Docket No.: SA-510
Exhibit No.: 9O

NATIONAL TRANSPORTATION SAFETY BOARD

Washington, D.C.

Hydraulic Fluid Subgroup Report
Report 95-44

NATIONAL TRANSPORTATION SAFETY BOARD
Office of Research and Engineering
Materials Laboratory Division
Washington, D.C. 20594

January 3, 1994

Systems Group--Hydraulic Fluid Sub Group Chairman's Factual Report Report No. 95-44

A. ACCIDENT

Place	: Aliquippa, Pennsylvania
Date	: September 8, 1994
Vehicle	: Boeing 737-3B7, N513AU
Operator	: USAir Flight 427
NTSB No.	: DCA 94-M-A076
Investigator	: Greg Phillips (AS-40)

B. COMPONENTS EXAMINED

Hydraulic Fluid Samples

C. GROUP MEMBERS

Monsanto	Boeing	Parker Bertea Aerospace
Frank Jakse Senior Research Specialist	Jean Ray Senior Specialist Engineer	Nandlal Matai Senior Engineer
Vicki Chlanda Research Chemist	John Calvin System/Component Analyst	Bob Moran Director, Product Integrity
Don Parker Technical Associate		

D. DETAILS OF EXAMINATION

1.0 General

Testing of hydraulic fluid samples from USAir flight 427 and other airplanes occurred at the Queeny Plant and the Corporate Research laboratories of Monsanto Co. in St Louis, Missouri, the chemical laboratories of Tinker Air Force Base Oklahoma City, Oklahoma, and at the Customer Support laboratories for Parker Bertea Aerospace (Parker) in Irvine, California. Analyses were performed in accordance with BMS 3-11J[1], ARP 598B[2],

applicable ASTM[3] standards or under the direction of the Hydraulic Fluids Sub Group. Particle contamination classifications were based on the rating system established by NAS 1638[4]. Boeing 737 series airplanes use hydraulic fluid in compliance with BMS 3-11 Type IV. At present there are two qualified manufacturers of BMS 3-11, Type IV fluid, Monsanto which makes Skydrol LD-4 and Skydrol 500B-4, and Chevron, which produces Hyjet IV-A^{Plus}. Boeing originally delivered N513AU with Hyjet IV-A hydraulic fluid, which is no longer produced. USAir presently uses Skydrol LD-4 fluid.

2.0 Analytical Procedures

2.1 Wet Chemical Analyses

The Monsanto Queeny laboratory conducted wet chemical analyses. After visual inspection for color and clarity, the samples were analyzed for percent water content (ASTM D-1744), acid number (ASTM D-974-87), specific gravity (Calculating Density Meter Mettler DMA46), and chlorine content (Dohrman MCTS-120 Automated Chlorine Analyzer). Each sample was also analyzed by gas chromatography (GC).

2.2 Particle Count Analysis by Laser-Light Scattering Technique

Particle counts were determined on samples using an automated laser light-scattering method. Samples were mechanically agitated for six minutes just prior to measurement to ensure homogeneity. A HIAC/Royco model 8000A was used to measure particle levels in five particle size ranges, as defined in NAS 1638. Fluid samples were retained in their original bottles throughout this procedure in order to minimize inadvertent contamination.

Approximately 50 ml of sample was consumed in this test. All automatic particle count results reported have been are normalized to 100 ml sample size. Particle contamination results and class ratings per NAS 1638 are reported in attached tables.

2.3 Particle Count Analysis by Manual Counting Method

Manual particle counting was conducted on fluid samples that had insufficient volume for the automatic laser light-scattering technique. Fluid samples were analyzed per Aerospace Recommended Practice 598B (ARP 598B) at either Tinker Air Force Base, Oklahoma City, Oklahoma, or the Parker laboratory, Irvine, California. Tinker Air Force

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[1]Boeing Material Specification 3-11 revision J, dated 22-DEC-93 by Boeing Commercial Airplane Co.

[2]Aerospace Recommended Practice published Dec, 1986 by the Society of Automotive Engineers (SAE),

[3]American Society for Testing and Materials

[4]National Aerospace Standard published Jan, 1964 by the Aerospace Industries Association of America, Inc.

Base used Millipore cellulose nitrate filter elements (Type AA, 0.8 um pore size). These filters were noted to locally darken and fragment after filtering Skydrol fluids. Parker used polysulfone filter elements (0.8 um pore size).

