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FATIGUE STRENGTH OF JOINTS WITH SPECIAL FASTENERS. PART II (DIE--ETC(U))
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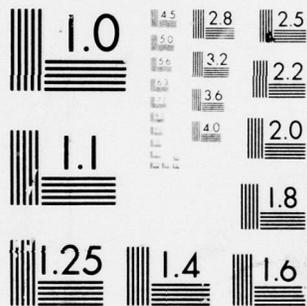
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**FATIGUE STRENGTH OF JOINTS
WITH SPECIAL FASTENERS
-PART II**

by

J.J. Gerharz

D. Schütz

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FATIGUE STRENGTH OF JOINTS WITH SPECIAL FASTENERS. - PART II.
(DIE SCHWINGFESTIGKEIT VON FÜGUNGEN MIT SONDERBEFESTIGUNGSELEMENTEN)

by

10
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11 Mar 77

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EDITOR'S SUMMARY

The Memorandum discusses the results of fatigue tests on three types of joint made with various fatigue resistant fasteners. The tests were carried out using both block programme and flight simulation loading sequences. The results are analysed and observations are made regarding the factors which influenced the fatigue lives of the joints tested.

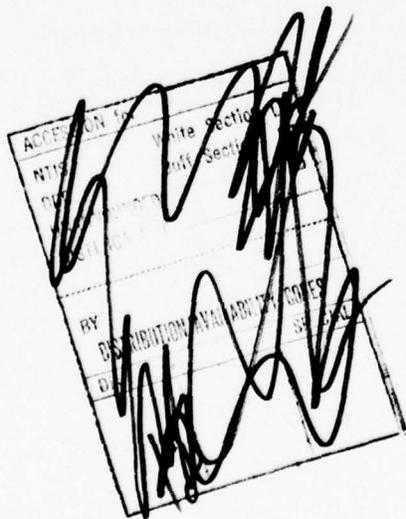
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1 FOREWORD

TM 69/73 (RAE Lib Trans 1914) reported on the results of research on the fatigue strength of joints with special fasteners; to continue this work an additional fastener was included in the investigations, the 'rate of utilisation' of the joints changed, and, in addition to the tests under block programme loading¹, some tests were carried out with a standardised flight by flight load sequence². The present Technical Memorandum contains the additional results together with a comprehensive discussion of all results. The majority of tests were 8-stage block programme tests in which the different effects of the special fasteners on the fatigue strength of the joints were investigated, thus establishing a criterion for evaluation. The smaller but more expensive part of the programme under the standardised flight simulation loading produced life curves which can be used as dimensioning data.

2.1 SPECIMENS

The types of specimen used in Ref 3 were adopted for the present investigation; only the diameter of the fasteners was reduced from 5/16 inch to 1/4 inch. This measure achieved a higher 'rate of utilisation' of the fasteners (defined as the ratio of transmitted load, ΔP , at the maximum loading of the sequence to the allowable bearing force). In order to obtain the same load transmission as with the joint specimens in Ref 3, the width of the specimens was reduced so that the following parameter combinations resulted:

Type of specimen	Load transmission LU	Rate of utilisation AG	Additional bending SB
2N	0-5%	0-10%	25%
H	40%	77%	50%
H2	40%	95%	0%

The types of specimen are shown in Fig 1. The table in Fig 2 contains the relevant data on the 1/4 inch fasteners and their fitting details. The specimens were produced and pretreated as described in Ref 3.

The additional fastener examined was Hi-Clamp-Up from the Hi-Shear Corporation which is already in use in several aircraft (C-130, C-5A).

2.2 LOADING PROGRAMME

The tests with the block loading programme described in Ref 1 were performed on resonance testing machines, the tests with the standardised flight simulation loading given in Ref 2 were carried out with all three types of joint and Hi-Lok fasteners on a Schenck 10 Mp-hydraulic pulse machine. The average test frequency was 30 Hz. With H2 and 2N joints tests were carried out at several loading levels to obtain life curves while joint H was only tested on one level.

3 PRESENTATION OF RESULTS

The individual results (life to failure) of the block programme tests are shown in Figs 3 to 5; the results of tests under flight simulation loading are shown in the form of life curves in Fig 6.

4 DISCUSSION OF RESULTS

The following discussion of the test results includes the values contained in TM 69/73.

4.1 Results of the block programme tests

The results of all block programme tests were analysed and lives for 50% probability of survival are plotted in Figs 7 to 9. Due to the comparatively small number of specimens per test series, only differences in life of more than a factor of 1.5 have been used for assessment; this corresponds to a level of significance of about 5%. The effects of the special fastener concerned, of the rate of utilisation (diameter of the fastener) and of shot peening the joint faces on life are discussed below; the results for the specimens with Hi-Lok bolts are used as a datum.

Joint type 2N (LU = 0 - 5%, SB = 25%) see Fig 7

Fastener and diameter:

- At 1/4 inch diameter the special fasteners extend life by between 20 and 150% as compared with the datum series. At 5/16 inch life differences are considerably smaller.
- While the greatest increase in life is achieved with 1/4 inch diameter Rivbolts, Rivbolt specimens with 5/16 inch only reach 75% of the life of the relevant datum series.
- The life span increases as the diameter of the fastener increases; the Rivbolt is the only exception.

Shot peening:

- Shot peening the joint faces resulted in an increase in life of more than double for Huckrimp and K-Fast special fasteners.

Joint type H (LU = 40%, SB = 50%) see Fig 8

Fastener and diameter:

- Differences in life with 1/4 inch fasteners are insignificant; at 5/16 inch Hi-Tigue and Rivbolt reach 100% increases.
- The choice of a larger diameter involves a worthwhile increase only in the case of the above-mentioned special fasteners.

Shot peening:

- Shot peening brought a two to five fold increase in life.

Joint type H2 (LU = 40%, SB = 0, double-shear) see Fig 9

Fastener and diameter:

- The life spans of the specimens with special fasteners are all smaller than that of the datum series; Rivbolt and Hi-Tigue fasteners show a particularly sharp drop for both diameters.
- Increasing the diameter leads to a significant increase in life only in the Rivbolt.

Shot peening:

- Shot peening resulted in a considerable increase in fatigue strength in all cases investigated.

The performance of the two significant variables influencing life, ie the use of different fasteners and shot peening the joint faces may be explained as follows:

- With the exception of the Rivbolt, the fasteners examined display very high clamping forces and so a major part of the transmitted load ΔP is transmitted by friction. A weak spot on the bore is thus protected and the majority of fractures emanate from the edge of the pressure cone produced by the gripping force in the gross cross-section of the specimen (see crack positions Table 1). For this reason there is relatively little difference in the life values to fracture achieved with the various fasteners.

- The increase in fatigue strength through shot peening the joint faces is a consequence of the beneficial compressive residual stresses produced in the gross cross-section where the fatigue cracks originate. The fatigue strength of the bore is hardly improved by shot peening, as is shown by a comparison of the results with specimen type H 5/16 inch with and without shot peening for the Hi-Loks. In some cases the crack occurred in the net cross-section despite prior shot peening; for these specimens no significant increase in life was observed, see Fig 8. A similar result was obtained for specimen type 2N, see Fig 7, where Hi-Lok specimens show no increase in fatigue strength since the cracks again emanate from the bore even after shot peening.

