

Appendices to Lab O-2

Investigation of Mercury Green and Yellow Lines, and White Light Fringes with the Michelson Interferometer

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Appendix A: Tabulated Data for Experiments 1a and 1b

Experiment 1a Raw Data

Fringes (exact)	Gauge Reading, g (mm) (all ± 0.005 mm)											
	1	2	3	4	5	6	7	8	9	10	11	
0	21.000	12.000	20.000	22.000	16.540	16.500	17.500	17.400	17.400	17.400	17.400	
50	21.060	11.935	20.065	22.060	16.420	16.380	17.400	17.335	17.335	17.335	17.335	
100	21.120	11.870	20.130	22.120	16.335	16.280	17.290	17.270	17.270	17.270	17.265	
150	21.180	11.805	20.200	22.180	16.280	16.225	17.220	17.205	17.205	17.205	17.200	
200	21.245	11.740	20.280	22.245	16.230	16.175	17.170	17.140	17.135	17.140	17.135	
250	21.315	11.680	20.350	22.315	16.175	16.120	17.120	17.070	17.070	17.070	17.070	
300	21.380	11.615	20.420	22.390	16.110	16.060	17.065	17.005	17.005	17.005	17.005	
350	21.450	11.560	20.485	22.465	16.030	15.990	17.000	16.940	16.940	16.940	16.940	
400	21.520	11.495	20.550	22.525	15.980	15.925	16.930	16.875	16.870	16.875	16.870	
450	21.590	11.430	20.610	22.595	15.915	15.860	16.865	16.810	16.805	16.810	16.805	
500	21.650	11.360	20.680	22.660	15.850	15.795	16.800	16.745	16.740	16.740	16.740	
550	21.720	11.300	20.745	22.725	15.785	15.730	16.730	16.675	16.670	16.675	16.670	
600	21.795	11.240	20.815	22.790	15.715	15.675	16.665	16.610	16.605	16.610	16.605	
650	21.850	11.165	20.890	22.850	15.650	15.600	16.590	16.545	16.540	16.545	16.540	
700	21.920	11.095	20.965	22.915	15.595	15.530	16.530	16.480	16.475	16.480	16.475	
750	21.990	11.025	21.030	22.985	15.530	15.465	16.465	16.410	16.410	16.415	16.410	
800	22.080	10.965	21.100	23.050	15.470	15.400	16.395	16.345	16.340	16.350	16.340	
850	22.140	10.900	21.170	23.120	15.405	15.335	16.330	16.280	16.275	16.280	16.275	
900	22.210	10.840	21.235	23.195	15.335	15.270	16.265	16.210	16.205	16.215	16.210	
950	22.280	10.780	21.300	23.270	15.270	15.205	16.195	16.145	16.140	16.150	16.140	
1000	22.350	10.715	21.365	23.340	15.195	15.140	16.130	16.075	16.070	16.080	16.075	
1050	22.420	10.650	21.430	23.410	15.140	15.075	16.065	16.010	16.005	16.020	16.010	
1100	22.490	10.575	21.490	23.475	15.070	15.005	16.000	15.945	15.940	15.950	15.945	
1150	22.555	10.520	21.560	23.540	15.005	14.940	15.930	15.880	15.875	15.885	15.880	
1200	22.620	10.460	21.630	23.600	14.940	14.880	15.870	15.815	15.810	15.820	15.810	
Date	<i>Aug 31, 05</i>			<i>Sep 1, 05</i>	<i>Sep 9, 05</i>					<i>Sep 21, 05</i>		

Experiment 1a Preprocessed Data

Fringes, i (exact)	Difference, $\Delta g = g_i - g_{i-1}$ (mm) (all ± 0.010 mm)											
	1	2	3	4	5	6	7	8	9	10	11	
50	0.060	0.065	0.065	0.060	0.120	0.120	0.100	0.065	0.065	0.065	0.065	
100	0.060	0.065	0.065	0.060	0.085	0.100	0.110	0.065	0.065	0.065	0.070	
150	0.060	0.065	0.070	0.060	0.055	0.055	0.070	0.065	0.065	0.065	0.065	
200	0.065	0.065	0.080	0.065	0.050	0.050	0.050	0.065	0.070	0.065	0.065	
250	0.070	0.060	0.070	0.070	0.055	0.055	0.050	0.070	0.065	0.070	0.065	
300	0.065	0.065	0.070	0.075	0.065	0.060	0.055	0.065	0.065	0.065	0.065	
350	0.070	0.055	0.065	0.075	0.080	0.070	0.065	0.065	0.065	0.065	0.065	
400	0.070	0.065	0.065	0.060	0.050	0.065	0.070	0.065	0.065	0.070	0.070	
450	0.070	0.065	0.060	0.070	0.065	0.065	0.065	0.065	0.065	0.065	0.065	
500	0.060	0.070	0.070	0.065	0.065	0.065	0.065	0.065	0.065	0.065	0.070	
550	0.070	0.060	0.065	0.065	0.065	0.065	0.070	0.070	0.070	0.065	0.070	
600	0.075	0.060	0.070	0.065	0.070	0.055	0.065	0.065	0.065	0.065	0.065	
650	0.055	0.075	0.075	0.060	0.065	0.075	0.075	0.065	0.065	0.065	0.065	
700	0.070	0.070	0.075	0.065	0.055	0.070	0.060	0.065	0.065	0.065	0.065	
750	0.070	0.070	0.065	0.070	0.065	0.065	0.065	0.070	0.065	0.065	0.065	
800	0.090	0.060	0.070	0.065	0.060	0.065	0.070	0.065	0.070	0.065	0.070	
850	0.060	0.065	0.070	0.070	0.065	0.065	0.065	0.065	0.065	0.065	0.070	
900	0.070	0.060	0.065	0.075	0.070	0.065	0.065	0.070	0.070	0.065	0.065	
950	0.070	0.060	0.065	0.075	0.065	0.065	0.070	0.065	0.065	0.065	0.070	
1000	0.070	0.065	0.065	0.070	0.075	0.065	0.065	0.070	0.070	0.070	0.065	
1050	0.070	0.065	0.065	0.070	0.055	0.065	0.065	0.065	0.065	0.060	0.065	
1100	0.070	0.075	0.060	0.065	0.070	0.070	0.065	0.065	0.065	0.070	0.065	
1150	0.065	0.055	0.070	0.065	0.065	0.065	0.070	0.065	0.065	0.065	0.065	
1200	0.065	0.060	0.070	0.060	0.065	0.060	0.060	0.065	0.065	0.065	0.070	
Date	Aug 31, 05			Sep 1, 05	Sep 9, 05						Sep 21, 05	

*Points affected in hysteresis in red and orange

**Acceptable data in blue

Experiment 1b Raw Data

Fadeouts (exact)	Gauge Reading, g (mm) (all ± 0.01 mm)															
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
0	24.96	18.78	13.00	16.78	14.89	16.44	14.88	16.44	17.58	17.58	17.56	17.54	17.55	17.54	17.54	17.54
1		18.37	13.37	16.43	15.35	16.06	15.32	16.05	17.19	17.20	17.19	17.16	17.16	17.17	17.16	17.16
2		18.00	13.76	16.04	15.67	15.66	15.72	15.67	16.81	16.80	16.81	16.77	16.77	16.78	16.77	16.77
3		17.61	14.14	15.65	16.11	15.29	16.10	15.29	16.43	16.43	16.43	16.38	16.38	16.39	16.38	16.38
4		17.23	14.53	15.27	16.47	14.90	16.47	14.91	16.04	16.04	16.03	16.00	16.00	16.00	16.00	16.00
5	22.96	16.84	14.92	14.89	16.87				15.66	15.66	15.65	15.61	15.61	15.61	15.62	15.61
6		16.47	15.32													
7		16.07	15.70													
8		15.68	16.07													
9		15.30	16.48													
10	21.05	14.92	16.85													
11		14.54	17.23													
12		14.15	17.62													
13		13.75	18.00													
14		13.38	18.39													
15	19.14	13.00	18.77													
20	17.22															
25	15.28															
30	13.34															
35	11.45															
40	9.53															
45	7.64															
50	5.64															
55	3.45															
60	1.43															
Date	Sep 02	Sep 6, 05			Sep 7, 05				Sep 9, 05				Sep 21, 05			

Experiment 1b Preprocessed Data

Fadeouts, i (exact)	Difference, $\Delta g = g_i - g_{i-1}$ (mm) (all ± 0.02 mm)															
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
1		0.41	0.37	0.35	0.46	0.38	0.44	0.39	0.39	0.38	0.37	0.38	0.39	0.37	0.38	0.38
2		0.37	0.39	0.39	0.32	0.40	0.40	0.38	0.38	0.4	0.38	0.39	0.39	0.39	0.39	0.39
3		0.39	0.38	0.39	0.44	0.37	0.38	0.38	0.38	0.37	0.38	0.39	0.39	0.39	0.39	0.39
4		0.38	0.39	0.38	0.36	0.39	0.37	0.38	0.39	0.39	0.4	0.38	0.38	0.39	0.38	0.38
5	2.00	0.39	0.39	0.38	0.40				0.38	0.38	0.38	0.39	0.39	0.39	0.38	0.39
6		0.37	0.40													
7		0.40	0.38													
8		0.39	0.37													
9		0.38	0.41													
10	1.91	0.38	0.37													
11		0.38	0.38													
12		0.39	0.39													
13		0.40	0.38													
14		0.37	0.39													
15	1.91	0.38	0.38													
20	1.92															
25	1.94															
30	1.94															
35	1.89															
40	1.92															
45	1.89															
50	2.00															
55	2.19															
60	2.02															
Date	Sep 02	Sep 6, 05			Sep 7, 05				Sep 9, 05				Sep 21, 05			

