

NATIONAL TRANSPORTATION SAFETY BOARD

Office of Research and Engineering
Materials Laboratory Division
Washington, D.C. 20594



June 9, 2022

MATERIALS LABORATORY ADDENDUM REPORT

Report No. 22-014B

1. ACCIDENT INFORMATION

Place : Wikieup, Arizona
Date : July 10, 2021
Vehicle : Beech C-90, N3688P
NTSB No. : WPR21FA266
Investigator : Albert Nixon, AS-WPR

2. COMPONENTS EXAMINED

Sections and remnants of wing spar caps

3. DETAILS OF THE EXAMINATION

This report is an addendum to the *22-014 Materials Laboratory Factual Report*, detailing a metallurgical examination of fractured wing spar caps from a Beech C-90 airplane. This airplane was involved in a fatal accident near Wikieup, AZ on July 10, 2021.

The left lower wing spar cap had exhibited a large fatigue crack, as illustrated and annotated in Figure 1. As detailed in the Factual Report, the thumbnail crack mostly exhibited striations, consistent with fatigue crack propagation. There were also a series of 'overstress jumps' along the crack, which consisted of local areas exhibiting dimpled rupture features (see Figure 2). This fatigue cracking initiated prior to the accident, and the total length of the main crack located between the two fastener holes was 2.484 inches, with a smaller crack initiating and propagating in the opposite direction, shown on the left side of the fastener hole in Figure 1. This smaller crack measured 0.312 inches long.

To better understand how long the larger fatigue crack had been present, a fatigue crack growth rate analysis was performed. Rather than the traditional method of counting all striations at random intervals along the crack depth, the most pronounced intermediate arrest marks along the length of the crack were recorded, such as typified in Figure 3. This was accomplished by imaging the crack using a field emission scanning electron microscope (FESEM) that recorded a series of micrographs, merged into a single montaged file. Direct measurements between the arrest marks could be recorded and annotated on the dynamic micrograph montage, as illustrated in Figure 4. Figure 5 through Figure 8 show typical areas examined using this technique with the FESEM.

The distance between the arrest marks, and their distance from the crack origin, as well as the cumulative crack length are recorded in Table I. The table depicts the areas where an overstress jump was located, by highlighting that row in orange. The final overstress jump was highlighted in red, with the last measurement at the end of the crack in blue. The number of arrest marks in this area was partly calculated from sampling rather than direct and complete measuring, as the difference between the striations and arrest marks became less distinctive, and the spacing between the arrest marks decreased.

Typically, 5 to 20 striations were observed between the intermediate arrest lines. The arrest lines exhibited a more distinct character relative to striations, often with radial features emanating from the convex side of the arrest lines, particularly in later crack growth cycles. Based on the consistency, density, and spacing, the intermediate crack arrest lines were assumed to be directly associated with flight cycles for this study. Individual striations were assumed to be related with loads from inflight maneuvers and wind gust loading, which would include landing cycles. Arrest marks are typically associated with a change in stress state, environment, or time interval associated with fatigue crack growth.

Figure 9 shows a plot of the cumulative number of arrest marks plotted against the crack length. In this plot, and for the purposes of this study, each arrest mark counted, along with each overstress jump, was considered a flight cycle. Overall, the shape of the plot exhibited a shape comparable to the classic fatigue crack growth slope, with a rapid initial increase, followed by a linear steady state region, ending with a rapid increase before fracture. The area of rapid crack growth occurred after the largest and final overstress jump on the fracture surface, represented by an orange rectangle in Figure 9.

Using a FESEM, the arrest marks were counted, and the distance between the arrest marks (or overstress jumps) was measured. This analysis assumed that each counted arrest mark (a feature consistent with crack growth) correlated directly to a flight cycle with no other comparable stresses. The examination also assumed that sampled regions were representative regions of fatigue crack growth at each particular crack depth, the fracture surface was flat, and that the spacing increased with crack growth.

Of note from the data in Table I and Figure 9 were the following highlights:

- The total number of intermediate arrest marks from the origin to crack terminus was calculated as 535.
- While 151 overstress jumps were recorded visually on the fracture surface, only 27 were explicitly noted here. This was due to the difficulty in distinguishing these marks from the larger intermediate arrest marks in the FESEM. However, an overstress jump was assumed to be one flight cycle event.
- The number of cycles from the largest and final overstress jump was 107.
- The number of cycles from the origin to the final overstress jump was 428.

The final overstress jump was important in this study, as it was anticipated that this feature could be correlated to an event in the flight history of the airplane. However, in a review of flight logs and maintenance events from January 2020 until the accident date, there were no such reported events, such as a hard landing or inflight buffeting, which could be correlated to approximately 100 to 120 flights prior to the accident.

Erik M Mueller
Materials Research Engineer



Figure 1 – Fracture surface of the fatigue crack on the lower wing spar cap, after disassembly, sectioning, and cleaning. The white dashed arrows denote the general crack propagation direction from the fastener hole.

