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CRACK DISTRIBUTION AND GROWTH RATES FOR CRITICAL
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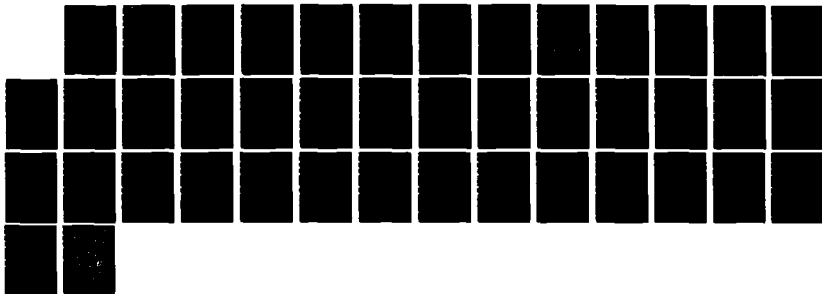
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MELBOURNE, VICTORIA

Aircraft Materials Technical Memorandum 396

CRACK DISTRIBUTION AND GROWTH RATES FOR CRITICAL FASTENER HOLES IN MIRAGE WING RH79 (J)

by

S. BOWLES

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Aircraft Materials Technical Memorandum 396

**CRACK DISTRIBUTION AND GROWTH RATES FOR
CRITICAL FASTENER HOLES IN MIRAGE WING RH79 (U)**

by

S. BOWLES

SUMMARY

Results of fractographic inspection of fatigue cracks found in the fastener holes (excepting hole 1 and SLAN rivet holes) in the inboard end of the lower flange of RH79 wing-spar, as a result of fatigue testing for 5600 hours, are presented. The largest crack found was only 2.18 mm deep and occurred in hole 10 in the rearward flange of the spar. Holes 1 to 4 remained crack-free as a result of the refurbishment procedures.



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INTRODUCTION

A summary of the size, location and condition of cracks found in fatigue-critical regions in the main spar of Mirage wing (RH79) after fatigue testing, is presented here; complete details of the cracks are included in an annex. This fractographic information was obtained specifically for comparison with acoustic emission (AE) data [1] resulting from continuous monitoring of this wing during fatigue testing. However, it will also be of interest to structural engineers concerned with the effectiveness of refurbishment procedures applied to this wing as part of the life extension program and also of interest for comparison with eddy-current inspection results.

TEST

Following service, this Mirage wing formed part of a reconstructed aircraft which underwent full-scale fatigue testing at the Swiss Federal Aircraft Factory (F+W) in Emmen, Switzerland. This wing was tested for 5600 hours (42 program blocks*) with refurbishment at 533 hours into the test. The wing was removed before failure and fractography carried out at ARL on fastener holes in the inboard end of the lower flange of the wing-spar and in the wing-skin rearward of this surface. Specifically the areas inspected (illustrated in Figure 1) include: (i) fastener holes 2 to 13 and the lower blind-anchor-nut hole in the rearward spar flange, (ii) fastener holes numbered 101 to 114, and 116 in the forward spar flange, (iii) the fairing-anchor-nut hole and (iv) fastener holes 1 to 10, and karman fairing holes KA, KB and associated rivet holes in the rearward wing-skin. In terms of refurbishment, close-tolerance fasteners had been used in the rear flange holes, with holes 1 to 5 also having interference-fit stainless steel bush inserts; interference-fit fasteners had been used in the forward flange holes. (Fractographic inspection of

* The loading sequence in the F+W full-scale fatigue test consisted of repetitive application of 24 "typical flights" arranged in a sequence of 200 test flights, collectively called a program block. The maximum load of 7.5 g, which only occurred twice during each program block (during test flights 48 and 150) was used in fractographic examination to identify crack growth between successive program blocks and hence to determine crack growth curves. One program block is equivalent to 133.3 test hours.

fastener hole number 1 and the two single leg anchor nut (SLAN) rivet holes next to it, was made by N.T. Goldsmith [2].)

The sections of the spar and the rearward wing-skin containing these fastener holes were cut from the bulk and broken open to reveal any cracks propagating from the holes in the rearward and forward directions. The general condition of each specimen, including indications of fretting damage other than on crack faces, was determined using a binocular microscope. The fracture faces of each of these specimens were then examined in detail using a "Ziess Universal" metallurgical microscope. Incremental crack depth measurements and crack growth curves were determined where possible.

The maximum crack depths (in both the forward and rearward directions) are given for each hole, in tables 1 to 4, along with indications of fretting between crack faces, fretting of fasteners or bushes in holes, and fretting on the spar and skin surfaces. Residual black product found at suspected fretting sites on the spar and skin surfaces was identified using x-ray analysis as aluminium oxide, consistent with fretting between these aluminium surfaces. (Identification of fretting sites was particularly useful to the AE study whose aim was to identify AE due to crack growth amidst other AE sources such as fretting.)

The largest crack observed in the rearward spar flange holes was 2.18 mm deep (in hole 10), while the largest crack observed in the forward spar flange holes was only 0.27 mm deep (in hole 104.)

Crack growth curves for cracks in holes 6, 8, 9, 11, 12, blind-anchor-nut hole, 101, 103, 104, 105 and 106 are presented in Figure 2. Unfortunately many of the crack faces, including those of the crack in hole 10, were severely fretted and crack growth data could not be obtained.

The complete details of the size (length along the bore of the hole, and the depth into the bulk) and the location (distance of the crack down the bore of the hole) of each crack in each of the holes in the spar, are listed in the annex; the cracks for which growth curves were obtained are indicated. The tables of figures show that most of the holes contain many active cracks of different sizes,

Consequently the quantification of the cracking activity, required for correlation with the AE activity, was extremely difficult.

Detailed crack size information and crack growth curves were not determined for cracks in the wing-skin.

