EIDGENÖSSISCHES FLUGZEUGWERK EMMEN

TECHN. ABTEILUNG BERICHT: S - 162

The Full Scale Fatigue Test P 3

carried out on the Fatigue History Simulator by F+W Emmen

by Jürg Branger

Report S - 162

THE FULL SCALE FATIGUE TEST P3

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Summary: In the specification of the PILATUS P3 trainer aircraft a safe life of 2500 hours is required. To proof it the last A.C. of the production was tested 1960 by F+W on it's new Fatigue History Simulator thus applying the first time a History Loading to a complete aircraft.
The evolution of the loading program, the construction of the test rig, the inspection methods, the test run and the results are reported.
After a fatigue test run of 5000 hours the test specimen failed in an ultimate load test at 90% of the design ultimate load. This was due to fatigue failures which were not detected previously.

List of Contents:

Paper presented at the Second Seminar on Fatigue and Fatigue Design, May 5th, 1964 at the Columbia University, New York, with the permission of the Service Technique Militaire (STM) in Berne, and by the kind invitation of Prof. A.M. Freudenthal, Columbia University, New York.

A. <u>The problem</u>

The P3, designed by PILATUS AG at Stans and ordered in quantity for the Swiss Air Force, is a two-seater trainer for basic training, aerobatics, night flying and instrument flying. (Fig. 1).

In the specification the following requirements concerning fatigue strength have been requested by the authority:

Safe-Life 2500 hors

Number of landings per hour: 4

Load spectrum per 1000 hours:

1800	times	+ 5 g
5600	times	+ 4 g
10400	times	+ 3 g
3700	times	- 2 g
370	times	- 3 g

Since the makers of the aircraft, Messrs. PILATUS, had no test facilities to proove that the aircraft would fulfil these requirements, we were requested by the authority to make an appropriate test. This was rather necessary as from the aircraft no static failure test was made which must be considered as extraordinary. Also extraordinary was the fact that we got for our full scale test the last aircraft of the production - this was in summer 1959.

At this time, our test facility - the fatigue history simulator, which is described in report T-197, was developed and ready for test. We had, however, not yet made a full scale test on it, and thus the P3 was to be the first aircraft. Since the facility is able to work any program automatically we tried to simulate the fatigue life of the aircraft as realistic as possible, though we had rather few statistics about this aircraft at that time. Today, we know that the program contained simplifications which should not be made.

After a lot of preparations and some preliminary runs the real test run began during August 1960.

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B. The loading program

Basing on some characteristic v - g - h records we formed 24 different partial programs of equal occurence (2 for take off, 4 for climb, 3 for ferry-, 4 for instrument-, 4 for aerobatic-flights, 4 for descent and 3 for landing), containing between 4 and 12 quasi-cycles. They were combined systematically to typical flights by chosing one partial program of each phase in the appropriate sequence. By doing all combinations we got [2 x 4x(3+4+4) x 4 x 3]=1056 different flights (Fig. 2), forming one period, representing 250 flying hours. It contains about 23'000 quasi cycles (quasi cycle, period: See report S-164, Fig. 3).

Each new aircraft coming off the production line is flight tested to an accurately defined test program with 4 flights, the third flight going to the limit loads, positive and negative. So the first 4 flights of the program cycle could be set. The other 1052 flights follow in a random sequence. To get it, we used the ballot-box method. 1052 flight numbers were put in a box, mixed and one by one taken out. The resulting sequence was put in our electronic computer ("ZEBRA"), as well as the 24 partial programs mentioned above, so that the machine did automatically stamp a long tape of approx. ~ 500 ft. length in the standard TELEX-Code, containing the whole period.

The fuel quantity of this aircraft is relatively small. Thus it was not necessary to simulate any change of the weight of the A.C. during the flights. Represented were 2 load groups, i.e.

positive loads 0 to +6 g in steps of 0,5 g and

negative loads 0 to -3 g also in steps of 0,5 g.

The negative load cases contained also the landing cases since they were not specially represented due to the uncritical undercarriage position. Therefore, -3 g means 2 g on landing. The different air load cases are represented in flight envelope Fig. 3 together with the principal date of the aircraft.

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C. <u>The test rig</u>

This test rig (Fig. 4 fuselage and tail, Fig. 5 wing) had to be designed so low to enable the crane to pass over. Thus 19 jacks were necessary, 16 of them for the wing in a lying position and all acting in tension. When at rest, the specimen is supported by the wingspar crossing in the fuselage.