The entire available fluid volume was used in the manual particle count analyses. After filtering the fluid sample into precleaned glassware, the sample bottle was rinsed thoroughly with precleaned solvent and the solvent filtered through the filter element. The original sample volume was calculated by subtracting the tare weight of the bottle from the gross weight of the bottle and fluid sample, then multiplying by 1.05 to account for the specific gravity of the fluid. All manual particle count results reported have been normalized to a 100 ml sample size. Particle contamination results and class ratings per NAS 1638 are reported in Appendices.

2.4 Microscopy Sample Preparation

Hydraulic fluid samples #39, #40, #56, #59, #64, #65, #68, and #71 were prepared for analysis by hand shaking each sample for 30 seconds, removing 10 ml of fluid, filtering using a Poretics polycarbonate membrane filter (0.8 um pore size), and rinsing with 10 ml of acetone. Samples #51 and #52 were prepared by adding ~3 ml of Skydrol LD-4, ultrasonicating, filtering using a Poretics membrane, rinsing with additional Skydrol and then with acetone. The remaining samples analyzed for composition at the research laboratories of Monsanto had been filtered at either Tinker AFB or Parker prior to submission.

2.5 Particle Characterization by Fourier Transform Infrared (FTIR) Microscopy

FTIR was performed at Monsanto Corporate Research laboratories on selected particles to determine compound information. A few particles were removed from each filter pad and placed on the surface of individual potassium bromide (KBr) crystals, an inert substrate. Representative particles were selected based on differing visual appearances and not all of the particles from any given sample were analyzed. Infrared spectra were then acquired using a Spectra-Tech microscope coupled to a Nicolet 800 FTIR spectrometer. Data were collected from 3800 cm^{-1} to 700 cm^{-1} at 4 cm^{-1} resolution, co-adding 128 scans.

2.6 Particle Characterization by Electron Probe Microscopy

Scanning electron microscopy/electron probe microanalysis was performed on selected filter sections at Monsanto Corporate Research laboratories to provide surface images and elemental detection on the filtered particles. Subsequent to FTIR examination, a random portion of each filter element, not to exceed 25% of the filter area, was selected for examination by this technique. A Cameca MicroBeam system having both surface imaging (back scatter electron) and element detection (energy dispersive) capabilities was used for data collection. Three representative areas of the isolated filter were examined at

200 times magnification. For each representative area, a back scatter surface image and a series of element specific images (dot maps) were collected.

3.0 As-received Fluid Samples

Three groups of samples were received and analyzed.

1. In-service samples from three airlines (referenced as in-service samples).
2. Rudder power control unit (RPCU) samples removed from six PCU's received at Parker for service (referenced as in-service RPCU samples).
3. Samples from the accident aircraft, further divided into two sub sets.
   i. From the rudder PCU (referenced as accident PCU samples).
   ii. From other components of the airplane (referenced as other accident samples).

Sample sizes varied with the in-service samples and the B link cavity RPCU samples containing about 200 milliliters (ml) each and the remaining samples were, in general, less than 100 ml. The volume of sample was the main determining factor in establishing the type and number of individual analyses on many of the samples. Sample collection protocols were not reported for the Southwest and United Airline samples. USAir in service samples were reportedly obtained following the instructions set forth in USAir Campaign Directive No. 29H00801.

Individual samples and data sets were assigned a discrete integer sample number (XX) as they were received. Additional or duplicate test data were assigned a decimal extension on the basic sample number (XX.X).

3.1 In-Service Sample Analysis

Analyses were performed on 104 in-service samples of fluid from 21 airplanes. Each airplane was sampled at four locations: "A system reservoir", "A system rudder PCU return", "B system reservoir" and "B system rudder PCU return". Eleven of the airplanes were from the USAir fleet (sample #1 through #44) five from Southwest Airlines (#74 through #113) and five from United airlines (#114 through #133). Two samples from each sample point were received from Southwest Airlines. See Table A for test data and results.

An automatic laser light-scattering particle counting method was performed on all of the in-service samples. The particle count data were converted to particle contamination class ratings for each size range and an overall fluid class was assigned per NAS 1638. For example, a fluid that contained class 5, 6, 7, 8 and 9 contamination in the five measured size ranges is considered to be a class 9 fluid.

From the classification data it was determined that, in total, the in-service samples ranged from a class 1 to class 13 and had a mean fluid classification of 7.5[5]. The fluid class

[5]Standard deviation 1.95

data from USAir averaged 7.6 with Southwest and United fluids averaging 8.5 and 5.7, respectively[6].

