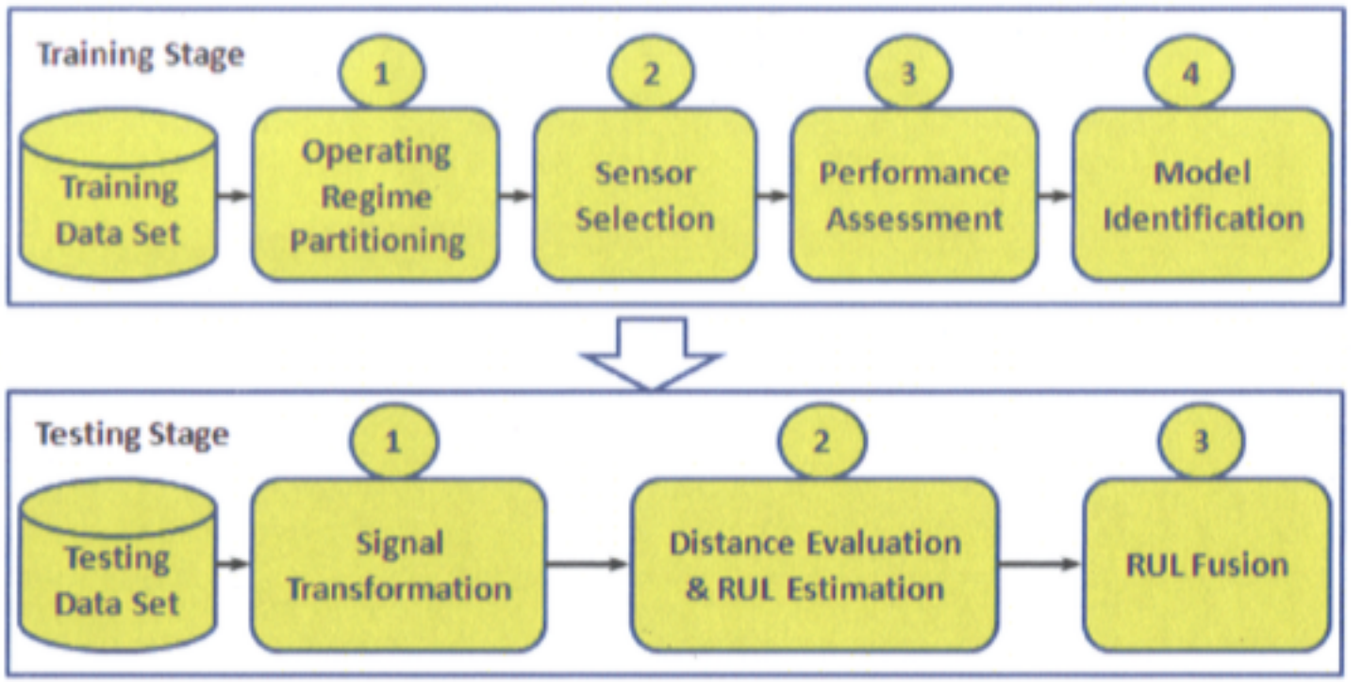
BTP

RUL Estimation of an Aircraft Turbine Engine

KEY TERMS

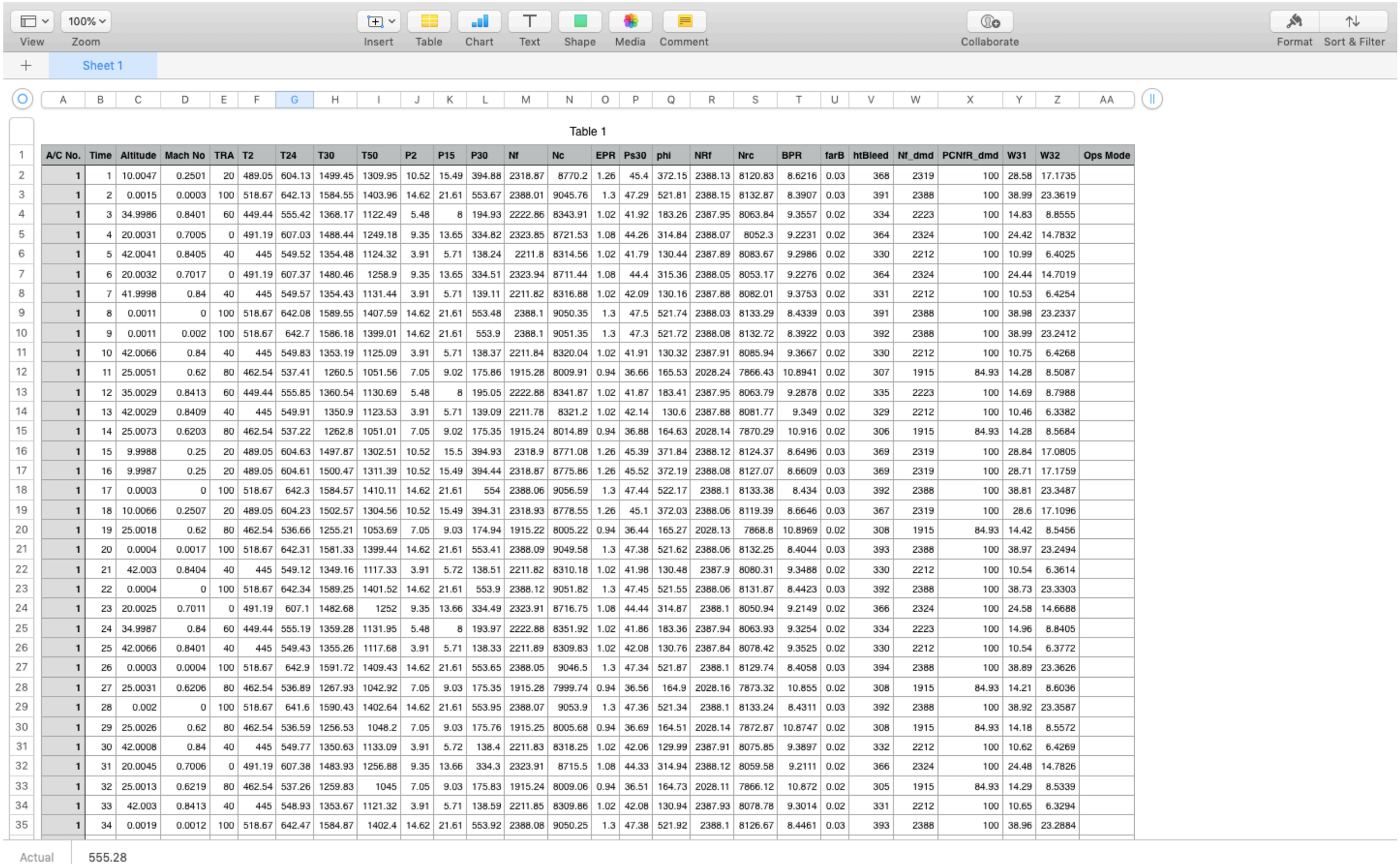
- **RUL :** Remaining useful life of the engine
- **LINEAR MULTIVARIATE REGRESSION (LMR):** ML method for finding the best fitting plane for a n-dimensional feature space
- **SIMILARITY :** the similarity between the test time series data and the training data based on distance
- **HEALTH INDICATOR (HI) :** this value indicates the RUL of the unit at a particular time cycle

APPROACH



- Performance assessment step transforms the selected sensor features to a HI value(using LMR)
- Model Identification involves fitting an exponential degradation pattern to the transformed HI time series values of an unit