The chordwise application is different for the positive and for the negative loads. It corresponds to the pressure distribution for the wing, as well for fuselage and tail.

The load applying points have been positioned along each rib (at crossing-points with spars or stringers), each point consisting of three Jo-Bolts which are replacing three corresponding rivets of the wing. Due to this method (Fig. 6) to distribute the loads into the wing, the wing was not weakened nor reinforced and, moreover, it was always possible to inspect the wing skin visually for fatigue defects. This method has proved very well.

D. <u>The inspection</u>

The inspection of the test specimen was fourfold:

1. The structure was inspected visually by an inspector for defects every day. With the P3 test, 24 hours test rig represented about 72 flying hours.
2. Each reduction in the stiffness of the structure would have been reported by the wing tip cut out switches at +6 and -3 g due to the higher deformation.
3. All load peaks from 0,5 to 0,5 g, all zero passages as also the sum of all steps carried out were counted and registered.
4. The load from 9 selected jacks were measured by precision strain gage dynamometers and registered (Fig.7). The recorder, however, was only switched on temporary, as the system has proved to work very reliable.

E. <u>The test and results</u>

As mentioned before, the last aircraft of the production was received as test specimen. The first aircraft of the production had meanwhile reached up to 500 flying hours. Loose rivets were remarked on some of these aircraft after a few hundred hours at the ⩵ joint of the wing skin at the outer third of the wing. The reason was assumed to be

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bad rivetting, overstressing during aerobatics, etc., even the colour of the nationality mark was suspected. Nobody thought fatigue as reason. Therefore, it was the first success of the test when the same occured also on test and thus fatigue was unequivocal reponsible for this defect.

Later some cracks on stringers appeared, on the upper surface of the wing, a defect which had occured already on flying aircraft. They were repaired and the usefulness of the repair could be remarked very well on the further test run.

After 1000 hours a fretting damage of the bolt on the sub-spar, connecting outer and centre wing occured. The bolt was replaced by one of harder steel, both parts were rubbed in with MoS_2 - powder and re-fitted. No further damage occured. A check on all service aircraft revealed 2 similar cases. Therefore, on all service aircraft the same action was taken with good results and no further damage occured. More severe damage could not be found during the test.

With respect to the very realistic program the authority decided, that a time-factor of two had to be proven. Therefore, the specimen was loaded 20 times the program, representing 5000 flying hours. After 2500 hours one overload of 7 g was put on the specimen by the rig which for that was controlled manually and held on the load until all measurements were made. After 5000 hours an ultimate load test was done. The specimen failed at 8 g, whilst the design ultimate load is 9 g. This was on April 14, 1961.

Despite very careful inspecting before this ultimate load test, the fatigue damage which lead to failure was not remarked. Even after failure, which showed first a unusual big bending of the wing the damage remained hidden. With this test one great advantage of the rig was apparent: As soon as one of the wing tips reached the stop contact due to excessive bending, the contact cuts out the whole test machinery, all pressures drop and the loads went fast but proportionally back and no further damage can result. The damage remains thus as it was at the very beginning of the final failure. This fact proofed to be very important.

Finally not the professional inspector but one of the hydraulic people found by chance on scratching the hand in a hidden corner a damage which can be termed as a classic example for a fatigue failure (Fig. 8, 9, 10 and 11).

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The failure occured by shear in the web plate of the main spar in both outer wings, at the attachment to the inner wing, due to a heavy fatigue damage.

A check of the stress calculation of this part showed, that the web and the rivetting did not reach an ultimate factor of 1,5. On all service aircraft the allowed limit was thus reduced temporary from +6 g to +5 g pending the reinforcing of this part. The fatigue test was with that concluded. We had thus found a weak point in a part of first importance.
We were able to strengthen it, before an accident occured. This in itself has payed for the whole test.

A further damage, which would, however, not have had such a fatal consequence, but could nevertheless not be tolerated, was found on stripping the aircraft after test. At the connection of the rear spar with the fuselage several sheared rivets were found as also buckled connecting plates. An inspection on all service aircraft showed in some cases the beginning of similar defects what has lead to an action for reinforcing this part on all aircraft. This measure was taken early enough so that no expensive repairs were necessary.