4.2 Results of tests under standardised flight simulation loading

All tests under flight simulation loading were carried out on joints with Hi-Lok fasteners. The loading sequence represented a typical stress history on the lower surface of a transport aircraft wing and the results in Fig 6 show the effects of type of joint and shot peening. The combination of these parameters determines the position and slope of the life curves. In a comparison of life curves for joints from the literature it appeared that the slope depends mainly on the position of the incipient crack, the distinction being whether the crack emanates in the net cross-section of the joint, ie from the bore, or the gross cross-section, ie from face of the joint. Fracture in the net cross-section leads in principle to a flat slope of the life curve ($\bar{K} \approx 10$), while fracture in the gross cross-section (specimen types H2 and 2N) results in a steeper slope ($\bar{K} \approx 4$). The flatter slope corresponds to the slope of the life curve of a notched bar with $\alpha_k = 2.5$ of the same material.

5 APPLICATION OF THE RESULTS TO THE DIMENSIONING OF JOINTS IN A WING LOWER SURFACE

The life curves on Sheets 10 to 12 can be used to calculate the life of joints in the lower surface of the wing of a transport aircraft. The representation in Fig 13 enables the effect of shot peening the joint face to be included in the calculation.

The life curves for specimen configurations H2 and 2N with Hi-Lok fasteners were compiled from the results of flight simulation tests at several load levels see Fig 6. All other life curves were derived from this, their slopes being dependent upon the combination of fastener and type of joint and the resultant crack position (see table). The relevant considerations were mentioned in the previous paragraph.

Table 1
Position of fatigue crack

Loading	Fastener	Specimen 2N		Specimen H		Specimen H2	
		1/4 inch diameter	5/16 inch diameter	1/4 inch diameter	5/16 inch diameter	1/4 inch diameter	5/16 inch diameter
Standardised flight simulation loading	Hi-Lok HL	N	-	G	-	G	-
Block programme loading	Hi-Lok	N	N	G	G/N	G	G
	Hi-Tigue	G	G	G	G	G	G
	Huckrimp	G	G	G	G	G	G
	K-Fast	G	G	G	G	G	G
	Rivbolt	N, G	N	G, N	G	N	N
	Hi-Clamp-Up	G	G*	G	G*	G	G*

G Crack in gross cross-section
N Crack in net cross-section
* estimated

The position of the life curves for the various fasteners in relation to one another is determined from the differences in lives obtained from the block programme tests. For this purpose the difference between the lives of joints with special fasteners and those of Hi-Lok joints at a specific reference stress has been entered in the life curve diagram for the Hi-Lok specimens (see Figs 10 to 12). The reference stress was chosen so that the maximum stress was the same in the block programme and flight simulation tests. Since the differences in life of the non-shot peened specimens are relatively small (maximum 1:2.5) it is recommended that for initial sizing the estimate of the fatigue strength of joints with special fasteners should always be based on the life curves of the Hi-Lok specimens. Moreover, the results of the present investigation can be used to select the optimum fastening; in every case, however, it is advisable to carry out fatigue tests with the particular joint configuration to confirm the life values thus estimated. With the aid of the diagrams on Fig 13 the gain in life to be anticipated from shot peening the joint faces can be estimated as a function of type of specimen, fastener and stress level.

In using the results of this investigation the following should be borne in mind:

- the results should only be used for joints made from aluminium alloys,
- the exception are the results for the joint specimens with Rivbolts which should only be applied to joints of 3.1354.5 or equivalent material,
- the results should be used in accordance with the typical characteristics of the specimen configuration, eg results with
 - joint specimen 2N for: skin-stringer connection of the basic structure
 - joint specimen H for: stringer run-out, joint (single-shear) with appropriate additional bending, and
 - joint specimen H2 for: joint (double-shear) with appropriate load transmission.

6 CONCLUSIONS

To summarise, the following observations may be made on the results of this investigation:

- In the range of stress levels common in level flight on the lower surface of a transport aircraft wing (ie approximately 100 N/mm^2) the differences in life to failure are small for joints with the various fasteners

investigated; if each individual specimen configuration is regarded separately the life values fall within a range of 1:2.5.

- Additional shot peening of the joint faces increases the life of the joint by factors of 2 to 5.
- The life prolonging effect of shot peening decreases with increasing stress levels. When the maximum applied stress is equal to the yield strength of the joint material no increase through shot peening is observed.
- Increasing the rate of utilisation by reducing the diameter of the fasteners from 5/16 inch to 1/4 inch can shorten life by up to a factor of 2.
- The parameters of the fasteners tested which permanently affect life are clamping force, fit, degree of cold working the rigidity of the head and nut support and the diameter of the fastener.

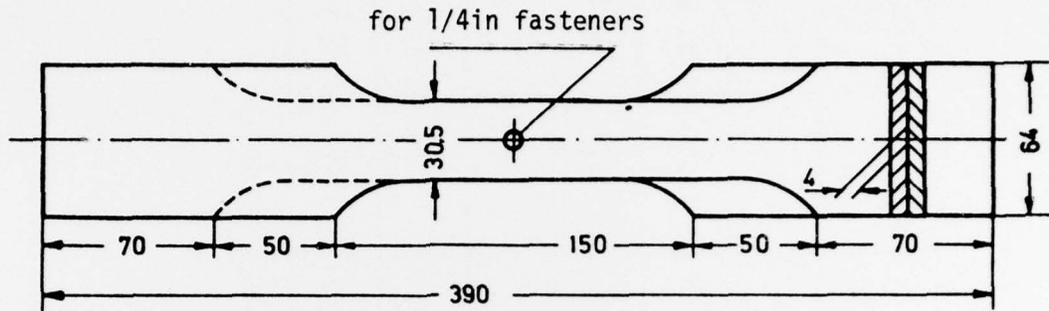
Which of these parameters has the predominant influence on the fatigue strength of the joints tested in each individual case depends on the type of joint; thus the predominant effect

- in double-shear joints with high load transmission and little additional bending (specimen type H2) stems from the parameters which modify friction contact at the joint faces, such as the clamping force,
- in joints with high additional bending (specimen type H) stems from the parameters which modify the bending resistance in the critical cross-section, such as the diameter of the fastener, and
- in joints with low load transmission and little additional bending (specimen type 2N) stems from all parameters which reduce the stress on the edge of the bore, such as clamping force, fit and cold working.