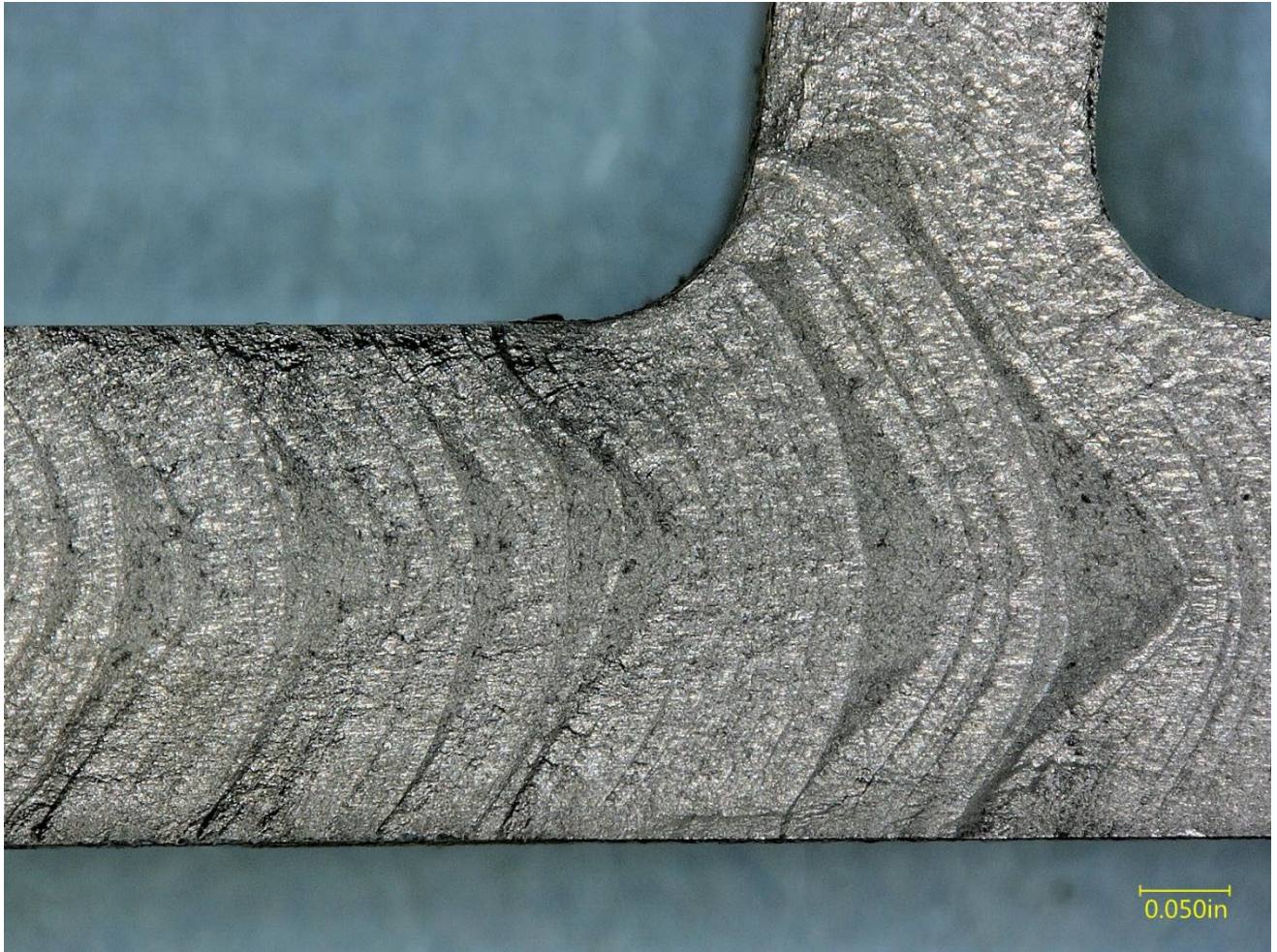


Figure 2 – Microscopic view of the fatigue crack in Figure 1, showing the darker colored overstress jumps along the spar cap.

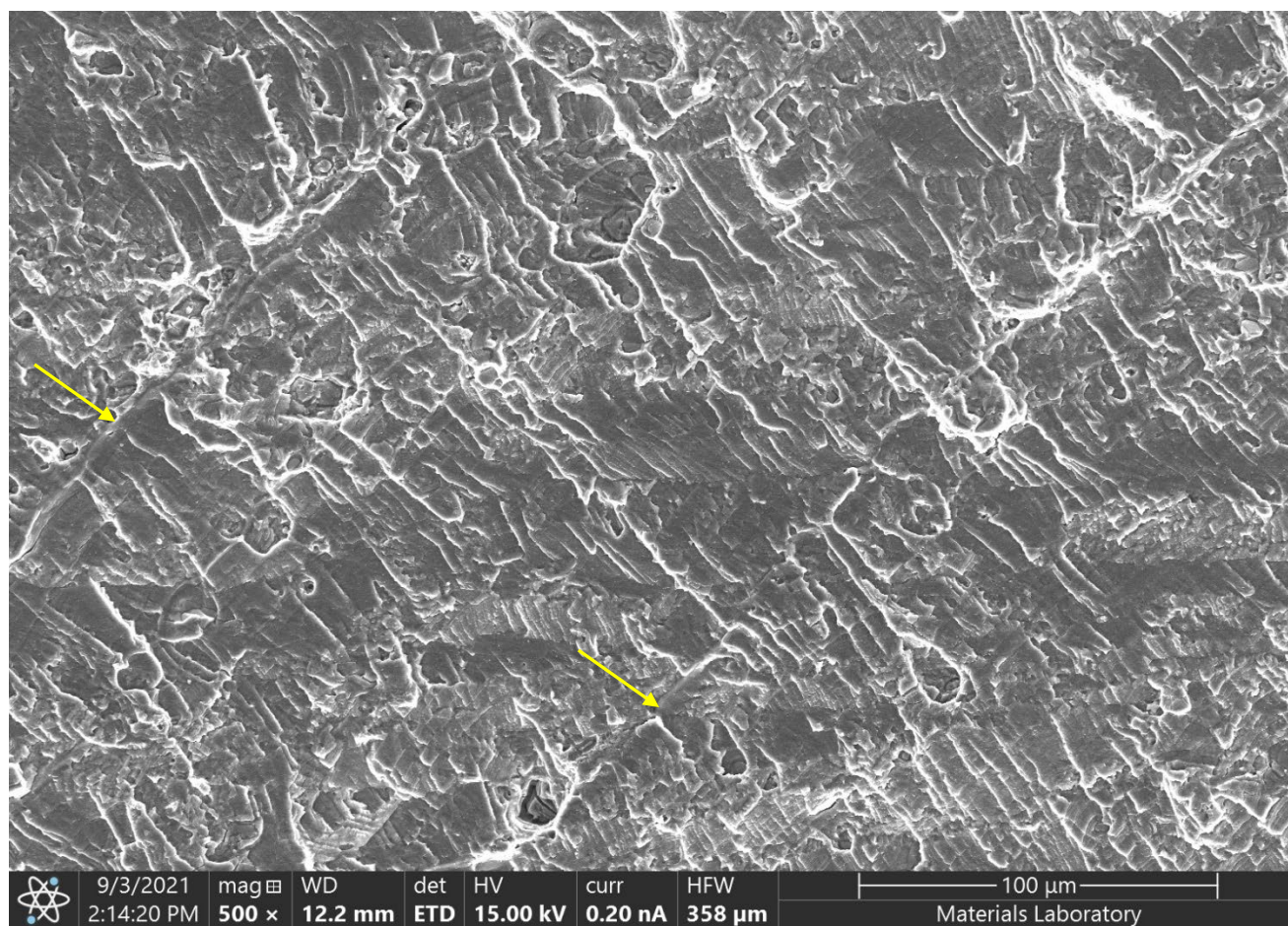


Figure 3 – SE micrograph of midpoint region, with intermediate arrest marks annotated (arrows) amongst smaller striations.

