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SONIC FATIGUE STUDY OF AN AIRCRAFT FLAP LIKE STRUCTURE

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ABSTRACT

Acoustic fatigue failures in aircraft are caused by the dynamic response of structures to unsteady pressure loading from aerodynamic and engine acoustic sources. Structural life is difficult to assess accurately and may be affected by steady, thermal, in-plane and out-of-plane panel loads. These failures result in increased maintenance and inspection burdens associated with the operation of the aircraft. Much research was performed in the late 60's to mid 70's on dynamic response methods and the generation of endurance data, culminating in the ESDU data sheets and AFFDL design guide. This information is still used today. However, the airframe manufacturer is required to meet more stringent performance and mass targets, which have been achieved through developments in optimised and efficient design of structures, and the introduction of new materials. There is a corresponding need for development of acoustic fatigue design methods and data. A three year research project is currently in progress using advanced analytical procedures, finite element analysis and complementary experimental studies to develop dynamic response prediction procedures which will result in guides for the design of box-type structures, such as flaps, constructed from conventional aluminium alloys, CFRP and GLARE materials. This paper reports upon the experimental phase of the project and the results.

INTRODUCTION

Acoustically induced fatigue failures in aircraft have been a design consideration for over thirty years. The problem was introduced with the advent of turbojet engines and the resulting high intensity acoustic pressure levels experienced on the aircraft structure. Acoustic fatigue failures can substantially increase the maintenance burden and life cycle cost of the aircraft.

Current aircraft acoustic fatigue certification practice includes the calculation of the component fatigue life based on the methods published in the Engineering Sciences Data Unit (ESDU) data sheets and compared with flight test results. In some cases it has been necessary to conduct an acoustic fatigue endurance test in a laboratory facility using either a whole aircraft component or a representative portion of the component. The latter method is used whenever a new or novel type of structure has been used in a high noise area where there may not be sufficient data to allow certification clearance completely by calculation.

A very good summary report in acoustic fatigue research technology is given in reference [1]. The report highlights the fact that in the early work it was not possible to get better agreement than to within a factor of two and predictions usually overestimate the response levels. In the new work attempts are being made to bridge the gap between the nomographs, analytical results and finite element computations.

For wing mounted engines on subsonic commercial aircraft, the flaps when deployed are usually subjected to a very high level of jet noise up to 155 dB. Therefore, it is important that the structure is designed robust enough to withstand the excitation throughout the whole life of the aircraft.

Flaps usually employ a conventional fabricated construction of thin skins stiffened by stringers on built up spanwise spars and chordwise ribs. From a structural dynamic viewpoint this is a very complex arrangement, particularly at the relatively high frequencies associated with jet noise; rather than behave like a beam, the flap tends to exhibit vibrations of the individual constituent skin panels. The ESDU procedures, strictly speaking, are not applicable to flap-like structures for two reasons. The first is that an individual skin panel in the flap structure cannot realistically be considered in isolation from the rest of the structure. Secondly, the flap has an aerofoil profile which means that the panels have variable curvature. Although curved panels and built-up structures are given in ESDU, the simplified models presented only approximate to the case of a box-type structure.

A three year research project has been set up which involves both the theoretical and experimental work. The aim of the theoretical work is to produce a realistic structural dynamic computer model of a box-type structure, which may be used at the initial stages of design. Conventional finite element modelling of a complete structure of this type at the frequencies of interest would involve an unwieldy number of degrees of freedom, particularly at the parameter study design stage. The theoretical approach represents an extension of a dynamic stiffness technique which has been successfully applied to the prediction of aircraft interior noise levels [2,3]. Elements of periodic structure theory [4] as applied to the forced response of box-type structures will also be considered.

The experimental work considers a simplified model of a box-type flap structure which are subjected to both modal testing and random noise excitation. This work will identify the basic physics of the dynamic response of the structure and it will serve to guide the theoretical modelling. A major element of both the theoretical and experimental work will be a study of the advantages to be gained from the use of advanced materials, and a comparison will be made between conventional aluminium construction, carbon fibre reinforced plastic, and the relatively new aluminium/fibreglass laminate GLARE.