Overall, this fractographic information shows that the pattern of crack distribution is much as expected, with the largest cracks occurring on the rearward flange; the greatest cracking activity occurred in the SLAN rivet holes [2]. Holes 1 to 4 remained crack-free; this indicates that the bushes installed during refurbishment were effective since from past experience holes in these positions are normally critical crack initiation sites. For the remaining rearward flange holes inspected, cracking activity was more prominent in the holes towards the outboard end of the spar: holes 10, 11, 12, 13 and the blind-anchor-nut hole. This may result from a load redistribution due to either the large cracks found growing in the rearward wing-skin or the boron-fibre reinforced patches on the wing skin (see Figure 1). The most active crack in the forward flange occurred in fastener hole 104, which seems to carry the main load from the forward fairing.

ACKNOWLEDGEMENTS

I am grateful to N.T. Goldsmith for his assistance with fractography and to both M.J. Muggerridge and B.E. Williams for conducting the x-ray analysis.

REFERENCES

1. S.J. Bowles, "AE load-cycle-dependence applied to monitoring fatigue crack growth under complex loading conditions", to be published.
2. N.T. Goldsmith, "Defect Failure Analysis Report". M26/83/NTG, Aeronautical Research Laboratories, Melbourne.

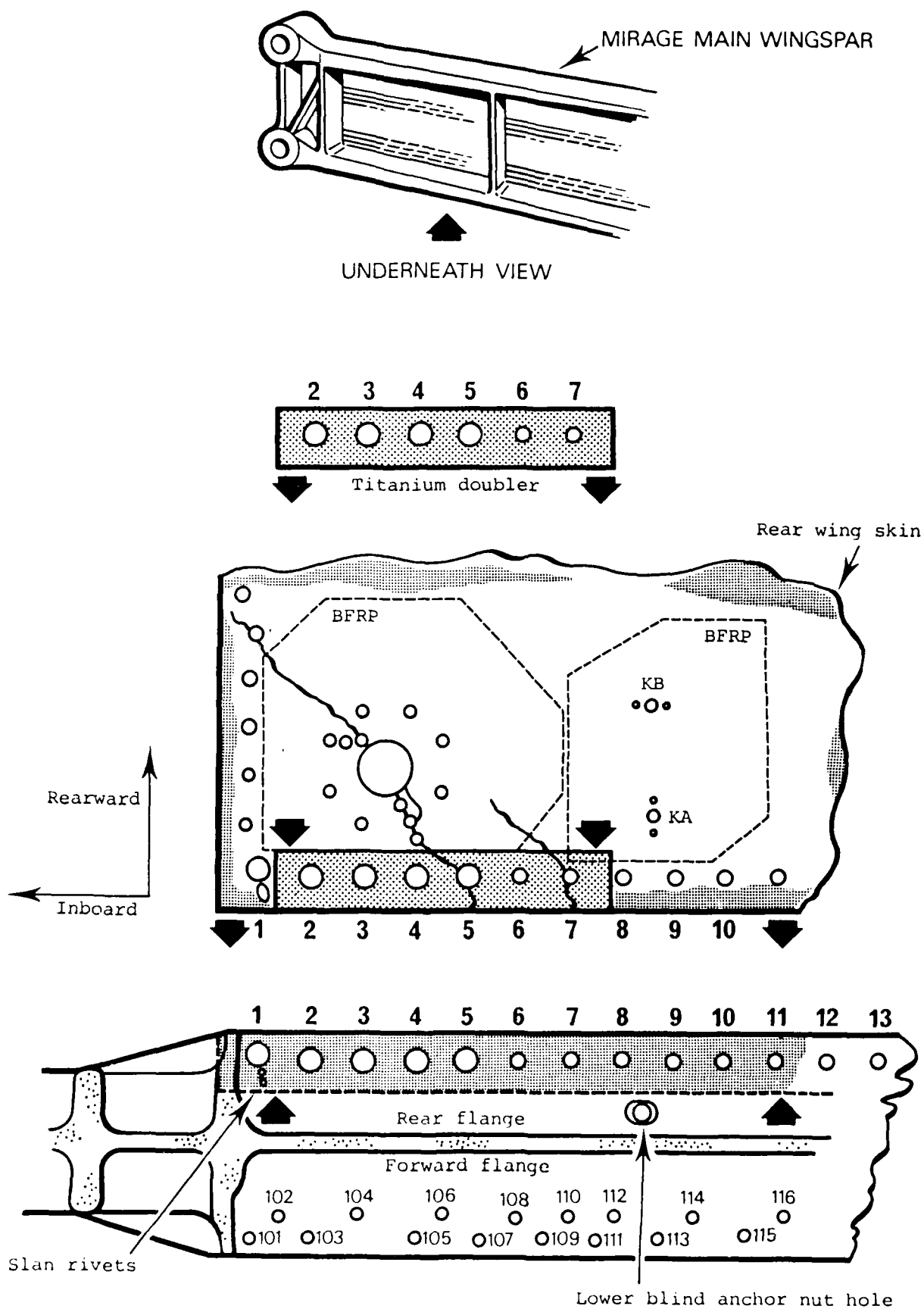


FIG. 1 LOCATION OF FASTENER HOLES IN THE MIRAGE WING-SPAR (LOWER FLANGE) AND THE ATTACHED REARWARD WING-SKIN.

BORON FIBRE REINFORCED PATCHES (BFRP) AND A TITANIUM DOUBLER USED IN SKIN REPAIR ARE SHOWN. MAJOR SKIN CRACKS ARE ALSO SHOWN.