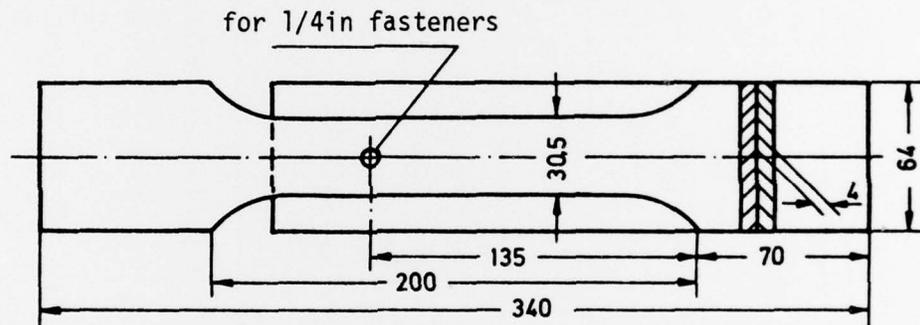
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Technische Mitteilung No.69/73
[Available as 'Fatigue strength of joints with special
fasteners', translated by B. Garland and edited by
F.E. Keates, RAE Library Translation 1914 (1977)] |

Specimen type 2N: 2-part specimen with low additional bending and load transmission



Specimen type H: High additional bending and load transmission



Specimen type H2: High load transmission + double-shear

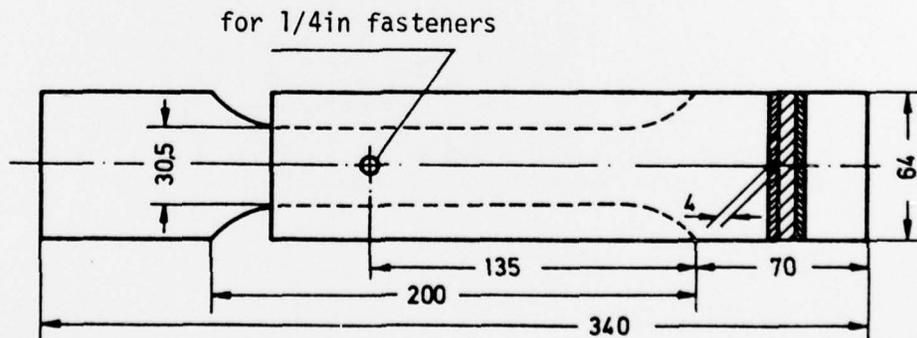


Fig 1 Specimen types 2N, H and H2

Fastener	Pin		Nut, collar		Starting torque (cm daN)	Clamping force (daN)	Seat of pin Δd (μm)
	Code	Material	Code	Material			
Hi-Lok	HL 11V-8 HL 10V-8	Ti 6-4	HL 79-8	2024	69-92	~500	-60 bis -80 (tolerance)
Hi-Tigue	HLT 411-8 HLT 410-8	Ti 6-4	HL 1386-8	Steel	94-104	~900	+100 bis +110
Huckrimp	7KS 100-V08 7KSP V08	Ti 6-4	KN LV-08	Ti 3-2.5	60-80	~1500	+0 bis +89
K-Fast	KL.B 11 V4F KL.B 10 V4F	Ti 6-4	KFN 541 L4F	Steel	105	~700	+75 bis +125
Rivbolt	RB 1000 NP4 RB 1002 NP4	Ti, Beta III Leg	RB 4000-4	Ti 6-4	-	-	~+150*
Hi-Clamp-Up	HLT 349-8 HLT 348-8	Steel, H-11	HL 1389-PBW-8	Steel	140-170	~1000	-60 bis -80

* Difference between bore diameter before installation and shank diameter after the pressing process.

Fig 2 Fastening systems and fitting data

Fügeflächen mit Zink-Chromat-Lack grundiert

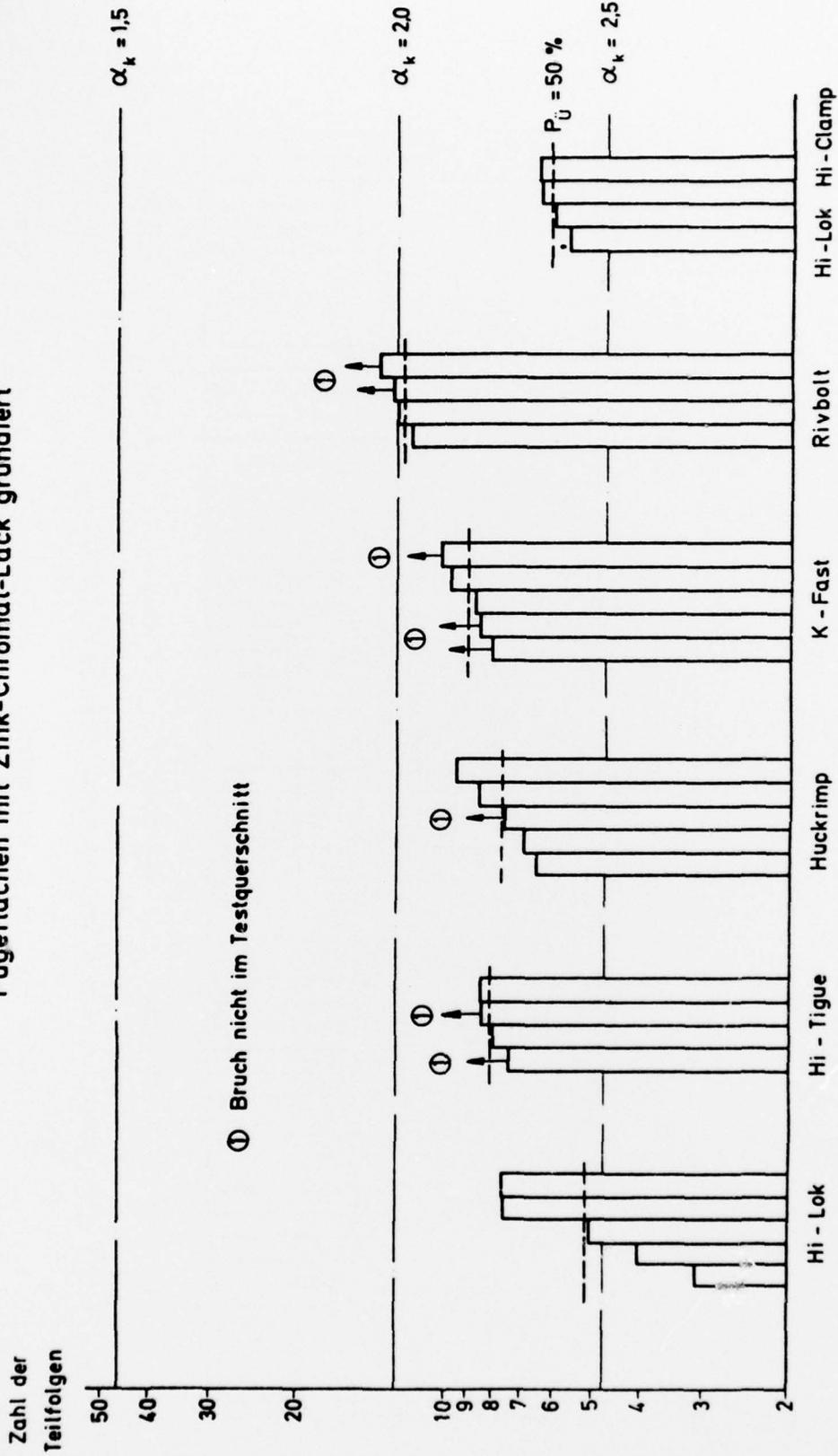


Fig 3 Results of block loading tests, specimen 2N, 1/4"

Key:
 Fügeflächen mit Zink-Chromat-Lack = joint faces primed with zinc chromate
 grundiert = primer
 Zahl der Teilfolgen = number of subsequences
 Bruch nicht im Testquerschnitt = fracture not in test cross-section