The present work will make fundamental contributions to structural dynamic modelling techniques. Additional result will be a design technique which is directly applicable to flaps, ailerons, fins and rudder box-type structures on an airframe. This paper describes the experimental part of the work.

DESIGN AND MANUFACTURING OF TEST SPECIMENS

The size and geometry of the box-type flap structure has been designed to fit the size of the Progressive Wave Tube (PWT) facility at Southampton University, where the experiments are being conducted. Three boxes have been made and are of conventional aluminium alloy, CFRP and GLARE materials. The design of the box is based on a representative section of a typical Airbus aircraft flap. Each box is approximately 1.2m x 0.7m x 0.2m in size.

The Aluminium box is made of 2024 alloy, which consists of two skins, two C-section spars, two inner ribs and two closing ribs as shown in figure 1. The CFRP box is made of 924C-TS(6K)-5-34% unidirectional prepreg material and the two closing ribs are made of aluminium alloy. The GLARE box is made of GLARE 3 (as top and bottom skin panels) and GLARE 2 (ribs and spars) and the two closing ribs are again made of aluminium alloy. Corresponding Tee coupons and beams have also been made for S-N data curve and damping measurements. GLARE 3 is made of three layers of 2024-T3 aluminium with thickness 0.2-0.3-0.4mm sandwiched with two layers of cross ply glass 50/50 each with thickness of 0.25 mm. GLARE 2 is made of three layers of 2024-T3 aluminium with thickness 0.2-0.3-0.4mm and two layers of unidirectional glass each with thickness of 0.25mm.

Strain gauges have been attached to many locations in each box-type structure and on the T-coupons. Finite element models were used to predict the box response shapes and the location of the strain gauges have been chosen based on the results.

EXPERIMENTS

The average loss factor of the CFRP material is found to be 0.004, whereas the equivalent loss factor of GLARE 3 and GLARE 2 are 0.003 and 0.002 respectively. The average loss factor of the 2024 aluminium is 0.002. The measurement was carried out using the half power bandwidth method with the beams freely suspended.

The average loss factor of the CFRP T-coupons (averaged over 21 specimens) when clamped onto a dynamic shaker is found to be 0.007. The increase in loss factor is due to the contribution from shearing effects, the joints of the coupons and the clamping set up. A typical dimension of the coupon is given in figure 2. GLARE T-coupons loss factor (averaged over 35 specimens) when clamped onto the shaker is measured as 0.0037. A typical dimension of the GLARE T-coupon is displayed in figure 3.

The CFRP T-coupons have been scanned before the shaker tests to check delamination and defects. Static tensile and compressive tests were carried out to determine peak strain location. Preliminary fatigue tests were conducted to determine excitation levels and relative response levels. Strain gauge locations were determined via finite element prediction (see figures 4 and 5 which show the area of high strain) and static test results. Due to the low density and high stiffness of CFRP materials, coupons are light (29.5 grams) and stiff. Tip mass loading method was used to increase response strain. The tip mass also reduces coupon response frequencies and increases response strain around 10 times (to 100u for RMS acceleration excitation of 1.34g). This strain levels is too low to cause fatigue damage. As a result, several higher excitation levels have been used to shake the coupons, namely 3.0, 5.0, 6.7, 7.5 and 8.75g RMS acceleration levels. As excitation level increases, temperature of coupon also increases which affects the estimation of the response strain. Correction was taken to eliminate the temperature effect.

Six CFRP coupons out of twenty one have been tested so far and the damage pattern is consistent and matches the FE prediction results. Delamination occurred at two corners of the T joint due to stress concentration and the propagation eventually forced the T joint apart, as given in figures 6 and 7. This followed by the delamination to propagate to the skin plate. Throughout the testing, C-scan on T coupons have been carried out regularly to review any damage. When any one strain gauge has failed, optical vibration detector was also used to monitor the response frequency of coupons. The resonace frequencies of T coupons were found to drop very quickly when damaged. A very preliminary S-N curve is displayed in figure 8. The shaker test is still in progress.