For instruction purposes in the Air Force we have, with every limited means, made a film of the test which will be kept as a historical document of our first full scale fatigue test. It is an amateur film made literally by one man - the electronic engineer of the team.
He has made all the work inclusive the script, the cutting etc. This film must thus not be viewed as one made by professionals. It is spoken in German. The pictures to see at the begin and at the end of the film were taken with a camera fitted in the fin of a HUNTER aircraft for firing tests, and shows the country side of Lucerne and its surroundings.

F. <u>Figures</u>

1 PILATUS P3 training aircraft
2 Simulated flight programs: Flight types Nr. 351 and 352.
3 P3, fatigue test loads
4 Fatigue test rig, fuselage and tail
5 Fatigue test rig, wing
6 Load applying to the wing
7 Record of the applied jack loads
8–11 } Fatigue failures of main spar

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References

ICAF Doc. 220 — Minutes of the Seventh Conference of the International Committee on Aeronautical Fatigue held in Paris on the 15th and 19th May, 1961.

ICAF Doc. 271 — Minutes of the Eighth Conference of the International Committee on Aeronautical Fatigue held in Rome, April 1963.

Branger J. — The Fatigue History Simulator, developed by F+W Emmen, F+W T-197, April 1964.

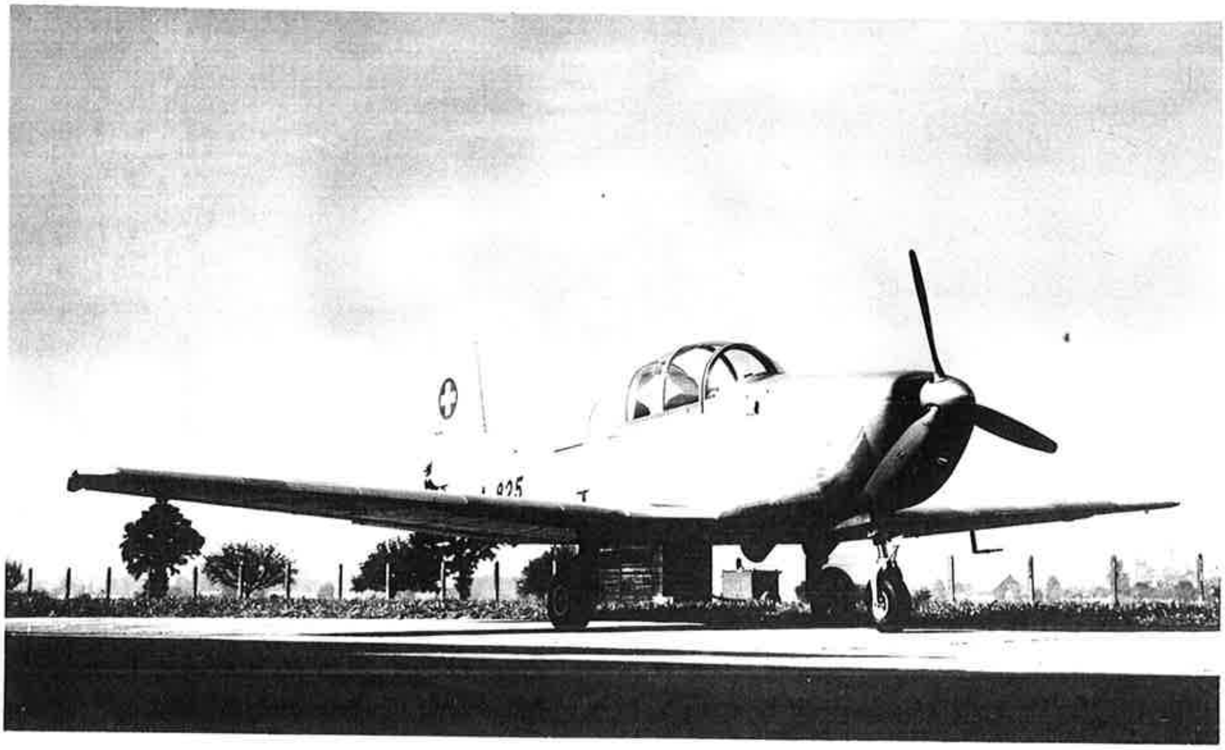

Fig. 1 Pilatus P 3 training aircraft

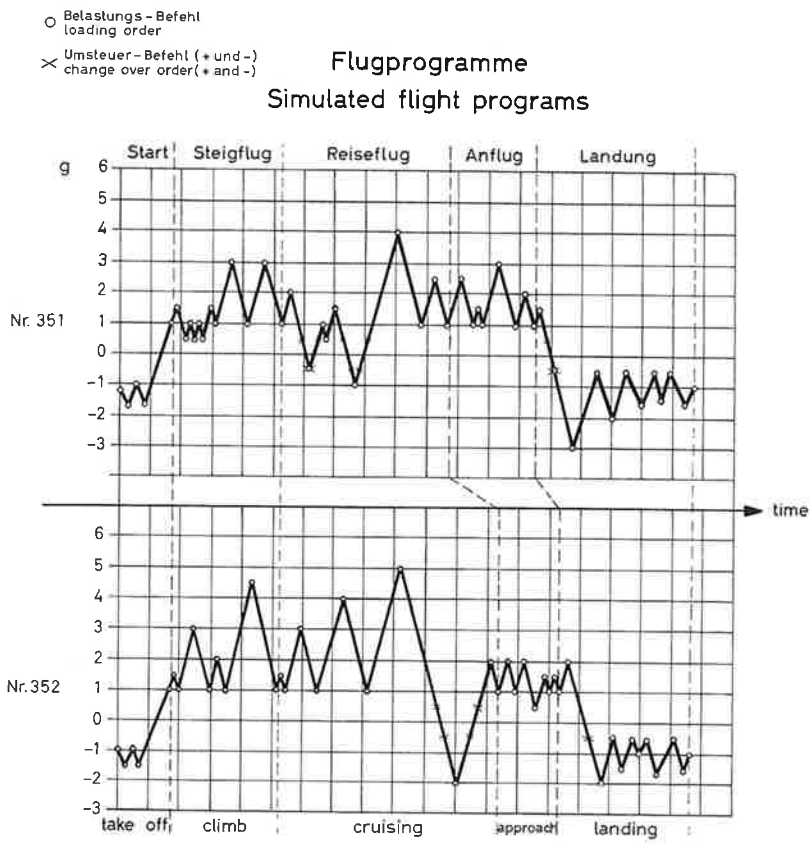

Fig. 2 Flight types nr. 351 and 352

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The full Scale Fatigue Test P-3	S - 162 Fig. 3

Ermüdungsversuch P-3

Techn. Daten:

Länge	8,75 m
Spannweite	10,40 m
Höhe	3,05 m
Tragfläche	16,50 m^2
Gewicht (max. Abfluggew.)	1500 kg
(G/F) max.	90,60 kg/m^2
Zul. pos. Lastvielfaches	6
Zul. neg. Lastvielfaches	3
Sicherheitsfaktor	1,5

Versuch: Lastfall B und E
Gewicht (ausgew. Mittel) 1415 kg
Schwerpunktslage gemittelt 1-2 sitzig

H 0 m
ϱ_0 0,12497 $kg\,sec^2 m^{-4}$
Belastungsprogramm nach Lastspectrum

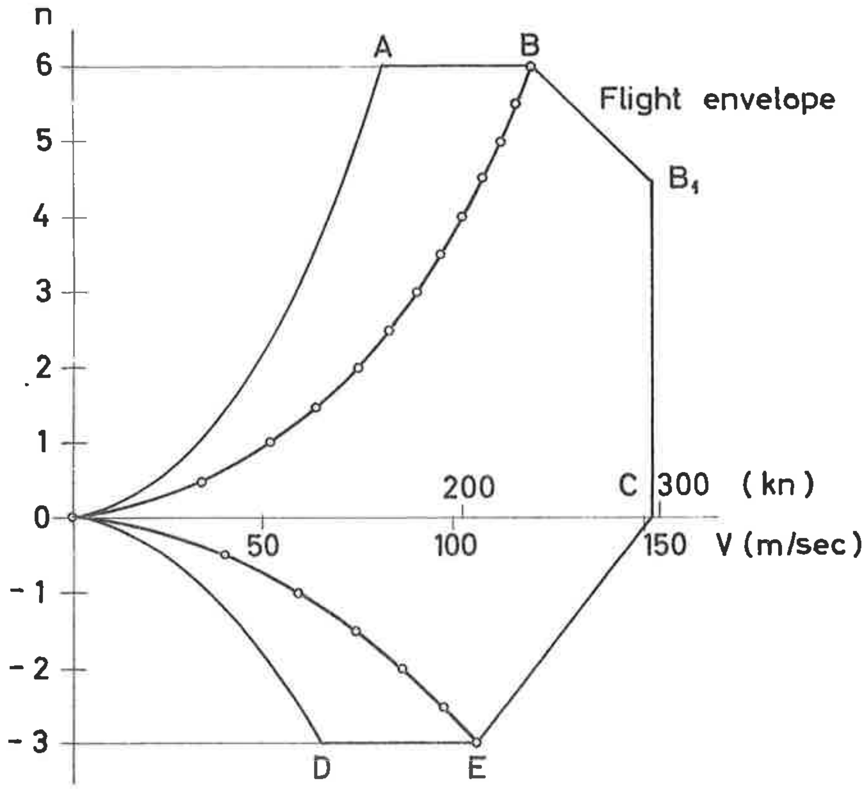
P-3 Fatigue test

Technical data:

Length	28 ft. 6 in.
Span	34 ft.
Height	10 ft.
Wing area	177 sq. ft.
Gross weight (max. take off),	3300 lb.
Wing loading	18,6 lb./sq. ft.
Limit load positiv	6 g
Limit load negativ	3 g
Ultimate factor	1,5

Test: Load case B and E
Weight (average chosen) 3120 lb.
Mean position for the center of gravity 1-2 seater

H 0 ft.
ϱ_0 0,002378 $lb.\,sec.^2\,ft.^{-4}$
Test program according to the load spectrum



g	Einzelhäufigkeit No. of occurrences
6	172
5,5	580
5	1220
4,5	2200
4	3300
3,5	4300
3	6100
2,5	7600
2	13500
1,5	38500
1	∞
0,5	16000
0	8000
-0,5	6000
-1	4300
-1,5	3620
-2	2430
-2,5	1270
-3	370

Fig. 3

P-3 Fatigue test loads

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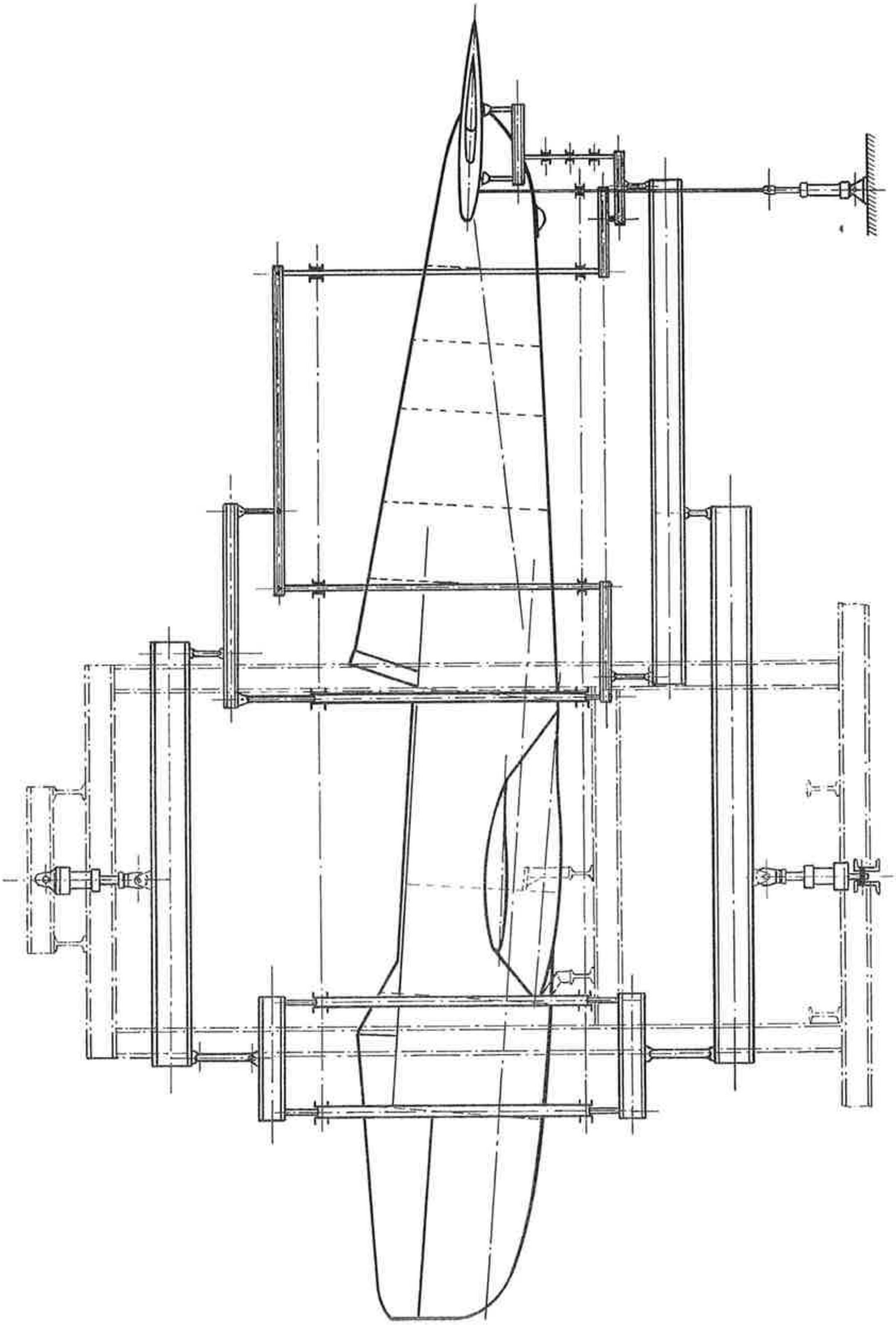
The full scale fatigue test P 3	S - 162 Fig. 4



