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FFA TN 1982-26

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The Aeronautical Research Institute of Sweden

FATIGUE EVALUATION OF WTS-3 GLASSFIBRE BLADE MATERIAL

BY

ANDERS F. BLOM

(FFA-TN-1982-26) FATIGUE EVALUATION OF WTS-3 GLASS FIBER BLADE MATERIAL (Aeronautical Research Inst. of Sweden) 27 p HC A03/MF A01

N83-17901

Unclas

G6/39 99758

STOCKHOLM 1982

1 OF 1

-- ***DTIC DOES NOT HAVE THIS ITEM***
-- 1 - AD NUMBER: D437177
-- 5 - CORPORATE AUTHOR: AERONAUTICAL RESEARCH INST OF SWEDEN STOCKHOLM
-- 6 - UNCLASSIFIED TITLE: FATIGUE EVALUATION OF WTS-3 GLASSFIBRE
-- BLADE MATERIAL,
--10 - PERSONAL AUTHORS: BLOM,A. F. ;
--11 - REPORT DATE: , 1982
--12 - PAGINATION: 27P
--14 - REPORT NUMBER: FFA-TN-1982-26
--20 - REPORT CLASSIFICATION: UNCLASSIFIED
--22 - LIMITATIONS (ALPHA): APPROVED FOR PUBLIC RELEASE; DISTRIBUTION
-- UNLIMITED. AVAILABILITY: NATIONAL TECHNICAL INFORMATION SERVICE,
-- SPRINGFIELD, VA. 22161. N83-17901.
--33 - LIMITATION CODES: 1 24

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The Aeronautical Research
Institute of Sweden
Structures Department

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Abstract

A first step in assessing the fatigue properties of the WTS-3 wind turbine blade material has been undertaken. Hereby flat test specimens of filament-wound material have been used for the fatigue tests. Wöhler-diagrams (SN-curves) have been produced both at purely tensile loading, $R = \sigma_{min}/\sigma_{max} = 0$ and at completely reversed loading, $R = -1$. The results show, as expected, that compressive loads are detrimental, due to local fibre-buckling, resulting in a substantial lowering of the entire SN-curve.

(stress ratio equals 0)

(stress ratio equals minus 1)

Sponsoring Agency: National Swedish Board for Energy Source Development (NE)

CONTENTS

1 INTRODUCTION

A first step in assessing the fatigue properties of the WTS-3 wind turbine blade material has been undertaken. Hereby flat test specimens of filament-wound material have been used for the fatigue tests. Wöhler-diagrams (SN-curves) have been produced both at purely tensile loading $R = \sigma_{min}/\sigma_{max} = 0$ and at completely reversed loading $R= -1$. The results show, as expected, that compressive loads are detrimental, due to local fibrebuckling, resulting in a substantial lowering of the entire SN-curve.

2 SPECIMENS AND MATERIAL

The WTS-3 wind turbine blade is a shell structure, see Fig. 1 [5], made of a filament wound glass reinforced epoxy material. The load carrying member of the construction is the spar which forms the leading edge cell. The trail edge cell provides for the aerodynamic contour of the airfoil. The blade root is bonded and bolted to an inner and an outer retention ring for attachement to the hub.

The material in both the spar and in the shell is a laminate consisting of E-glass filaments bonded with an Epon 826/Jeffamine D-230 epoxy resin.

Fibre orientation in the spar is changing gradually from ±30°, to the span direction, in the inboard region to ±20° in the tip region. In the shell 23% of the filaments are oriented at 90° to the span direction, these filaments form the top and bottom layers, and the remaining 77% of the filaments are oriented at ±60° to the span direction.

For this study it was agreed [1-4] to use specimens as shown in Fig. 2 with a fibre orientation of ±30° to the load axis. These specimens were fabricated from a filament wound cylinder, made by Hamilton Standard.

The free length of the specimens is short enough to avoid Euler-buckling why the same kind of specimen is used both under tensile and compressive loading.

3 EXPERIMENTS AND RESULTS

All test specimens were provided with tabs, see Fig. 2, in order to protect the fibres from the hydraulic grips. The fatigue tests were carried out in closed-loop servo-hydraulic test machines at a controlled frequency of 10 Hz in order to avoid any temperature rise due to hysteretic heating. All tests were performed in a laboratory environment with normal humidity and a temperature $T \approx 22°C$.

The first set of experiments were carried out at a stress ratio $R = \sigma_{min}/\sigma_{max} = 0$, i.e. under a purely tensile loading. The results from these tests are summarized in Fig. 3 and Table 1.

The second set of data were produced at a stress ratio $R = -1$, i.e. under completely reversed loading. These data are summarized in Fig. 4 and Table 2.

It is found, as expected, that compressive loading results in shorter fatigue life than tensile loading does. This is due to local fibre buckling when the laminate is loaded in compression.

4 COMPARISON OF RESULTS WITH HS-DATA

In Fig. 5 are shown tensile fatigue test data, obtained from Hamilton Standard [5], for a ±30° filament wound laminate of the same material that is being studied in the present work. The data in Fig. 5 were produced with a stress ratio $R = 0.1$.

In order to compare the data in Fig. 3 with those in Fig. 5 we assume that the ultimate tensile strength (UTS) of the laminates would be the same irrespective of the tests being performed by Hamilton Standard or the FFA.