Modal analysis of the flap-like box specimens starting with the aluminium box is being conducted. The acoustic endurance testing of the boxes will follow. The results will be reported in the future papers.

SUMMARY

This paper gives a summary of the three year research project currently in progress on sonic fatigue study of an aircraft flap-like structure. The research includes using advanced analytical procedures, finite element analysis and complementary experimental studies with the aims to develop dynamic prediction procedures which will result in guides for the design of box-type structures such as flaps. The experimental work currently in progress is also reported. The experimental work includes the measurement of loss factors of aluminium alloy, CFRP and GLARE materials, S-N data curve measurement of CFRP and GLARE, modal analysis of Aluminium, CFRP and GLARE flap-like boxes, acoustic endurance testing of the boxes. The measured results obtained so far agreed with finite element predictions.

REFERENCES

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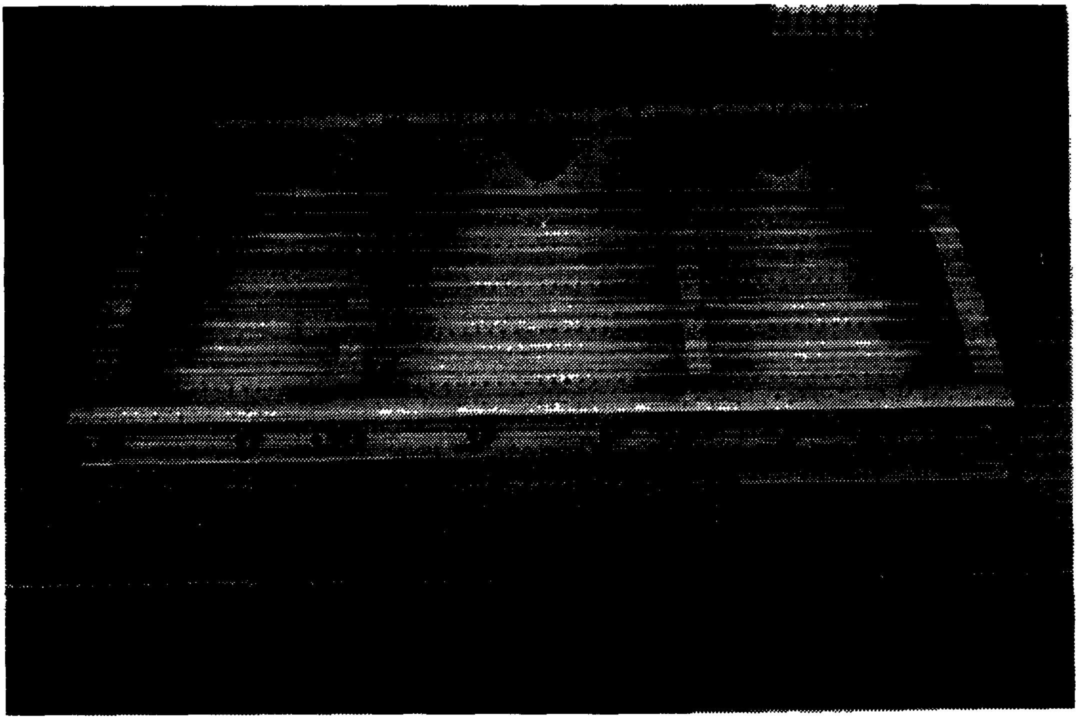