Fig 4

Fügeflächen mit Zink-Chromat-Lack grundiert

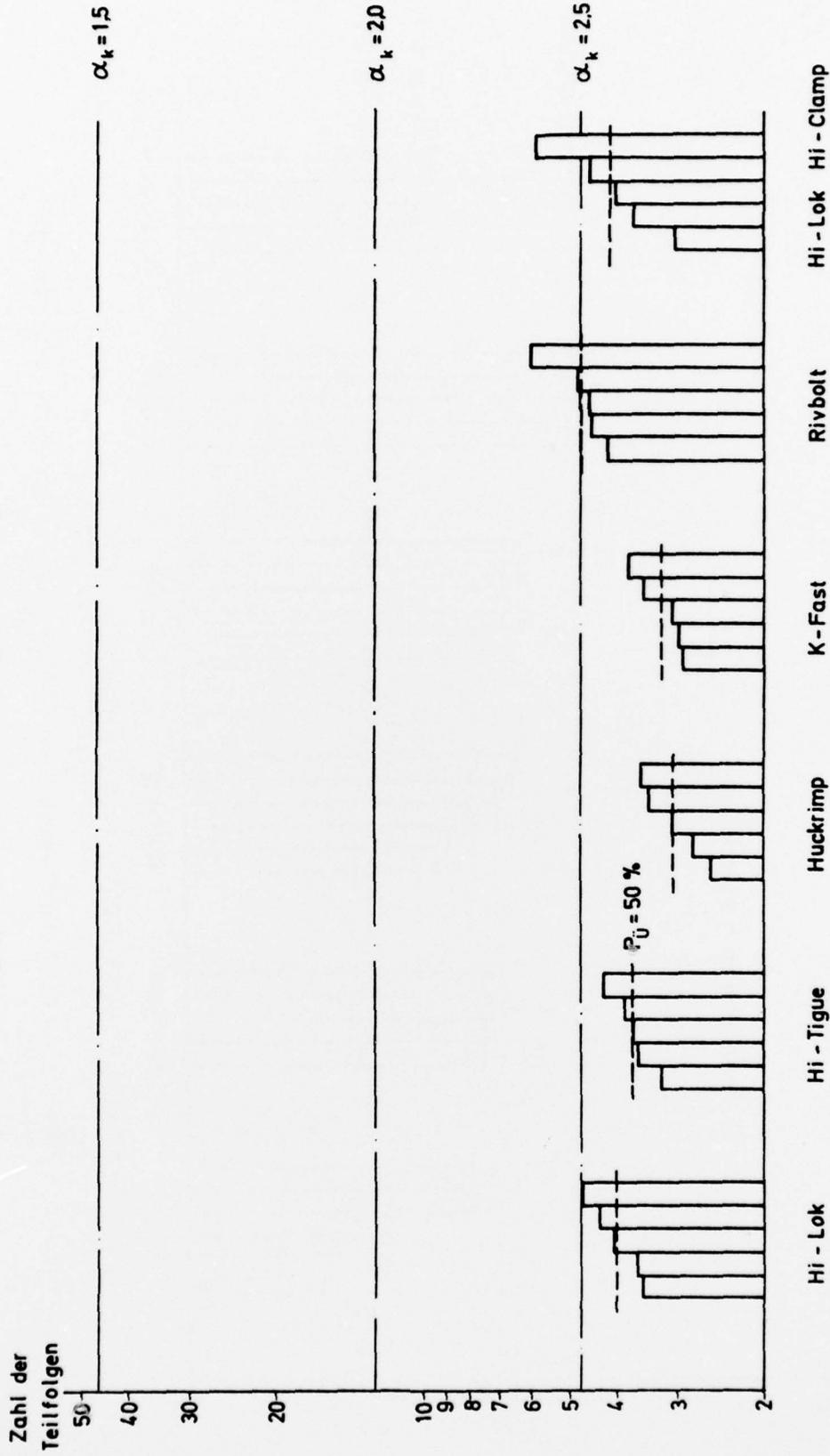


Fig 4 Results of block loading tests, specimen H, 1/4"

Key:
 Fügeflächen mit Zink-Chromat-Lack = joint faces primed with zinc chromate
 grundiert primer
 Zahl der Teilfolgen = number of subsequences



Fig 5 Results of block loading tests, specimen H2, 1/4"

Key:

Fügeflächen mit Zink-Chromat-Lack = joint faces primed with zinc chromate
 grundiert
 Zahl der Teilfolgen = number of subsequences