*Acceptable data in blue

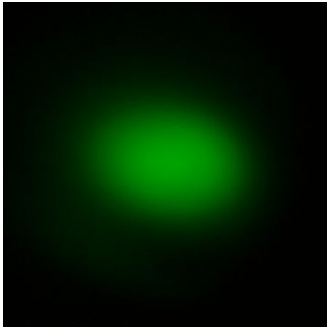
**Appendix B: Images of Fringes
Captured with the Fuji Finepix S602 Camera
on Sep 13, 2005**

Specifications

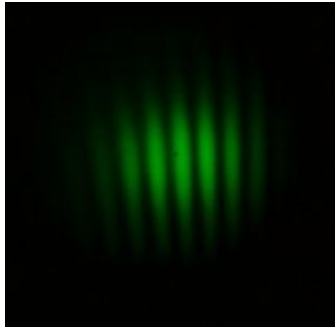
- Manual mode
- Auto white balance

Experiment 1a

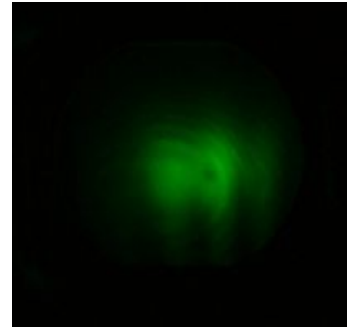
Green fringes:



(a) centered circular fringes



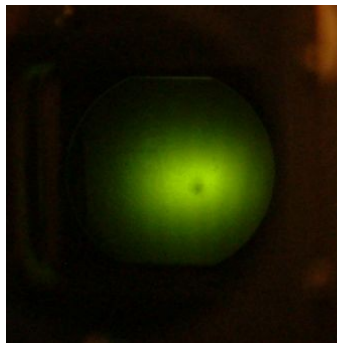
(b) fine localized fringes



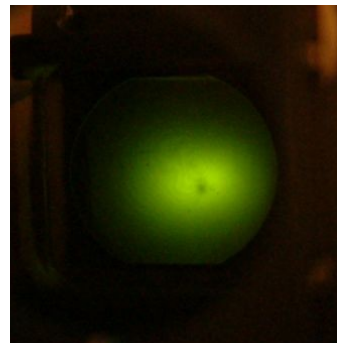
(c) wide localized fringes

Experiment 1b

Yellow fringes:



(d) distinct fringes

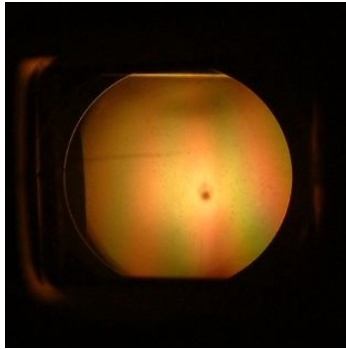


(e) fadeout, faint fringes

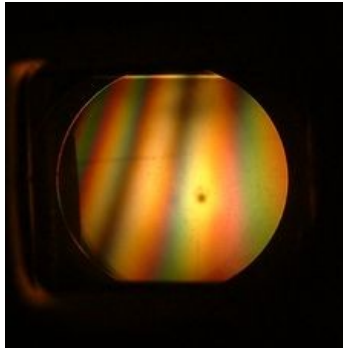
Experiment 1c

Define path difference, $pd = d_{M_1-M} - d_{M_2-M}$
zero path difference, $zpd = pd$, when $pd = 0$; found at gauge reading, 16.000 ± 0.005 mm

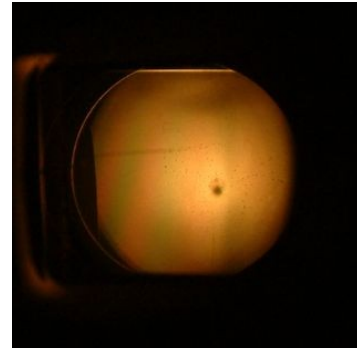
White fringes:



(a) $pd < zpd$

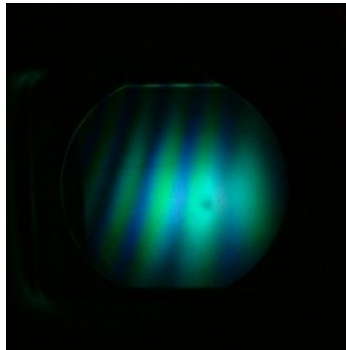


(b) at zpd

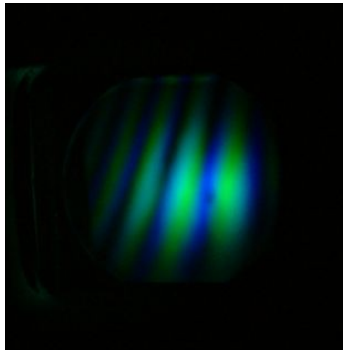


(c) $pd > zpd$

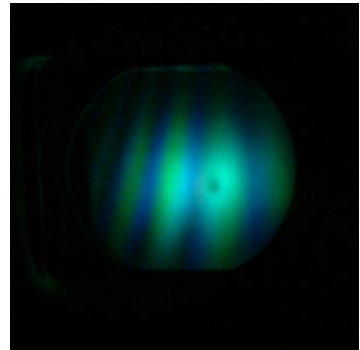
Mercury white fringes:



(d) $pd < zpd$



(e) at zpd



(f) $pd > zpd$

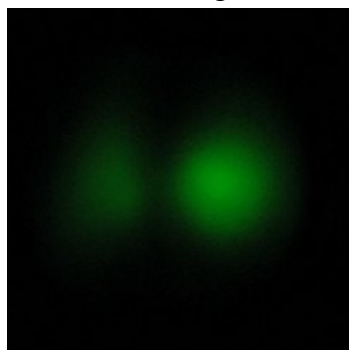
Appendix C: Images of Fringes Captured with the Nikon D70 Camera on Sep 14, 2005

Specifications

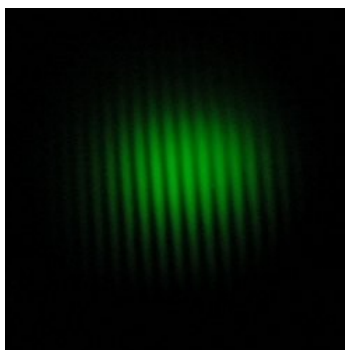
- Manual mode
- Tungsten white balance

Experiment 1a

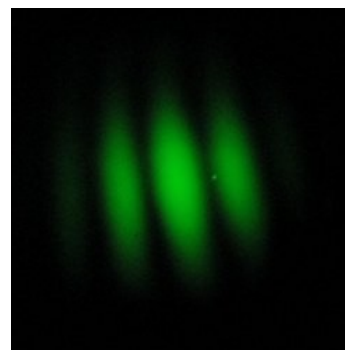
Green localized fringes:



(a) circular fringes near zpd

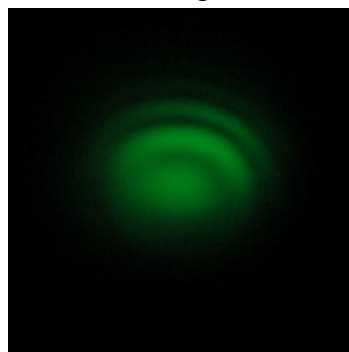


(b) fine localized fringes

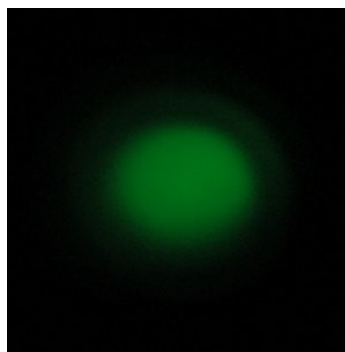


(c) wide localized fringes

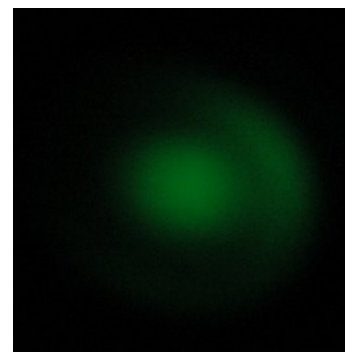
Green circular fringes:



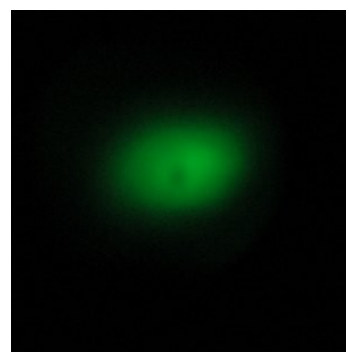
(d) $pd \lll zpd$



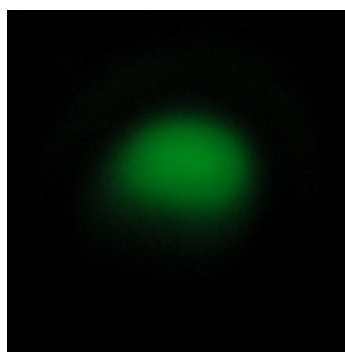
(e) $pd \ll zpd$



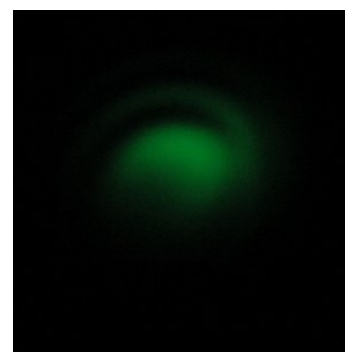
(f) $pd < zpd$



(g) $pd > zpd$



(h) $pd \gg zpd$



(i) $pd \ggg zpd$

Experiment 1b

Yellow fringes:



(a) distinct fringes



(b) fadeout, faint fringes

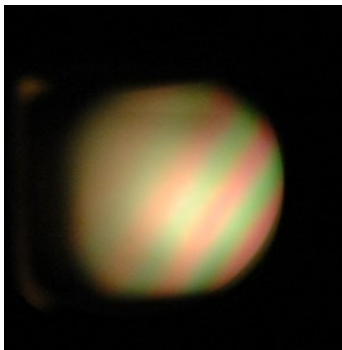
Experiment 1c

Define

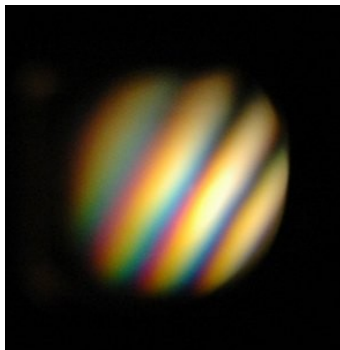
path difference, $pd = d_{M_1-M} - d_{M_2-M}$

zero path difference, $zpd = pd$, when $pd = 0$; found at gauge reading, 16.000 ± 0.005 mm

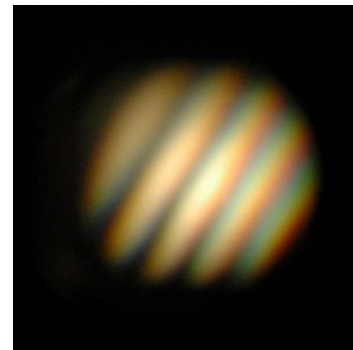
White fringes:



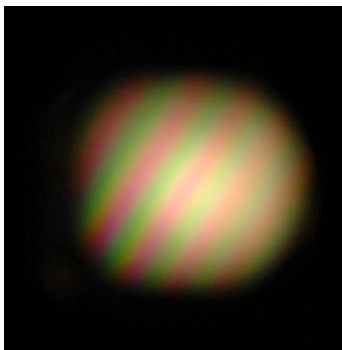
(c) $pd < zpd$



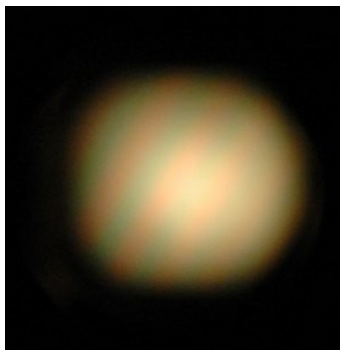
(d) $pd = zpd - \delta l$



(e) at zpd

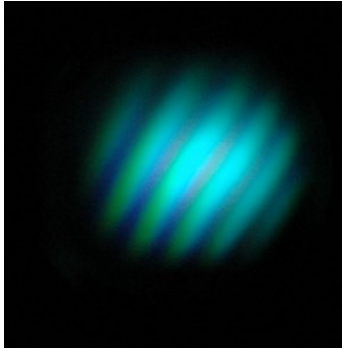


(f) $pd = zpd + 2\delta l$

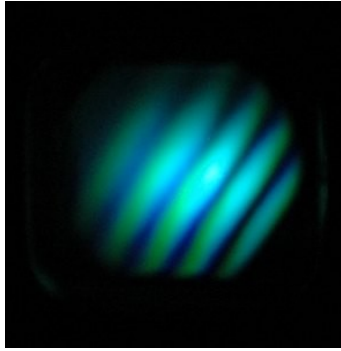


(g) $pd > zpd$

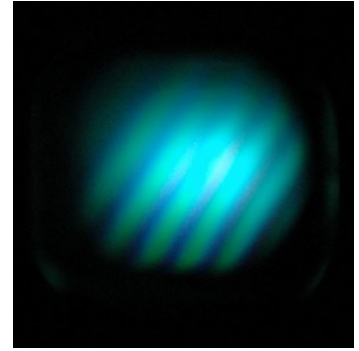
Mercury white fringes:



