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CRACK GROWTH VARIABILITY AND ITS EFFECT ON RISK ANALYSIS OF FRACTURE PREDICTION

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Introduction

The probability distribution of a crack length at a critical location on an airframe is a key input for the evaluation of risk of failure by fracture. At any given time during the flight history, this distribution depends on the initial surface condition of the structural component, the crack growth behaviour of the material and the applied load history. MIL-STD 1530C [1] allows the use of a single master crack growth curve to derive the subsequent crack length distributions from the initial crack length distribution, without explicitly taking into consideration the well-recognized scatter in crack growth rates due to uncertainties in material properties. Our previous work [2, 3] indicates that the distribution of initial flaw size and the crack growth law plays a major role in the results of risk analysis of fracture. Thus, the need to consider the variability of crack growth curve is necessary for accurate prediction of the risk of failure. This paper investigates the effect of crack growth variability in the context of probabilistic risk analysis of fracture of airframe structures.

Testing of Specimen

The coupon test specimen configuration is shown in Figure 1. It is manufactured from 6.35 mm thick 7075-T7351 aluminium bare plate. Each specimen has a 2.0 mm hole in the centre with a 0.5 mm slot on each side of the hole. A sharp pre-crack was generated by applying a constant amplitude load with a maximum stress equalling to 70% of the peak spectrum load and a stress ratio of R = 0.1, until the pre-crack reached a length of about 2.0 mm on each side of the notch. During pre-cracking, load shedding was applied by reducing the load from 70% to 60%, in order to reduce the plasticity effects at the crack tip. The crack growth curves of the specimens are shown in Figure 2, the crack growth curve corresponding to varying confidence levels are shown in Figure 3 and the coefficient of variation as a function of initial crack size and flight hours is shown in Figure 4.