For flat specimens, as shown in Fig. 2, the ultimate tensile strength is given to 40 000 psi [5] which corresponds to 275.7 MPa.

Measurements performed at FFA on the same kind of specimens that are being fatigue tested give UTS = $\frac{960.6}{t}$ [MPa] where the thickness t of the tested specimens varies between 3.8-3.9 mm.

As this value of UTS is lower than that one obtained by Hamilton Standard it is likely that there is more resin in the FFA-specimens than in the HS-specimens. Measurements show that the FFA-specimens have a resin content of about 31 weight per cent. Since most of the load is carried by the fibres we will use an effective thickness t_{eff} = $= 960.6/275.7 \approx 3.5$ mm when comparing the two different sets of fatigue data in Figs. 3 and 5 respectively.

The compared data are shown in Fig. 6 and it is seen that longer lifetimes were obtained at the FFA than at Hamilton Standard. This may partly be explained by mean stress effects, the experiments being performed with R = 0 at the FFA and R = 0.1 at HS. Other possible reasons for the difference could be different tabs on the specimens, different clamping devices or different test frequencies.

5 DISCUSSION AND FUTURE WORK

The fatigue mechanism for an angle-ply laminate with $\theta < 45°$ (θ = angle between fibres and load direction) is delamination which will initiate at the free edges of a laminate due to the existence of interlaminar shear stresses at these edges [8].

The tested specimens are therefore likely to have yielded conservative results since the wind turbine blades do not have any free edges.

Fatigue damage in angle-ply laminates with $\theta > 2°$ is matrix controlled [8]. Thus we may expect the fatigue properties of the laminate to deteriorate when tests are performed in a humid environment and/or at elevated temperatures.

It is therefore suggested to perform a new series of tests in a similar manner as described earlier in this report but in moisture and at the maximal design temperature $T = 95°F \approx 35°C$.

6 REFERENCES

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No	Width [mm]	Load [kN] Min	Load [kN] Max	σ_F [MPa]	N (Cycles)	% UTS	Comment
1	50.8	0	49.0	275.6	1	100	
2	50.7	0	48.5	273.3	1	100	
3	50.5	0	36.0	203.7	< 10	73.9	
4	50.7	0	10.0	56.4	2×10^7	20.4	Not failed
5	50.8	0	29.9	163.1	430	59.2	
6	50.8	0	25.0	140.6	4600	51.0	
7	50.0	0	20.0	114.3	89800	41.5	
8	50.6	0	25.0	141.2	4200	51.2	
9	50.0	0	17.0	97.1	768700	35.2	
10	50.6	0	20.0	112.9	35100	41.0	
11	50.6	0	20.0	112.9	31300	41.0	
12	50.6	0	16.0	90.3	1841500	32.8	
13	50.7	0	25.0	140.9	2640	51.1	
14	50.7	0	20.0	112.7	6200	40.9	
15	50.6	0	20.0	112.9	46300	41.0	
16	50.7	0	16.0	90.2	227009	32.7	overload
17	50.8	0	14.0	78.7	1363000	28.5	
18	50.4	0	12.0	68.0	11254000	24.7	
19	50.6	0	16.0	90.3	2685200	32.8	
20	50.7	0	15.0	84.5	779200	30.6	
21	50.6	0	15.0	84.7	602100	30.7	
22	50.7	0	15.0	84.7	567900	30.7	
23	50.8	0	14.0	78.7	4386000	28.5	
24	50.7	0	18.0	101.4	125770	36.8	

Table 1 Results R = 0. Effective thickness t_{eff} = 3.5 mm
σ_{UTS} = 275.7 MPa

No	Width [mm]	Load [kN] Min	Load [kN] Max	N [cycles]	Comment
25	50.8	-20.0	20.0	400	
26	50.8	-15.0	15.0	1000	
27	50.5	-10.0	10.0	32000	
28	50.9	- 9.0	9.0	359300	
29	50.7	- 9.0	9.0	92000	
30	50.7	-10.0	10.0	29900	
31	50.8	- 9.0	9.0	327900	
32	50.8	- 8.0	8.0	660400	
33	51.0	- 7.0	7.0	4175800	
34	50.8	- 7.0	7.0	4153400	
35	50.7	- 6.0	6.0	10400000	Not failed
36	50.9	-12.0	12.0	4900	
37	50.9	-15.0	15.0	1300	
38	50.9	-10.0	10.0	80300	
39	51.0	- 7.0	7.0	3975500	
40	50.8	-15.0	15.0	700	