Figure 1 Aluminium Box Structure with Top Skin Removed

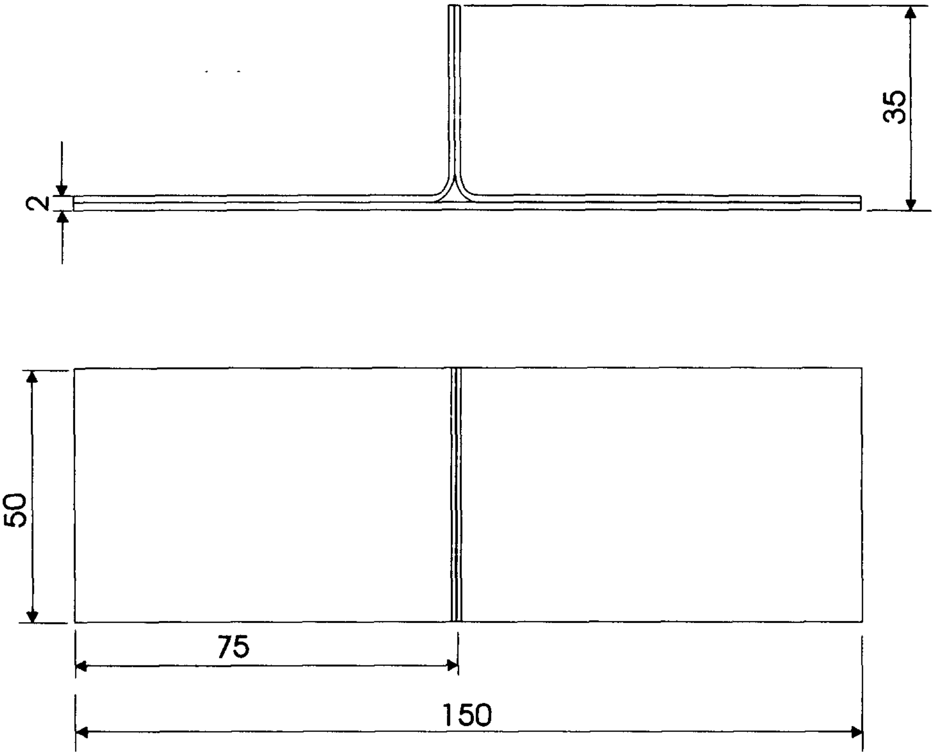

Figure 2 The Dimension of a CFRP Tee-Coupon in mm

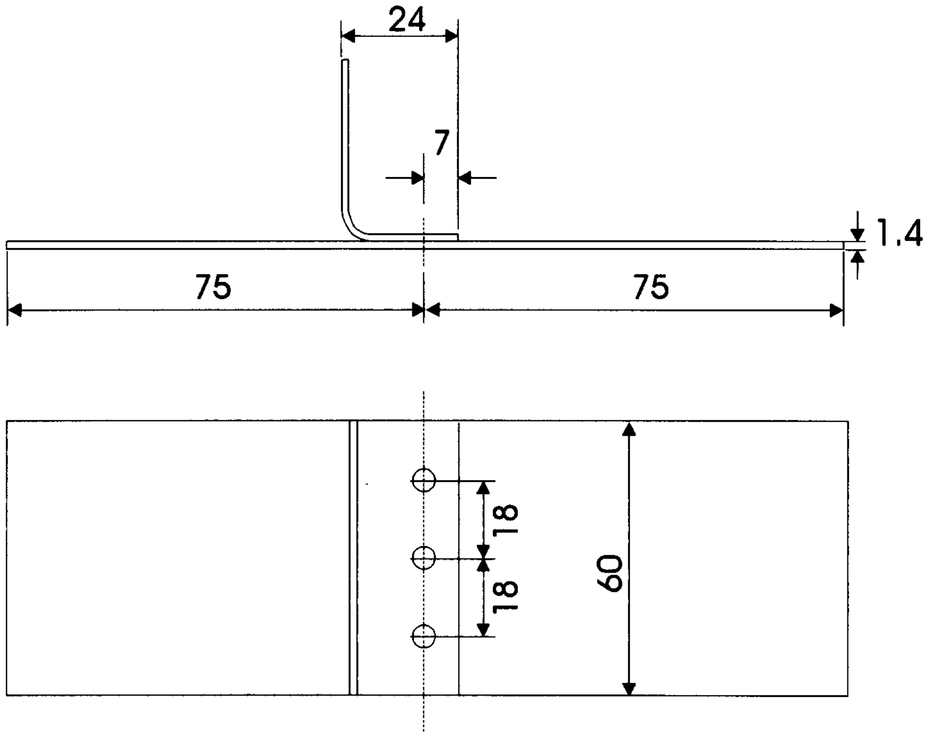