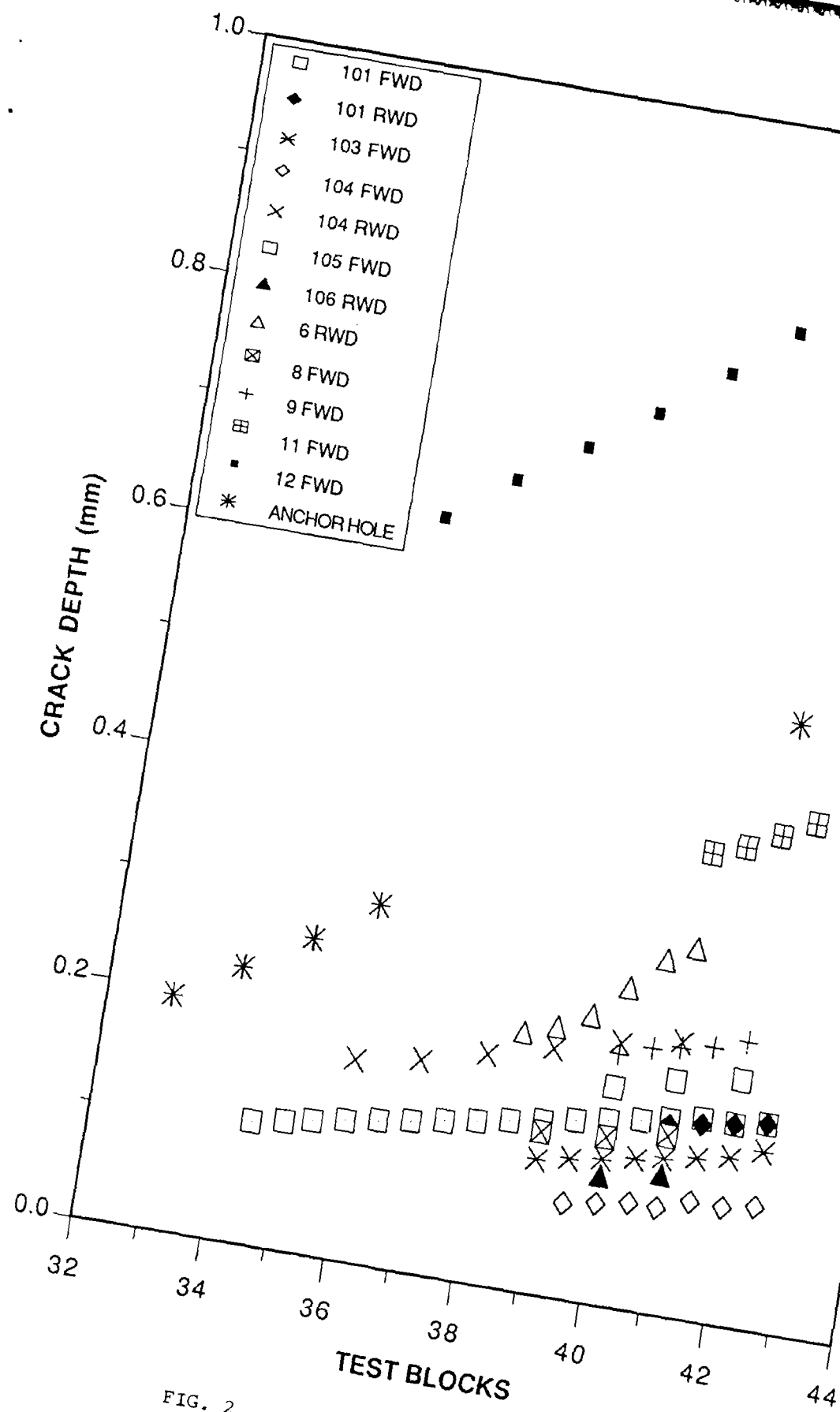


FIG. 2

CRACK GROWTH CURVES FOR MIRAGE
WING RH79.

TABLE I. SUMMARY OF CRACKING AND FRETTING ACTIVITY - REAR SPAR FLANGE

HOLE NUMBER	1st RIVET	2nd RIVET	1	2	3	4	5	6	7	8	9	10	11	12	13	LOWER BLIND ANCHOR NUT
MAX. CRACK DEPTH, FWD (mm)	joins with 2nd rivet	1.33	-	-	-	-	0.59	0.09	0.09	0.17	0.27	0.15	0.65	0.86	0.64	0.57
MAX. CRACK DEPTH, RWD (mm)	1.98	joins with 1st rivet	-	-	-	-	-	0.41	0.21	0.28	0.21	2.18	0.58	0.32	0.57	0.14
CRACK GROWTH CURVE FOR THIS HOLE	< See reference 2 ->	-	-	-	-	-	-	fig.2	-	fig.2	fig.2	-	fig.2	fig.2	-	fig.2
FRETTING - LOWER SPAR SURFACE	-	-	minor	<-----major----->	<-----major----->	<-----major----->	<-----major----->	<-----major----->	<-----major----->	<-----major----->	<-----major----->	<-----major----->	<-----major----->	<-----major----->	<-----major----->	<-----major----->
FRETTING - UPPER SPAR SURFACE	-	-	-	-	-	-	-	-	-	-	-	minor	-	-	-	-
FRETTING - IN HOLE BORE	-	-	<-----bush fretting----->	-	-	-	-	-	-	-	-	-	-	-	-	-
FRETTING - BETWEEN CRACK FACES	<- major ->	-	-	-	-	-	<-----minor, mostly black----->	<-----minor, mostly black----->	<-----minor, mostly black----->	<-----minor, mostly black----->	<-----minor, mostly black----->	major v.black	<-----minor, mostly black----->	<-----minor, mostly black----->	<-----minor, mostly black----->	<-----minor, mostly black----->

TABLE 2. SUMMARY OF CRACKING AND FRETTING ACTIVITY - REAR WING SKIN

HOLE NUMBER	1st RIVET	2nd RIVET	1	2	3	4	5	6	7	8	9	10
MAX. CRACK DEPTH FORWARD (mm)	skin cut away	-	-	<0.05	-	-	to skin edge	1.76	to skin edge	1.8	-	0.15
MAX. CRACK DEPTH REARWARD (mm)	-	skin cut away	-	0.05	-	-	to drain plug & beyond fig.1	0.33	69 as per fig.1	-	-	-
FRETTING BETWEEN SKIN & DOUBLER	-	-	-	-	-	-	<----- major ----->	-	-	-	-	-
FRETTING - BETWEEN CRACK FACES	-	-	-	N.I.	-	-	major,	minor,	major,	minor,	-	N.I.

