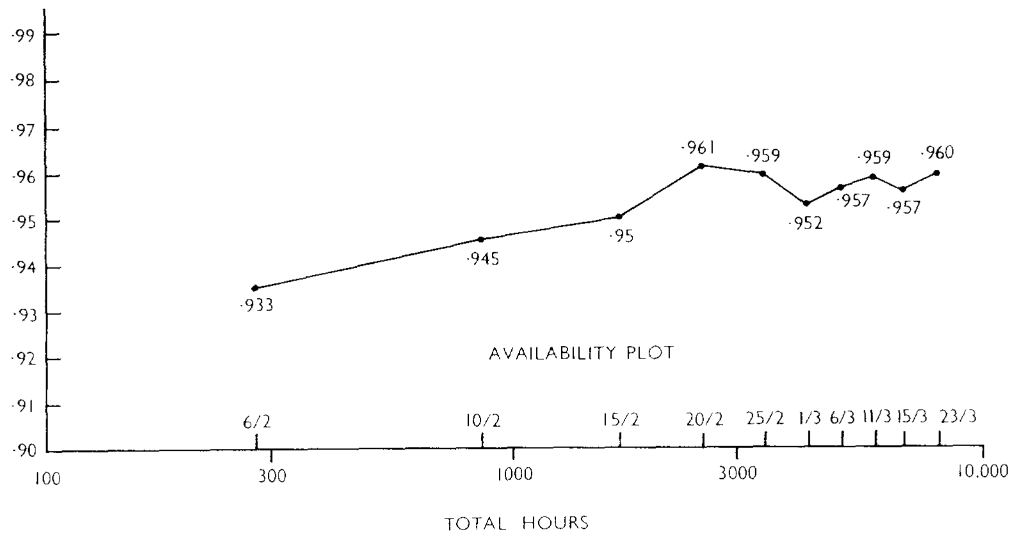

FIG. 6—AVAILABILITY PLOT—LOG-LIN SCALE (TIME BASE : TOTAL TIME)

Comparison with Weibull

It has been shown(4) that the Duane model and the Weibull repairable system failure rate model are the same. From an engineer's point of view, however, the Duane model has significant advantages over Weibull plotting:

(*a*) It recognizes changes in equipment reliability with operating time and provides a means of reliability prediction.

(*b*) It requires less high-quality data. Weibull plotting demands times to each failure (rarely available) while Duane requires only the number of failures in successive operating periods together with the total operating time in the period.

(*c*) A Duane plot can be quickly updated as new data are received: it is truly a running plot of events. With Weibull plotting, on the other hand, when any new times to failure are received the whole set has to be re-ranked in order of times to failure and new plotting positions determined.

(*d*) Plotting can be started at any time through equipment life and trends can be quickly identified as failures occur.

(*e*) It is sufficiently simple to be considered for use at ship level.

Conclusion

The Duane Model is becoming more widely accepted and used for programme and resources planning and for progressing reliability achievement(2). So far the method has been mainly applied in the field where it was discovered, namely during development testing. Preliminary investigations indicate, however, that the basic method and its extensions could have wide applicability in the field of in-service failure data analysis and presentation.

Acknowledgement

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