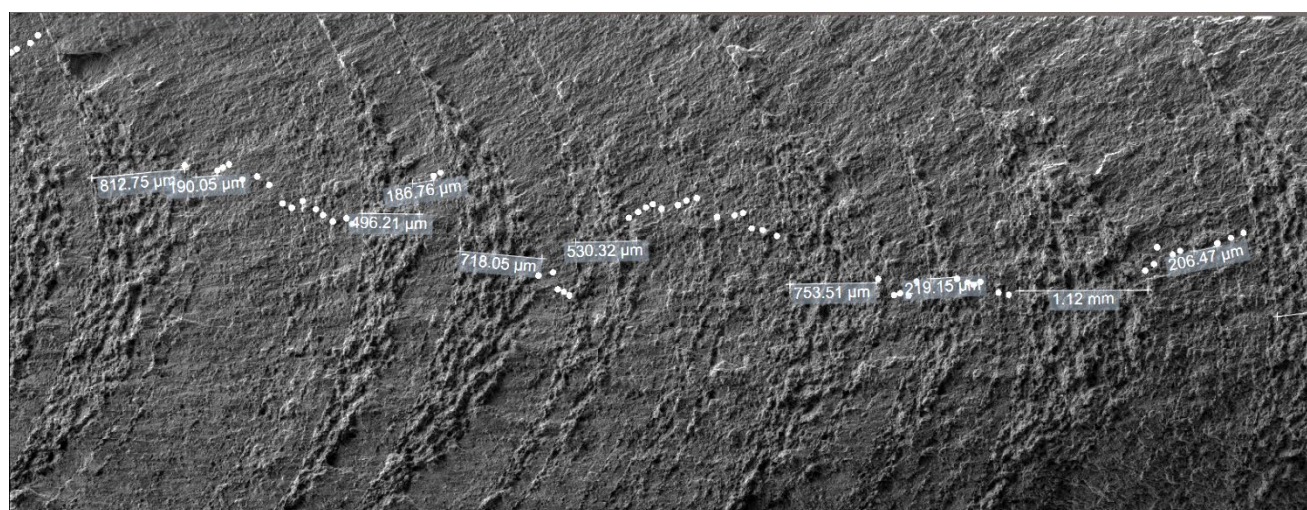


Figure 4 – Montage of SE micrographs on the outboard surface, showing distance between intermediate arrest marks, between the crescent-shaped intermittent overstress jumps.

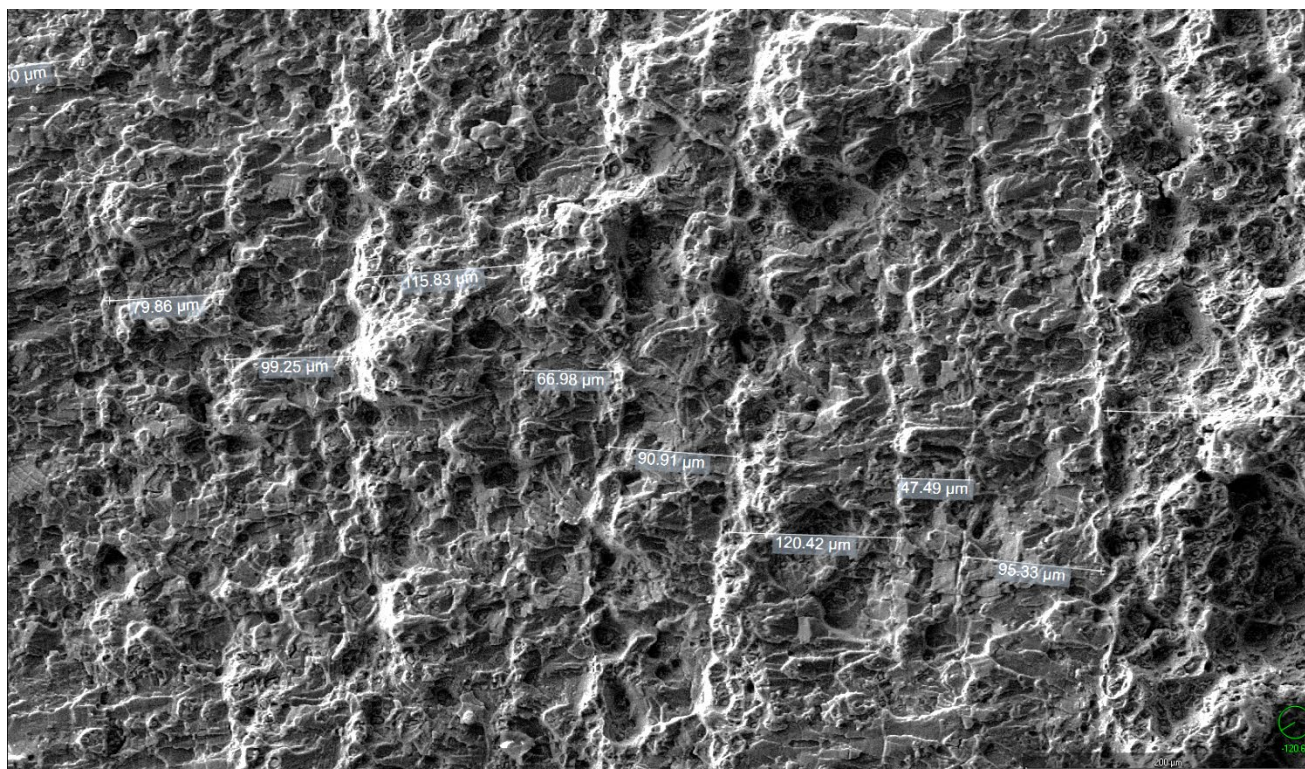


Figure 5 – SE micrograph montage of measured distances between arrest marks and overstress jumps on a typical area of the fracture surface.