Table 2 Results R = -1. t_{eff} = 3.5 mm

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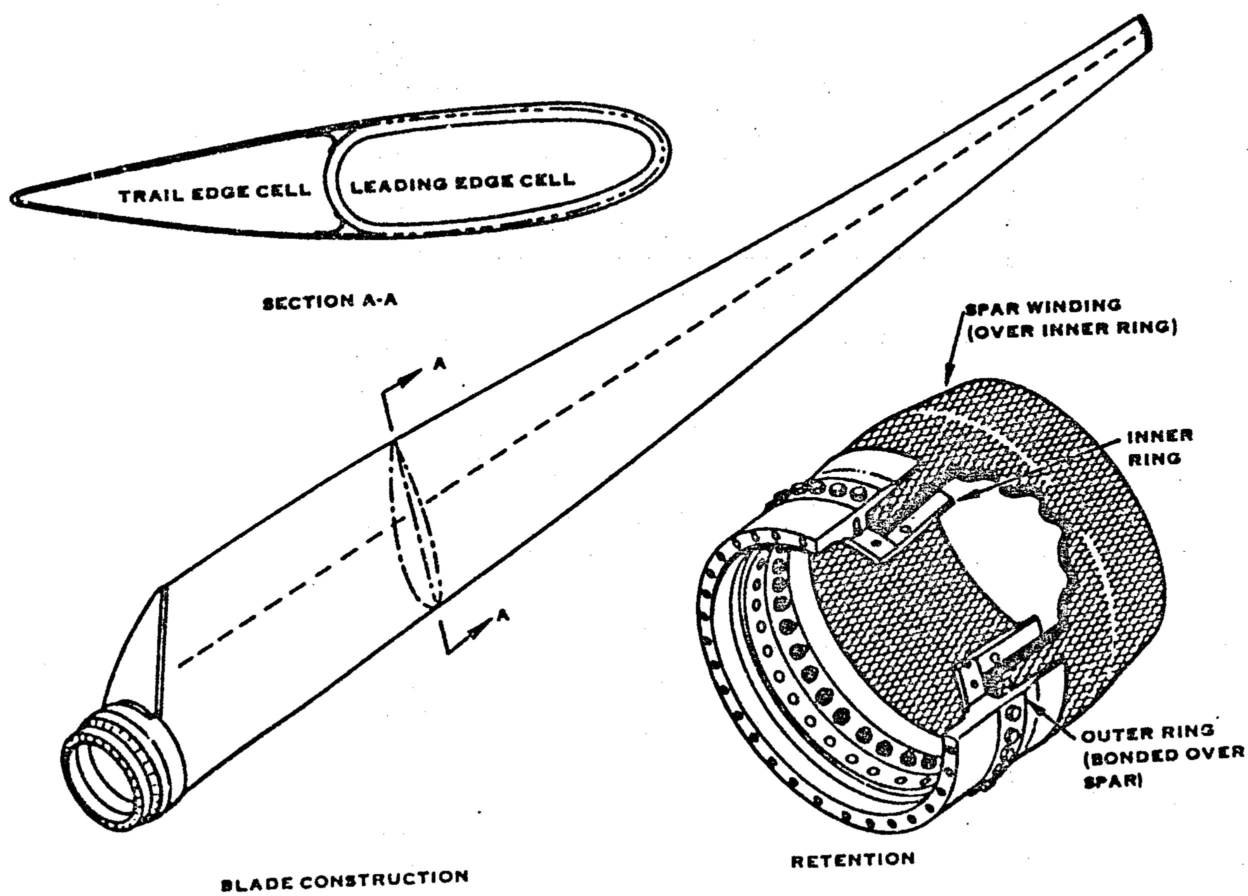

Fig. 1 WTS-3 blade construction
from Ref. [6]