Fig 6

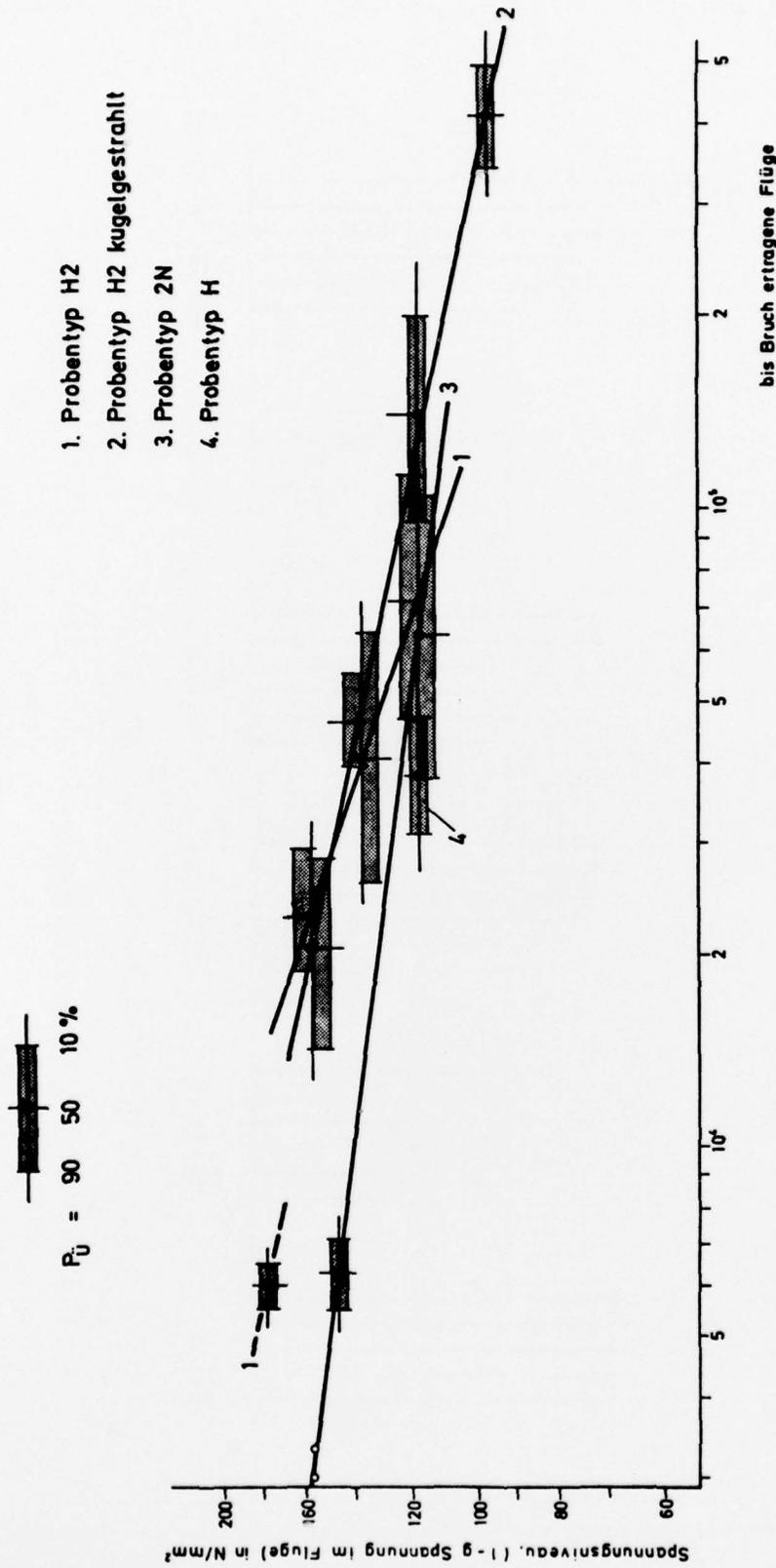


Fig 6 Results of flight simulation tests with Hi-Lok 1/4" fastener

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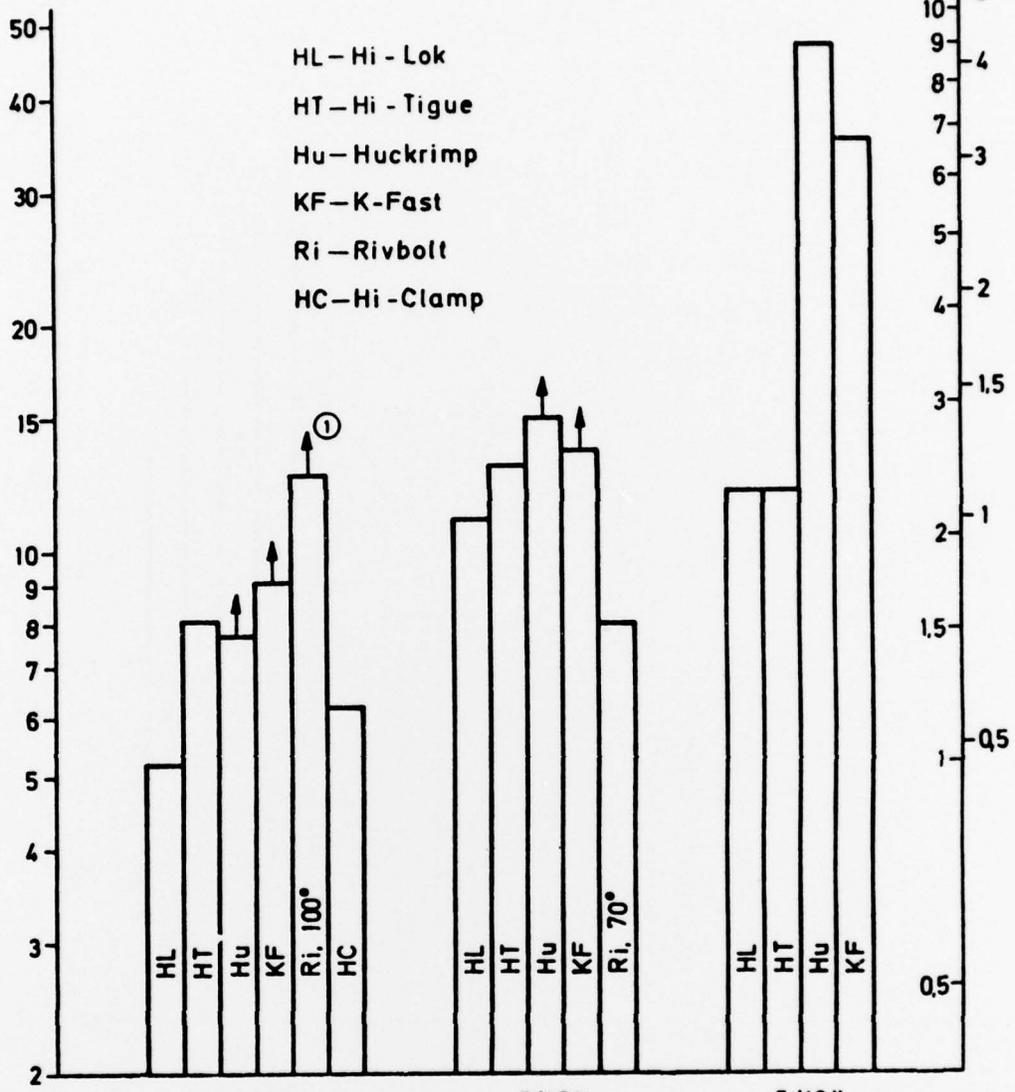
- Spannungsniveau = stress level
- Spannung im Flügel = stress in flight
- Bis Bruch ertragene Flüge = flights to failure

- 1. Specimen type H2
- 2. Specimen type H2 shot peened
- 3. Specimen type 2N
- 4. Specimen type H

Zahl der Teilfolgen
($P_0 = 50\%$)

① Bruch teilweise nicht im Testquerschnitt (siehe Blatt 3)

bezogene Lebensdauer
1/4" 5/16"



LÜ = 0.5%

SB = 25%

$\bar{R} = -0.35$

$\bar{Q}_0 = 177 \text{ N/mm}^2$

Fig 7 Comparison of fasteners with specimen type 2N

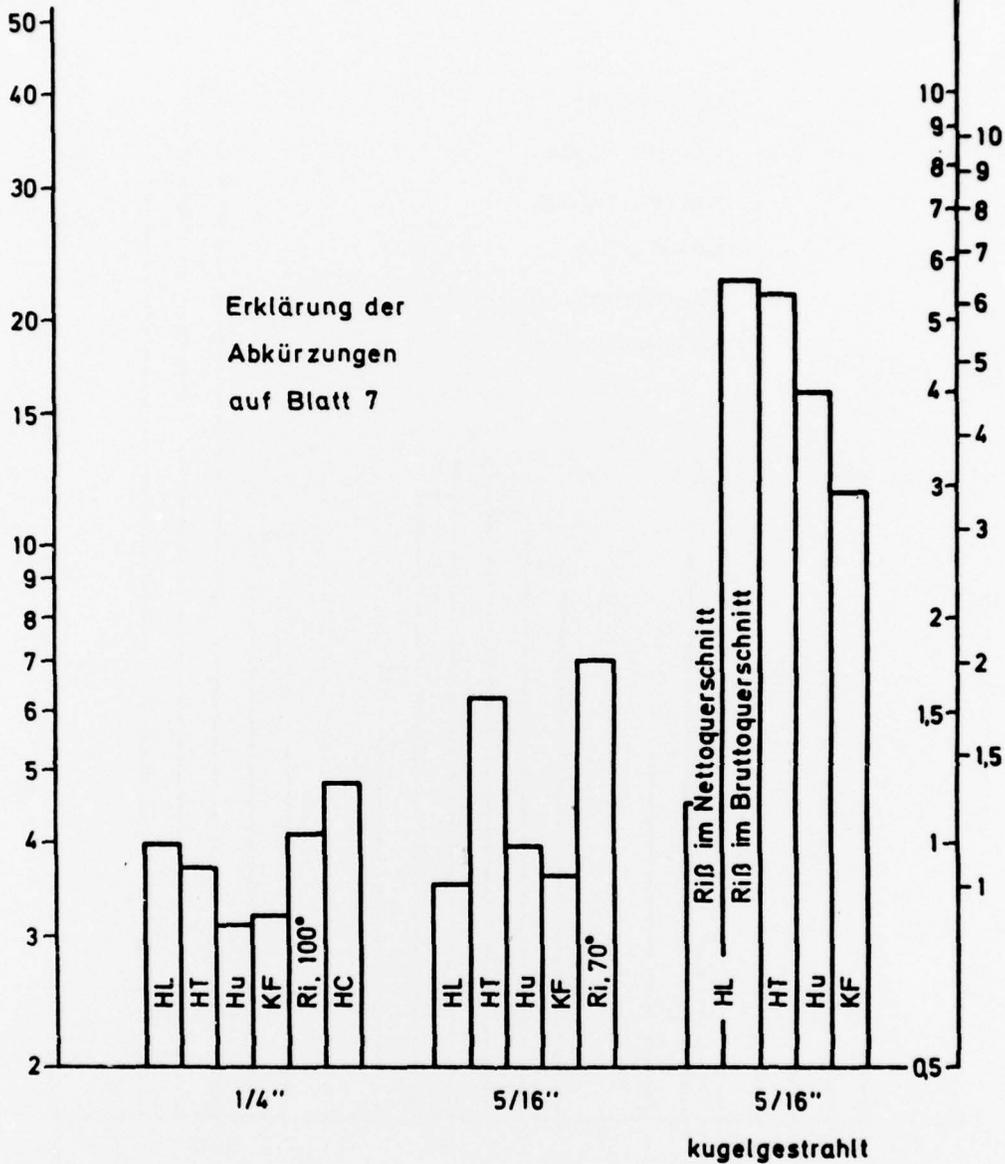
Key:
 Bruch teilweise nicht in Testquerschnitt (siehe Blatt 3) = fracture partially not in test cross-section (see Fig 3)
 Bezogene Lebensdauer = relative life span
 Zahl der Teilfolgen = number of subsequences
 Kugelgestrahlt = shot peened