N.I. = not inspected

TABLE 3. SUMMARY OF CRACKING AND FRETTING ACTIVITY - REAR WING SKIN

HOLE NUMBER	RIVET FWD OF KA	KA	RIVET RWD OF KA	RIVET INBOARD OF KB	KB	RIVET OUTBOARD OF KB
MAX. CRACK DEPTH FORWARD (mm)	1.48	-	2.00	-	-	-
MAX. CRACK DEPTH REARWARD (mm)	1.96	-	0.58	-	-	-
FRETTING BETWEEN CRACK FACES	minor, black in spots	-	minor, black in spots	-	-	-

ANNEX

MIRAGE WING - RH 79
MAIN SPAR (LOWER SURFACE)

HOLE NUMBER: 5
CRACK DISTRIBUTION

forward of hole:

distance from lower surface (mm)	surface length (mm)	depth (mm)
1.19	1.19	0.59

rearward of hole:

distance from lower surface (mm)	surface length (mm)	depth (mm)
-	-	-

ANNEX

MIRAGE WING - RH 79
MAIN SPAR (LOWER SURFACE)

HOLE NUMBER: 6
CRACK DISTRIBUTION

forward of hole:

rearward of hole:

distance from lower surface (mm)	surface length (mm)	depth (mm)	distance from lower surface (mm)	surface length (mm)	depth (mm)
0.51	0.19	0.07	1.40	2.17	0.41 *
1.89	0.14	0.05	3.81	0.16	0.10
2.07	0.06	0.02	3.98	0.06	0.02
2.64	0.14	0.06	4.11	0.23	0.09
2.85	0.09	0.05	4.37	0.06	0.03
2.93	0.10	0.06	4.56	0.07	0.03
3.97	0.24	0.09	4.67	0.08	0.03
4.96	0.10	0.03	5.41	0.13	0.04
5.06	0.16	0.05	5.73	0.04	0.01
5.44	0.09	0.03	5.99	0.10	0.04
7.36	0.50	0.03	6.47	0.05	0.03
11.01	0.06	0.02	6.81	0.14	0.05
			7.00	0.07	0.02
			8.00	0.10	0.05
			8.32	0.05	0.02
			8.55	0.06	0.03

* A crack growth curve for this crack is given in figure 2.

ANNEX

MIRAGE WING - RH 79
MAIN SPAR (LOWER SURFACE)

HOLE NUMBER: 7
CRACK DISTRIBUTION
forward of hole:

distance from lower surface (mm)	surface length (mm)	depth (mm)
4.91	0.04	0.02
5.32	0.12	0.03
6.41	0.13	0.06
6.77	0.19	0.06
7.07	0.17	0.09
7.34	0.07	0.04
7.59	0.06	0.03
8.12	0.07	0.03
8.36	0.20	0.06
9.44	0.07	0.04
9.63	0.06	0.03
9.70	0.06	0.03
9.75	0.10	0.05

rearward of hole:

distance from lower surface (mm)	surface length (mm)	depth (mm)
0.34	0.47	0.21
0.72	0.45	0.20
1.19	0.13	0.08
1.35	0.29	0.11
1.65	0.29	0.16
1.93	0.46	0.19
2.39	0.17	0.09
2.49	0.44	0.12
3.06	0.25	0.11
3.38	0.41	0.15
3.79	0.07	0.03
3.98	0.28	0.10
4.32	0.08	0.05
4.39	0.16	0.07
4.76	0.16	0.06
5.68	0.19	0.05
6.07	0.02	0.01
6.22	0.05	0.02
7.64	0.07	0.03
10.18	0.18	0.07
10.98	0.27	0.03

ANNEX

MIRAGE WING - RH 79
MAIN SPAR (LOWER SURFACE)

HOLE NUMBER: 8
CRACK DISTRIBUTION

forward of hole:

distance from lower surface (mm)	surface length (mm)	depth (mm)
0.0	0.17	0.15
0.67	0.07	0.05
0.77	0.05	0.02
1.51	0.11	0.06
1.63	0.16	0.07
1.92	0.18	0.06
2.15	0.09	0.06
2.22	0.13	0.07
2.41	0.19	0.07
2.69	0.15	0.08
2.83	0.18	0.11
3.00	0.20	0.08
3.21	0.71	0.17 *
3.90	0.09	0.05
4.25	0.07	0.04
4.31	0.13	0.05
4.54	0.03	0.02
4.57	0.15	0.04
4.82	0.14	0.05
4.96	0.14	0.06
5.09	0.21	0.08
5.31	0.07	0.04
5.40	0.09	0.04
5.64	0.24	0.08
5.86	0.11	0.05
6.26	0.12	0.03
6.39	0.07	0.02
6.65	0.12	0.04
6.94	0.05	0.03
6.99	0.06	0.04
7.01	0.38	0.08
7.86	0.11	0.02
7.99	0.11	0.03
8.32	0.06	0.02
8.64	0.17	0.03
9.45	0.09	0.04
10.96	0.04	0.01

rearward of hole:

distance from lower surface (mm)	surface length (mm)	depth (mm)
0.17	0.25	0.20
0.17	0.22	0.15
0.33	0.19	0.13
0.57	0.18	0.08
0.76	0.33	0.13
1.16	0.26	0.10
1.33	2.00	0.28
3.18	0.28	0.13
3.48	0.03	0.03
3.53	0.54	0.17
4.07	1.05	0.21
5.10	0.17	0.13
5.21	0.20	0.11
5.55	0.04	0.02
5.60	0.13	0.07
5.82	0.14	0.07
6.02	0.21	0.10
6.54	0.03	0.01
6.60	0.05	0.02
6.94	0.12	0.02
7.16	0.06	0.03
7.51	0.03	0.02
7.73	0.04	0.02
7.76	0.08	0.05
8.19	0.03	0.02
9.08	0.07	0.04
9.41	0.09	0.03
9.55	0.06	0.03
11.97	0.15	0.02
12.12	0.04	0.02
12.17	0.26	0.03

ANNEX

MIRAGE WING - RH 79
MAIN SPAR (LOWER SURFACE)