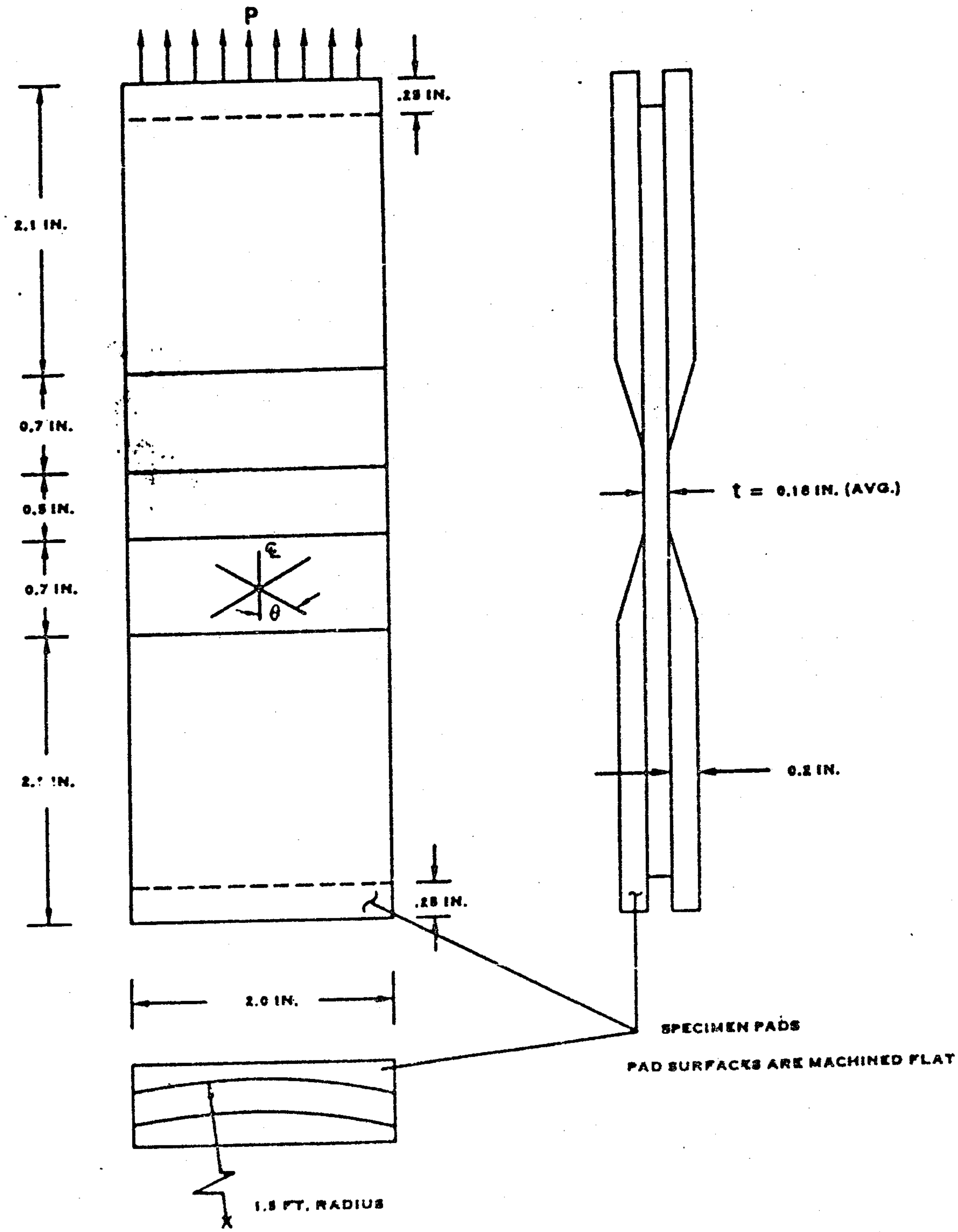

Fig. 2 Fatigue test specimen

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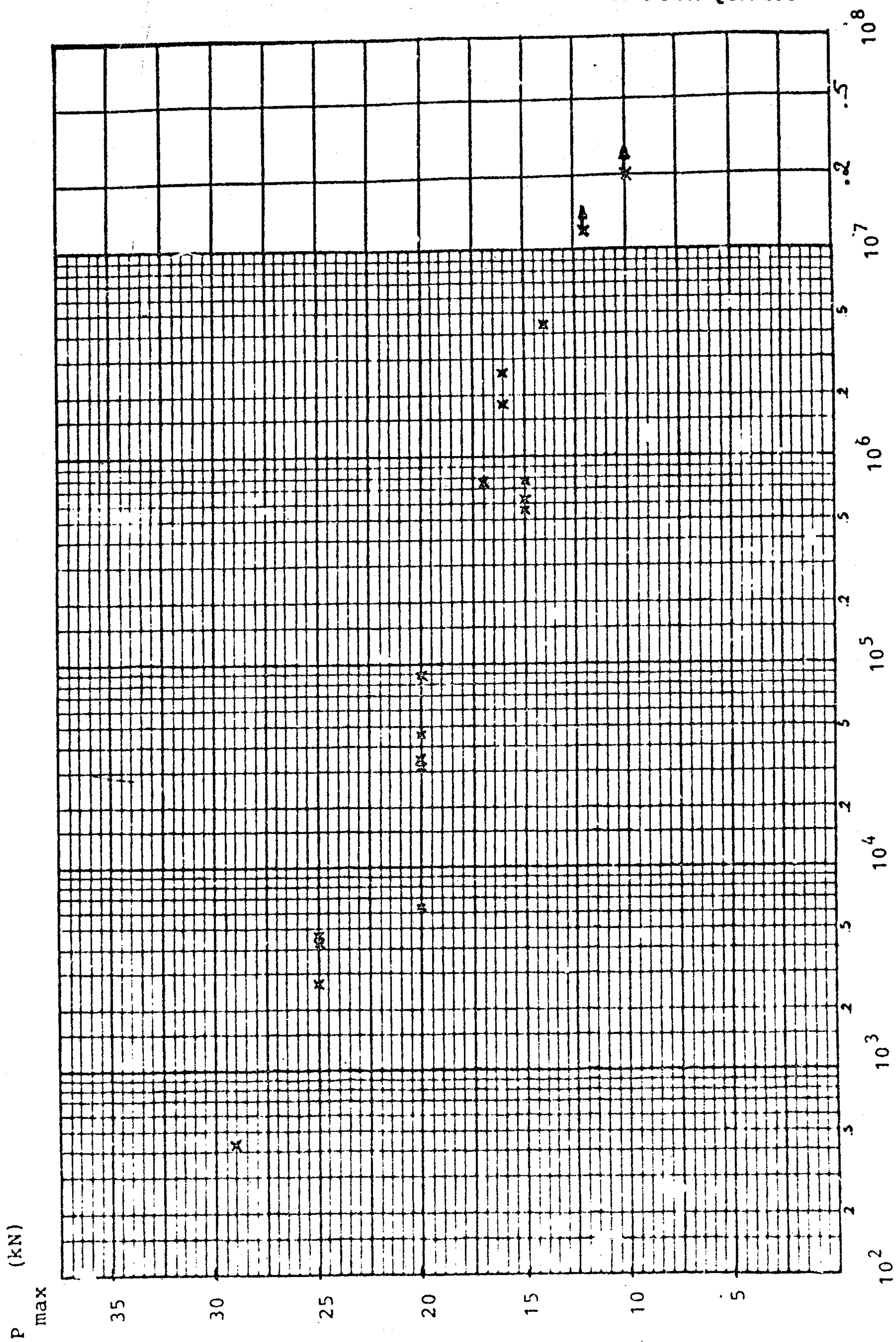