Wet chemical analyses were performed on the in-service samples from each airplane. The test results are presented in Table A. All of the samples met the applicable limits set for a new fluid in BMS 3-11.

Each of these samples were analyzed by gas chromatography (GC) to detect other fluid contaminates, such as jet fuel or lubricating oils. This method also determined the relative content of Skydrol and Hyjet in the sample. None of the in-service samples were found to be contaminated with other fluids.

3.2 In-service RPCU samples

Two fluid samples were removed upstream of the filters and one from the link cavity of each of the six in-service RPCU's. These samples were labeled as being from the "large filter", "yaw damper filter" and the "B system link cavity" and are listed in Table B as samples #56 through #73. The B link cavity samples were each in excess of 150 ml while the samples from upstream of the large filter and the yaw damper filter were all less than 100 ml. Automatic particle counts and GC analysis were performed on the six samples from the B system link cavities of the in-service RPCUs. Due to sample size limitations, the particulate contamination levels for these samples were determined by the manual count method as described above.

Ten samples (#56 through #65) from four of the in-service RPCUs were filtered and counted at Tinker AFB and eight samples (#66 through #73) were filtered and manually counted at Parker. In addition to samples #66 through #73, Parker manually counted one sample (#65) that had been previously filtered and counted at Tinker AFB.

3.3 Samples from the Accident Airplane

3.31 Samples from the Accident Airplane Rudder PCU

On September 29, 1994[7] six hydraulic fluid samples from the accident airplane and one sample from the Parker hydraulic test stand were analyzed at Monsanto's fluids laboratory. Two of these samples (#138 and #139) were from the standby rudder PCU and were reportedly completely consumed in testing. Sample #139 had been intentionally spiked by the NTSB with a small quantity of chlorine bleach prior to analysis. The results of the tests for this sample were therefore invalidated. The remaining liquid portions of these samples were retained and further analyzed as samples #51 through #55. After automatic particle counting, samples #51 and #52 were centrifuged in an attempt to separate the particles. During the separation process the samples were inadvertently contaminated by

[6]Standard deviations of 1.74 for USAir, 1.78 for Southwest and 1.30 for United.

[7]Prior to the formation of the Hydraulic Fluid Sub Group.

material that was later determined to be polystyrene. The polystyrene contamination was subsequently removed by filtering the samples and flushing with clean filtered Skydrol. The particle contamination in samples #53, #54 and #55 were measured and classified by manual counting.

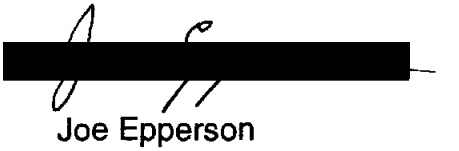
In addition to the above listed samples, four samples from the accident RPCU were retained at Parker. These samples (#134 through #137) were filtered and manually counted by Parker. Unfortunately, the count method did not follow the particle size ranges listed in ARP 598 and NAS 1638 and were therefore not comparable.

3.32 Other Accident Samples

Fluid samples were also received from other components on the aircraft, identified in Table C. These are identified in Appendix C as samples #45 through #50. Due to the possibility of artifacts introduced by the reported extensive fire and mechanical damage and to the reported extensive disassembly necessary for fluid sample retrieval, these samples were retained but not subjected to particle counting. Gas chromatography spectra were acquired from all samples and specific gravity measurements were made on samples #45, #46, #48 and #50.

3.4 Particle Identification on Accident Samples

The filtered particles from several selected samples were subjected to FTIR and EDS as described in the Analytical Procedures section above. The selected samples included two from the in-service group (#39 and #40), eight from USAir flight 427 (#51, #52, #53, #55, #134, #135, #136 and #137) and eleven from the link cavities of the in-service RPCUs (#56, #57, #58, #59, #60, #61, #62, #63 #64, #65, #68 and #71). Classifications for the analyzed particle types are presented in Table D. Due to the complexity of FTIR spectra, matches to specific chemical compounds were not always possible, in which case the generic chemical group of type was listed in the table. For the particles subjected to EDS analysis, the table listing show elements identified in each particle type but not their relative percentage concentrations.