DATASET



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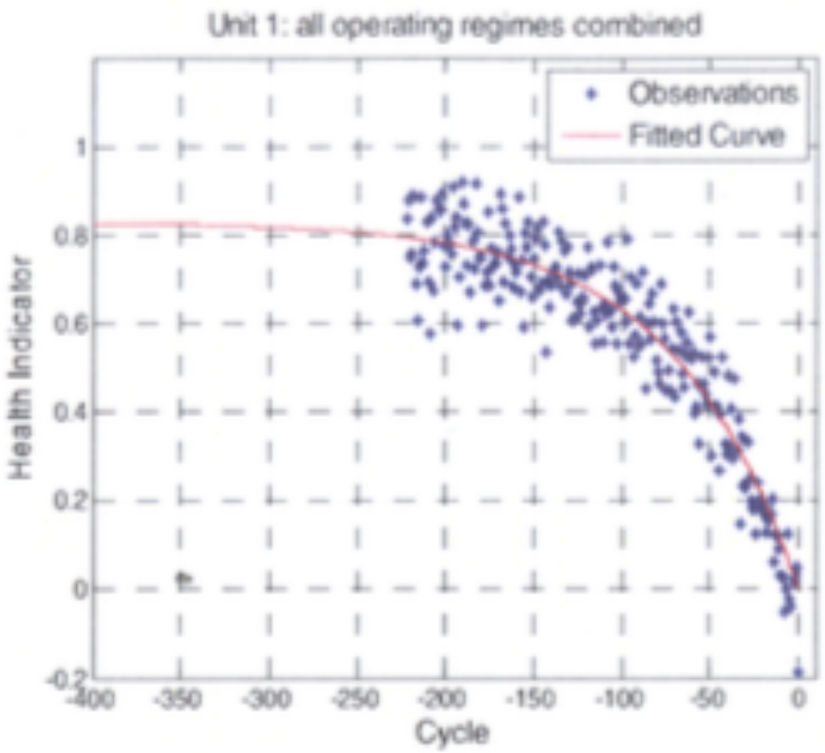
Sheet 1