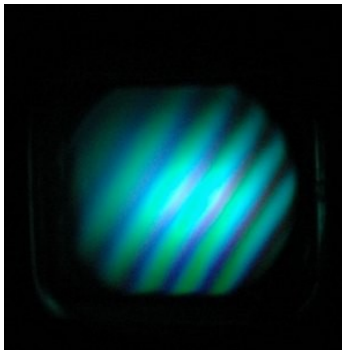
(a) $pd \ll zpd$



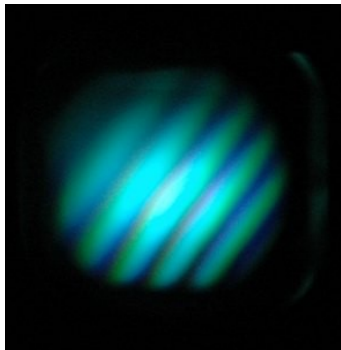
(b) $pd < zpd$



(c) at zpd



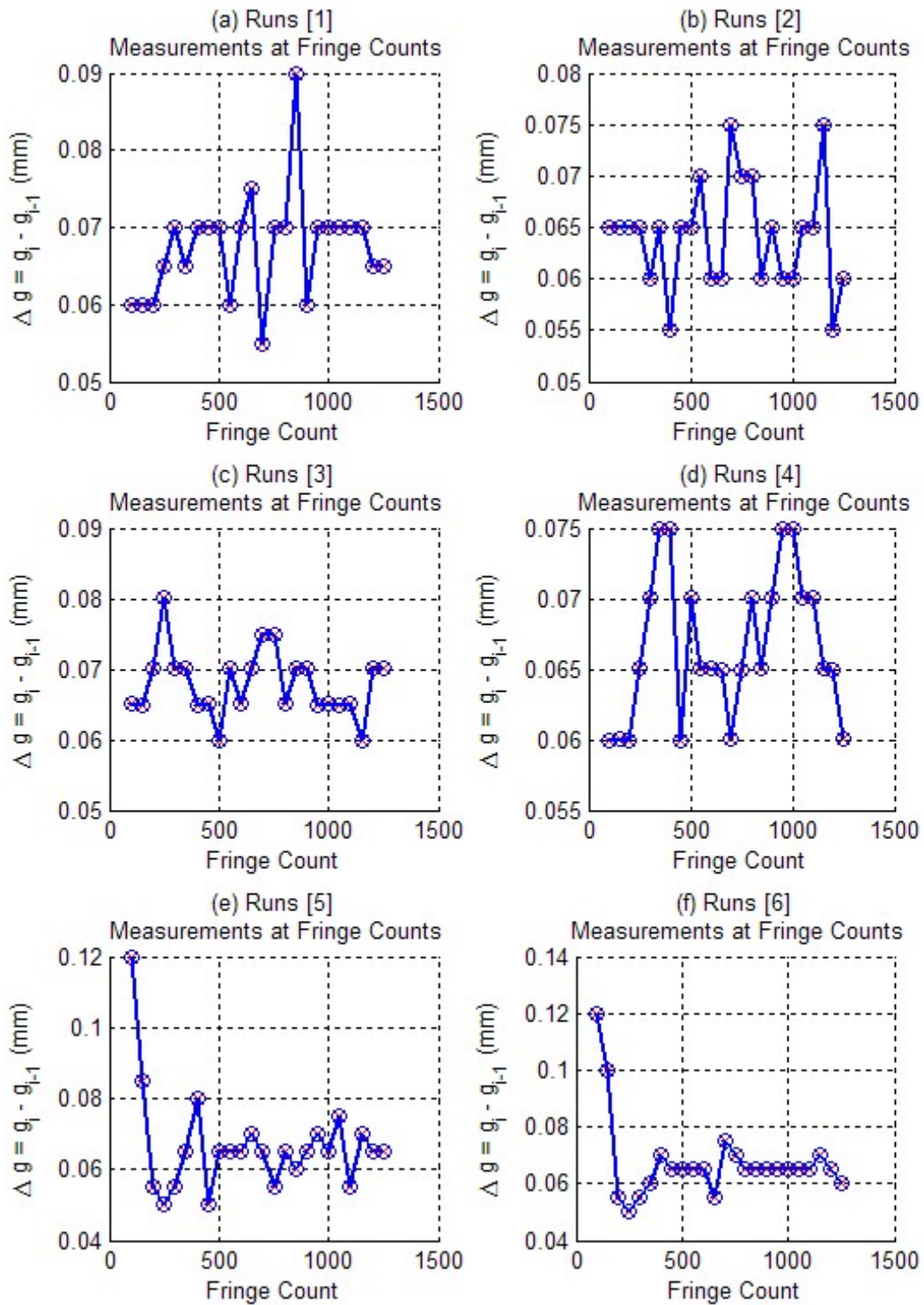
(d) $pd > zpd$

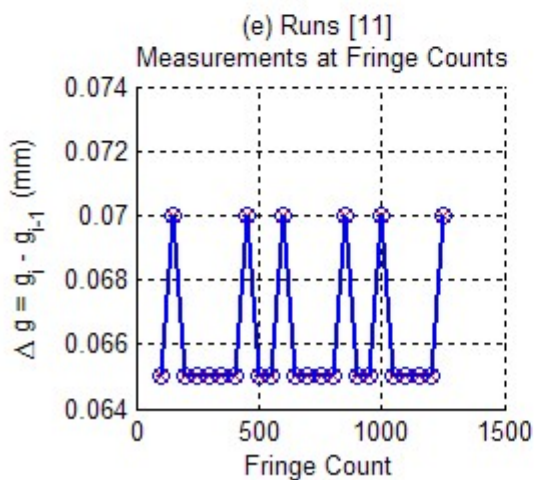
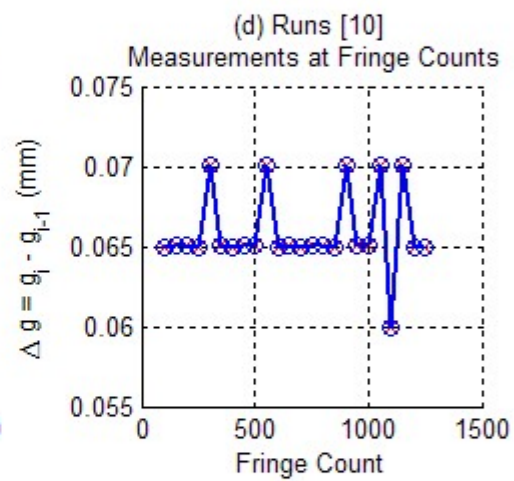
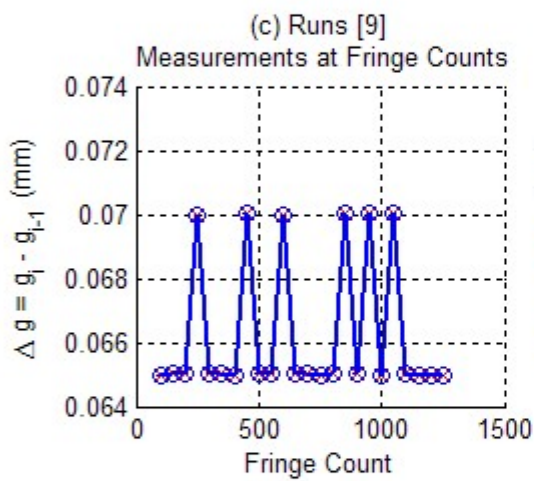
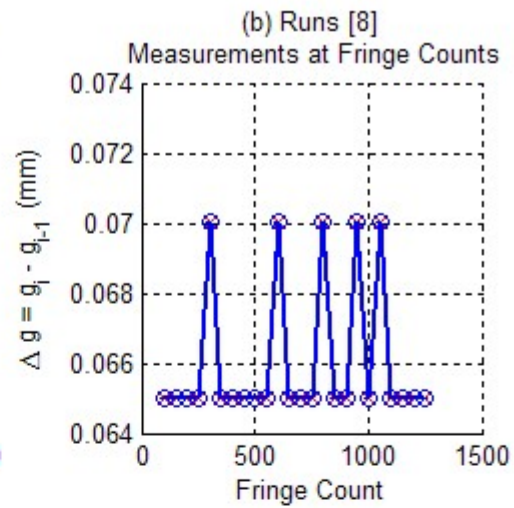
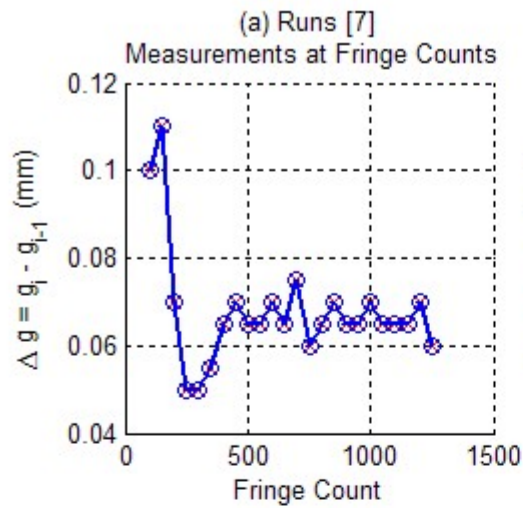


(e) $pd \gg zpd$

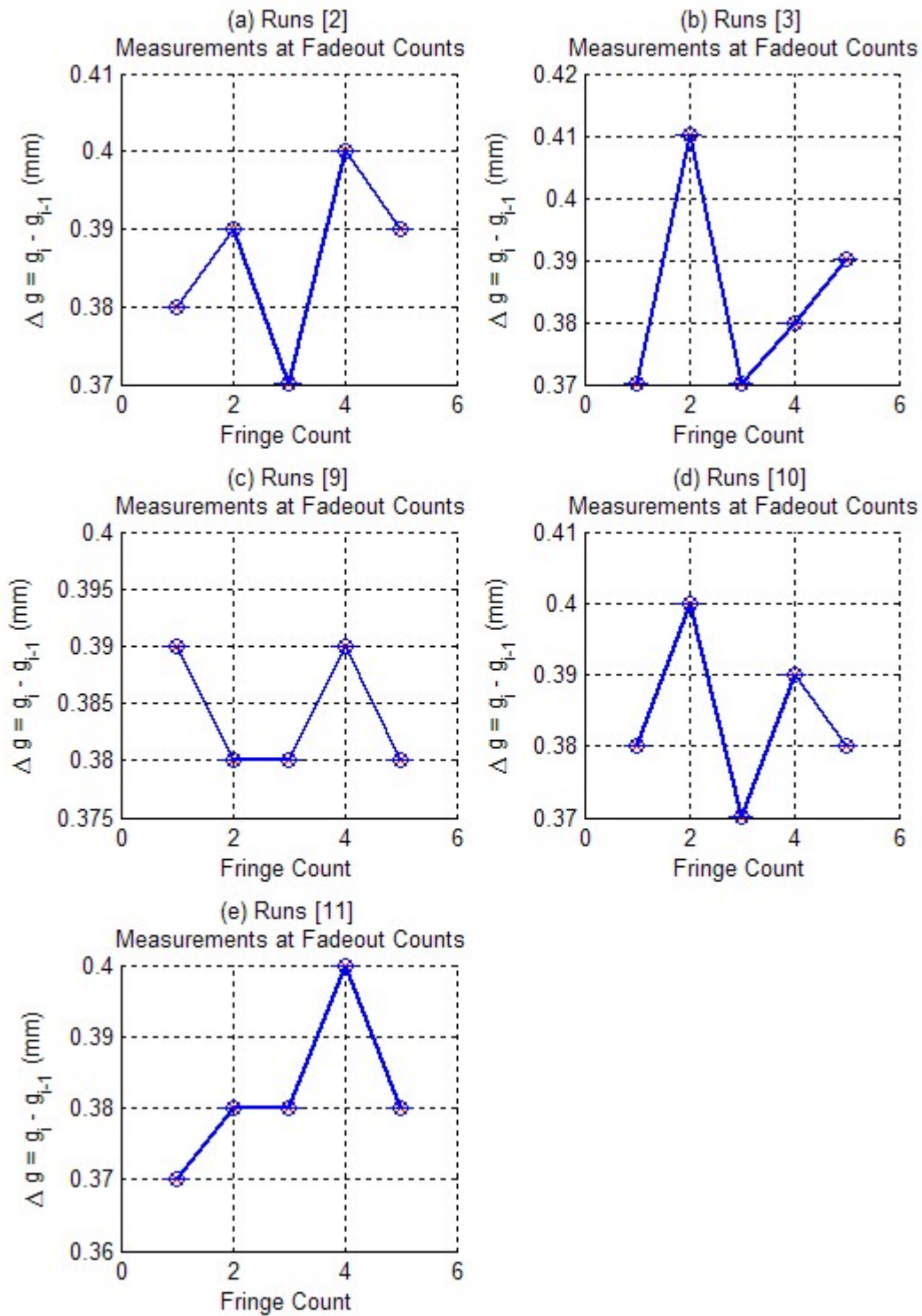
Appendix D: Graphs of Individual Runs for Experiment 1a and 1b