HOLE NUMBER: 9
CRACK DISTRIBUTION

forward of hole:

rearward of hole:

distance from lower surface (mm)	surface length (mm)	depth (mm)	distance from lower surface (mm)	surface length (mm)	depth (mm)
0.17	0.26	0.06	0.00	0.30	0.21
0.72	0.28	0.08	0.55	0.27	0.11
1.04	0.17	0.08	0.92	0.35	0.14
1.20	0.31	0.08	1.25	0.09	0.06
1.44	0.33	0.11	1.35	0.04	0.07
1.61	0.74	0.27 *	1.41	0.13	0.07
2.47	0.06	0.04	1.60	0.06	0.05
2.50	0.10	0.06	1.68	0.18	0.11
2.58	0.12	0.05	1.86	0.18	0.10
2.69	0.14	0.07	2.02	0.20	0.07
3.01	0.12	0.08	2.20	0.18	0.14
3.27	0.06	0.02	2.39	0.28	0.17
3.55	0.05	0.03	2.61	0.30	0.16
3.61	0.09	0.04	2.86	0.22	0.11
3.69	0.19	0.09	3.09	0.46	0.13
4.01	0.07	0.03	3.36	0.46	0.12
4.28	0.10	0.03	3.74	0.66	0.13
4.66	0.53	0.10	4.40	0.16	0.07
5.45	0.54	0.10	4.55	0.18	0.09
5.93	0.50	0.07	4.81	0.10	0.03
6.43	0.63	0.06	4.98	0.20	0.04
7.08	0.12	0.02	5.18	0.13	0.04
8.50	0.17	0.04	5.28	0.14	0.04
11.90	0.11	0.02	7.14	0.05	0.09
12.10	0.18	0.04	7.15	0.09	0.06
			7.26	0.07	0.05
			7.71	0.08	0.03
			10.55	0.08	0.01

* A crack growth curve for this crack is given in figure 2.

ANNEX

MIRAGE WING - RH 79
MAIN SPAR (LOWER SURFACE)

HOLE NUMBER: 9
CRACK DISTRIBUTION

forward of hole:

distance from lower surface (mm)	surface length (mm)	depth (mm)
1.34	0.09	0.03
2.09	0.09	0.03
2.43	0.05	0.01
3.52	0.10	0.02
4.17	0.06	0.01
4.75	0.14	0.03
4.90	0.10	0.03
5.09	0.10	0.03
5.47	0.31	0.04
5.81	0.09	0.03
5.90	0.32	0.05
6.21	0.12	0.03
6.33	0.08	0.03
6.42	0.34	0.07
6.77	0.05	0.02
6.82	0.16	0.05
6.97	0.09	0.02
7.19	0.33	0.04
7.60	0.34	0.05
7.99	0.09	0.04
8.08	0.36	0.09
8.36	0.25	0.10
8.59	0.15	0.10
8.71	0.33	0.11
9.04	0.65	0.08
9.69	0.30	0.07
9.93	0.34	0.10
10.21	0.76	0.14
10.94	0.19	0.11
11.10	2.26	0.15
13.59	0.41	0.07
13.95	0.14	0.07
14.07	0.13	0.08
14.17	0.88	0.10
15.24	0.33	0.11
15.53	0.30	0.11
15.83	0.06	0.02
15.87	0.27	0.07
16.34	0.06	0.02

rearward of hole:

distance from lower surface (mm)	surface length (mm)	depth (mm)
0.00	3.88	2.18
3.89	0.67	0.23
4.68	0.19	0.07
4.85	0.30	0.08
5.03	0.43	0.07
5.46	0.09	0.05
5.57	0.06	0.02
5.63	0.10	0.01
5.76	0.09	0.02
5.81	0.10	0.02
6.39	0.08	0.03
6.47	0.05	0.01
6.54	0.32	0.06
6.72	0.41	0.06
7.24	0.16	0.06
7.41	0.05	0.03
7.57	0.03	0.02
7.83	0.09	0.04
8.37	0.07	0.04
8.43	1.61	0.11
10.15	0.02	0.02
10.31	0.09	0.03
10.79	0.16	0.05

ANNEX

MIRAGE WING - RH 79
MAIN SPAR (LOWER SURFACE)

HOLE NUMBER: 11
CRACK DISTRIBUTION

forward of hole:

distance from lower surface (mm)	surface length (mm)	depth (mm)
0.00	0.80	0.53
1.12	2.72	0.65 *
3.98	0.43	0.31
4.31	0.36	0.29
4.58	0.57	0.26
5.15	0.35	0.14
5.52	0.19	0.13
5.80	0.12	0.07
5.90	0.15	0.05
6.07	0.13	0.06
6.30	0.13	0.05
11.36	0.10	0.02

rearward of hole:

distance from lower surface (mm)	surface length (mm)	depth (mm)
0.19	0.08	0.09
0.21	2.21	0.58
2.25	1.19	0.48
3.86	0.98	0.36
4.69	0.54	0.22
5.20	0.33	0.14
5.48	0.59	0.21
6.07	0.52	0.21
6.91	0.10	0.04
7.06	0.05	0.02
7.49	0.24	0.12
7.89	0.31	0.13
8.48	0.29	0.10
8.78	0.21	0.10
9.63	0.30	0.10
11.61	0.45	0.03
12.10	0.10	0.02
16.56	0.26	0.18

* A crack growth curve for this crack is given in figure 2.

ANNEX

MIRAGE WING - RH 79
MAIN SPAR (LOWER SURFACE)

HOLE NUMBER: 12
CRACK DISTRIBUTION

forward of hole:

distance from lower surface (mm)	surface length (mm)	depth (mm)
0.70	2.76	0.86 *

rearward of hole:

distance from lower surface (mm)	surface length (mm)	depth (mm)
0.20	0.62	0.32
0.64	0.12	0.06
1.18	0.38	0.16

* A crack growth curve for this crack is given in figure 2.