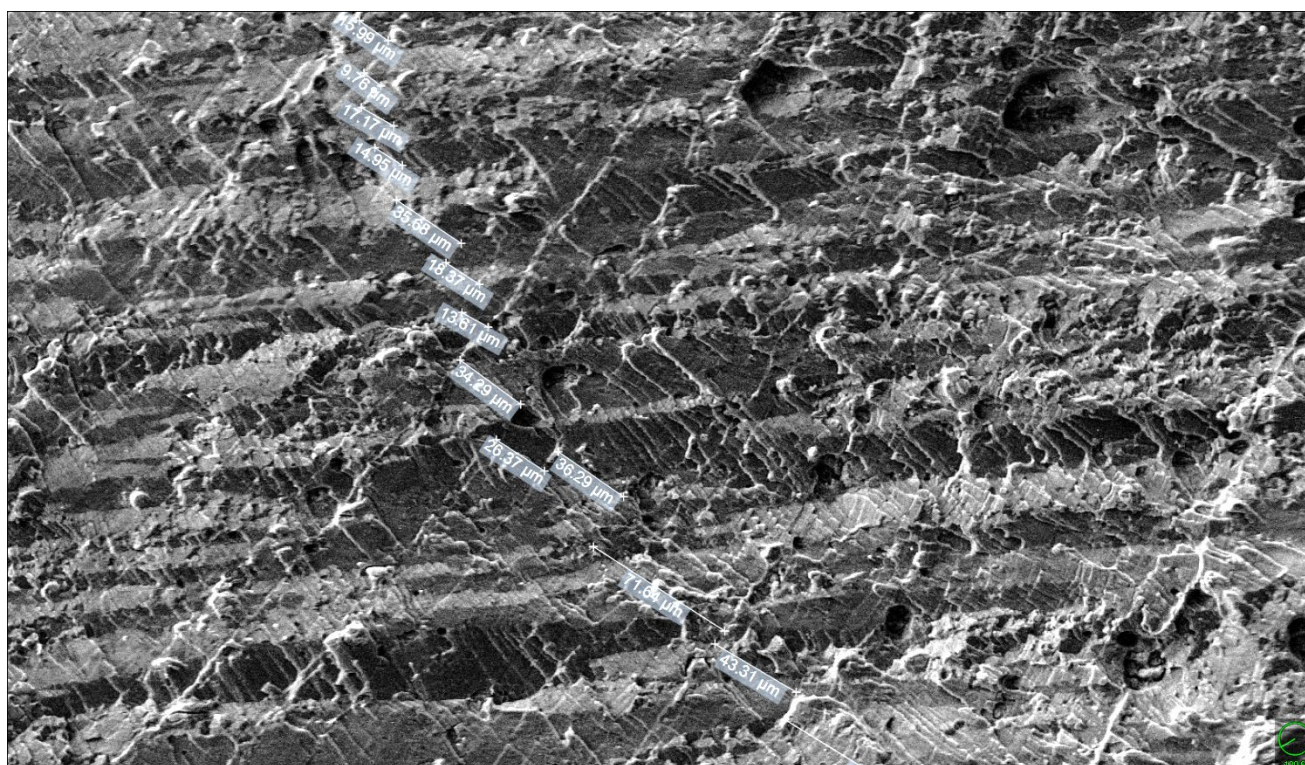


Figure 6 – SE micrograph montage of measured arrest mark distances near the initiation site.

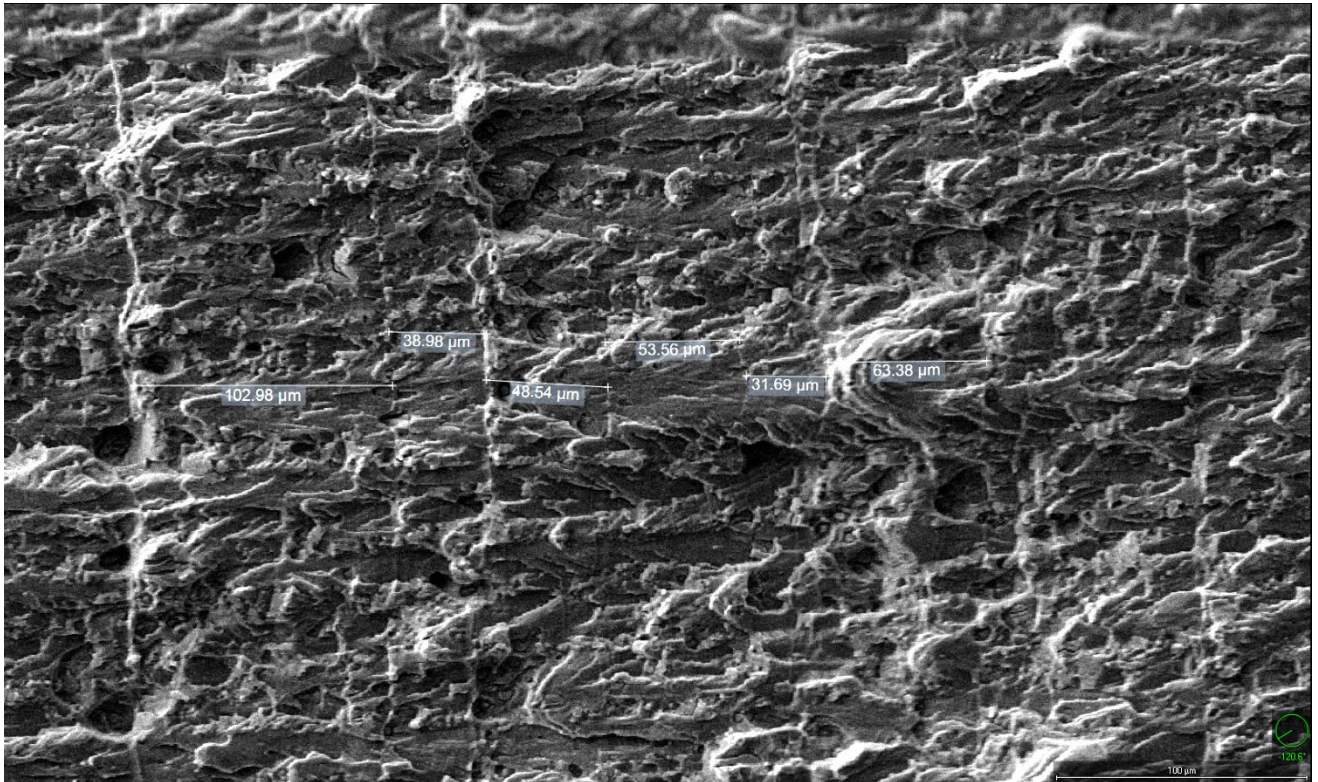


Figure 7 – SE micrograph montage of measured intermediate arrest mark gaps.