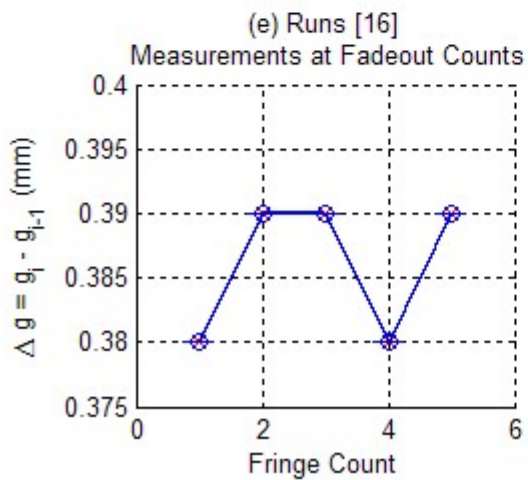
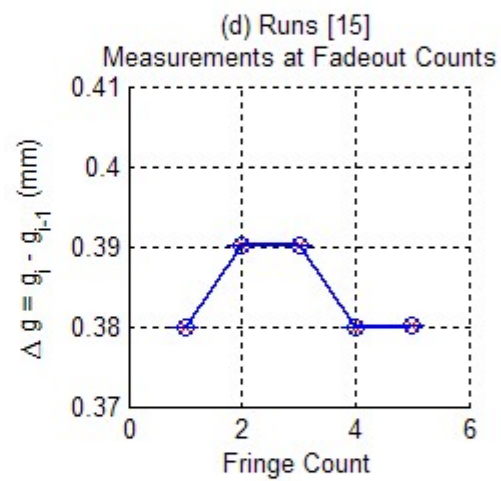
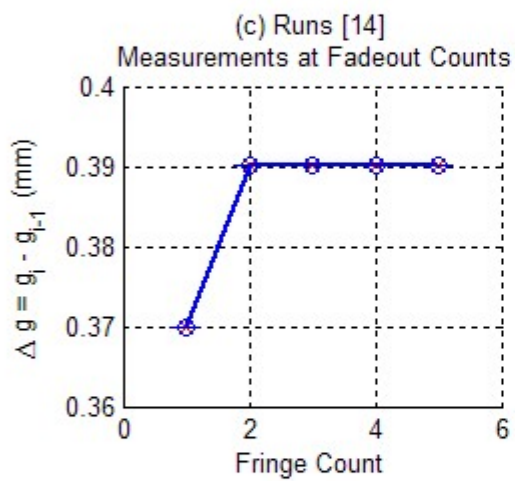
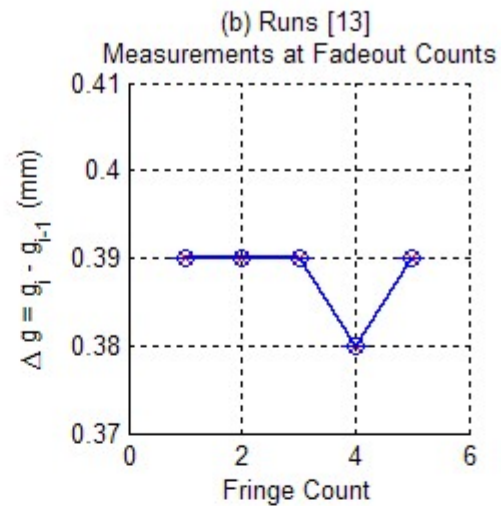
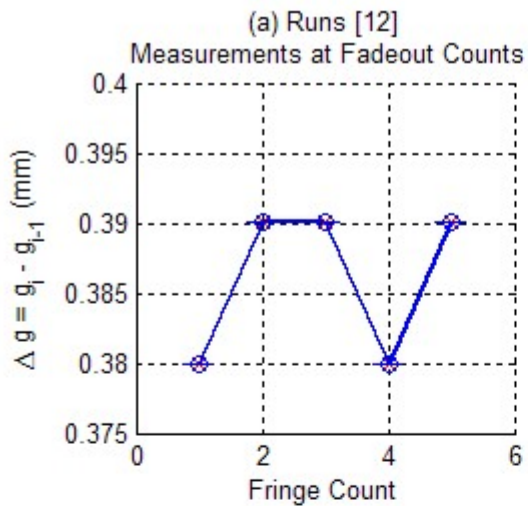
Experiment 1a