ANNEX

MIRAGE WING - RH 79
MAIN SPAR (LOWER SURFACE)

HOLE NUMBER: 13
CRACK DISTRIBUTION

forward of hole:

distance from lower surface (mm)	surface length (mm)	depth (mm)
0.00	3.37	0.64
3.85	0.28	0.19
4.19	0.25	0.16
4.42	0.25	0.17
4.71	0.35	0.16
5.09	0.11	0.05
9.38	0.06	0.03
10.75	0.11	0.04
11.51	0.07	0.01
11.93	0.07	0.02

rearward of hole:

distance from lower surface (mm)	surface length (mm)	depth (mm)
0.49	2.65	0.57
2.58	2.74	0.39
5.36	0.43	0.16
5.78	0.21	0.11
8.42	0.18	0.05
10.42	0.07	0.03
10.68	0.16	0.06
11.20	0.06	0.03
11.26	0.31	0.09
11.70	0.14	0.07
12.15	0.27	0.11
12.46	0.10	0.03
12.71	0.06	0.04
13.02	0.37	0.10
13.38	0.16	0.07
13.55	0.08	0.05

ANNEX

MIRAGE WING - RH 79
MAIN SPAR (LOWER SURFACE)

HOLE NUMBER: Lower Fairing-Anchor-Nut hole
CRACK DISTRIBUTION

forward of hole:

distance see below (!) (mm)	surface length (mm)	depth (mm)
1.38	0.30	0.14
2.16	0.06	0.03
2.28	0.03	0.02
2.62	0.14	0.07

rearward of hole:

distance see below (!) (mm)	surface length (mm)	depth (mm)
0.00	1.11	0.57 *
1.14	2.07	0.51
4.66	0.33	0.13
7.94	0.31	0.14

* A crack growth curve for this crack is given in figure 2.

! Distance from the shoulder of the counter-sunk hole

ANNEX

MIRAGE WING - RH 79
MAIN SPAR (LOWER SURFACE)

HOLE NUMBER: 101
CRACK DISTRIBUTION

forward of hole:

distance from lower surface (mm)	surface length (mm)	depth (mm)
2.62	1.61	0.20 *
5.52	0.10	0.03
5.63	0.10	0.03
5.73	0.09	0.03
5.80	0.33	0.08
10.99	0.23	0.02

rearward of hole:

distance from lower surface (mm)	surface length (mm)	depth (mm)
0.00	0.23	0.24 *
3.07	0.09	0.03
5.92	0.10	0.06
6.06	0.32	0.13
6.37	0.05	0.04

* Crack growth curves for these cracks is given in figure 2.

ANNEX

MIRAGE WING - RH 79
MAIN SPAR (LOWER SURFACE)

HOLE NUMBER: 102
CRACK DISTRIBUTION

forward of hole:

distance from lower surface (mm)	surface length (mm)	depth (mm)
1.02	0.06	0.03
2.26	0.06	0.03
5.10	0.08	0.02
9.49	0.06	0.01
9.57	0.04	0.01
10.49	5.46	0.05 #

rearward of hole:

distance from lower surface (mm)	surface length (mm)	depth (mm)
4.45	0.62	0.10
5.93	0.21	0.04
6.16	0.35	0.05
6.51	0.11	0.02
9.07	7.77	0.06 #

Multiple origin

ANNEX

MIRAGE WING - RH 79
MAIN SPAR (LOWER SURFACE)

HOLE NUMBER: 103
CRACK DISTRIBUTION

forward of hole:

distance from lower surface (mm)	surface length (mm)	depth (mm)	
0.21	0.16	0.08	@
0.00	0.06	0.07	
0.78	0.09	0.04	
0.88	0.12	0.05	
1.02	0.09	0.03	
1.48	0.25	0.04	
1.77	0.08	0.04	
1.92	0.18	0.08	
2.03	0.44	0.15	
2.60	0.38	0.14	*
2.95	0.19	0.11	
3.55	0.24	0.05	
3.84	0.05	0.02	
3.94	0.16	0.06	
4.10	0.11	0.04	
4.22	0.12	0.07	
4.36	0.11	0.03	
4.68	0.15	0.05	
5.43	0.48	0.12	
6.11	0.08	0.03	
8.65	0.09	0.02	
11.04	0.13	0.05	
11.22	0.10	0.05	

rearward of hole:

distance from lower surface (mm)	surface length (mm)	depth (mm)	
0.12	0.16	0.05	@
0.00	0.12	0.15	
0.71	0.25	0.06	
1.00	0.62	0.07	
1.79	0.04	0.01	
2.53	0.11	0.05	
2.66	0.13	0.06	
2.80	0.21	0.08	
3.03	0.11	0.04	
3.21	0.11	0.06	
3.43	0.03	0.02	
3.58	0.16	0.04	
5.30	0.08	0.03	
7.11	0.04	0.01	
7.79	0.04	0.01	
7.95	0.05	0.03	
10.30	0.28	0.03	
10.59	0.40	0.02	

* A crack growth curve for this crack is given in figure 2.

@ Cracked along spar surface.

ANNEX

MIRAGE WING - RH 79
MAIN SPAR (LOWER SURFACE)

HOLE NUMBER: 104
CRACK DISTRIBUTION

forward of hole:

distance from lower surface (mm)	surface length (mm)	depth (mm)
0.64	0.10	0.04
0.87	1.91	0.25 *
2.80	1.92	0.14
4.76	0.51	0.10
5.25	0.88	0.05
6.19	0.41	0.06
10.37	0.08	0.01
10.66	0.17	0.01

rearward of hole:

distance from lower surface (mm)	surface length (mm)	depth (mm)
0.92	0.11	0.05
1.16	0.17	0.07
1.48	0.08	0.04
1.56	0.04	0.02
2.61	2.96	0.27 *
5.62	0.46	0.03
6.20	0.05	0.03
6.25	0.67	0.03
6.90	0.14	0.04
7.07	0.13	0.06
7.66	0.09	0.03
8.00	0.18	0.05
8.41	0.07	0.02
9.13	0.26	0.02
15.30	0.13	0.02
18.46	0.05	0.01

* A crack growth curve for these cracks is given in figure 2.