Joe Epperson
Senior Metallurgist

Table A: In Service Airplane Fluid Data

SAMPLE NUMBER	AC ID	AIRLINE	SAMPLED BY	HYD SYSTEM	SAMPLE LOCATION	SAMPLE SIZE	COUNT TYPE	AT	5 to 15 MICRON	15 to 25 MICRON	25 to 50 MICRON	50 to100 MICRON	>100 MICRON	FLUID CLASS	MOISTURE (Wt %)	ACID NO (mg KOH/gm)	CHLORINE (ppm)	SPECIFIC GRAVITY	SKYDROL /HYJET (%/%)	OTHER TESTS
1	392	USAir	USAir	B	Rudder PCU	~200	Auto	M	4630	326	86	14	0	5						
2	392	USAir	USAir	A	Rudder PCU	~200	Auto	M	13562	1326	328	22	2	6						
3	392	USAir	USAir	B	Reservoir	~200	Auto	M	22180	554	120	14	2	7	0.43	0.34	17	1.0118	81/19	GC
4	392	USAir	USAir	A	Reservoir	~200	Auto	M	62654	1798	242	18	2	8	0.4	0.35	23	1.0118	84/16	GC
5	389	USAir	USAir	B	Rudder PCU	~200	Auto	M	109524	11838	2694	212	36	9						
6	389	USAir	USAir	A	Rudder PCU	~200	Auto	M	20754	2082	414	40	2	7						
7	389	USAir	USAir	B	Reservoir	~200	Auto	M	13320	1242	344	52	12	6	0.34	0.19	32	1.0119	87/13	GC
8	389	USAir	USAir	A	Reservoir	~200	Auto	M	9234	922	224	24	8	6	0.35	0.29	22	1.0122	83/17	GC
9	523	USAir	USAir	B	Rudder PCU	~200	Auto	M	93948	12370	2746	286	40	9						
10	523	USAir	USAir	A	Rudder PCU	~200	Auto	M	19854	2220	384	36	6	7						
11	523	USAir	USAir	B	Reservoir	~200	Auto	M	20804	1920	582	72	12	7	0.38	0.25	32	1.0109	94/6	GC
12	523	USAir	USAir	A	Reservoir	~200	Auto	M	25950	3002	998	158	32	8	0.23	0.1	15	1.0172	100/0	GC
13	588	USAir	USAir	B	Rudder PCU	~200	Auto	M	3762	156	32	0	0	4						
14	588	USAir	USAir	A	Rudder PCU	~200	Auto	M	2098	182	70	12	0	5						
15	588	USAir	USAir	B	Reservoir	~200	Auto	M	10336	1336	638	60	4	7	0.31	0.1	19	1.012	99/1	GC
16	588	USAir	USAir	A	Reservoir	~200	Auto	M	21956	2882	1354	268	36	8	0.28	0.15	27	1.0126	99/1	GC
17	573	USAir	USAir	B	Rudder PCU	~200	Auto	M	12236	1476	194	22	0	6						
18	573	USAir	USAir	A	Rudder PCU	~200	Auto	M	18796	1542	288	28	6	7						
19	573	USAir	USAir	B	Reservoir	~200	Auto	M	10486	1198	404	44	6	6	0.33	0.38	20	1.0101	83/17	GC
20	573	USAir	USAir	A	Reservoir	~200	Auto	M	9528	1194	420	38	2	6	0.41	0.54	34	1.0098	75/25	GC
21	581	USAir	USAir	B	Rudder PCU	~200	Auto	M	127580	17930	2760	118	12	9						
22	581	USAir	USAir	A	Rudder PCU	~200	Auto	M	19160	1134	294	60	4	7						
23	581	USAir	USAir	B	Reservoir	~200	Auto	M	206574	20118	4806	574	102	10	0.28	0.14	14	1.0104	98/2	GC
24	581	USAir	USAir	A	Reservoir	~200	Auto	M	37552	7040	3954	766	126	10	0.32	0.19	27	1.0104	95/5	GC
25	514	USAir	USAir	B	Rudder PCU	~200	Auto	M	21106	2124	500	56	12	7						
26	514	USAir	USAir	A	Rudder PCU	~200	Auto	M	38090	4414	1242	150	8	8						
27	514	USAir	USAir	B	Reservoir	~200	Auto	M	17628	1060	264	26	4	7	0.22	0.1	16	1.0106	99/1	GC
28	514	USAir	USAir	A	Reservoir	~200	Auto	M	26408	494	70	6	2	4	0.26	0.14	25	1.0107	99/1	GC
29	335	USAir	USAir	B	Rudder PCU	~200	Auto	M	39720	2568	574	38	6	8						
30	335	USAir	USAir	A	Rudder PCU	~200	Auto	M	24962	1544	304	28	0	7						
31	335	USAir	USAir	B	Reservoir	~200	Auto	M	10272	1096	298	28	4	6	0.39	0.24	29	1.0096	82/18	GC
32	335	USAir	USAir	A	Reservoir	~200	Auto	M	91804	5138	956	66	10	9	0.44	0.59	30	1.0104	78/22	GC
33	346	USAir	USAir	B	Rudder PCU	~200	Auto	M	51866	7108	1332	114	16	8						