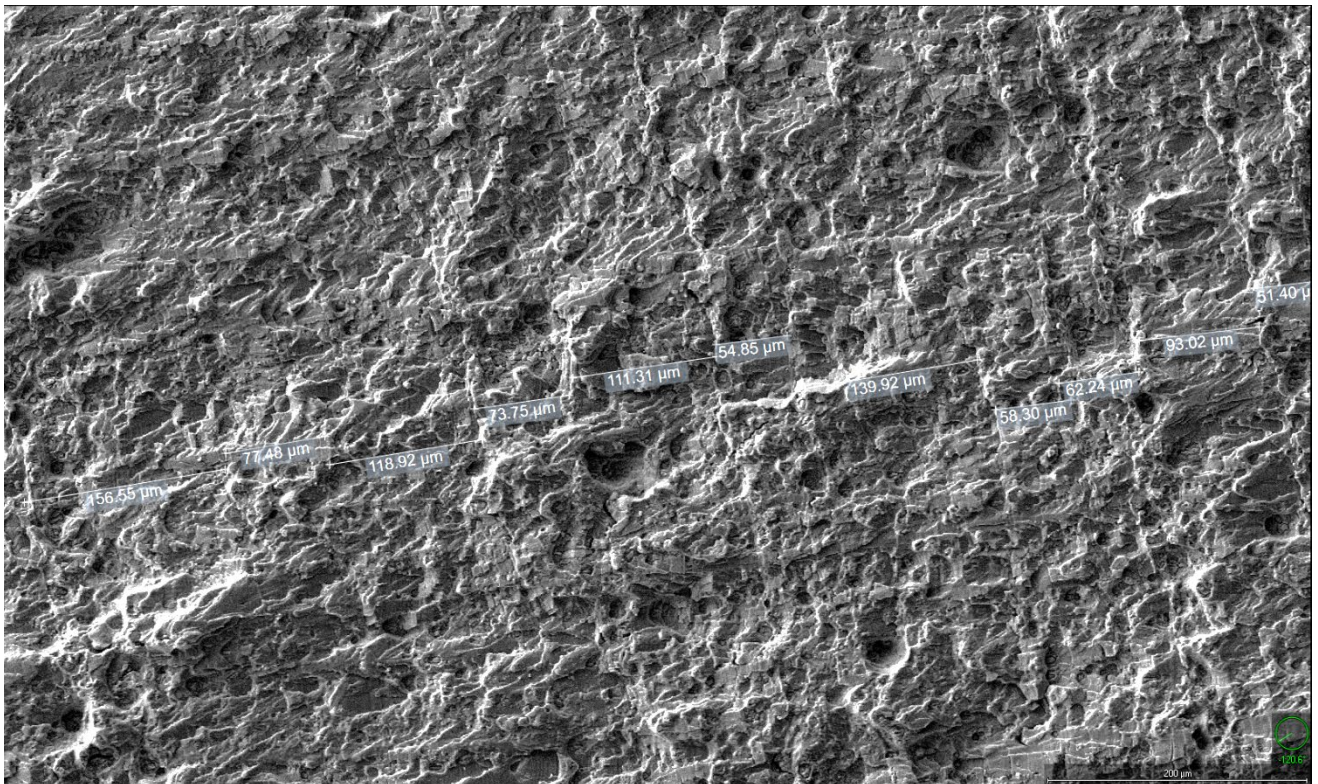


Figure 8 – SE micrograph montage of more erratically spaced intermediate arrest marks.