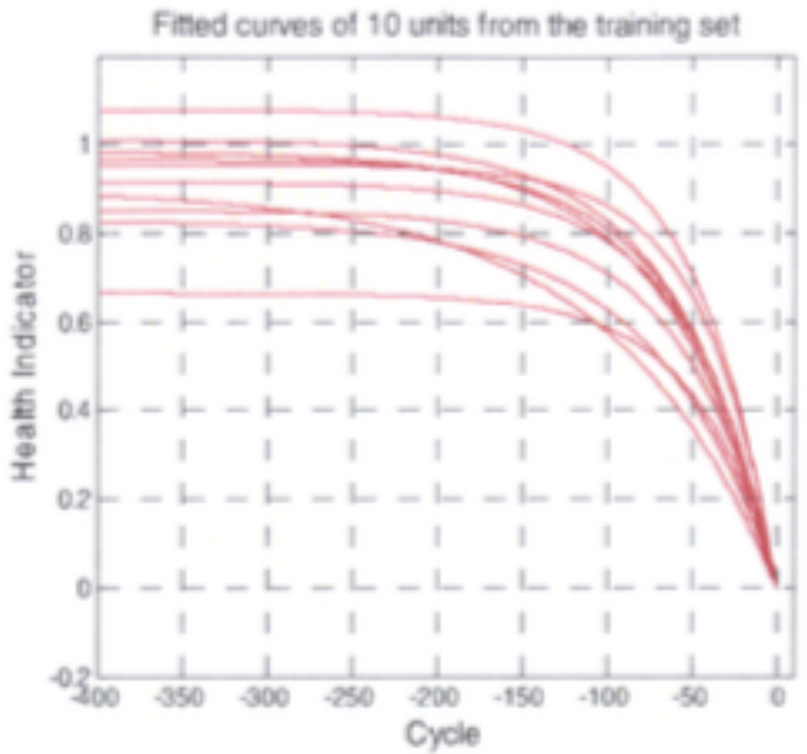
Table 1

A/C No.	Time	Altitude	Mach No	TRA	T2	T24	T30	T50	P2	P15	P30	Nf	Nc	EPR	Ps30	phi	NRf	Nrc	BPR	farB	htBleed	Nf_dmd	PCNfR_dmd	W31	W32	Ops Mode
1	1	10.0047	0.2501	20	489.05	604.13	1499.45	1309.95	10.52	15.49	394.88	2318.87	8770.2	1.26	45.4	372.15	2388.13	8120.83	8.6216	0.03	368	2319	100	28.58	17.1735	
1	2	0.0015	0.0003	100	518.67	642.13	1584.55	1403.96	14.62	21.61	553.67	2388.01	9045.76	1.3	47.29	521.81	2388.15	8132.87	8.3907	0.03	391	2388	100	38.99	23.3619	
1	3	34.9986	0.8401	60	449.44	555.42	1368.17	1122.49	5.48	8	194.93	2222.86	8343.91	1.02	41.92	183.26	2387.95	8063.84	9.3557	0.02	334	2223	100	14.83	8.8555	
1	4	20.0031	0.7005	0	491.19	607.03	1488.44	1249.18	9.35	13.65	334.82	2323.85	8721.53	1.08	44.26	314.84	2388.07	8052.3	9.2231	0.02	364	2324	100	24.42	14.7832	
1	5	42.0041	0.8405	40	445	549.52	1354.48	1124.32	3.91	5.71	138.24	2211.8	8314.56	1.02	41.79	130.44	2387.89	8083.67	9.2986	0.02	330	2212	100	10.99	6.4025	
1	6	20.0032	0.7017	0	491.19	607.37	1480.46	1258.9	9.35	13.65	334.51	2323.94	8711.44	1.08	44.4	315.36	2388.05	8053.17	9.2276	0.02	364	2324	100	24.44	14.7019	
1	7	41.9998	0.84	40	445	549.57	1354.43	1131.44	3.91	5.71	139.11	2211.82	8316.88	1.02	42.09	130.16	2387.88	8082.01	9.3753	0.02	331	2212	100	10.53	6.4254	
1	8	0.0011	0	100	518.67	642.08	1589.55	1407.59	14.62	21.61	553.48	2388.1	9050.35	1.3	47.5	521.74	2388.03	8133.29	8.4339	0.03	391	2388	100	38.98	23.2337	
1	9	0.0011	0.002	100	518.67	642.7	1586.18	1399.01	14.62	21.61	553.9	2388.1	9051.35	1.3	47.3	521.72	2388.08	8132.72	8.3922	0.03	392	2388	100	38.99	23.2412	
1	10	42.0066	0.84	40	445	549.83	1353.19	1125.09	3.91	5.71	138.37	2211.84	8320.04	1.02	41.91	130.32	2387.91	8085.94	9.3667	0.02	330	2212	100	10.75	6.4268	
1	11	25.0051	0.62	80	462.54	537.41	1260.5	1051.56	7.05	9.02	175.86	1915.28	8009.91	0.94	36.66	165.53	2028.24	7866.43	10.8941	0.02	307	1915	84.93	14.28	8.5087	
1	12	35.0029	0.8413	60	449.44	555.85	1360.54	1130.69	5.48	8	195.05	2222.88	8341.87	1.02	41.87	183.41	2387.95	8063.79	9.2878	0.02	335	2223	100	14.69	8.7988	
1	13	42.0029	0.8409	40	445	549.91	1350.9	1123.53	3.91	5.71	139.09	2211.78	8321.2	1.02	42.14	130.6	2387.88	8081.77	9.349	0.02	329	2212	100	10.46	6.3382	
1	14	25.0073	0.6203	80	462.54	537.22	1262.8	1051.01	7.05	9.02	175.35	1915.24	8014.89	0.94	36.88	164.63	2028.14	7870.29	10.916	0.02	306	1915	84.93	14.28	8.5684	
1	15	9.9988	0.25	20	489.05	604.63	1497.87	1302.51	10.52	15.5	394.93	2318.9	8771.08	1.26	45.39	371.84	2388.12	8124.37	8.6496	0.03	369	2319	100	28.84	17.0805	
1	16	9.9987	0.25	20	489.05	604.61	1500.47	1311.39	10.52	15.49	394.44	2318.87	8775.86	1.26	45.52	372.19	2388.08	8127.07	8.6609	0.03	369	2319	100	28.71	17.1759	