SAMPLE NUMBER	AC ID	AIRLINE	SAMPLED BY	HYD SYSTEM	SAMPLE LOCATION	SAMPLE SIZE	COUNT TYPE	AT	5 to 15 MICRON	15 to 25 MICRON	25 to 50 MICRON	50 to100 MICRON	>100 MICRON	FLUID CLASS	MOISTURE (Wt %)	ACID NO (mg KOH/gm)	CHLORINE (ppm)	SPECIFIC GRAVITY	SKYDROL /HYJET (%/%)	OTHER TESTS
34	346	USAir	USAir	A	Rudder PCU	~200	Auto	M	62566	7276	1376	122	34	8						
35	346	USAir	USAir	B	Reservoir	~200	Auto	M	35560	4224	1482	192	74	9	0.27	0.09	16	1.0104	98/2	GC
36	346	USAir	USAir	A	Reservoir	~200	Auto	M	54050	7222	3488	650	94	9	0.31	0.17	22	1.0107	96/4	GC
37	337	USAir	USAir	B	Rudder PCU	~200	Auto	M	17300	1696	510	60	14	7						
38	337	USAir	USAir	A	Rudder PCU	~200	Auto	M	23658	2286	618	58	14	7						
39	337	USAir	USAir	B	Reservoir	~200	Auto	M	777268	145602	58634	8172	1368	13	0.33	0.2	17	1.0108	96/4	GC
40	337	USAir	USAir	A	Reservoir	~200	Auto	M	108856	17930	7708	990	170	10	0.37	0.24	22	1.0115	95/5	GC
41	349	USAir	USAir	B	Rudder PCU	~200	Auto	M	63490	7714	1448	110	12	8						
42	349	USAir	USAir	A	Rudder PCU	~200	Auto	M	204576	19978	4358	694	208	10						
43	349	USAir	USAir	B	Reservoir	~200	Auto	M	30121	3500	1280	208	34	8	0.27	0.05	9	1.0109	99/1	GC
44	349	USAir	USAir	A	Reservoir	~200	Auto	M	149660	7674	1592	136	30	10	0.3	0.05	11	1.0106	97/3	GC
													Average of USAir Samples	**7.6**	**1.74 Standard Deviation**					
74	682	SW	SW	A	Rudder Return	~200	Auto	M	85516	6238	1448	132	12	9						
75	682	SW	SW	A	Reservoir	~200	Auto	M	58032	8190	3322	394	62	9	0.48	0.35	14	1.0041	9/91	GC
76	682	SW	SW	B	Rudder Return	~200	Auto	M	56482	4452	1042	90	10	8						
77	682	SW	SW	B	Reservoir	~200	Auto	M	13334	1970	724	74	14	7	0.48	0.33	25	1.0033	8/92	GC
78	682	SW	SW	A	Rudder Return	~200	Auto	M	16272	1644	500	40	6	6						
79	682	SW	SW	A	Reservoir	~200	Auto	M	20248	2418	686	84	12	7						
80	682	SW	SW	B	Rudder Return	~200	Auto	M	26934	3456	1134	136	20	8						
81	682	SW	SW	B	Reservoir	~200	Auto	M	8074	952	276	38	14	6						
82	337	SW	SW	A	Rudder Return	~200	Auto	M	71820	5112	1214	130	10	8						
83	337	SW	SW	A	Reservoir	~200	Auto	M	19424	2180	698	100	22	7	0.49	0.34	25	1.0016	0/100	GC
84	337	SW	SW	A	Rudder Return	~200	Auto	M	62136	4152	1004	88	8	8						
85	337	SW	SW	B	Reservoir	~200	Auto	M	247806	45938	20114	2482	200	12	0.36	0.24	17	1.0009	0/100	GC
86	337	SW	SW	B	Rudder Return	~200	Auto	M	63336	4102	1038	84	20	8						
87	337	SW	SW	A	Reservoir	~200	Auto	M	17370	2008	704	86	14	7						
88	337	SW	SW	B	Rudder Return	~200	Auto	M	280210	25768	7026	414	70	10						
89	337	SW	SW	B	Reservoir	~200	Auto	M	67934	10494	4472	572	70	10						
90	327	SW	SW	A	Rudder Return	~200	Auto	M	133980	24722	10664	1346	138	11						
91	327	SW	SW	A	Reservoir	~200	Auto	M	131814	24386	10484	1196	102	11	0.5	0.33	24	1.0028	7/93	GC
92	327	SW	SW	B	Rudder Return	~200	Auto	M	87282	4384	1198	96	12	9						
93	327	SW	SW	B	Reservoir	~200	Auto	M	46788	2062	618	108	8	8	0.4	0.24	18	1.0013	6/94	GC
94	327	SW	SW	A	Rudder Return	~200	Auto	M	56668	3112	842	104	16	8						
95	327	SW	SW	A	Reservoir	~200	Auto	M	50640	8236	3106	420	52	9						