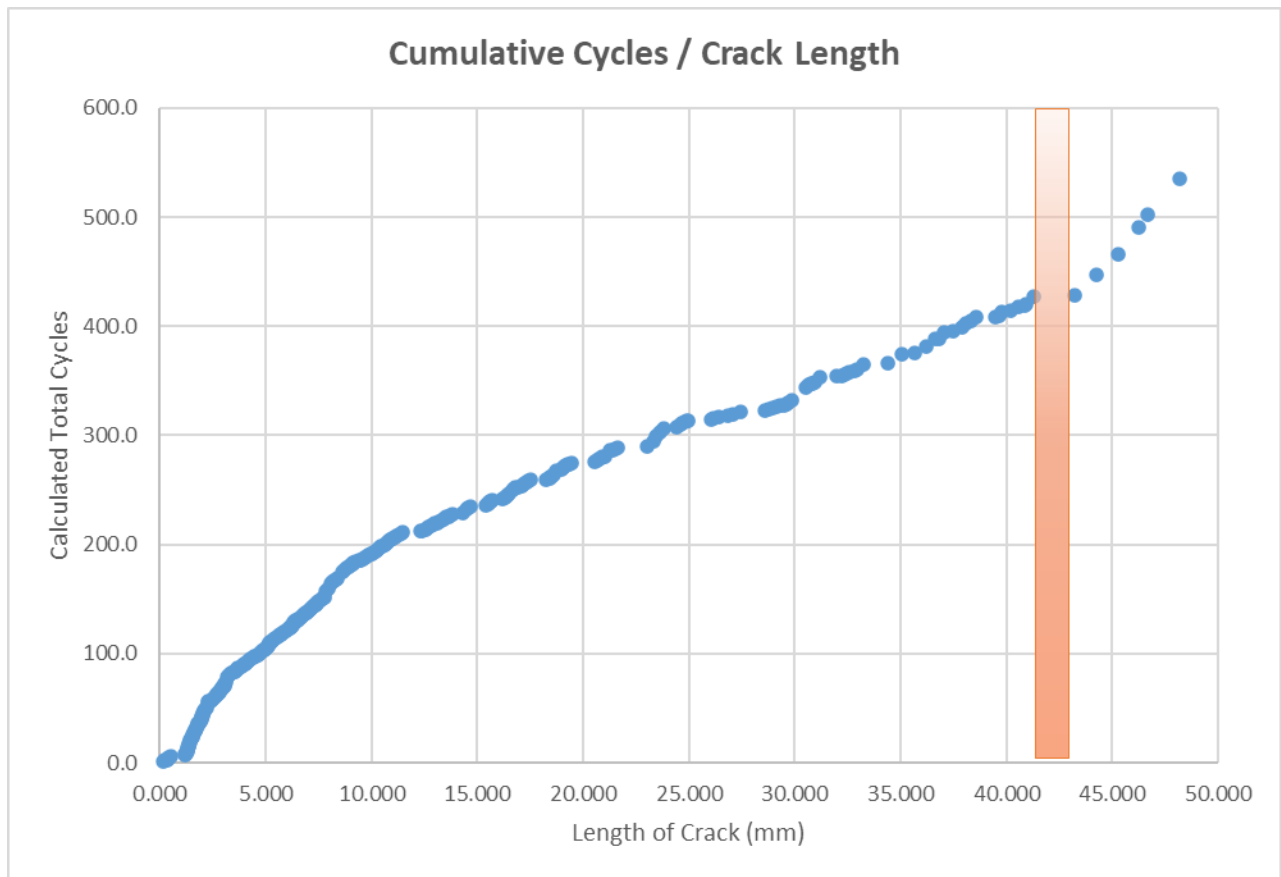


Figure 9 – Chart of the data of the cumulative number of measured intermediate arrest marks (as cycles) plotted against the fatigue crack length. The orange area is the largest overstress jump, corresponding to Figure 13 in the Factual Report.

Table I – The measured lengths of the cumulative intermediate arrest marks counted along the fatigue crack at continuing distance from the initiation site. The rows highlighted in orange are overstress jumps, with the red one the largest and final overstress jump. The final blue row denotes an area where the number of arrest marks were interpolated rather than directly counted.

Distance from Origin (mm)	Distance Measured (μm)	Increment (μm)	Arrest Marks #	da/dN (μm/cycle)	Increment Cycles #	Total Cycles #
0	0	Origin				0
0.151	150.900	150.900	1	150.900	1	1
0.210	59.500	59.500	1	59.500	1	2
0.331	120.100	120.100	1	120.100	1	3
0.421	90.930	90.930	1	90.930	1	4
0.437	15.370	15.370	1	15.370	1	5
0.559	122.200	122.200	1	122.200	1	6
1.190	630.700	630.700	1	630.700	1	7
1.224	34.200	34.200	1	34.200	1	8
1.233	9.070	9.070	1	9.070	1	9
1.283	49.680	49.680	1	49.680	1	10
1.297	14.540	14.540	1	14.540	1	11
1.310	12.940	12.940	1	12.940	1	12
1.330	19.850	19.850	1	19.850	1	13
1.347	17.030	17.030	1	17.030	1	14
1.359	11.540	11.540	1	11.540	1	15
1.371	12.070	12.070	1	12.070	1	16
1.384	13.060	13.060	1	13.060	1	17
1.398	14.770	14.770	1	14.770	1	18
1.422	23.380	23.380	1	23.380	1	19
1.448	26.200	26.200	1	26.200	1	20
1.467	18.720	18.720	1	18.720	1	21
1.500	32.900	32.900	1	32.900	1	22
1.514	13.900	13.900	1	13.900	1	23
1.536	22.250	22.250	1	22.250	1	24
1.550	14.600	14.600	1	14.600	1	25
1.579	28.530	28.530	1	28.530	1	26
1.603	23.580	23.580	1	23.580	1	27
1.619	16.360	16.360	1	16.360	1	28
1.671	52.280	52.280	1	52.280	1	29
1.676	5.240	5.240	1	5.240	1	30
1.705	28.690	28.690	1	28.690	1	31
1.723	17.580	17.580	1	17.580	1	32
1.742	19.240	19.240	1	19.240	1	33
1.790	48.430	48.430	1	48.430	1	34
1.811	20.550	20.550	1	20.550	1	35
1.829	18.060	18.060	1	18.060	1	36
1.859	30.270	30.270	1	30.270	1	37
1.895	35.670	35.670	1	35.670	1	38
1.946	50.900	50.900	1	50.900	1	39

1.969	23.270	23.270	1	23.270	1	40
1.976	6.850	6.850	1	6.850	1	41
1.992	16.090	16.090	1	16.090	1	42
2.002	9.760	9.760	1	9.760	1	43
2.019	17.170	17.170	1	17.170	1	44
2.034	14.950	14.950	1	14.950	1	45
2.070	35.680	35.680	1	35.680	1	46
2.088	18.570	18.570	1	18.570	1	47
2.102	13.600	13.600	1	13.600	1	48
2.136	34.290	34.290	1	34.290	1	49
2.162	26.370	26.370	1	26.370	1	50
2.199	36.290	36.290	1	36.290	1	51
2.271	71.840	71.840	4	17.960	4	55
2.314	43.700	43.700	1	43.700	1	56
2.422	107.760	107.760	1	107.760	1	57
2.442	20.120	20.120	1	20.120	1	58
2.545	102.980	102.980	1	102.980	1	59
2.584	38.980	38.980	1	38.980	1	60
2.633	48.540	48.540	1	48.540	1	61
2.686	53.560	53.560	1	53.560	1	62
2.718	31.690	31.690	1	31.690	1	63
2.782	63.980	63.980	1	63.980	1	64
2.800	18.290	18.290	1	18.290	1	65
2.829	28.820	28.820	1	28.820	1	66
2.877	48.420	48.420	1	48.420	1	67
2.921	44.000	44.000	1	44.000	1	68
2.958	36.740	36.740	1	36.740	1	69
3.011	52.660	52.660	1	52.660	1	70
3.042	31.210	31.210	1	31.210	1	71
3.063	20.680	20.680	1	20.680	1	72
3.081	18.770	18.770	1	18.770	1	73
3.139	57.640	57.640	1	57.640	1	74
3.215	75.950	75.950	5	15.190	5	79
3.271	55.750	55.750	1	55.750	1	80
3.289	18.390	18.390	1	18.390	1	81
3.396	107.230	107.230	1	107.230	1	82
3.496	99.650	99.650	1	99.650	1	83
3.552	55.530	55.530	1	55.530	1	84
3.601	49.630	49.630	1	49.630	1	85
3.659	57.700	57.700	1	57.700	1	86
3.694	35.170	35.170	1	35.170	1	87
3.858	164.140	164.140	1	164.140	1	88
3.904	45.380	45.380	1	45.380	1	89
3.989	85.030	85.030	1	85.030	1	90
4.031	42.460	42.460	1	42.460	1	91
4.097	65.460	65.460	1	65.460	1	92
4.161	64.460	64.460	1	64.460	1	93
4.215	54.130	54.130	1	54.130	1	94