Fig. 3 Results R = 0

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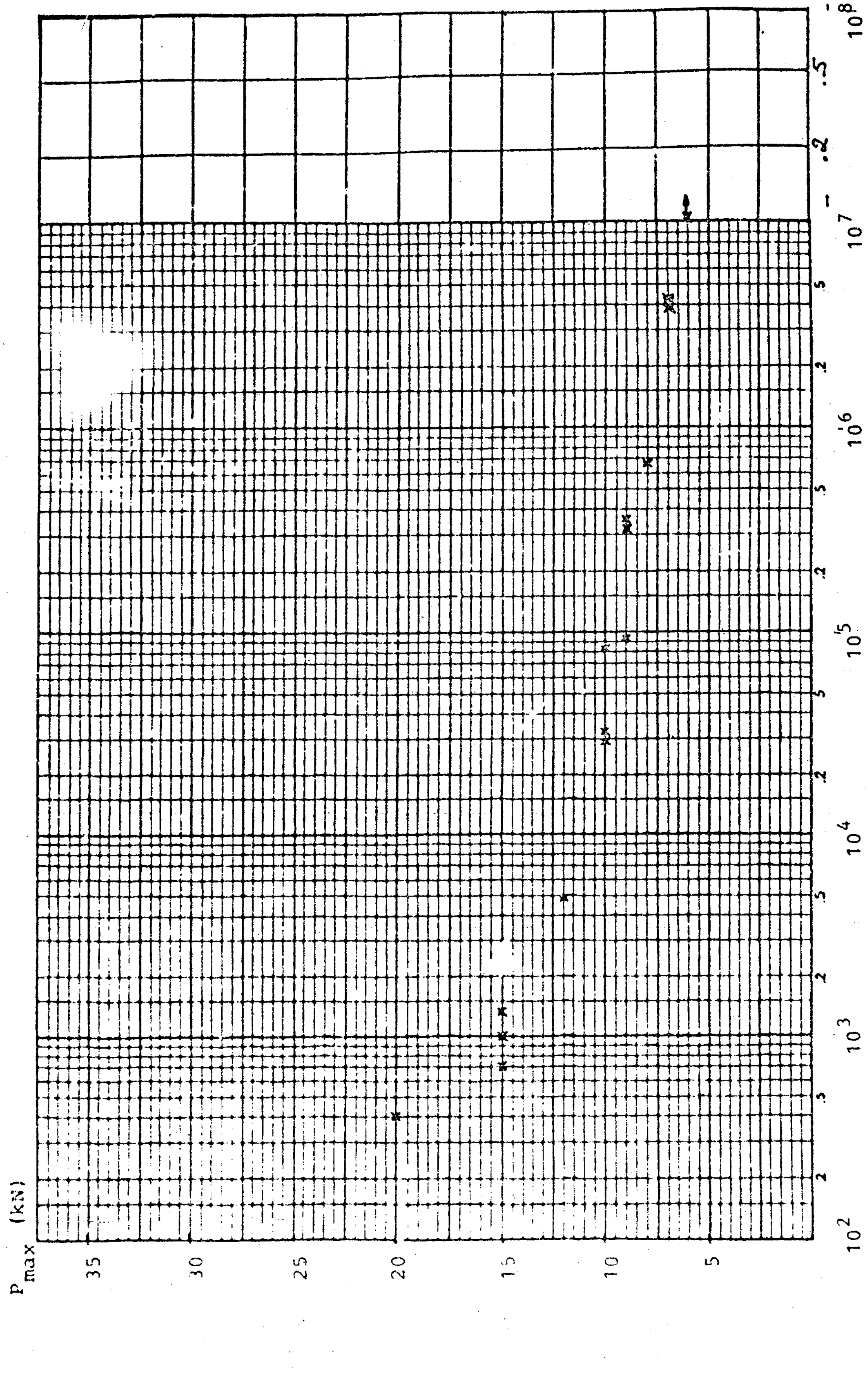