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The full scale fatigue test

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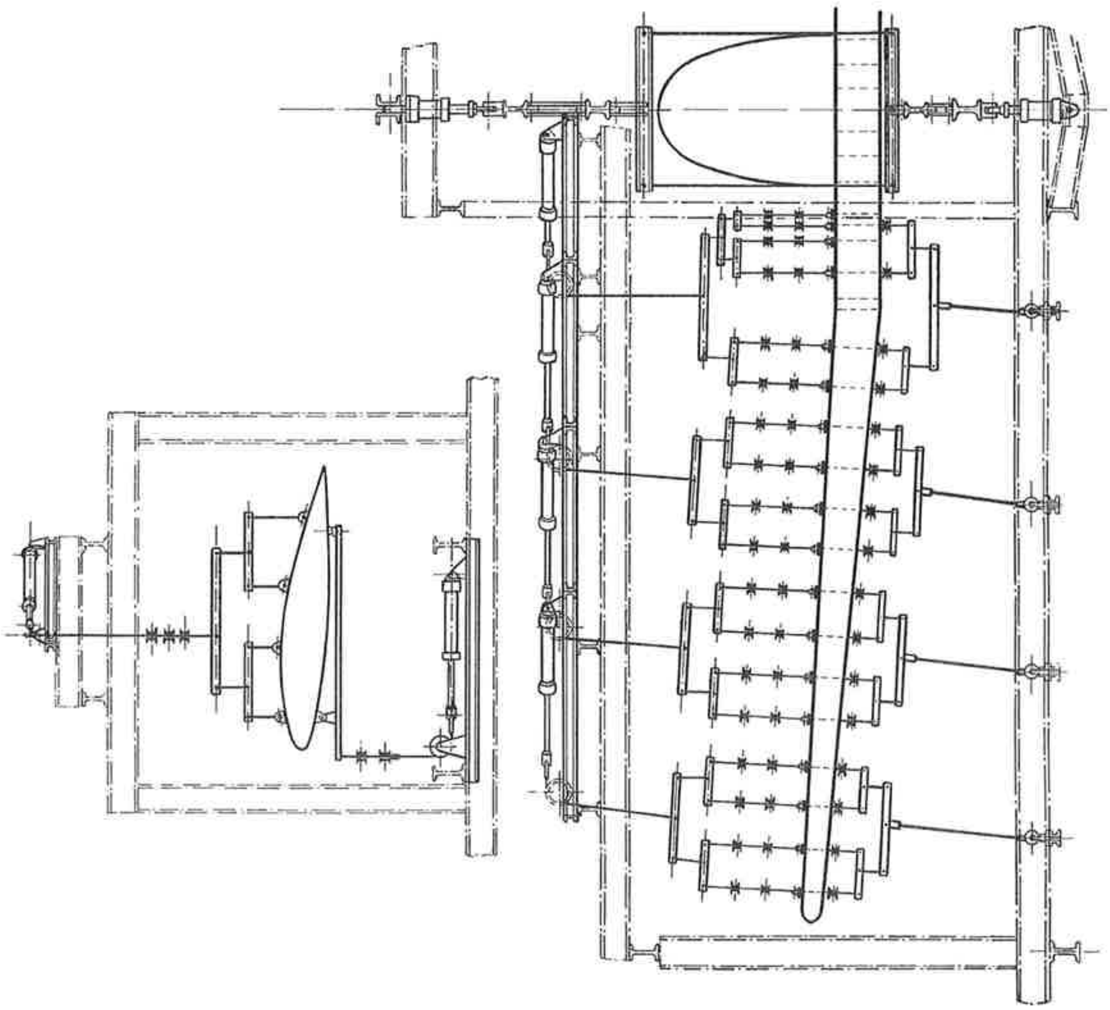
Fig. 5