4.307	91.910	91.910	1	91.910	1	95
4.391	83.510	83.510	1	83.510	1	96
4.457	66.190	66.190	1	66.190	1	97
4.535	78.600	78.600	1	78.600	1	98
4.647	111.900	111.900	1	111.900	1	99
4.702	55.260	55.260	1	55.260	1	100
4.748	45.680	45.680	1	45.680	1	101
4.804	55.470	55.470	1	55.470	1	102
4.893	89.270	89.270	1	89.270	1	103
4.939	45.740	45.740	1	45.740	1	104
4.994	55.720	55.720	1	55.720	1	105
5.071	77.020	77.020	1	77.020	1	106
5.123	51.350	51.350	1	51.350	1	107
5.139	15.910	15.910	1	15.910	1	108
5.171	32.200	32.200	1	32.200	1	109
5.197	26.600	26.600	1	26.600	1	110
5.255	57.410	57.410	1	57.410	1	111
5.301	46.050	46.050	1	46.050	1	112
5.386	85.130	85.130	1	85.130	1	113
5.435	49.340	49.340	1	49.340	1	114
5.523	87.900	87.900	1	87.900	1	115
5.587	63.370	63.370	1	63.370	1	116
5.671	84.620	84.620	1	84.620	1	117
5.741	69.440	69.440	1	69.440	1	118
5.814	72.970	72.970	1	72.970	1	119
5.881	67.280	67.280	1	67.280	1	120
5.957	75.780	75.780	1	75.780	1	121
6.040	83.230	83.230	1	83.230	1	122
6.125	85.150	85.150	1	85.150	1	123
6.148	22.560	22.560	1	22.560	1	124
6.212	64.350	64.350	1	64.350	1	125
6.256	43.880	43.880	1	43.880	1	126
6.277	20.630	20.630	1	20.630	1	127
6.327	50.110	50.110	1	50.110	1	128
6.358	31.060	31.060	1	31.060	1	129
6.425	67.180	67.180	1	67.180	1	130
6.492	66.900	66.900	1	66.900	1	131
6.539	46.740	46.740	1	46.740	1	132
6.613	74.750	74.750	1	74.750	1	133
6.685	71.610	71.610	1	71.610	1	134
6.789	104.100	104.100	1	104.100	1	135
6.832	43.410	43.410	1	43.410	1	136
6.897	64.510	64.510	1	64.510	1	137
6.967	69.600	69.600	1	69.600	1	138
7.020	53.560	53.560	1	53.560	1	139
7.072	52.140	52.140	1	52.140	1	140
7.123	50.340	50.340	1	50.340	1	141
7.190	67.720	67.720	1	67.720	1	142

7.247	56.270	56.270	1	56.270	1	143
7.317	70.780	70.780	1	70.780	1	144
7.368	50.880	50.880	1	50.880	1	145
7.410	41.630	41.630	1	41.630	1	146
7.453	42.740	42.740	1	42.740	1	147
7.508	55.750	55.750	1	55.750	1	148
7.588	80.150	80.150	1	80.150	1	149
7.662	73.270	73.270	1	73.270	1	150
7.712	50.610	50.610	1	50.610	1	151
7.759	46.330	46.330	1	46.330	1	152
7.868	109.510	109.510	5	21.902	5	157
7.972	104.300	104.300	3	34.767	3	160
8.116	143.050	143.050	5	28.610	5	165
8.173	57.310	57.310	1	57.310	1	166
8.209	35.710	35.710	1	35.710	1	167
8.324	115.000	115.000	1	115.000	1	168
8.395	71.790	71.790	1	71.790	1	169
8.619	224.000	224.000	6	37.333	6	175
8.704	84.770	84.770	1	84.770	1	176
8.824	120.000	120.000	3	40.000	3	179
8.929	105.240	105.240	1	105.240	1	180
8.990	61.040	61.040	1	61.040	1	181
9.107	116.780	116.780	1	116.780	1	182
9.140	33.270	33.270	1	33.270	1	183
9.241	100.320	100.320	1	100.320	1	184
9.397	156.570	156.570	1	156.570	1	185
9.475	77.480	77.480	1	77.480	1	186
9.594	118.920	118.920	1	118.920	1	187
9.667	73.750	73.750	1	73.750	1	188
9.779	111.300	111.300	1	111.300	1	189
9.834	54.800	54.800	1	54.800	1	190
9.974	140.000	140.000	1	140.000	1	191
10.032	58.300	58.300	1	58.300	1	192
10.094	62.240	62.240	1	62.240	1	193
10.187	93.020	93.020	1	93.020	1	194
10.239	51.400	51.400	1	51.400	1	195
10.308	69.300	69.300	1	69.300	1	196
10.385	77.380	77.380	1	77.380	1	197
10.477	91.700	91.700	1	91.700	1	198
10.530	53.240	53.240	1	53.240	1	199
10.605	75.060	75.060	1	75.060	1	200
10.674	68.580	68.580	1	68.580	1	201
10.735	60.810	60.810	1	60.810	1	202
10.813	78.420	78.420	1	78.420	1	203
10.889	75.600	75.600	1	75.600	1	204
10.996	107.500	107.500	1	107.500	1	205
11.022	25.970	25.970	1	25.970	1	206
11.139	117.100	117.100	1	117.100	1	207