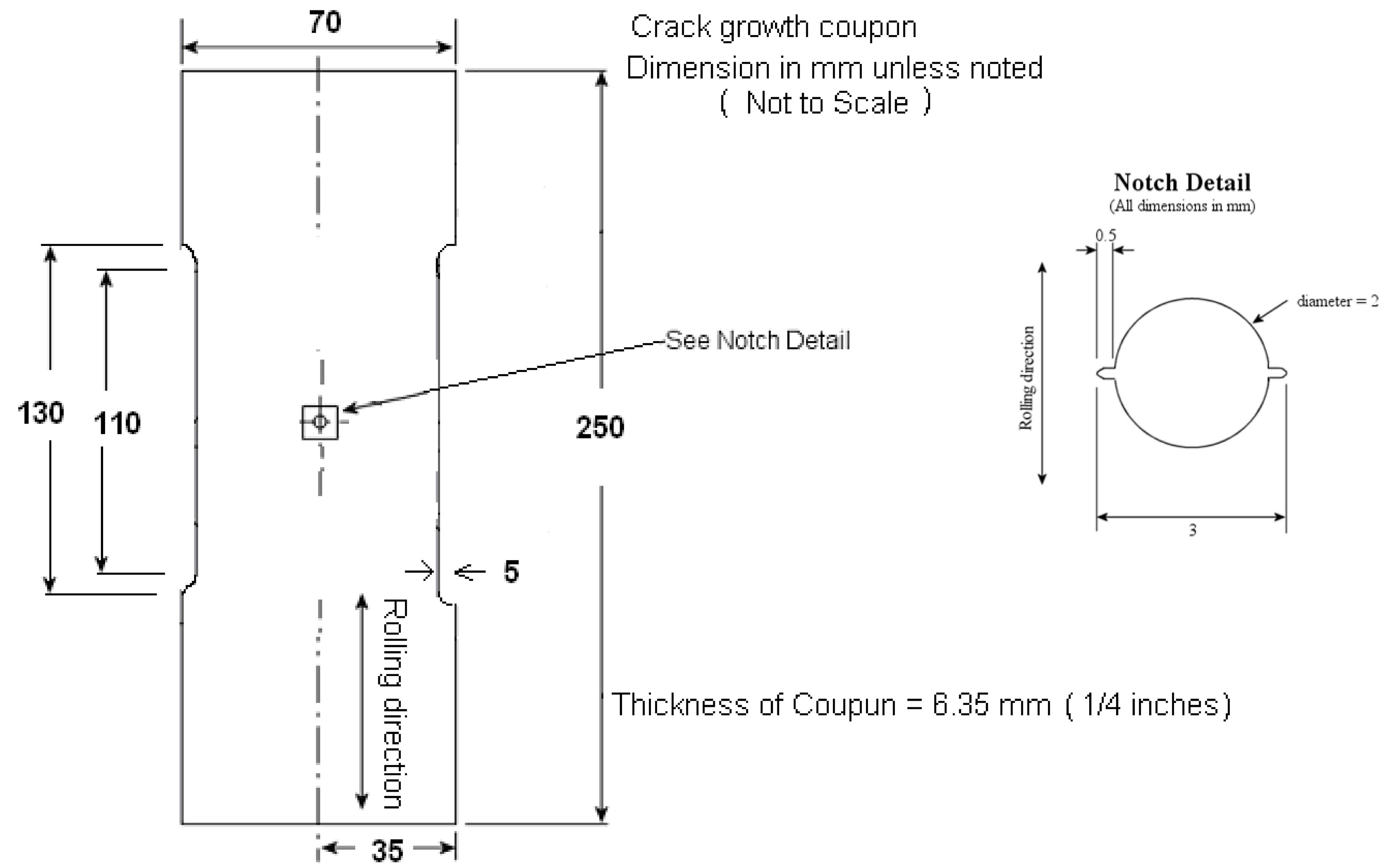

Figure 1 Coupon test specimen geometry

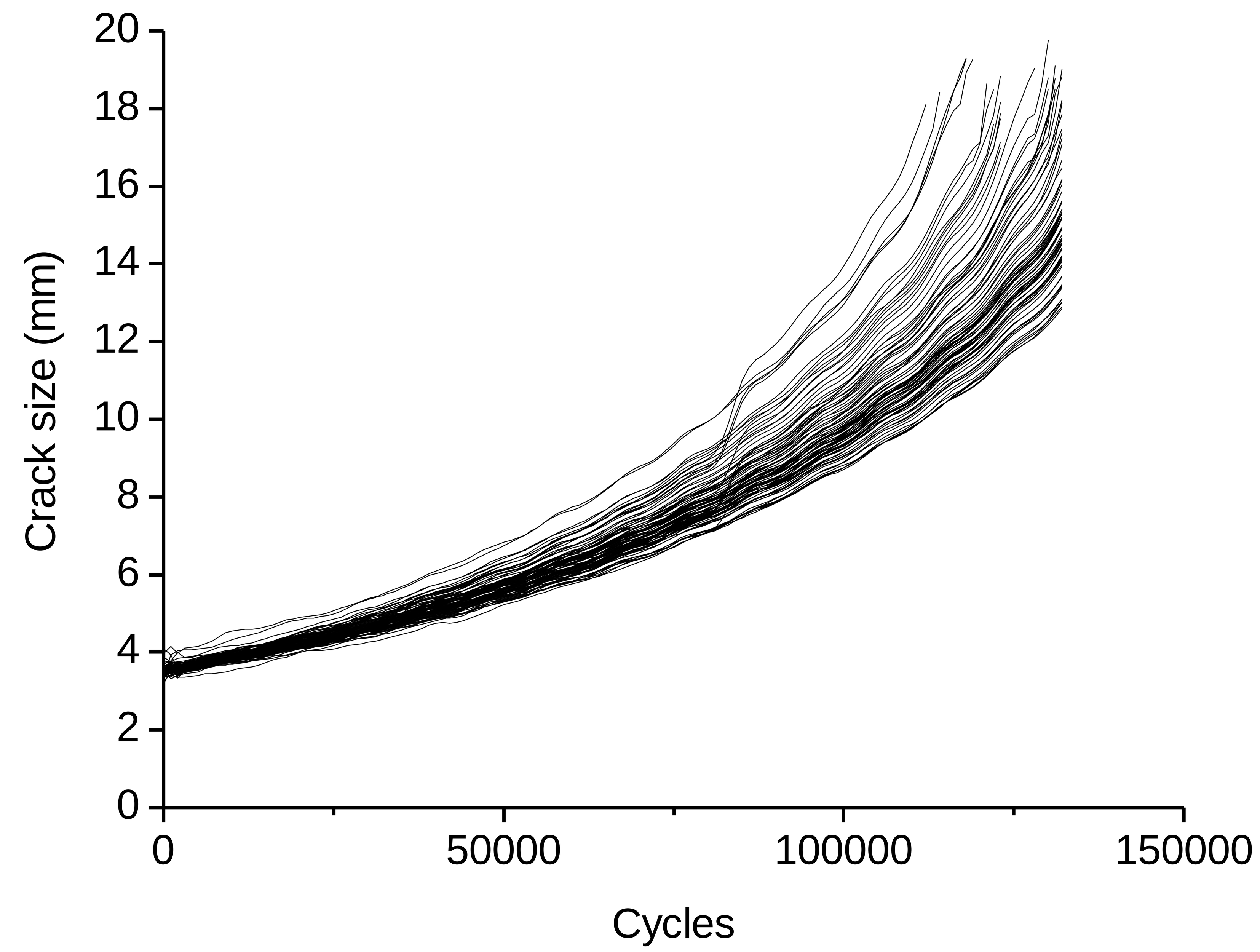

Figure 2 Crack growth curves of 85 test specimens

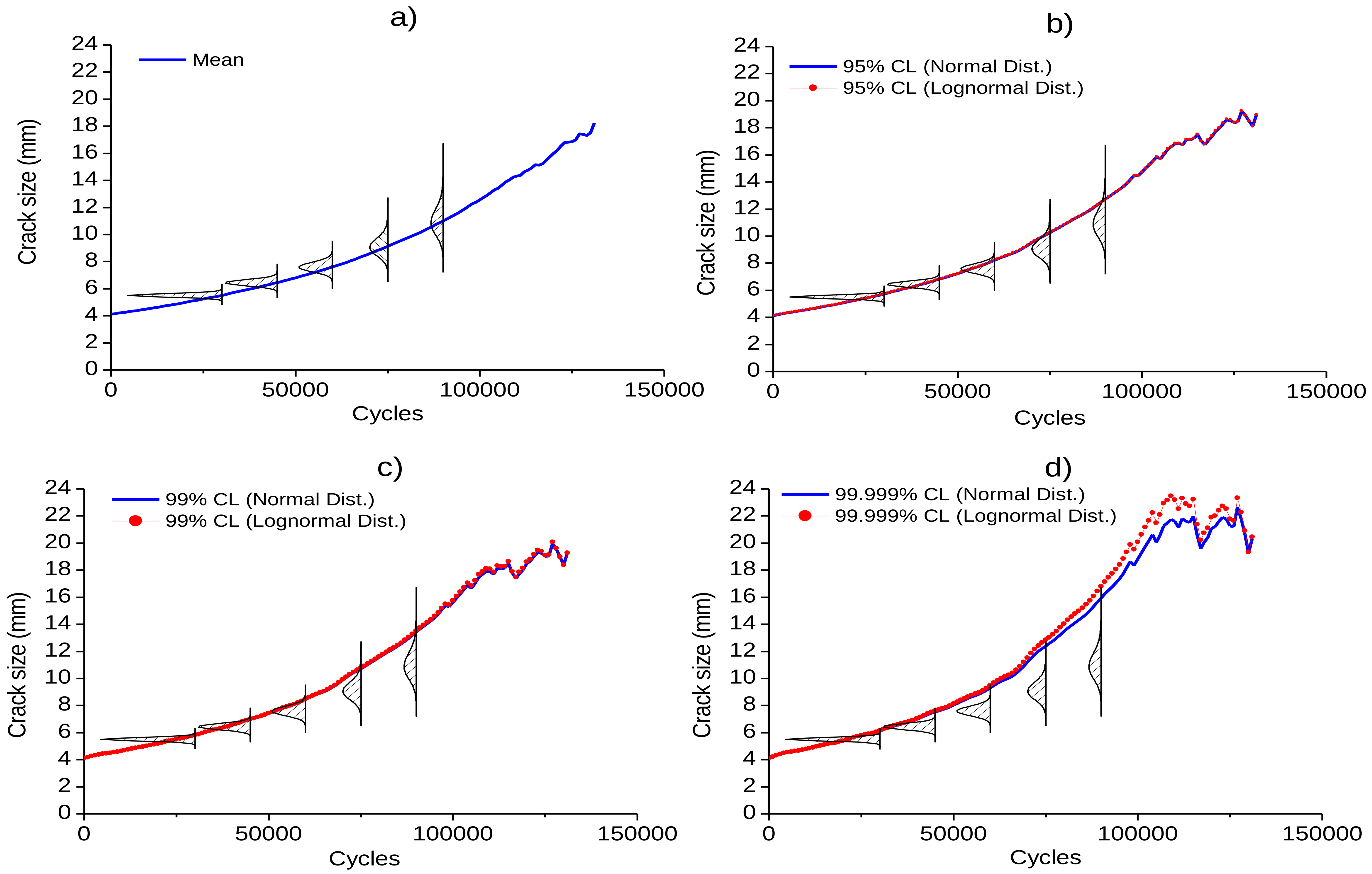

Figure 3 Variability of crack size with respect to the number of cycles, showing the crack growth curves corresponding to a confidence level (CL), a) 50% CL b) 95% CL c) 99% CL and d) 99.999% CL