1	17	0.0003	0	100	518.67	642.3	1584.57	1410.11	14.62	21.61	554	2388.06	9056.59	1.3	47.44	522.17	2388.1	8133.38	8.434	0.03	392	2388	100	38.81	23.3487	
1	18	10.0066	0.2507	20	489.05	604.23	1502.57	1304.56	10.52	15.49	394.31	2318.93	8778.55	1.26	45.1	372.03	2388.06	8119.39	8.6646	0.03	367	2319	100	28.6	17.1096	
1	19	25.0018	0.62	80	462.54	536.66	1255.21	1053.69	7.05	9.03	174.94	1915.22	8005.22	0.94	36.44	165.27	2028.13	7868.8	10.8969	0.02	308	1915	84.93	14.42	8.5456	
1	20	0.0004	0.0017	100	518.67	642.31	1581.33	1399.44	14.62	21.61	553.41	2388.09	9049.58	1.3	47.38	521.62	2388.06	8132.25	8.4044	0.03	393	2388	100	38.97	23.2494	
1	21	42.003	0.8404	40	445	549.12	1349.16	1117.33	3.91	5.72	138.51	2211.82	8310.18	1.02	41.98	130.48	2387.9	8080.31	9.3488	0.02	330	2212	100	10.54	6.3614	
1	22	0.0004	0	100	518.67	642.34	1589.25	1401.52	14.62	21.61	553.9	2388.12	9051.82	1.3	47.45	521.55	2388.06	8131.87	8.4423	0.03	392	2388	100	38.73	23.3303	
1	23	20.0025	0.7011	0	491.19	607.1	1482.68	1252	9.35	13.66	334.49	2323.91	8716.75	1.08	44.44	314.87	2388.1	8050.94	9.2149	0.02	366	2324	100	24.58	14.6688	
1	24	34.9987	0.84	60	449.44	555.19	1359.28	1131.95	5.48	8	193.97	2222.88	8351.92	1.02	41.86	183.36	2387.94	8063.93	9.3254	0.02	334	2223	100	14.96	8.8405	
1	25	42.0066	0.8401	40	445	549.43	1355.26	1117.68	3.91	5.71	138.33	2211.89	8309.83	1.02	42.08	130.76	2387.84	8078.42	9.3525	0.02	330	2212	100	10.54	6.3772	
1	26	0.0003	0.0004	100	518.67	642.9	1591.72	1409.43	14.62	21.61	553.65	2388.05	9046.5	1.3	47.34	521.87	2388.1	8129.74	8.4058	0.03	394	2388	100	38.89	23.3626	
1	27	25.0031	0.6206	80	462.54	536.89	1267.93	1042.92	7.05	9.03	175.35	1915.28	7999.74	0.94	36.56	164.9	2028.16	7873.32	10.855	0.02	308	1915	84.93	14.21	8.6036	
1	28	0.002	0	100	518.67	641.6	1590.43	1402.64	14.62	21.61	553.95	2388.07	9053.9	1.3	47.36	521.34	2388.1	8133.24	8.4311	0.03	392	2388	100	38.92	23.3587	
1	29	25.0026	0.62	80	462.54	536.59	1256.53	1048.2	7.05	9.03	175.76	1915.25	8005.68	0.94	36.69	164.51	2028.14	7872.87	10.8747	0.02	308	1915	84.93	14.18	8.5572	
1	30	42.0008	0.84	40	445	549.77	1350.63	1133.09	3.91	5.72	138.4	2211.83	8318.25	1.02	42.06	129.99	2387.91	8075.85	9.3897	0.02	332	2212	100	10.62	6.4269	
1	31	20.0045	0.7006	0	491.19	607.38	1483.93	1256.88	9.35	13.66	334.3	2323.91	8715.5	1.08	44.33	314.94	2388.12	8059.58	9.2111	0.02	366	2324	100	24.48	14.7826	
1	32	25.0013	0.6219	80	462.54	537.26	1259.83	1045	7.05	9.03	175.83	1915.24	8009.06	0.94	36.51	164.73	2028.11	7866.12	10.872	0.02	305	1915	84.93	14.29	8.5339	
1	33	42.003	0.8413	40	445	548.93	1353.67	1121.32	3.91	5.71	138.59	2211.85	8309.86	1.02	42.08	130.94	2387.93	8078.78	9.3014	0.02	331	2212	100	10.65	6.3294	
1	34	0.0019	0.0012	100	518.67	642.47	1584.87	1402.4	14.62	21.61	553.92	2388.08	9050.25	1.3	47.38	521.92	2388.1	8126.67	8.4461	0.03	393	2388	100	38.96	23.2884	