11.189	49.800	49.800	1	49.800	1	208
11.324	135.100	135.100	1	135.100	1	209
11.406	81.800	81.800	1	81.800	1	210
11.498	92.300	92.300	1	92.300	1	211
12.311	812.700	812.700	1	812.700	1	212
12.396	85.240	85.240	1	85.240	1	213
12.586	190.050	190.050	1	190.050	1	214
12.639	52.700	52.700	1	52.700	1	215
12.694	54.700	54.700	1	54.700	1	216
12.789	95.050	95.050	1	95.050	1	217
12.923	134.780	134.780	1	134.780	1	218
13.013	89.700	89.700	1	89.700	1	219
13.109	95.800	95.800	1	95.800	1	220
13.189	79.860	79.860	1	79.860	1	221
13.288	99.250	99.250	1	99.250	1	222
13.404	115.800	115.800	1	115.800	1	223
13.471	66.980	66.980	1	66.980	1	224
13.562	90.910	90.910	1	90.910	1	225
13.682	120.490	120.490	1	120.490	1	226
13.730	47.490	47.490	1	47.490	1	227
13.825	95.330	95.330	1	95.330	1	228
14.321	496.210	496.210	1	496.210	1	229
14.508	186.760	186.760	4	46.690	4	233
14.570	61.870	61.870	1	61.870	1	234
14.666	95.640	95.640	1	95.640	1	235
15.384	718.000	718.000	1	718.000	1	236
15.501	117.890	117.890	1	117.890	1	237
15.535	33.550	33.550	1	33.550	1	238
15.589	54.110	54.110	1	54.110	1	239
15.639	50.260	50.260	1	50.260	1	240
15.683	43.360	43.360	1	43.360	1	241
16.213	530.320	530.320	1	530.320	1	242
16.305	91.720	91.720	1	91.720	1	243
16.379	74.750	74.750	1	74.750	1	244
16.447	67.610	67.610	1	67.610	1	245
16.512	64.470	64.470	1	64.470	1	246
16.653	141.750	141.750	4	35.438	4	250
16.732	78.500	78.500	1	78.500	1	251
16.797	65.650	65.650	1	65.650	1	252
16.942	144.810	144.810	1	144.810	1	253
17.097	154.810	154.810	1	154.810	1	254
17.169	71.690	71.690	1	71.690	1	255
17.229	60.210	60.210	1	60.210	1	256
17.317	88.110	88.110	1	88.110	1	257
17.431	114.200	114.200	1	114.200	1	258
17.507	75.410	75.410	1	75.410	1	259
18.260	753.500	753.500	1	753.500	1	260
18.401	140.520	140.520	1	140.520	1	261

18.453	52.430	52.430	1	52.430	1	262
18.528	74.850	74.850	1	74.850	1	263
18.604	75.620	75.620	1	75.620	1	264
18.737	133.000	133.000	4	33.250	4	268
18.956	219.000	219.000	1	219.000	1	269
19.047	91.580	91.580	1	91.580	1	270
19.098	50.950	50.950	1	50.950	1	271
19.153	54.720	54.720	1	54.720	1	272
19.276	123.150	123.150	1	123.150	1	273
19.356	79.940	79.940	1	79.940	1	274
19.455	98.800	98.800	1	98.800	1	275
20.575	1120.000	1120.000	1	1120.000	1	276
20.670	95.370	95.370	1	95.370	1	277
20.719	48.950	48.950	1	48.950	1	278
20.850	130.670	130.670	1	130.670	1	279
20.920	70.630	70.630	1	70.630	1	280
21.037	116.370	116.370	1	116.370	1	281
21.243	206.470	206.470	5	41.294	5	286
21.386	143.000	143.000	1	143.000	1	287
21.499	113.000	113.000	1	113.000	1	288
21.625	125.300	125.300	1	125.300	1	289
23.055	1430.000	1430.000	1	1430.000	1	290
23.315	260.950	260.950	5	52.190	5	295
23.454	138.350	138.350	4	34.588	4	299
23.636	182.580	182.580	4	45.645	4	303
23.827	190.140	190.140	3	63.380	3	306
24.433	606.000	606.000	1	606.000	1	307
24.594	161.880	161.880	3	53.960	3	310
24.688	93.100	93.100	1	93.100	1	311
24.804	116.260	116.260	1	116.260	1	312
24.901	97.060	97.060	1	97.060	1	313
24.954	53.520	53.520	1	53.520	1	314
26.024	1070.000	1070.000	1	1070.000	1	315
26.192	167.930	167.930	1	167.930	1	316
26.407	214.220	214.220	1	214.220	1	317
26.849	442.590	442.590	1	442.590	1	318
27.084	235.240	235.240	1	235.240	1	319
27.445	360.570	360.570	3	120.190	3	322
28.605	1160.000	1160.000	1	1160.000	1	323
28.762	157.540	157.540	1	157.540	1	324
28.954	191.190	191.190	1	191.190	1	325
29.128	173.970	173.970	1	173.970	1	326
29.290	162.000	162.000	1	162.000	1	327
29.519	229.700	229.700	1	229.700	1	328
29.624	104.200	104.200	1	104.200	1	329
29.707	83.260	83.260	1	83.260	1	330
29.836	129.120	129.120	2	64.560	2	332
30.547	710.800	710.800	12	59.233	12	344

30.670	122.850	122.850	2	61.425	2	346
30.756	86.740	86.740	1	86.740	1	347
30.820	63.340	63.340	1	63.340	1	348
30.920	100.310	100.310	1	100.310	1	349
31.218	298.000	298.000	4	74.500	4	353
31.968	750.400	750.400	1	750.400	1	354
32.193	224.400	224.400	1	224.400	1	355
32.340	147.400	147.400	1	147.400	1	356
32.461	120.800	120.800	1	120.800	1	357
32.596	135.390	135.390	1	135.390	1	358
32.829	233.000	233.000	1	233.000	1	359
32.969	139.550	139.550	1	139.550	1	360
33.229	259.700	259.700	5	51.940	5	365
34.382	1153.000	1153.000	1	1153.000	1	366
35.068	686.420	686.420	9	76.269	9	375
35.648	580.000	580.000	1	580.000	1	376
36.225	577.120	577.120	6	96.187	6	382
36.624	398.850	398.850	6	66.475	6	388
36.805	181.500	181.500	1	181.500	1	389
37.045	240.000	240.000	5	48.000	5	394
37.481	436.000	436.000	1	436.000	1	395
37.920	439.000	439.000	4	109.750	4	399
38.103	183.000	183.000	4	45.750	4	403
38.344	240.700	240.700	2	120.350	2	405
38.537	192.400	192.400	3	64.133	3	408
39.502	965.000	965.000	1	965.000	1	409
39.628	126.800	126.800	1	126.800	1	410
39.782	153.500	153.500	3	51.167	3	413
40.211	429.400	429.400	1	429.400	1	414
40.555	344.100	344.100	4	86.025	4	418
40.870	315.000	315.000	1	315.000	1	419
40.935	64.580	64.580	1	64.580	1	420
41.265	330.500	330.500	7	47.214	7	427
43.225	1960.000	1960.000	1	1960.000	1	428
44.235	1010.000	1010.000	19	53.158	19	447
45.295	1060.000	1060.000	19	55.789	19	466
46.226	930.400	930.400	25	37.216	25	491
46.672	446.000	446.000	11	40.545	11	502
48.201	1529.000	1529.000	32.83	46.573	33	535