Figure 3 The Dimension of a GLARE Tee-Coupon in mm

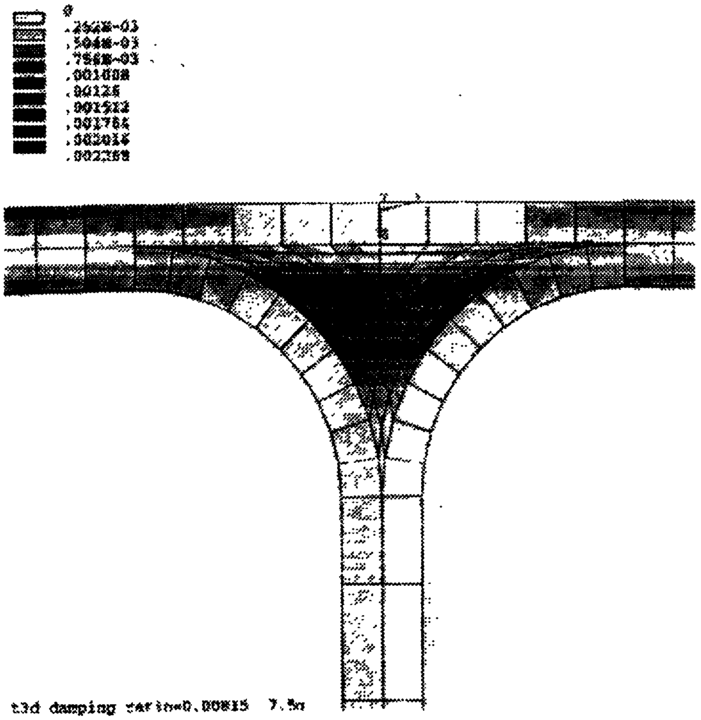

Figure 4 CFRP Tee-Coupon FE Results - Strain ε_z