Actual 555.28

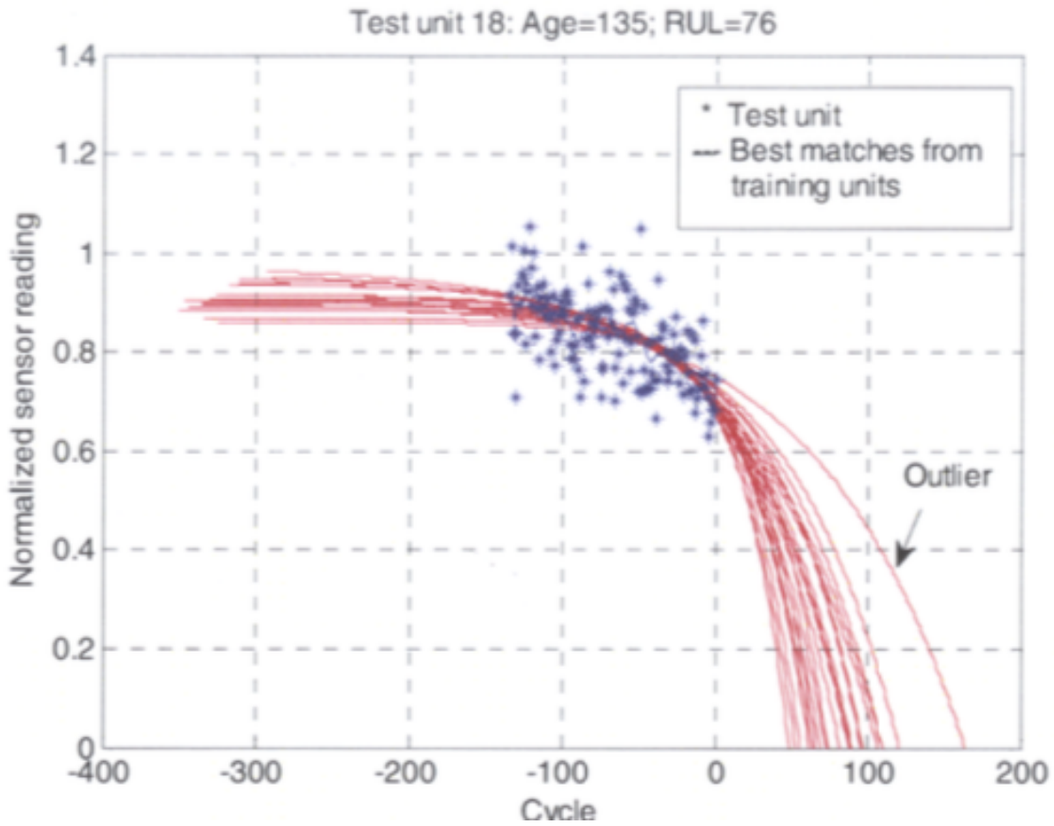
MODEL IDENTIFICATION





Exponential degradation curves are fitted to the transformed HI values of the units as shown, these are then stored for later use in estimating the RUL of the unknown test data

RUL ESTIMATION



RUL estimation from the best matched training units that have run-to-failure history. Each curve represents the degradation pattern of one unit. The final RUL of the test unit is estimated based on the RULs given by each matched training unit, preference given to one with higher similarity score.