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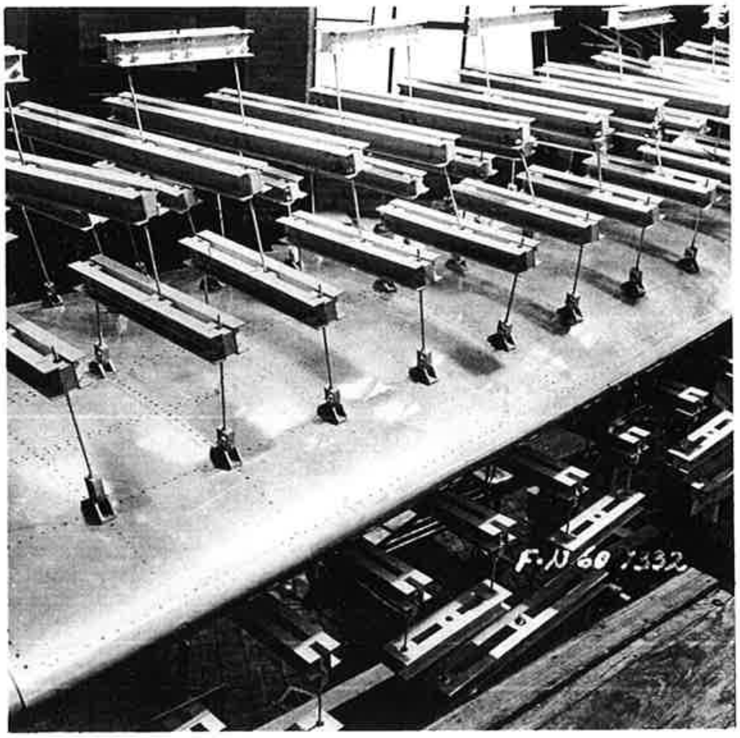

Fig. 6 Load applying to the wing (by 3 Jo-Bolts at crossing points rib-stringer)

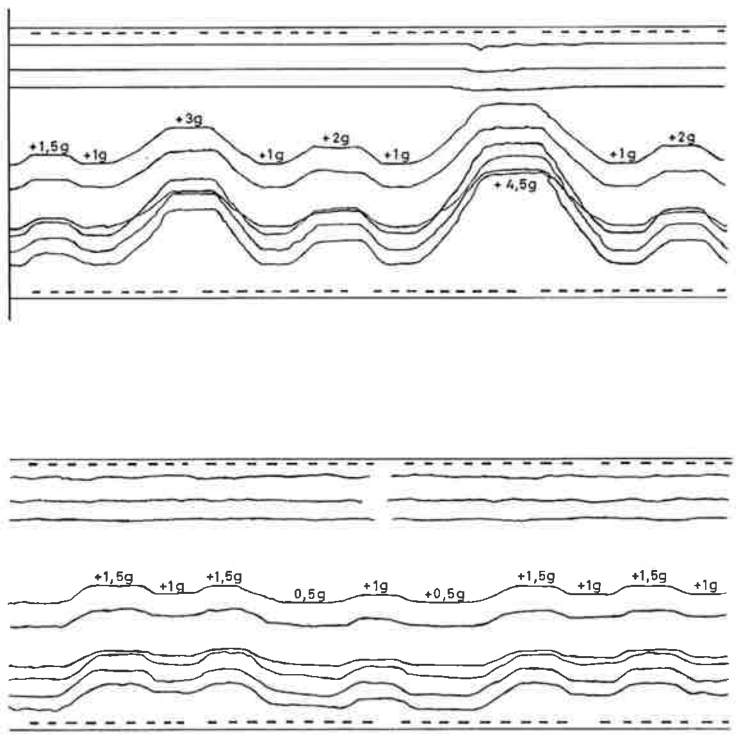

Fig. 7 Record of the applied jack loads

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Fatigue failure of the main spar attachment of the outer wing to the centre wing

port
(failure of rivets)