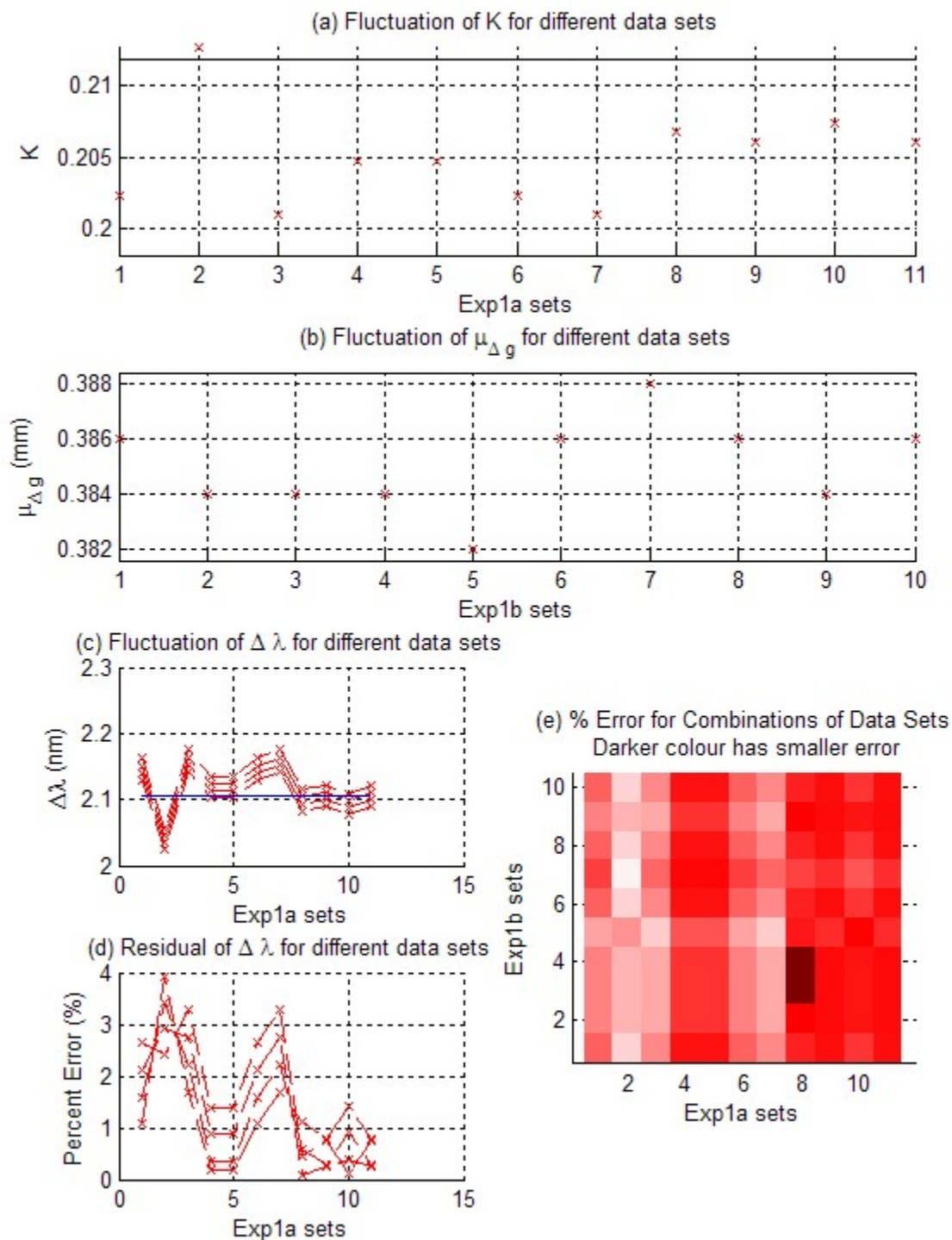


Experiment 1b





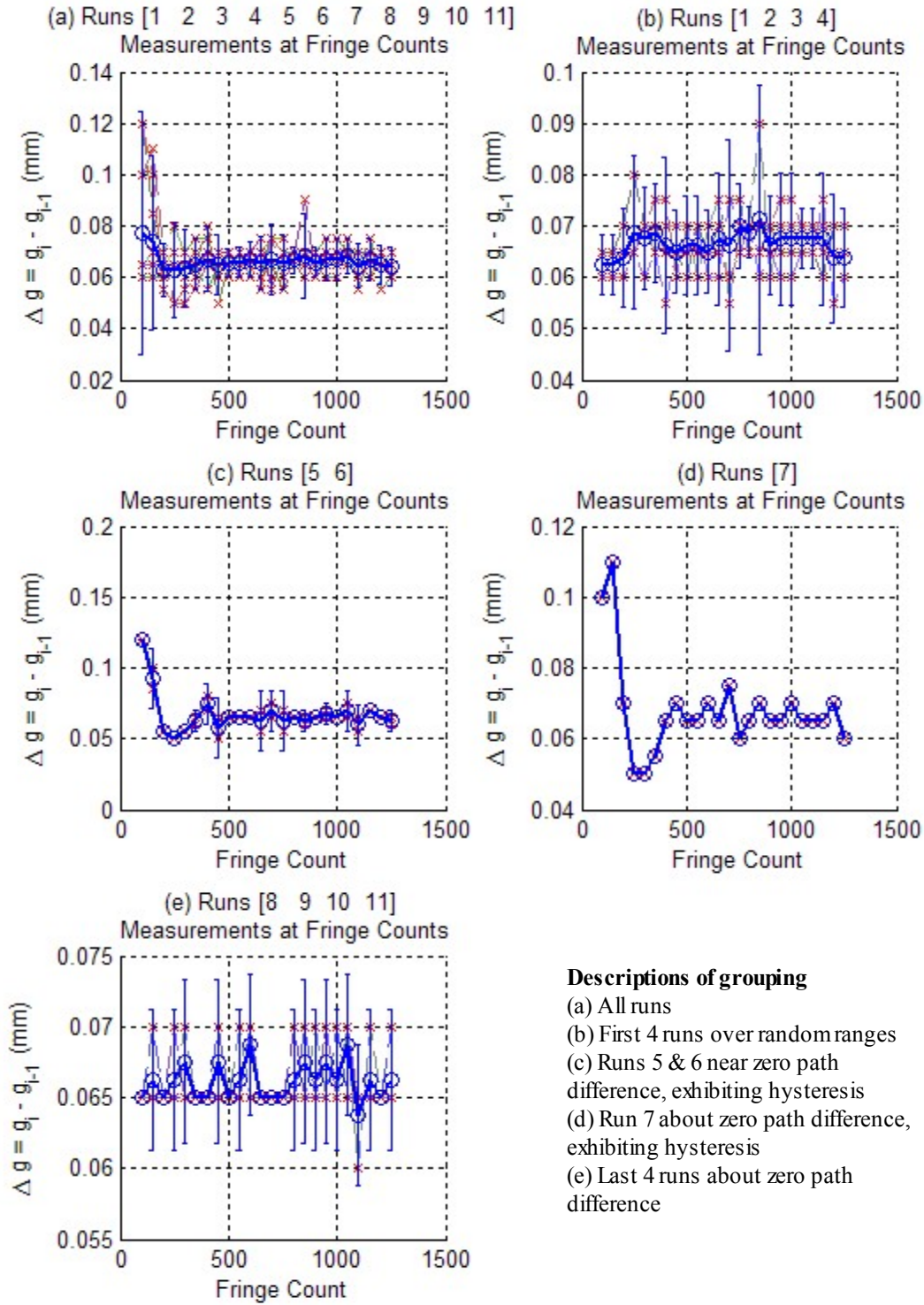
Collated Data



Appendix E: Runs of Experiment 1a and 1b grouped into classes

(note that the error bars are two times the standard deviation)

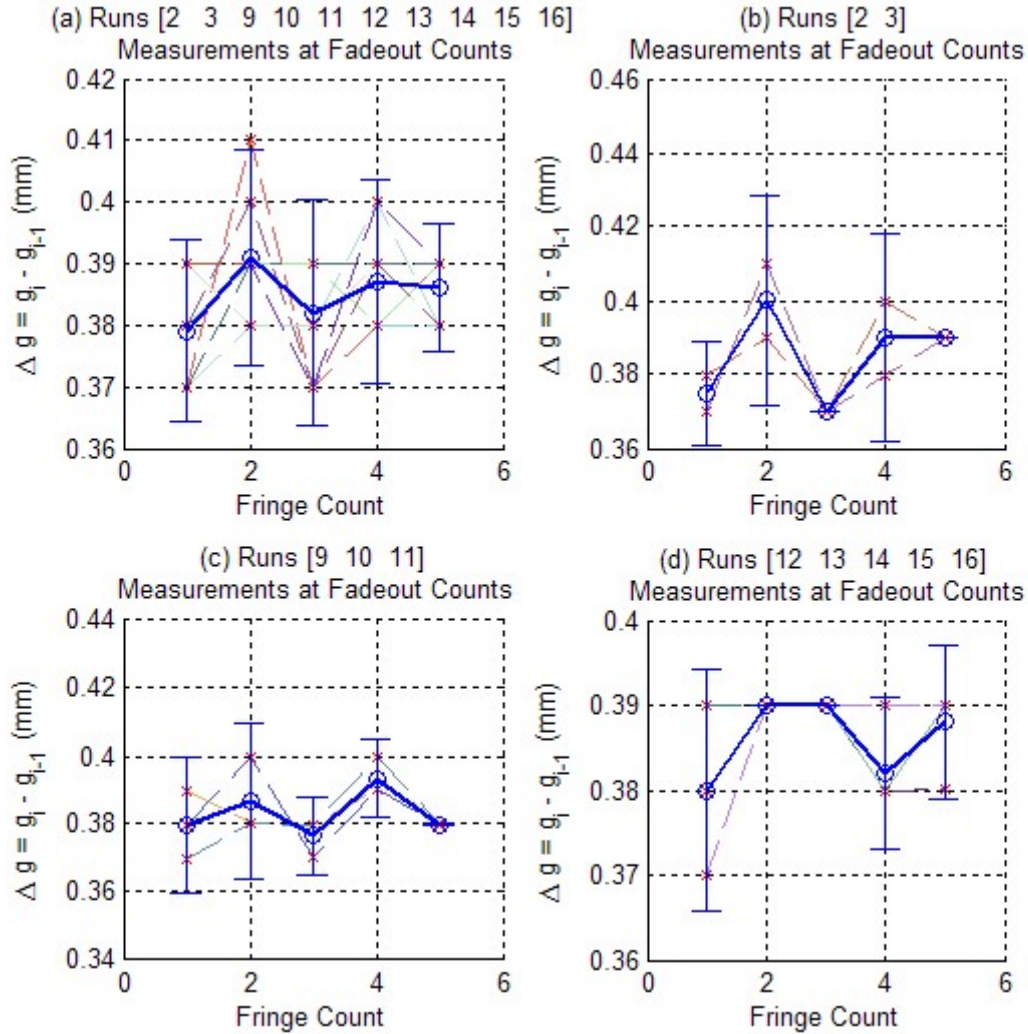
Experiment 1a



Descriptions of grouping

- (a) All runs
- (b) First 4 runs over random ranges
- (c) Runs 5 & 6 near zero path difference, exhibiting hysteresis
- (d) Run 7 about zero path difference, exhibiting hysteresis
- (e) Last 4 runs about zero path difference

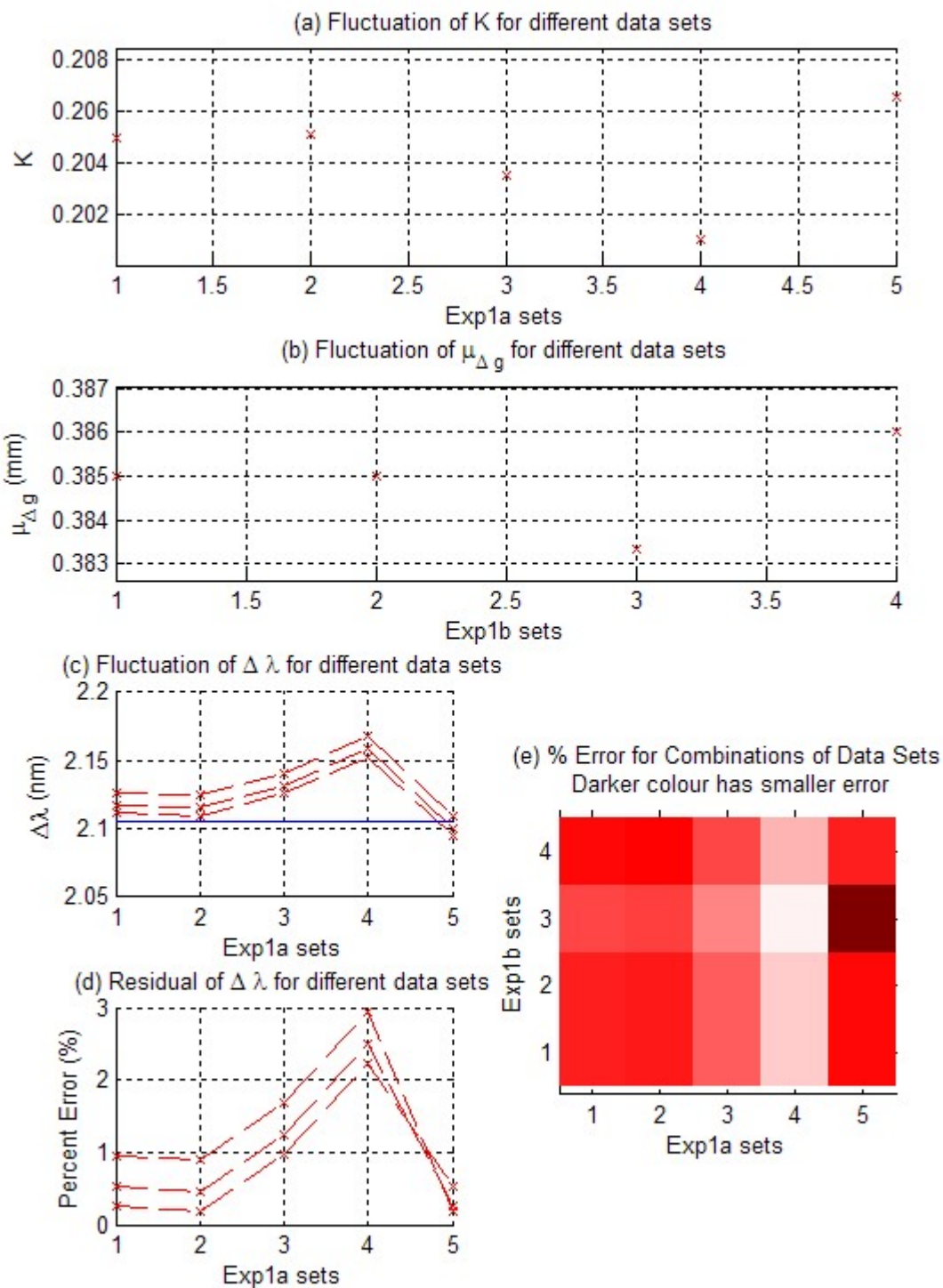
Experiment 1b



Descriptions of grouping

- (a) All relevant runs; other runs were not within the valid range of calibration
- (b) Runs 2 & 3 were extracted from a larger range, but fit to the range calibrated
- (c) Runs 9-11 done, about zero path difference, on Sep 09, 2005
- (d) Runs 12-16 done, about zero path difference, on Sep 21, 2005