SAMPLE NUMBER	AC ID	AIRLINE	SAMPLED BY	HYD SYSTEM	SAMPLE LOCATION	SAMPLE SIZE	COUNT TYPE	AT	5 to 15 MICRON	15 to 25 MICRON	25 to 50 MICRON	50 to100 MICRON	>100 MICRON	FLUID CLASS	MOISTURE (Wt %)	ACID NO (mg KOH/gm)	CHLORINE (ppm)	SPECIFIC GRAVITY	SKYDROL /HYJET (%/%)	OTHER TESTS
96	327	SW	SW	B	Rudder Return	~200	Auto	M	109584	4556	1114	92	18	9						
97	327	SW	SW	B	Reservoir	~200	Auto	M	39198	2538	814	70	8	8						
98	314	SW	SW	A	Rudder Return	~200	Auto	M	61798	5154	1816	194	26	8						
99	314	SW	SW	A	Reservoir	~200	Auto	M	9630	1014	370	68	14	6	0.49	0.29	14	1.0013	0/100	GC
100	314	SW	SW	B	Rudder Return	~200	Auto	M	73572	5622	1404	98	16	9						
101	314	SW	SW	B	Reservoir	~200	Auto	M	143024	32078	20042	3562	362	12	0.36	0.25	12	1	0/100	GC
102	314	SW	SW	A	Rudder Return	~200	Auto	M	154204	11220	3380	380	42	10						
103	314	SW	SW	A	Reservoir	~200	Auto	M	35696	4368	1714	280	42	8						
104	314	SW	SW	B	Rudder Return	~200	Auto	M	83990	5006	1226	94	12	9						
105	314	SW	SW	B	Reservoir	~200	Auto	M	23694	5356	3298	616	88	9						
106	387	SW	SW	A	Rudder Return	~200	Auto	M	3090	344	138	16	2	4						
107	387	SW	SW	A	Reservoir	~200	Auto	M	2200254	369546	93584	5226	180	13	0.26	0.2	33	0.9997	0/100	GC
108	387	SW	SW	B	Rudder Return	~200	Auto	M	39390	2686	890	124	20	8						
109	387	SW	SW	B	Reservoir	~200	Auto	M	42824	8688	3392	352	52	9	0.34	0.19	27	1.0011	0/100	GC
110	387	SW	SW	A	Rudder Return	~200	Auto	M	36568	3880	1406	210	34	8						
111	387	SW	SW	A	Reservoir	~200	Auto	M	23392	4040	1590	208	30	8						
112	387	SW	SW	B	Rudder Return	~200	Auto	M	7506	922	290	34	6	6						
113	387	SW	SW	B	Reservoir	~200	Auto	M	21924	4454	1928	228	44	8						
											Average of SW Samples			**8.5**	**1.78 Standard Deviation**					
114	1	UA	UA	A	Rudder Return	~200	Auto	M	12982	626	114	14	12	6						
115	1	UA	UA	A	Reservoir	~200	Auto	M	21190	3498	1776	252	50	8	0.38	0.34	14	1.0007	0/100	GC
116	1	UA	UA	B	Rudder Return	~200	Auto	M	20492	1934	562	74	14	7						
117	1	UA	UA	B	Reservoir	~200	Auto	M	3334	350	158	28	2	5	0.35	0.29	24	1.0008	0/100	GC
118	2	UA	UA	A	Rudder Return	~200	Auto	M	18330	2266	876	128	14	7						
119	2	UA	UA	A	Reservoir	~200	Auto	M	3524	142	24	2	0	4	0.35	0.28	27	1.0008	0/100	GC
120	2	UA	UA	B	Rudder Return	~200	Auto	M	28004	2750	852	102	26	7						
121	2	UA	UA	B	Reservoir	~200	Auto	M	2670	168	66	6	0	4	0.35	0.29	29	1.0008	0/100	GC
122	3	UA	UA	A	Rudder Return	~200	Auto	M	4534	508	128	26	12	6						
123	3	UA	UA	A	Reservoir	~200	Auto	M	11738	1520	590	80	22	7	0.33	0.3	10	1.0011	0/100	GC
124	3	UA	UA	B	Rudder Return	~200	Auto	M	7998	1150	398	54	2	6	0.35	0.33	18	1.0011	0/100	GC
125	3	UA	UA	B	Reservoir	~200	Auto	M	19052	1982	612	62	8	7						
126	4	UA	UA	A	Rudder Return	~200	Auto	M	2636	238	68	6	2	4						
127	4	UA	UA	A	Reservoir	~200	Auto	M	4248	576	268	48	16	7	0.36	0.38	13	1.0013	0/100	GC
128	4	UA	UA	B	Rudder Return	~200	Auto	M	5144	286	66	6	6	5						