ANNEX

MIRAGE WING - RH 79
MAIN SPAR (LOWER SURFACE)

HOLE NUMBER: 105
CRACK DISTRIBUTION

forward of hole:

rearward of hole:

distance from lower surface (n.m)	surface length (mm)	depth (mm)	distance from lower surface (mm)	surface length (mm)	depth (mm)
0.25	0.11	0.03	0.62	0.05	0.02
0.38	0.07	0.02	2.64	0.08	0.02
0.44	0.95	0.21 *	2.92	0.06	0.04
1.60	0.45	0.18	2.98	0.98	0.06
2.15	0.16	0.10	4.22	0.79	0.04
2.36	0.04	0.02	10.96	0.07	0.03
2.42	0.22	0.11	21.80	0.04	0.01
2.85	0.04	0.02			
3.36	0.38	0.09			
3.88	0.02	0.01			
4.56	0.05	0.01			
4.65	0.06	0.02			
4.84	0.16	0.08			
5.00	0.24	0.05			
5.27	0.06	0.01			
5.34	0.36	0.11			
5.96	2.55	0.09 #			
8.67	0.22	0.06			
15.22	1.49	0.01			
16.87	0.05	0.01			
17.26	0.65	0.01			

* A crack growth curve for this crack is given in figure 2.

Multiple origins

ANNEX

MIRAGE WING - RH 79
MAIN SPAR (LOWER SURFACE)

HOLE NUMBER: 106
CRACK DISTRIBUTION

forward of hole:

distance from lower surface (mm)	surface length (mm)	depth (mm)
6.27	0.20	0.04
6.49	0.40	0.03
6.99	0.17	0.04
11.47	0.08	0.02
11.97	0.21	0.07
13.84	0.20	0.07
14.60	0.04	0.01
14.71	0.06	0.04
15.51	0.16	0.01

rearward of hole:

distance from lower surface (mm)	surface length (mm)	depth (mm)
1.04	0.16	0.06
1.41	0.05	0.01
2.35	0.13	0.03
2.58	0.11	0.05
2.97	0.23	0.03
3.22	1.63	0.15 *
4.98	0.84	0.17
9.06	0.18	0.08
10.62	0.43	0.17
11.02	0.27	0.17
11.58	0.10	0.07
11.69	0.10	0.08
12.08	0.19	0.07
13.44	0.49	0.18
14.25	0.09	0.06
14.46	0.42	0.19
14.95	0.27	0.14
15.22	0.23	0.11
15.87	1.09	0.04
17.07	0.16	0.09
17.42	0.16	0.07
17.58	0.36	0.11
18.11	0.24	0.10
18.38	0.19	0.13
18.82	0.15	0.08
19.05	0.35	0.14
19.47	0.09	0.05
19.61	0.33	0.11
20.40	0.32	0.13
21.23	0.10	0.06

* A crack growth curve for this crack is given in figure 2.

ANNEX

MIRAGE WING - RH 79
MAIN SPAR (LOWER SURFACE)

HOLE NUMBER: 107
CRACK DISTRIBUTION

forward of hole:

distance from lower surface (mm)	surface length (mm)	depth (mm)
0.00	0.14	0.11
0.46	0.08	0.03
0.72	0.09	0.03
0.85	0.32	0.07
1.18	0.10	0.02
1.43	0.13	0.03
1.68	0.15	0.10
1.96	0.14	0.08
2.07	0.17	0.08
2.38	0.14	0.08
2.55	0.75	0.16
3.28	0.11	0.10
3.38	0.80	0.07
4.68	0.16	0.05
4.98	0.05	0.01
5.05	0.58	0.04
8.62	0.04	0.01
8.90	0.05	0.03
11.19	0.05	0.03
18.18	0.09	0.01

rearward of hole:

distance from lower surface (mm)	surface length (mm)	depth (mm)
0.99	0.06	0.01
1.69	0.04	0.02
3.85	0.03	0.01
4.23	0.07	0.02
7.46	0.27	0.01
8.10	0.18	0.03
8.31	0.17	0.02

ANNEX

MIRAGE WING - RH 79
MAIN SPAR (LOWER SURFACE)

HOLE NUMBER: 108
CRACK DISTRIBUTION

forward of hole:

distance from lower surface (mm)	surface length (mm)	depth (mm)
1.73	0.07	0.02
3.09	0.06	0.01
4.24	0.07	0.02
4.38	0.08	0.02
4.46	0.05	0.01
21.13	0.49	0.01
21.64	0.20	0.01
21.94	0.06	0.01
distance from upper surface	surface length	depth
7.44	0.12	0.01
8.49	0.04	0.01
9.72	0.11	0.01
9.88	0.06	0.01
10.03	0.05	0.01

rearward of hole:

distance from lower surface (mm)	surface length (mm)	depth (mm)
2.23	0.04	0.02
3.46	0.05	0.02
3.52	0.02	0.02
4.39	0.05	0.03
4.70	0.32	0.01
5.08	0.04	0.02
5.39	0.15	0.07
5.59	0.58	0.06
6.73	0.51	0.02
7.32	0.26	0.02
7.80	0.16	0.01
7.98	0.11	0.05
8.10	0.26	0.04
8.10	0.26	0.01
8.86	0.57	0.01
9.61	0.41	0.02
16.35	0.02	0.01

ANNEX

MIRAGE WING - RH 79
MAIN SPAR (LOWER SURFACE)

HOLE NUMBER: 109
CRACK DISTRIBUTION

forward of hole:

distance from lower surface (mm)	surface length (mm)	depth (mm)
0.03	0.03	0.02
0.31	0.08	0.02
0.88	0.09	0.03
2.05	0.11	0.02

rearward of hole:

distance from lower surface (mm)	surface length (mm)	depth (mm)
1.20	0.07	0.03
8.88	0.22	0.01

ANNEX

MIRAGE WING - RH 79
MAIN SPAR (LOWER SURFACE)