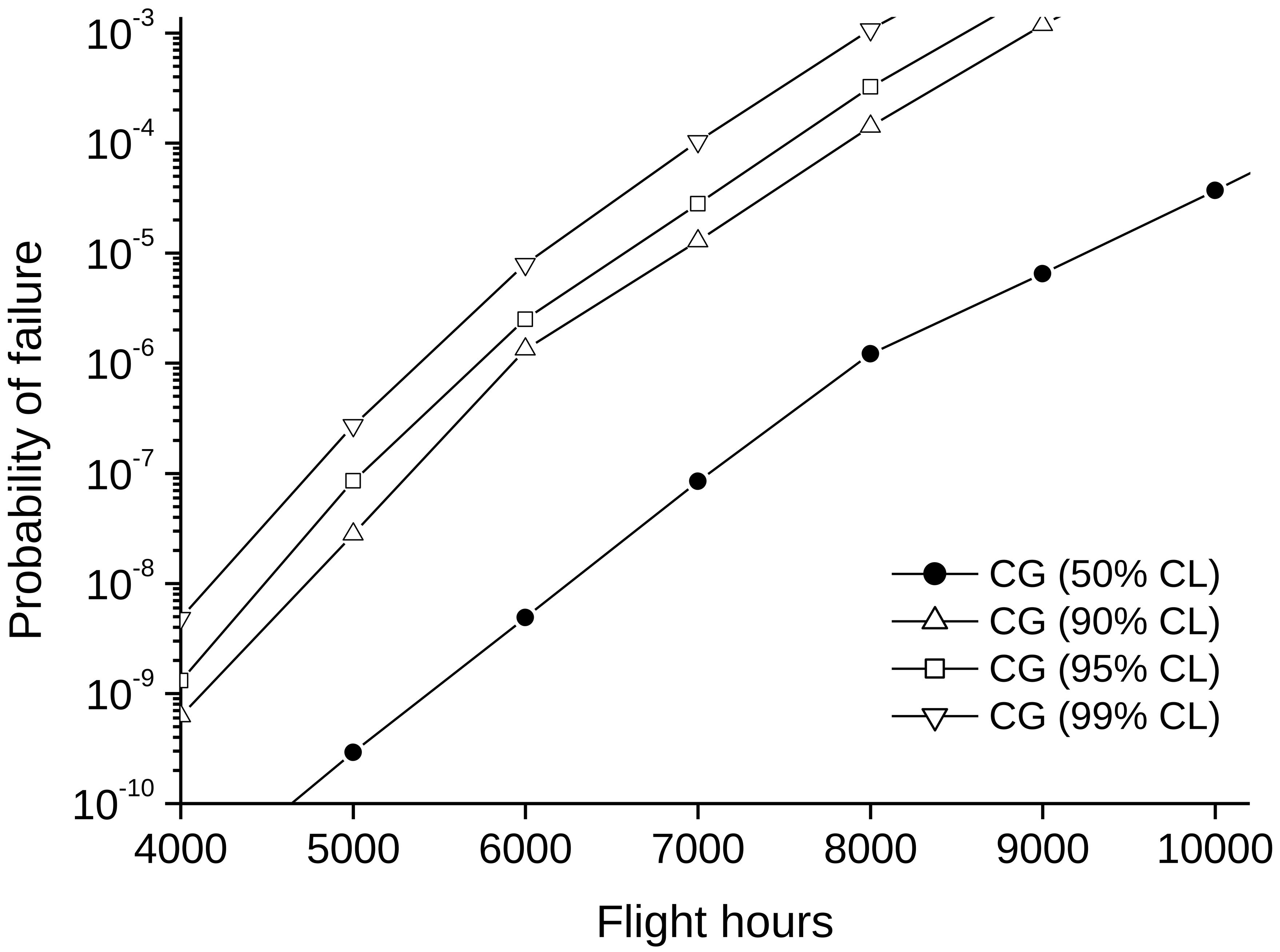

Figure 5 Probability of failure with increasing number of flight hours for each corresponding confidence level.