SAMPLE NUMBER	AC ID	AIRLINE	SAMPLED BY	HYD SYSTEM	SAMPLE LOCATION	SAMPLE SIZE	COUNT TYPE	AT	5 to 15 MICRON	15 to 25 MICRON	25 to 50 MICRON	50 to100 MICRON	>100 MICRON	FLUID CLASS	MOISTURE (Wt %)	ACID NO (mg KOH/gm)	CHLORINE (ppm)	SPECIFIC GRAVITY	SKYDROL /HYJET (%/%)	OTHER TESTS
129	4	UA	UA	B	Reservoir	~200	Auto	M	3382	350	110	14	6	5	0.36	0.33	12	1.0012	0/100	GC
130	5	UA	UA	A	Rudder Return	~200	Auto	M	6118	398	96	14	2	5						
131	5	UA	UA	A	Reservoir	~200	Auto	M	3526	292	82	12	0	4	0.33	0.29	17	1.0011	0/100	GC
132	5	UA	UA	B	Rudder Return	~200	Auto	M	1336	156	28	12	2	4						
133	5	UA	UA	B	Reservoir	~200	Auto	M	4284	490	204	36	8	6	0.35	0.25	32	1.0011	0/100	GC
													Average of UA Samples	**5.7**			**1.30 Standard Deviation**			
													Average of All Samples	**7.5**			**1.95 Standard Deviation**		