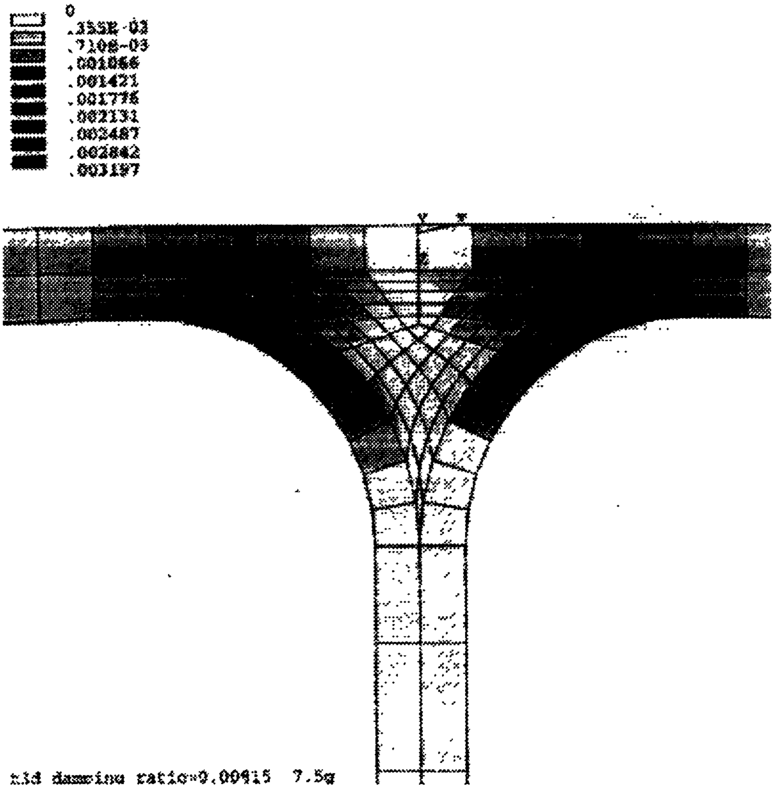

Figure 5 CFRP Tee-Coupon FE Results - Strain εyz

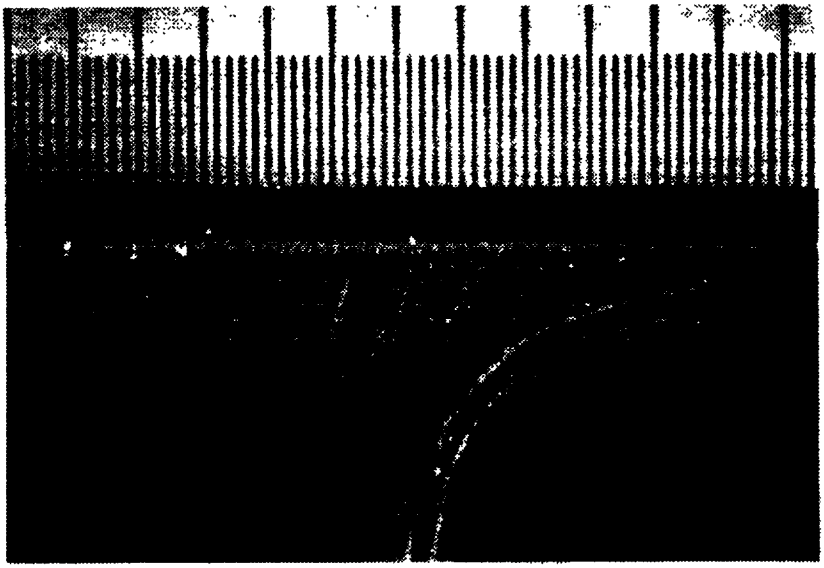

Figure 6 Fatigue Crack of a Typical CFRP Coupon (side A)