Fig. 4 Results R = -1

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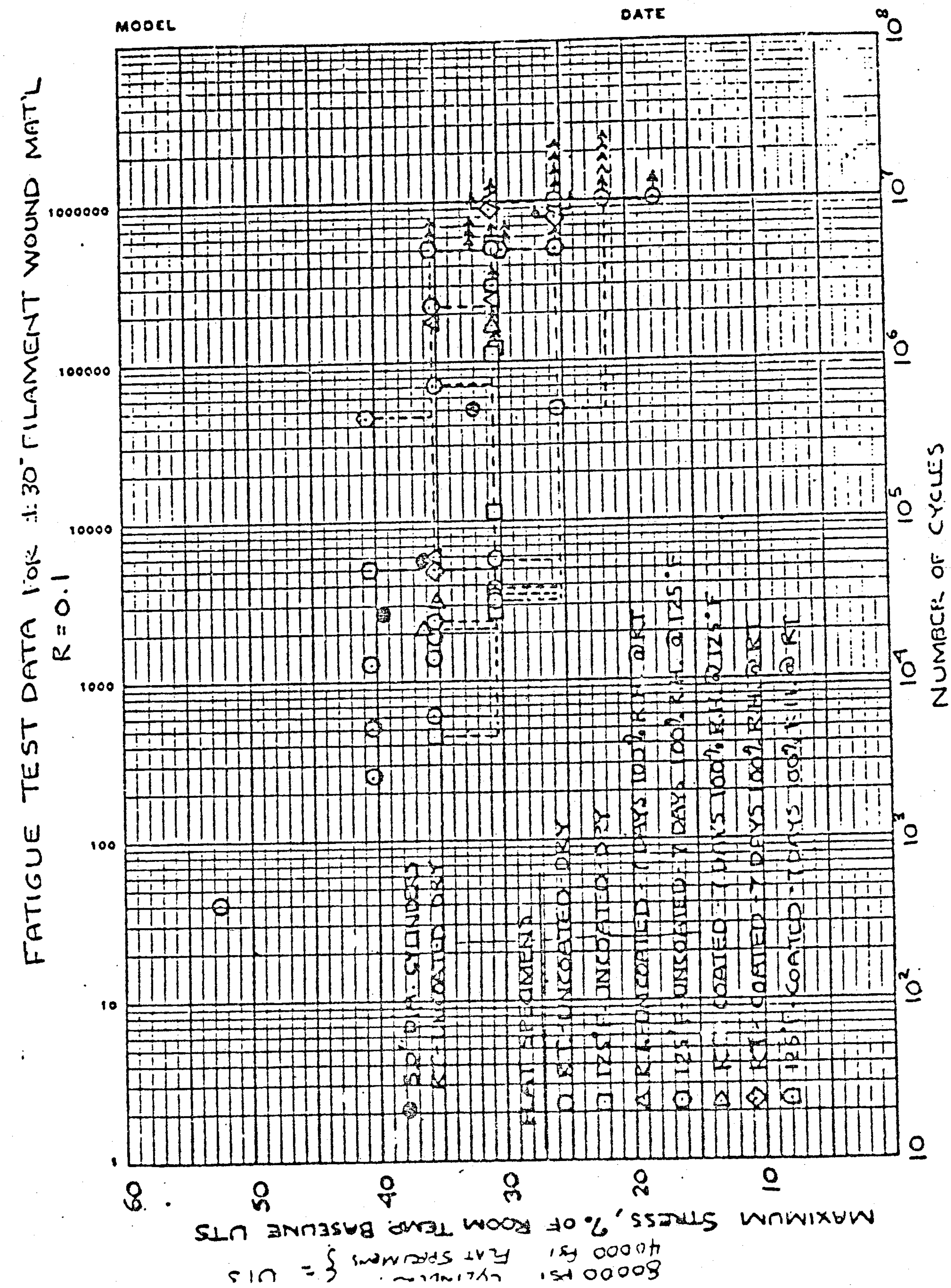

Fig. 5 Fatigue test data from Hamilton Standard. Ref. [5]. R = 0.1

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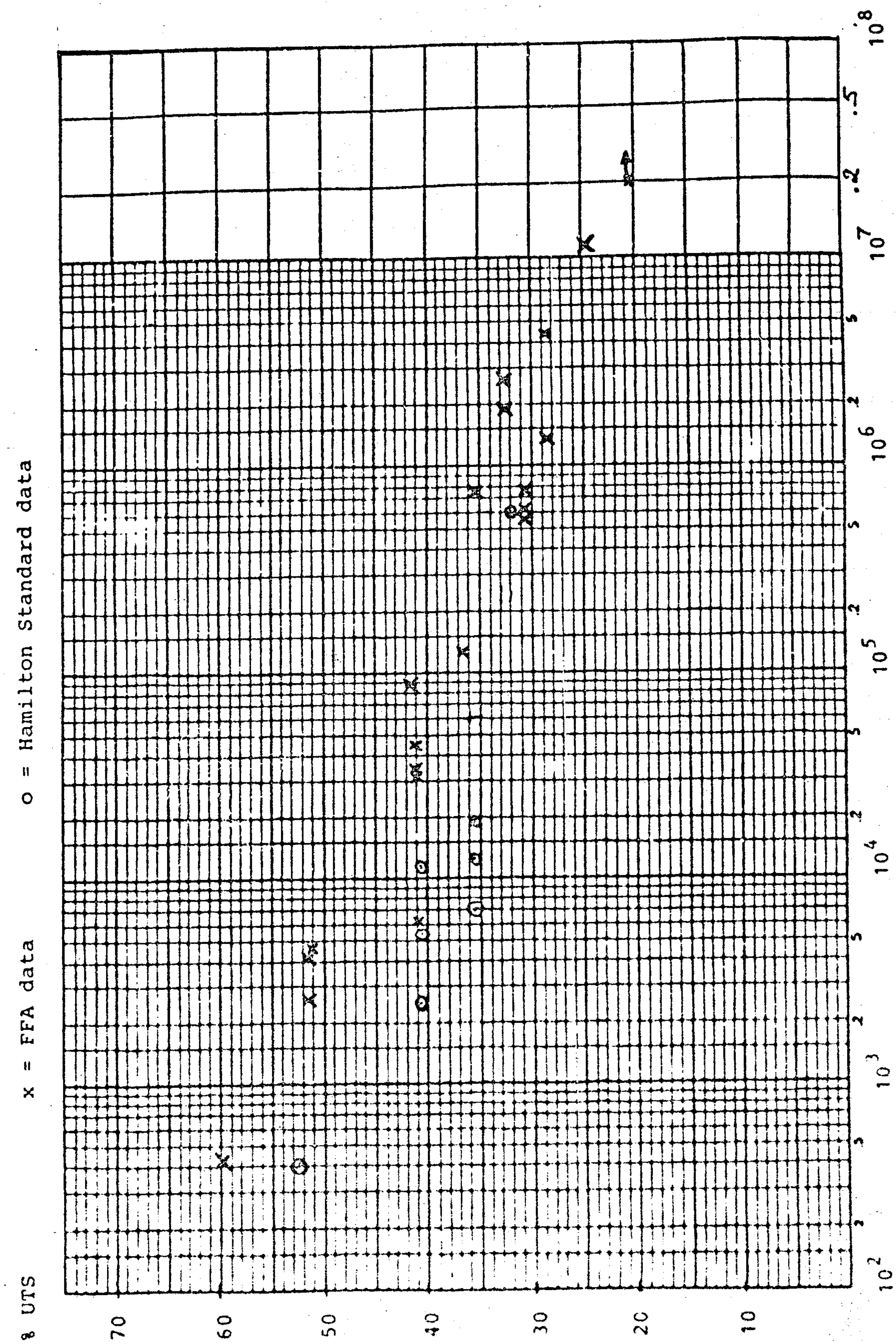