Collated Data

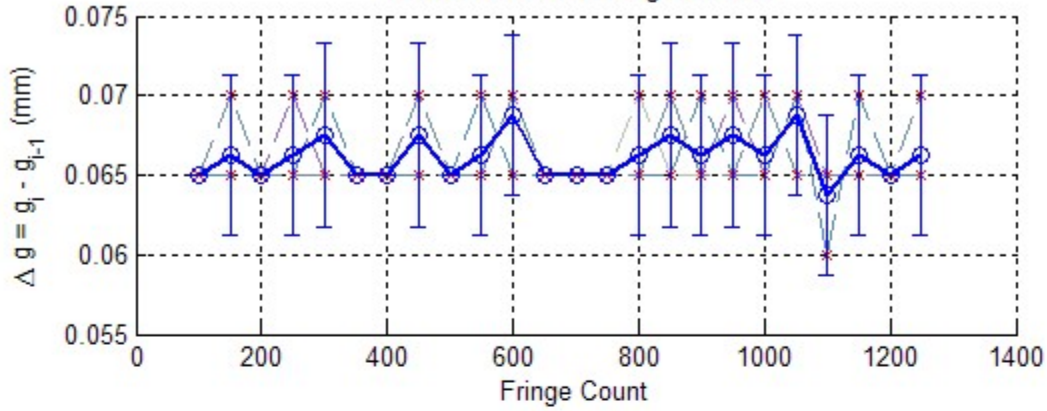


Appendix F: Determination of Means of K and Δg

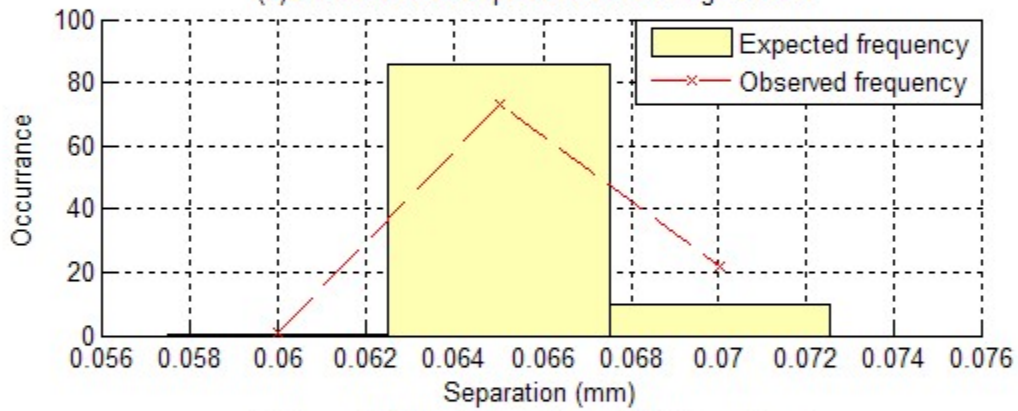
(note that the error bars are two times the standard deviation)

Experiment 1a

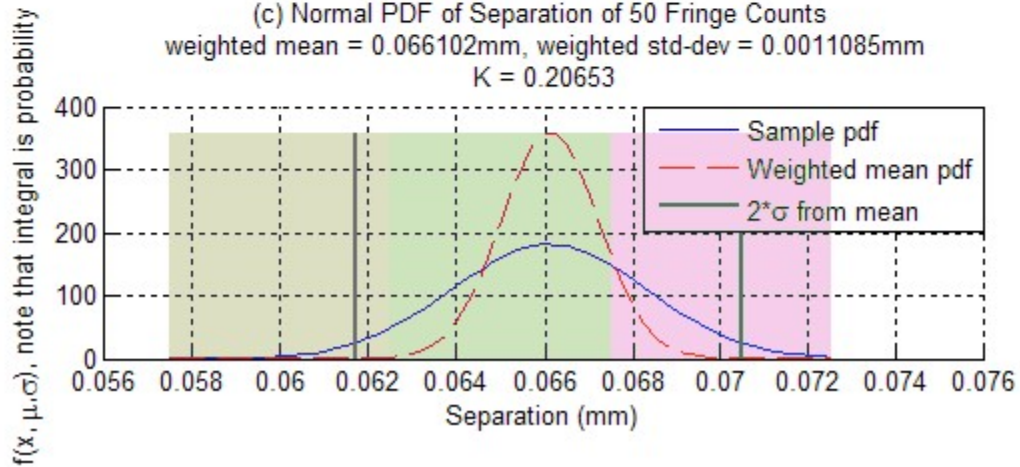
(a) Experiment 1a: Runs [8 9 10 11]
Measurements at Fringe Counts



(b) Distribution of Separation of 50 Fringe Counts

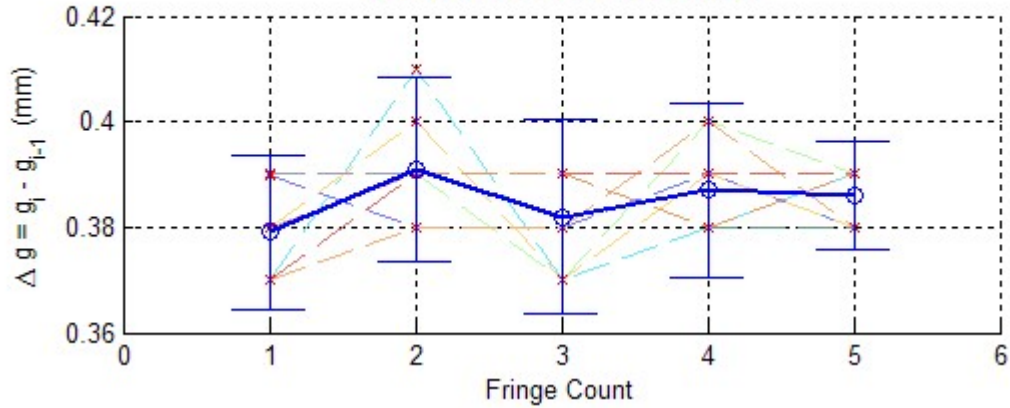


(c) Normal PDF of Separation of 50 Fringe Counts
weighted mean = 0.066102mm, weighted std-dev = 0.0011085mm
 $K = 0.20653$

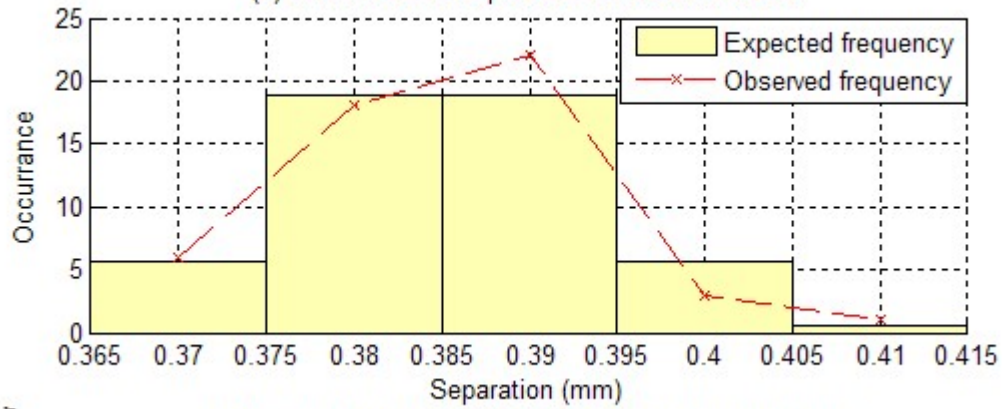


Experiment 1b

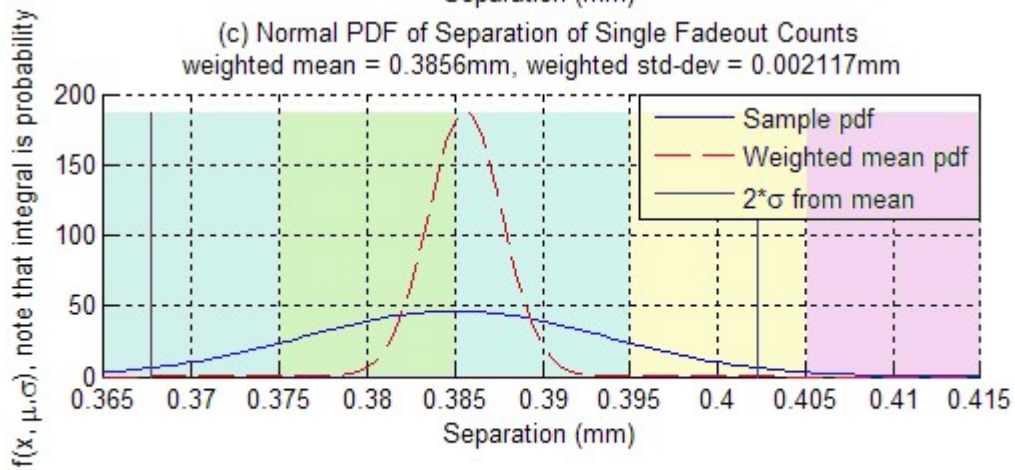
(a) Experiment 1b: Runs [2 3 9 10 11 12 13 14 15 16]
Measurements at Fadeout Counts