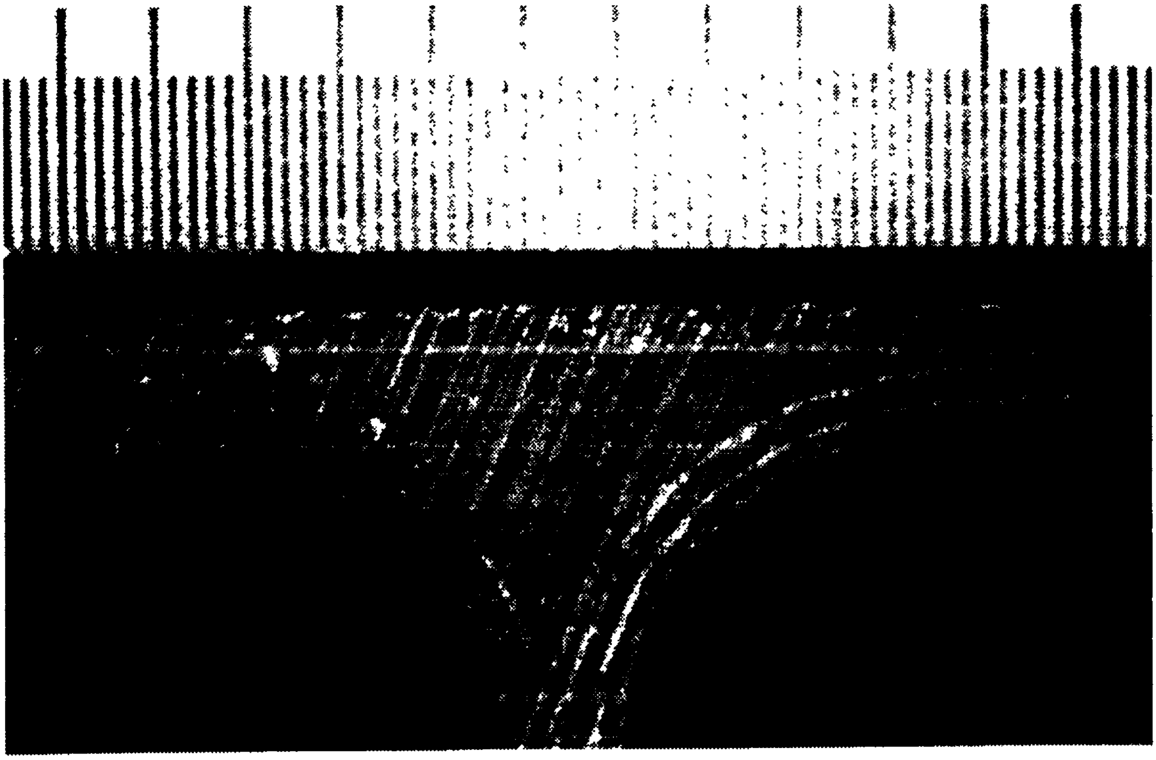

Figure 7 Fatigue Crack of a Typical CFRP Coupon (side B)

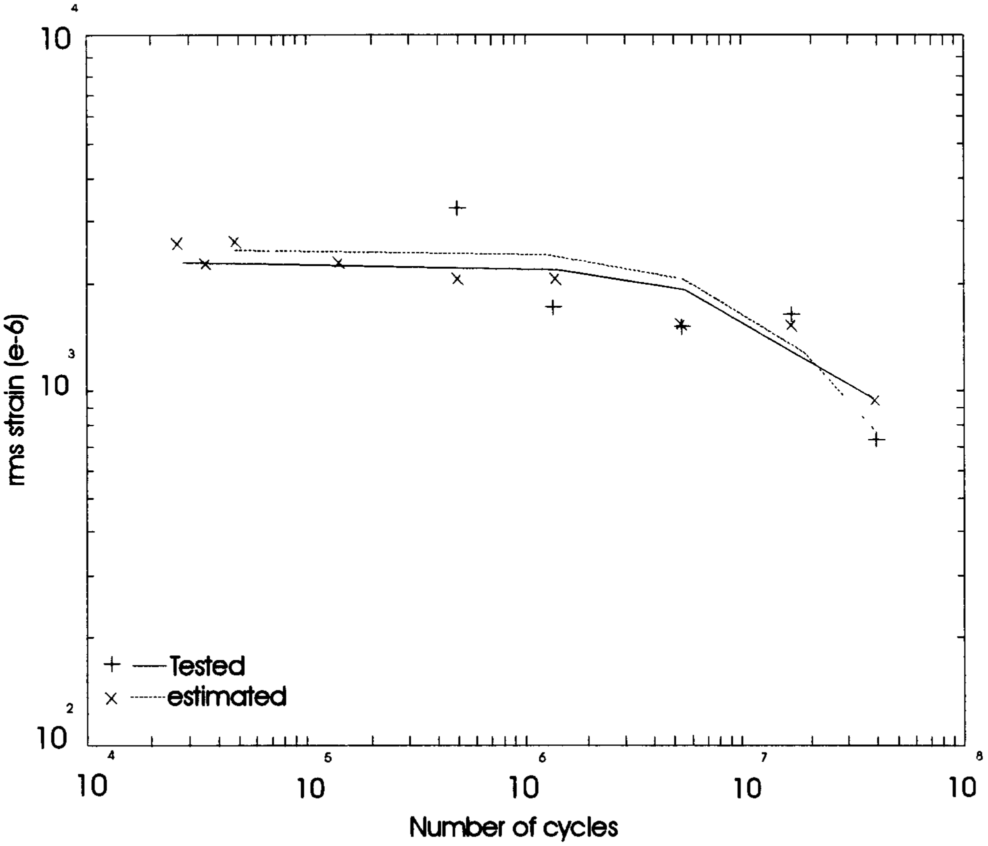

Figure 8 Comparison of CFRP Tee-Coupon tested and estimated Fatigue S-N Data