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Fig 8

Zahl der
Teilfolgen
($P_{\bar{0}} = 50\%$)

bezogene
Lebensdauer
1/4" 5/16"



LÜ = 40%

$\bar{R} = -0,35$

SB = 50%

$\bar{\sigma}_a = 177 \text{ N/mm}^2$

Fig 8 Comparison of fasteners with specimen type H

Key:

Erklärung der Abkürzungen auf Blatt 7 = for explanation of abbreviations see Fig 7

Bezogene Lebensdauer = relative life span

Zahl der Teilfolgen = number of subsequences

Kugelgestraht = shot peened

Riß im Nettoquerschnitt = Failure net cross section

Riß im Bruttoquerschnitt = Failure gross cross section

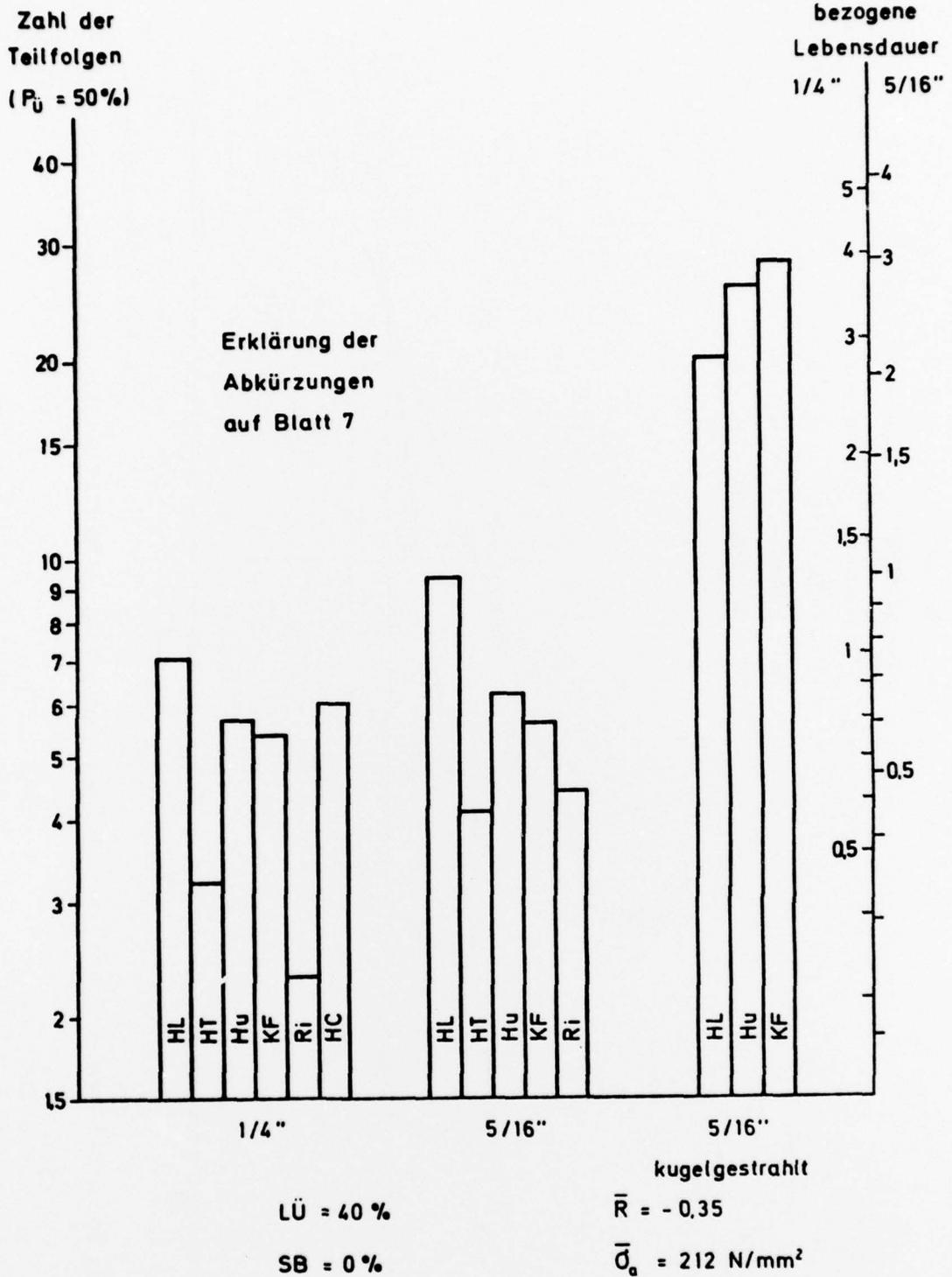


Fig 9 Comparison of fasteners with specimen type H2

Key:
 Erklärung der Abkürzungen = for explanation of abbreviations
 auf Blatt 7 see Fig 7
 Bezogene Lebensdauer = relative life span
 Zahl der Teilfolgen = number of subsequences
 Kugelgestrahlt = shot peened

Fig 10

1/4" 5/16"

- HL — Hi-Lok — D — D
- HT — Hi-Tigue — O — O
- Hu — Huckrimp — Δ — Δ
- KF — K-Fast — □ — □
- Ri — Rivbolt — ◇ — ◇
- HC — Hi-Clamp-Up — ▽ — ▽

Spannungsniveau
(1-g Spannung im Flüge)