(b) Distribution of Separation of Fadeout Counts



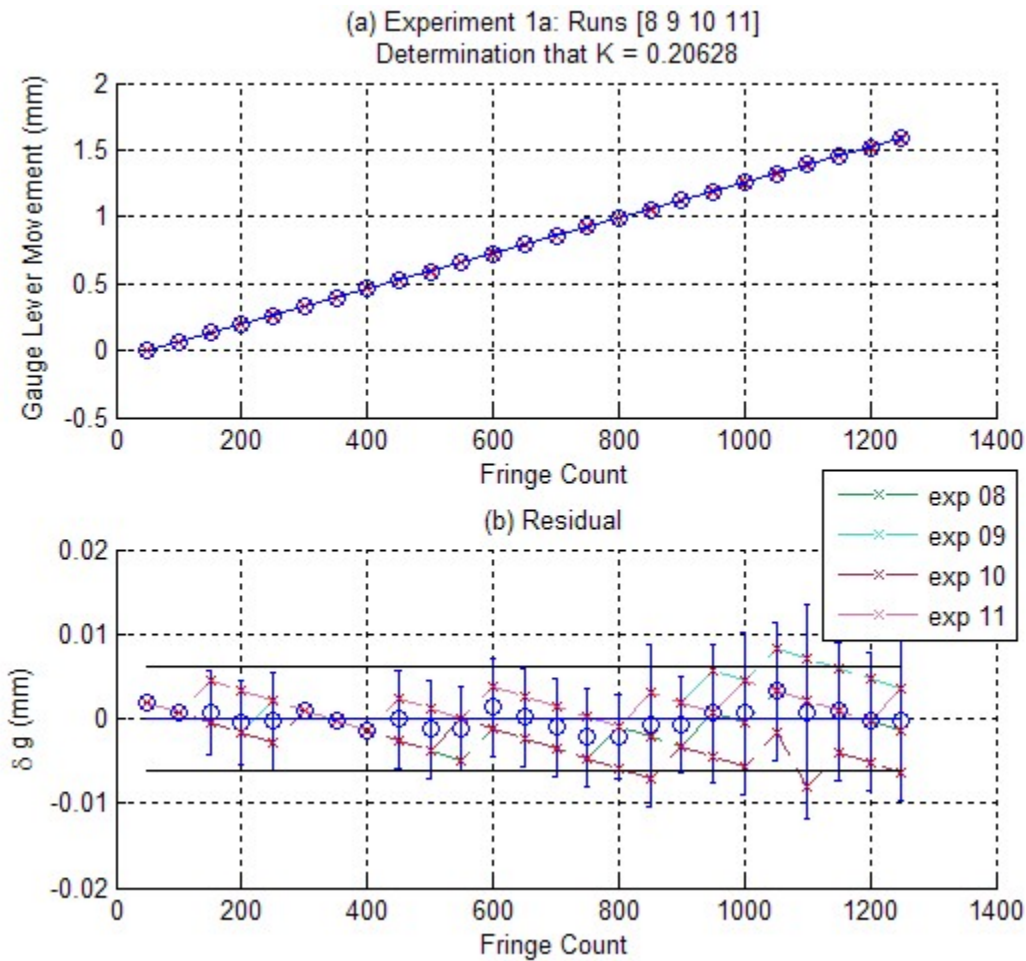
(c) Normal PDF of Separation of Single Fadeout Counts
weighted mean = 0.3856mm, weighted std-dev = 0.002117mm



Appendix G: Various Graphical Analyses of Experiment 1a

This section describes why the difference between consecutive gauge readings were used instead of using the gauge readings directly. In the latter case, when plotted in a graph (such as Graph (a)) of gauge reading vs. fringe count, a straight monotonic trend is observed. Taking the gradient of the linear fit of the data would help in determining the results in the experiments (K for experiment 1a).

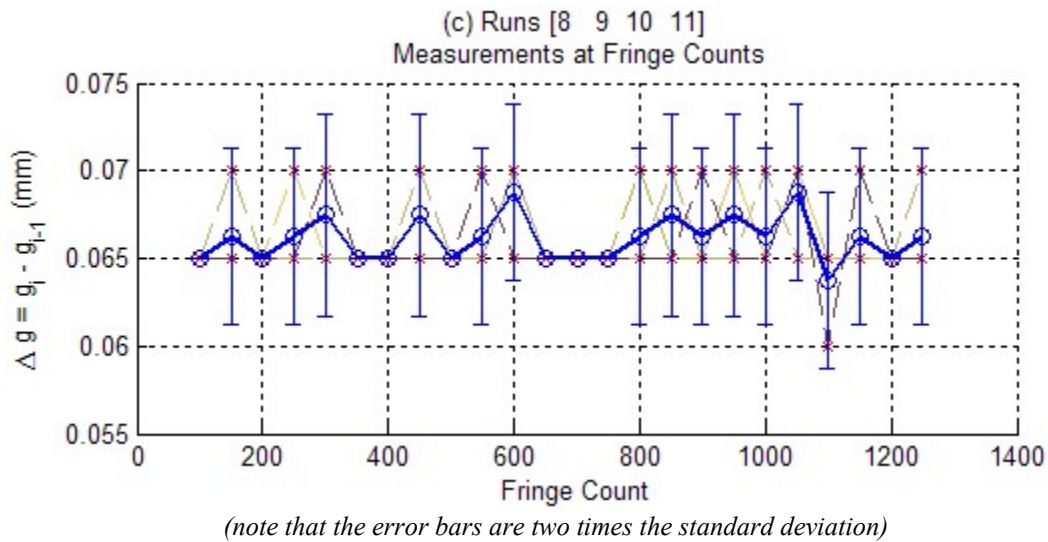
However, when viewing the residual plot (Graph (b)), one can see divergence, which could imply a discrepancy in the linearity assumption of the data. But given the nature of the experiment, where reading at a fringe count depends on the readings at previous fringe counts, when an error occurs at one point, that error would be propagated. This leads to the divergence that is difficult to avoid.



(note that the error bars are two times the standard deviation)

Fortunately, this is remedied by using the difference between consecutive gauge readings.

If a particular reading is too high or too low, then only that point would be affected. Future differences would have values independent of previous ones and there would be no divergence due to the effects aforementioned. This can be seen in Graph (c).



Appendix H: Brief investigation of K as a function of gauge screw position

By considering data from each run of Experiment 1a individually and discarding points affected by hysteresis, the calibration factor, K , is investigated for dependency on gauge screw position. With a preliminary study, Figure H.XXII suggests that K roughly decreases for higher g , i.e. when mirror M_1 is farther from the beamsplitter. Noting that the full screw gauge range is 0.00mm to 25.00mm, this analysis only covers half the range. Nevertheless, this emphasizes the importance of conducting measurements over small gauge ranges. A more thorough analysis of this property, with more experiments, can be further investigated with more detail to verify this observation.

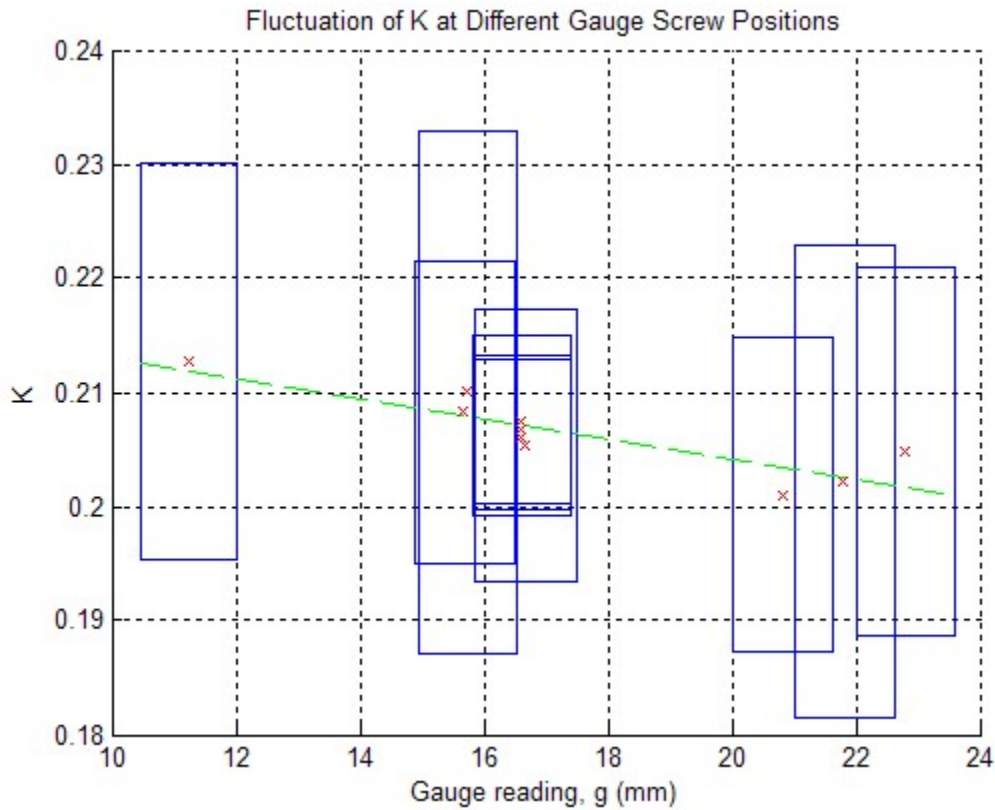


Figure H.XXII: Width of rectangle marks range over which each K value is valid. Height represents the standard deviation of the K value.