Fig. 6 Comparison of test data

LIST OF FFA WIND ENERGY REPORTS PUBLISHED UNDER CONTRACT WITH NE

Report no	NE Project no	Title	Confidential = C Open = O
141-1	5060-141	Nya horisontalaxlade vindturbinaggregat (HA) med integrerade transmissioner. Preliminär gransk-ning av möjliga lösningar	O
151-1	5060-151	Preliminär undersökning av en horisontalaxlad vindturbins prestanda vid snedanblåsning	O
151-2	"	Preliminär konstruktionsgranskning av 4 MW s k HA-Vipparmsaggregat (Storken) med 110 m rotor-diameter	O
151-3	"	Sammanfattande rapport dec 1976 avseende NE-projekten inom vindenergiområdet, nr 5060-141 och 5060-151	O
AU-1447	5060-511	Kravspecifikation	O
DU-1485	5060-511	Funktionsteknisk studie av pilvingerotor	O

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AU-1416	5060-311	Sammanfattning av NE-projekt 5060-311 AK. Alternativa konfigurationer, Vindturbinaggregat, September 1977	O
del 2	"	Pilvinkel-Turbin (PVT)-Princip, egenskapsanalys, etapp 1, samt inledande prov 1977	O
del 3	"	Vertikalaxlade vindturbinaggregat av Darrieus-typ med fribärande torn, projekt "Poseidon" - Preliminär projektanalys av land- och sjöbaserade versioner	O
del 4	"	Vindturbinaggregat typ "Lill-Poseidon" 200 kW ostagad Darrieus. -Preliminär projektbeskrivning Sjö- och landbaserade varianter	O
del 5	"	Vindturbinaggregat typ "Storken", 4-5 MW. - Preliminära projektutkast, etapp 2	O
del 6	"	Vindturbinaggregat typ "X-DUR"och "E-DUR", 5-7 MW hybridturbinaggregat. - Preliminär projektbeskrivning	C
del 7	"	Bandbladsrotor: Konstruktionsbeskrivning och inledande prov	O
del 8	"	Försök med bandbladsrotor (BB-turbin).	C
del 9	"	Pilvinkelturbin, preliminär undersökning av en PV-modellrotors driftsegenskaper i vindturbinmodellrigg	O
del 10	"	Beskrivning av DUR-nav samt inledande försök med HA- och VA-turbiner i dubbelrotation, november 1977	O
del 11	"	E-DUR-turbinen. Inledande egenskapsprov i FFA vindturbinprovrigg, oktober 1977	O
del 12	"	Flerrotors vertikalaxlat vindturbinaggregat typ 3-D i 10 MW-klassen, sjöbaserat. - Preliminär projektanalys, etapp 1	O
del 13	"	Preliminära funktionsprov med modell av 3-D vindturbinaggregat, oktober 1977	O
del 14	"	Visualisering i modellskala i två och tre dimensioner (2-D, 3-D) som hjälpmedel vid teknikvärdering avseende miljöestetik för vindturbiner i MW-storlek	O
del 15	"	Sammanfattande överblick av delrapporter inom projekt AU-1416, 1977	