Fig. 8

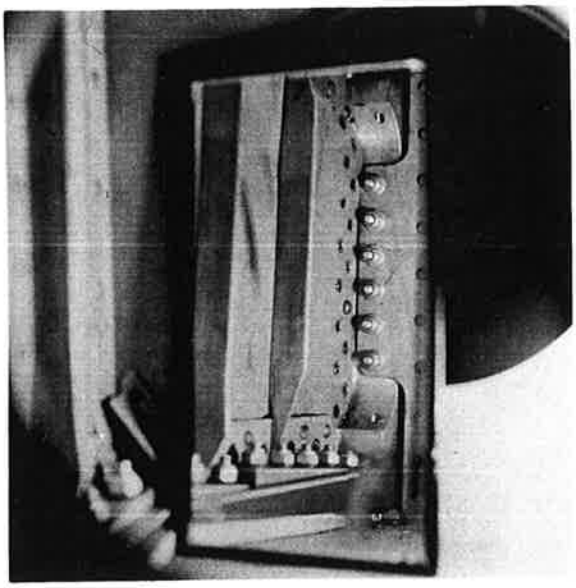

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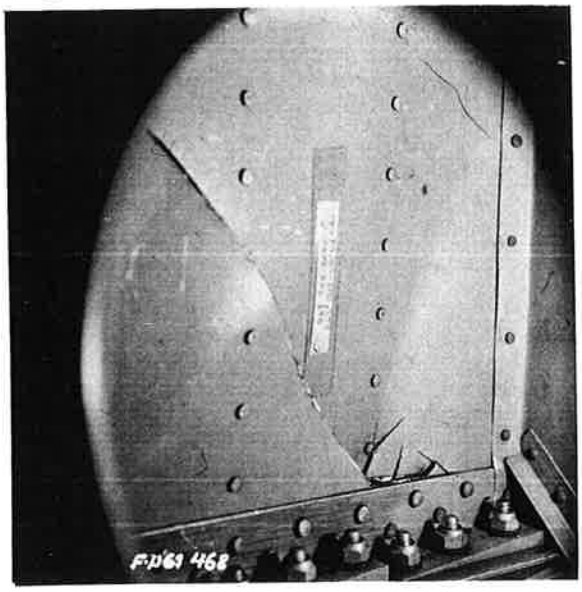
Fig. 9



front face

rear face

views in mirror

failure of web

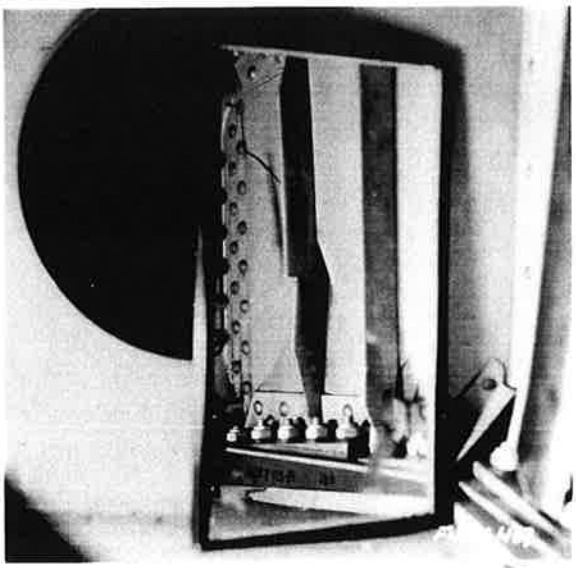


Fig. 10

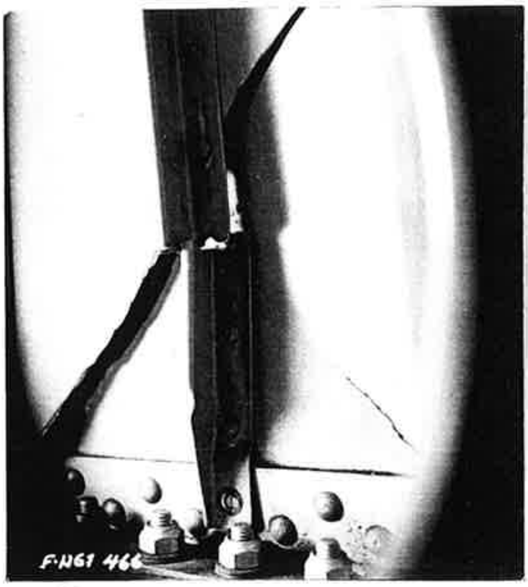


Fig. 11

stbd
front face

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