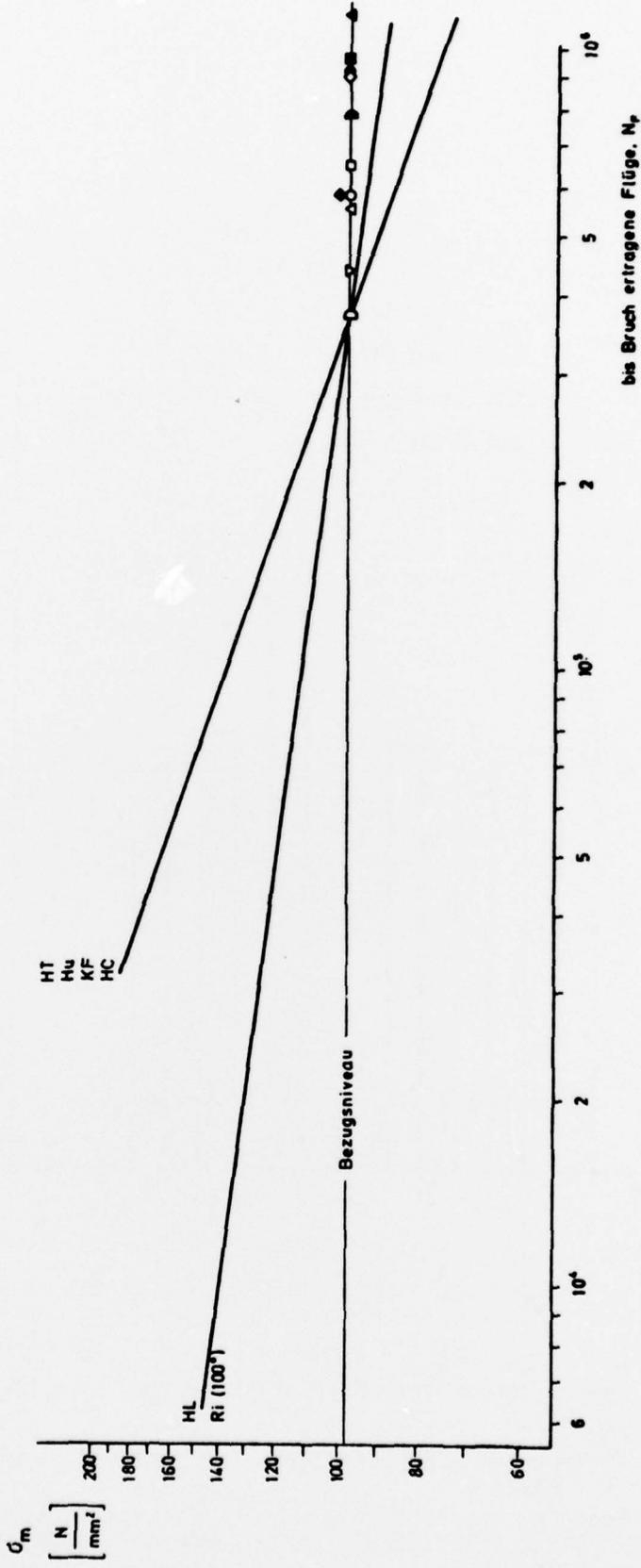


Fig 10 Life curves for joint type 2N, non-shot peened, with 1/4" and 5/16" fasteners

Key:
 Spannungsniveau = stress level
 Spannung im Flüge = stress in flight
 Bis Bruch ertragene Flüge = flights to failure
 Bezugsniveau = reference stress

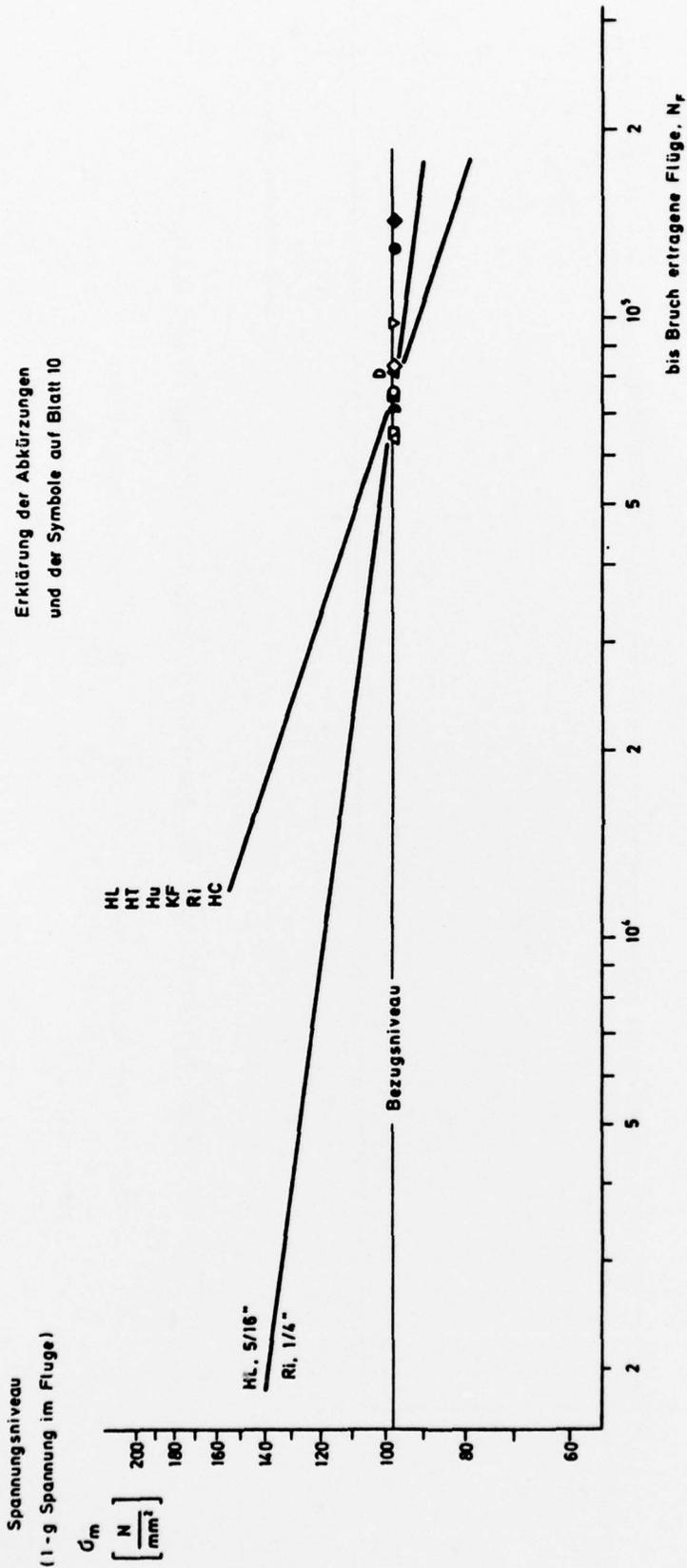


Fig 11 Life curves for joint type H, non-shot peened, with 1/4" and 5/16" fasteners

Key:
 Erklärung der Abkürzungen = for explanation of abbreviations
 und der Symbole auf Blatt 10 see Fig 10
 Spannungsniveau = stress level
 Spannung im Fluge = stress in flight
 Bis Bruch ertragene Flüge = flights to failure
 Bezugsniveau = reference stress