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Report no	NE Project no	Title	Confi-dential = C Open = O
AU-1472 del 1	5060-312	Sammanfattningsrapport gällande NE-projekt 5060-312 AK. Alternativa Konfigurationer - Vindturbinaggregat. September 1978	O
del 2	"	Inledande försök med Dubbelbladssystem (MPB-variant 1) vid VA/TS-turbiner (Vertikalaxlade/ Tvärströms-). Oktober 1978	O
del 3	"	Inledande försök med L-bladsarrangemang vid VA/TS-turbiner. bladlastpulsation och turbin-prestanda. Oktober 1978	O
del 4	"	Framtagning av en 2x3 m vindtunnelmodell av VA-turbin med tillämpning av dubbelblads- och L-bladssystem, samt med fribärande mast. November 1978	O
del 5	"	Sjöbaserade vindenergisystem i Sverige. - Lokaliseringsmöjligheter, systemutformning, teknikvärdering. November 1978	O
del 6	"	Dynamiska studier av pilvinkel (HA-PV-) turbin, vindbyrespons vid MW-storlekar, jämte inledande experiment med enbladig PV-variant. Januari 1979	O
del 7	"	Vindenergi -Teknisk utlandsuppföljning inom delprogramområdena vertikalaxelturbiner (VA-) jämte sjöbasering. Första halvåret 1978. Januari 1979	O
del 8	"	Kompletterande inledande försök med dubbelblads-system vid VA-turbiner - gällande orkanparke-ringsbuckling, jämte rökströmningsförsök. December 1978	O

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AU-1504 del 2	5060-313	Preliminära vindtunnelprov med 2x3 m L/DB-turbin i FFA låghastighetstunnel L1 August 1979	O
AU-1504 del 8	5060 313	Alternativa konfigurationer Lägesrapport 1 March 1979	O
AU-1504 del 6	5060 313	Förslag till program för utveckling av prototyp till ett vertikaltaxlat vindturbinaggregat med s k L/DB-turbin, typ L-XX, 1,5 - 3 MW December 1979	O
AU-1504 del 4	5060 313	Vertikalaxlad vindturbin typ L-180, 15-20 MW Projektanalys av basprojekt alternativ 1 för sjöbasering. January 1980	O
AU-1577 Part 1	5060 314	New Concepts in Vertical Axis Wind Turbines (VAWT) and Applications to Large Multi MW-size, Off-shore Wind Turbine Systems November 1980	O
AU-1577 Part 2	5060 314	"L-180 POSEIDON" - A New System Concept in Vertical Axis Wind Turbine Technology August 1980	O
AU-1635	5061 451	A Preliminary Theoretical Study of Double Blade 2-D Aerodynamics for Applications to Vertical Axis Wind Turbines. April 1981	O

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AU-1499 Part 2	5061 012	Nonlinear analysis of membranes December 1978	O
AU-1499 Part 3	5061 012	Dynamics of Flexible Rotor-Tower System August 1979	O
AU-1499 Part 5	5061 012	The Gust as a Coherent Structure in the Turbulent Boundary Layer May 1979	O
AU-1499 Part 6	5061 012	Combined effects of periodic and stochastic loads on the fatigue of wind turbine parts October 1979	O
AU-1499 Part 7	5061 012	A Preliminary Wind Tunnel Study of Wind Mill Wake Dispersion in Various Flow Conditions September 1979	O
AU-1499 Part 8	5061 012	BASPL - A Finite-Element Postprocessor September 1979	O
AU-1499 Part 9	5061 012	Fatigue of Fibre-Reinforced Plastics A Literature Survey August 1979	O
AU-1499 Part 10	5061 012	Momentum Theory Analysis of Unconventional Wind Energy Extraction Schemes October 1979	O
AU-1499 Part 11	5061 012	A Preliminary Evaluation of a Model Proposed by P Lissaman for the Wake Behind a Rotor in a Turbulent Flow October 1979	O
AU-1499 Part 12	5061 012	Torsional Oscillations of the Rotor Disc for Horizontal Axis Wind Turbines with Hinged of Teetered Blades August 1979	O

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HU-2218	5061 101	Study of WECS Farm Area and WECS Safety Limit Requirements Minutes from Expert Meeting IEA R & D WECS Annex I Sub-Task A1 May 1980	O
HU-2229	5061 102	Safety of Wind Energy Conversion System (WECS) with Horizontal Axis February 1981	O
HU-2189 Part 1	5061 013	Optimized Pitch Controller for Load Alleviation on Wind Turbines August 1980	O
HU-2189 Part 2	5061 013	Nonlinear Finite Element Analysis - An Alternative Formulation August 1980	O
HU-2189 Part 3	5061 013	The Velocity Induced by the Wake of a Wind Turbine in a Shear Layer, Including Ground Effect September 1980	O
HU-2189 Part 4	5061 013	A Comparison of Results Obtained with Two Different Methods for Calculation of Horizontal Axis Wind Turbine Performance. December 1980	O
HU-2189 Part 5	5061 013	Measurements of Wake Interaction Effects on the Power Output from Small Wind Turbine Models June 1981	O

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HU-2262 Part 2	5061 014	Beam - A Computer Program for Analysis of Rotating Cantilevered Beams July 1981	O
HU-2262 Part 3	5061 014	Long Range Laser Anemometry with Particular Reference to Wind Power Development October 1981	O
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HU-2262 Part 5	5061 014	Roll Up Model for Rotor Wake Vorticies November 1981	O
HU-2262 Part 6	5061 014	A Pitch Control System for Large Scale Wind Turbines December 1981	O
FFA TN 1982-01	5062 101	A Preliminary Estimation of the Expected Noise Levels from the Swedish WECS Prototypes Maglarp and Näsudden April 1982	O
FFA TN 1982-09	5061 015	Fatigue Evaluation of Wind Turbines Part 1: Theoretical background June 1982	O
FFA TN 1982-19	5061 452	Aeroelastic Stability and Dynamic Response Analysis of the LDB-125 Vertical Axis Wind Turbine October 1982	O
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