HOLE NUMBER: 110
CRACK DISTRIBUTION

forward of hole:

distance from lower surface (mm)	surface length (mm)	depth (mm)
0.18	0.13	0.04
0.86	0.74	0.11
1.55	0.80	0.11
2.32	0.19	0.04
4.41	0.14	0.03
4.80	0.07	0.03
5.03	0.24	0.05
5.50	0.06	0.02
5.56	0.06	0.02
5.78	0.02	0.01
5.96	0.05	0.01
6.02	0.13	0.01
9.48	0.04	0.01
9.52	0.03	0.01

rearward of hole:

distance from lower surface (mm)	surface length (mm)	depth (mm)
3.88	0.02	0.01
3.91	0.04	0.01
8.92	0.10	0.03
9.58	0.03	0.01
11.32	0.14	0.01
12.29	0.06	0.01
12.41	0.06	0.01
12.51	0.11	0.02
12.64	0.04	0.01
12.75	0.21	0.02
13.02	0.07	0.02
13.09	0.05	0.02
13.26	0.06	0.02
13.73	0.37	0.02
15.38	0.67	0.02
16.72	0.08	0.03
distance from upper surface (mm)	surface length (mm)	depth (mm)
2.75	0.03	0.01
7.66	0.06	0.01

ANNEX

MIRAGE WING - RH 79
MAIN SPAR (LOWER SURFACE)

HOLE NUMBER: 111
CRACK DISTRIBUTION

forward of hole:

distance from lower surface (mm)	surface length (mm)	depth (mm)
0.96	0.06	0.02
1.42	0.06	0.01
1.55	0.08	0.01
1.86	0.02	0.01
2.40	0.02	0.01
11.06	0.06	0.01
18.30	0.03	0.01

rearward of hole:

distance from lower surface (mm)	surface length (mm)	depth (mm)
0.24	0.05	0.06
1.91	0.06	0.03
2.02	0.28	0.05
2.30	0.10	0.02
2.47	0.04	0.02
2.94	0.26	0.02
3.20	0.07	0.01
3.48	0.29	0.04
3.99	0.99	0.03
5.06	0.36	0.05
5.44	1.60	0.04
7.04	4.28	0.04

ANNEX

MIRAGE WING - RH 79
MAIN SPAR (LOWER SURFACE)

HOLE NUMBER: 112
CRACK DISTRIBUTION

forward of hole:

distance from lower surface (mm)	surface length (mm)	depth (mm)
10.82	0.05	0.02
11.29	0.04	0.02
16.63	0.10	0.05
17.72	0.13	0.05
17.99	0.06	0.03
18.18	0.17	0.05
distance from upper surface (mm)	surface length (mm)	depth (mm)
2.59	0.06	0.02

rearward of hole:

distance from lower surface (mm)	surface length (mm)	depth (mm)
2.93	0.21	0.07
3.54	0.06	0.03
4.55	0.08	0.05
4.70	0.08	0.03
5.03	0.12	0.05
5.28	0.09	0.04
6.01	0.05	0.03
6.02	0.08	0.06
6.25	0.03	0.01
6.27	0.03	0.02
6.33	0.09	0.04
6.50	0.11	0.05
6.63	0.07	0.04
6.87	0.12	0.06
7.57	0.02	0.01
11.75	0.10	0.04
12.33	0.08	0.05
12.82	0.03	0.01
16.37	0.05	0.02
19.25	0.09	0.01
19.47	0.17	0.01

ANNEX

MIRAGE WING - RH 79
MAIN SPAR (LOWER SURFACE)

HOLE NUMBER: 113
CRACK DISTRIBUTION

forward of hole:

distance from lower surface (mm)	surface length (mm)	depth (mm)
0.63	0.05	0.02
1.47	0.08	0.02
2.26	0.13	0.01
2.49	0.12	0.01
3.66	0.06	0.01
4.70	0.04	0.01
5.11	0.21	0.02
7.26	0.07	0.02
7.50	0.58	0.03

rearward of hole:

distance from lower surface (mm)	surface length (mm)	depth (mm)
5.39	0.03	0.01
5.42	0.03	0.01
9.26	0.04	0.01

ANNEX

MIRAGE WING - RH 79
MAIN SPAR (LOWER SURFACE)

HOLE NUMBER: 114
CRACK DISTRIBUTION

forward of hole:

distance from lower surface (mm)	surface length (mm)	depth (mm)
1.49	0.10	0.03
3.87	0.23	0.04
4.11	0.71	0.05
4.82	0.55	0.05
5.45	0.17	0.02
5.65	0.37	0.04
9.86	0.07	0.03
10.29	0.09	0.03
11.23	0.05	0.02

rearward of hole:

distance from lower surface (mm)	surface length (mm)	depth (mm)
1.49	0.05	0.01
2.68	0.11	0.03
2.84	0.34	0.04
3.19	0.10	0.04
3.74	0.79	0.02
4.60	1.49	0.04
6.09	0.20	0.02
6.39	1.96	0.03
9.08	0.03	0.01
9.79	0.07	0.02

ANNEX

MIRAGE WING - RH 79
MAIN SPAR (LOWER SURFACE)

HOLE NUMBER: 116
CRACK DISTRIBUTION

forward of hole:

distance from lower surface (mm)	surface length (mm)	depth (mm)
0.09	0.09	0.01
1.91	0.23	0.01
3.75	1.15	0.03
15.47	0.14	0.01

rearward of hole:

distance from lower surface (mm)	surface length (mm)	depth (mm)
7.80	0.04	0.01
14.99	0.55	0.01
17.68	0.09	0.01
17.83	0.04	0.01
17.90	0.12	0.02
18.13	0.56	0.02
19.13	0.25	0.03

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16. ABSTRACT Results of fractographic inspection of fatigue cracks found in the fastener holes (excepting hole 1 and SLAN rivet holes) in the inboard end of the lower flange of RH79 wing-spar, as a result of fatigue testing for 5600 hours, are presented. The largest crack found was only 2.18 mm deep and occurred in hole 10 in the rearward flange of the spar. Holes 1 to 4 remained crack-free as a result of the refurbishment procedures.							

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