Fig 12

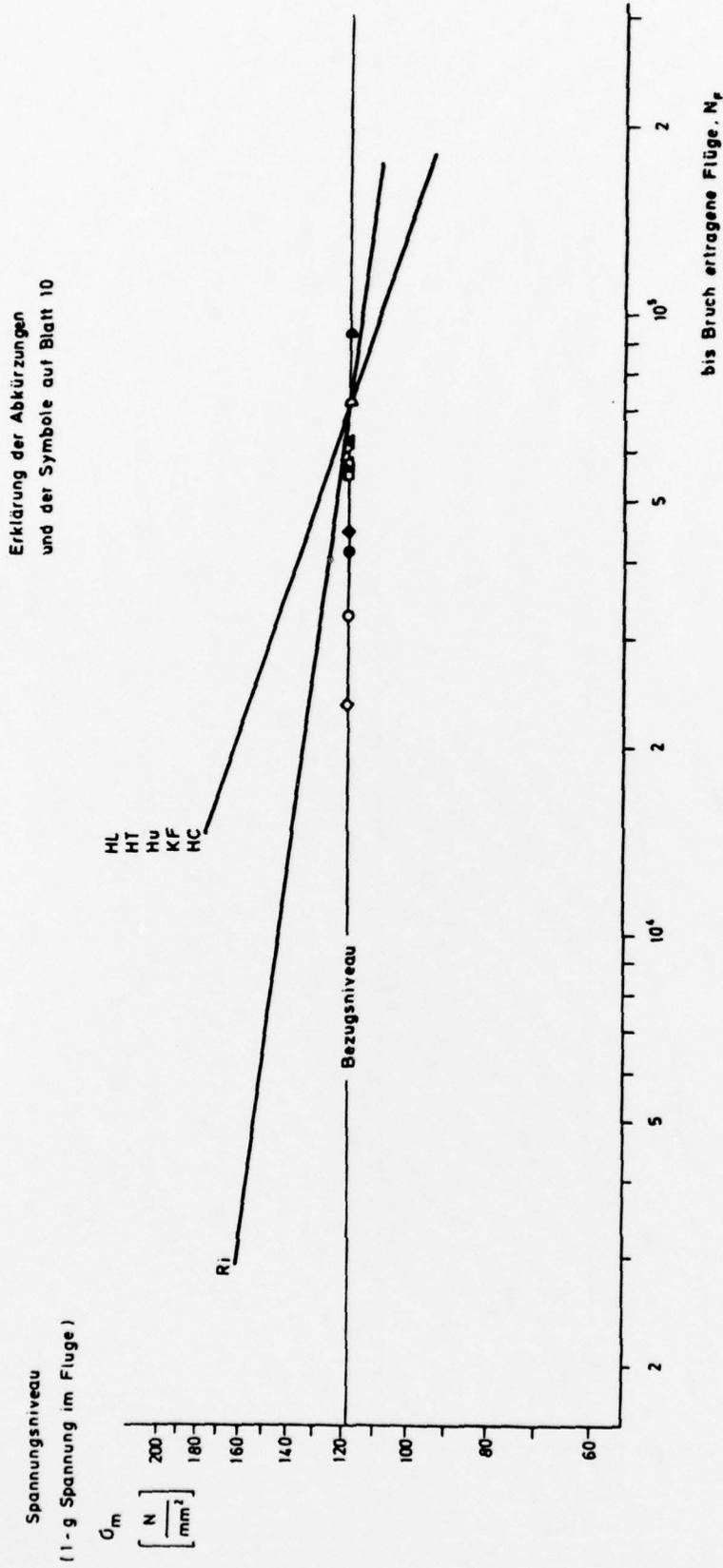
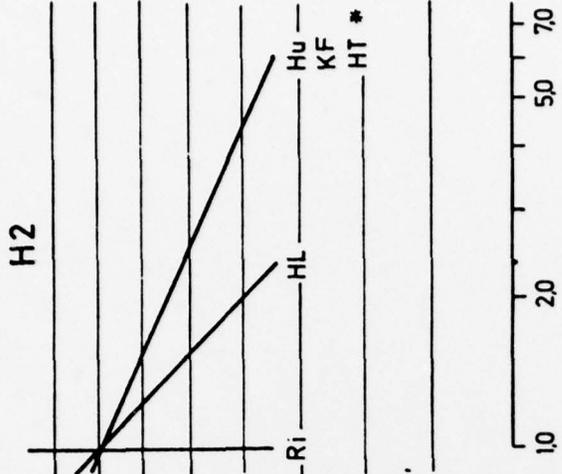
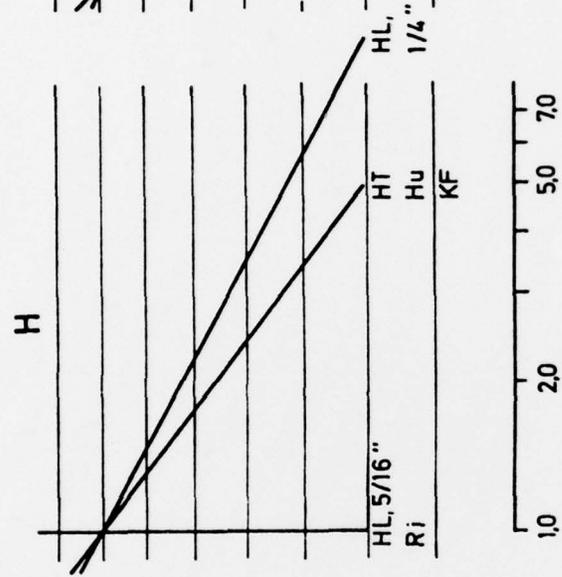
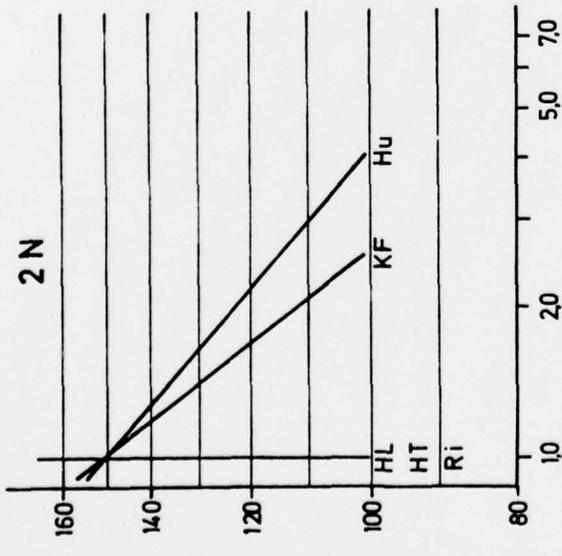


Fig 12 Life curves for joint type H2, non-shot peened, with 1/4" and 5/16" fasteners

Key:
 Erklärung der Abkürzungen = for explanation of abbreviations
 und der Symbole auf Blatt 10 = see Fig 10
 Spannungsniveau = stress level
 Spannung im Flüge = stress in flight
 Bis Bruch ertragene Flüge = flights to failure
 Bezugsniveau = reference stress

Erklärung der Abkürzungen auf Blatt 10

Spannungsniveau
 σ_m (1-g Spannung im Fluge)



Lebensdauer kugelgestrahlt
 Lebensdauer nicht kugelgestrahlt

* geschätzt

Fig 13 Effect of shot peening the joint faces

Key:
 Erklärung der Abkürzungen = for explanation of abbreviations
 auf Blatt 10 = see Fig 10
 Spannungsniveau = stress level
 Spannung im Fluge = stress in flight
 Lebensdauer kugelgestrahlt = life shot peened
 Lebensdauer nicht kugelgestrahlt = life non-shot peened
 Geschätzt = estimated

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