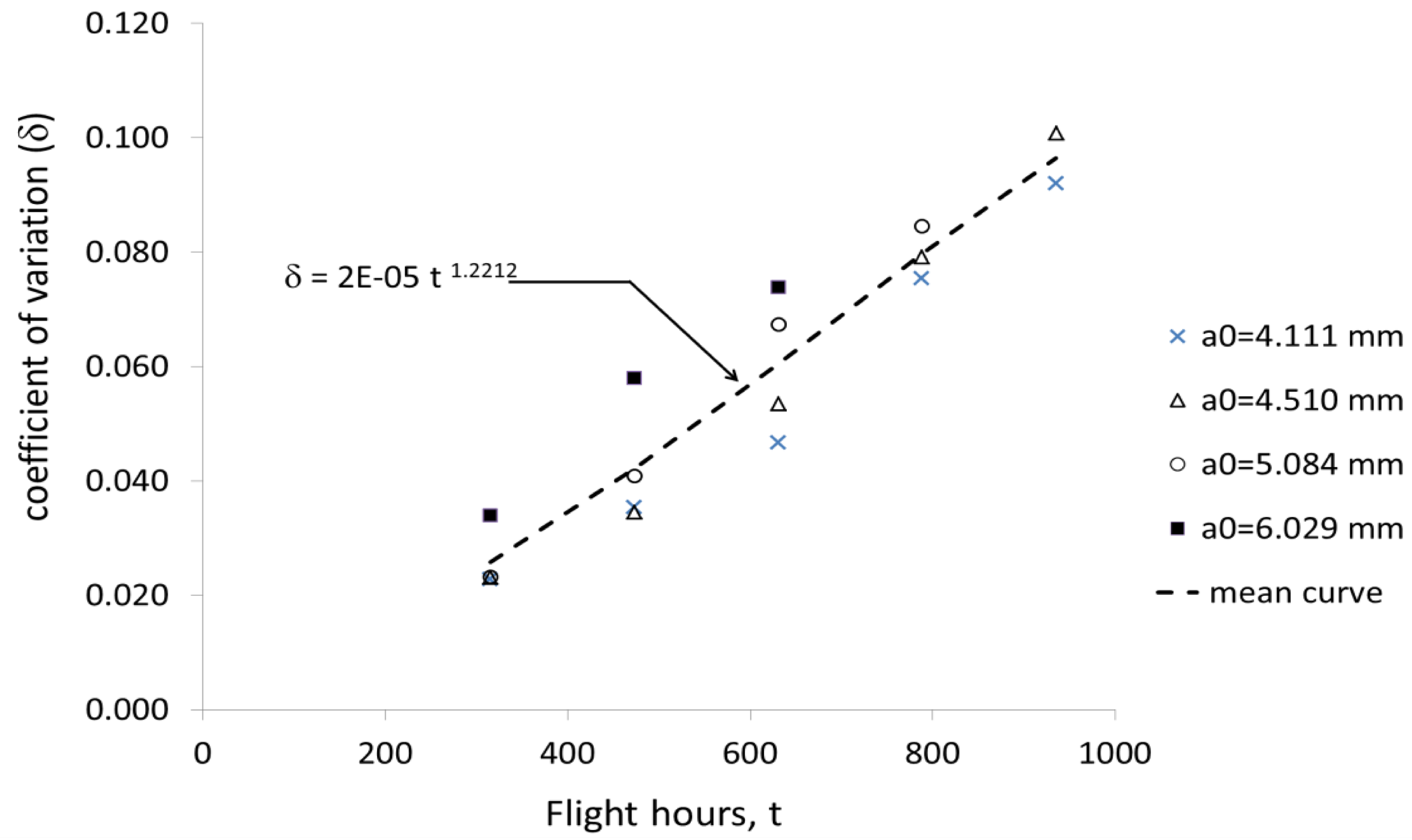

Figure 4 Coefficient of variation of crack sizes with increasing number of flight hours for various initial crack size.

Discussion of Results

Figure 5 shows that specifying confidence levels of a crack growth curve in the risk analysis will result in a significant difference in the predicted risk values. It is observed that increasing the confidence from 90% to 99% increases the risk prediction by approximately a magnitude. As a consequence, given the observed coefficient of variation from the test results, increasing the confidence level requirement of the risk prediction of fracture resulted in a significant increase in risk values.

Conclusions

The following conclusion may be drawn:

1. Variation of crack sizes is highly correlated with number of load cycles (i.e., flight hours) and, to a lesser degree, correlated with the initial crack size.
2. Risk analysis of fracture prediction can vary significantly depending on the confidence level of the crack growth curve used.
3. Second order probabilistic risk analyses of fracture may be performed for different confidence levels when crack growth variability data is available.

References

[1] US Department of Defence, *MIL-STD-1530C, Aircraft Structural Integirty Program (ASIP)*. 2005.

[2] Torregosa, R.F. and W. Hu, *Probabilistic risk analysis of fracture of aircraft structures using a Bayesian approach to update the distribution of the equivalent initial flaw sizes.* Fatigue & Fracture of Engineering Materials & Structures, 2013.

[3] Torregosa, R.F. and W. Hu,*C-130H Centre Wing Lower Surface Panel Number 3 Probabilistic Risk Analysis*,Defence Science and Technology Organisation,DSTO-RR-0371,2011.