Table B: In Service RPCU Fluid Data

SAMPLE NUMBER	AC ID	AIRLINE	SAMPLED BY	SERVICE TIME (HRS)	HYD SYSTEM	SAMPLE LOCATION	SAMPLE SIZE (ml)	COUNT TYPE	AT	5 to 15 MICRON	15 to 25 MICRON	25 to 50 MICRON	50 to100 MICRON	>100 MICRON	FIBERS	FLUID CLASS	SKYDROL - HYJET (%)	OTHER TESTS
56	RPCU 1528A	USAir	Parker		B	Link Cavity	68.67	Manual	T	261,521	33,114	15,413	3,481	1,694	221	13	79/21	GC
56.1	RPCU 1528A	USAir	Parker	9,137	B	Link Cavity	~140	Auto	M	272,606	29,228	8,186	846	122		11		GC
57	RPCU 1528A	USAir	Parker		B	Yaw Damp Filter	19	Manual	T	323,365	35,932	14,369	1,415	458	632	11		
58	RPCU 1528A	USAir	Parker		B	Large filter	31.29	Manual	T	137,483	17,455	5,454	2,963	2,195	1,373	13		
59	RPCU 128A	USAir	Parker		B	Link Cavity	75.6	Manual	T	43,807	11,140	4,817	452	280	128	11	100/0	GC
59.1	RPCU 128A	USAir	Parker	53,523	B	Link Cavity	~130	Auto	M	363,294	24,342	5,378	556	136		11		
60	RPCU 128A	USAir	Parker		B	Yaw Damper	21.76	Manual	T									
61	RPCU 128A	USAir	Parker		B	Large Filter	78.65	Manual	T			3,255	435	1,252	126	13		
62	RPCU 1097A	USAir	Parker		B	Large Filter	21.31	Manual	T	67,272	16,019	15,988	8,007	641	243	13		
63	RPCU 1097A	USAir	Parker		B	Yaw Damper	17.85	Manual	T	76,508	57,379	51,641	7,646	791	185	13		
64	RPCU 1097A	USAir	Parker		B	Link Cavity	62.9	Manual	T	49,397	6,747	2,714	1,537	580	54	12	92/8	GC
64.1	RPCU 1097A	USAir	Parker	7,541	B	Link Cavity	~120	Auto	M	275,282	35,756	12,386	1,750	414		11		
65	RPCU 1822A	China Air	Parker		B	Link Cavity	81.59	Manual	T	1,016,914	60,990	22,599	1,516	1,554	308	13	88/12	GC
65.1	RPCU 1822A	China Air	Parker	15,308	B	Link Cavity	~140	Auto	M	1,581,310	94,774	16,712	1,396	218		13		
65.2	RPCU 1822A	China Air	Parker	15,308	B	Link Cavity	81.6	Manual	P	322,639	66,805	10,455	2,033	1,835	164	13		
66	RPCU 1822A	China Air	Parker		B	Yaw Damp Filter	15	Manual	P	1,242,890	185,814	5,661	733	573	60	13		
67	RPCU 1822A	China Air	Parker		B	Large filter	5	Manual	P			132,575	17,171	7,288	280	13		
68	RPCU 2665A	Qantis	Parker		B	Link Cavity	65.8	Manual	P	56,693	9,606	6,091	1,124	592	46	12	0/100	GC
68.1	RPCU 2665A	Qantis	Parker	6,932	B	Link Cavity	~120	Auto	M	575,326	31,636	8,576	1,062	162		12		
69	RPCU 2665A	Qantis	Parker		B	Yaw Damp Filter	20.9	Manual	P	277,732	40,354	5,958	1,053	718	249	12		
70	RPCU 2665A	Qantis	Parker		B	Large filter	26.25	Manual	P	448,762	29,486	4,583	2,617	5,257	1,829	13		
71	RPCU 1633A	Boeing	Parker		B	Link Cavity	67.4	Manual	P	809,375	220,736	67,141	10,117	908	30	13	48/52	GC
71.1	RPCU 1633A	Boeing	Parker		B	Link Cavity	~120	Auto	M	1,390,582	111,114	18,178	1,568	370		13		
72	RPCU 1633A	Boeing	Parker		B	Yaw Damp Filter	11.2	Manual	P	1,009,880	193,146	72,808	1,958	899	142	13		
73	RPCU 1633A	Boeing	Parker		B	Large filter	29.4	Manual	P	2,825,850	611,565	638,980	90,680	2,857	150	13		
																In Service RPCU Average	**12.4**	
																Standard Deviation	**0.83**	

Table C: Accident Airplane Fluid Data

SAMPLE NUMBER	AC ID	AIRLINE	SAMPLED BY	HYD SYSTEM	SAMPLE LOCATION	SAMPLE SIZE	COUNT TYPE	AT	5 to 15 MICRON	15 to 25 MICRON	25 to 50 MICRON	50 to100 MICRON	>100 MICRON	FIBERS	FLUID CLASS	MOISTURE (Wt %)	ACID NO (mg KOH/gm)	CHLORINE (ppm)	SPECIFIC GRAVITY	SKYDROL-HYJET (%/%)	OTHER TESTS
45	Flt 427	USAir	Parker		Aileron PCU Manifold Rod End cyl	<20													In process		GC
46	Flt 427	USAir	Parker		Aileron PCU Servo Valve	<20													In process		GC
47	Flt 427	USAir	Parker		Aileron PCU Filter Bowl	<10															GC
48	Flt 427	USAir	Parker		Aileron PCU Flt Spoiler Anti Cavitation Valve	~40													In process		GC
49	Flt 427	USAir	Parker		Aileron PCU Manifold Outside Filter	<10															GC
50	Flt 427	USAir	Parker		Aileron PCU #3 Flt Spoiler	~40													In process		GC
51	Flt 427	USAir	Parker	B	Link Cavity	~70	Auto	M	990,506	90,648	19,294	2,556	362		12	0.55	0.54	46	1.0155	84/16	GC
52	Flt 427	USAir	Parker	A	Return #1	~70	Auto	M	318,062	28,978	5,536	670	108		11	0.38	0.34	11	1.0417	97/3	GC
53	Flt 427	USAir	Parker	A	Return #2	50.4	Manual	T	170,032	75,871	10,161	289	160	239	11						
53.1	Flt 427	USAir	Parker	A	Return #2	~100	Auto	M	72,570	7,596	2,072	200	16		9	0.38	0.13	11	1.0503	97/3	GC
54	Flt 427	Parker	Parker		test stand	~90	Auto	M	2,918	532	220	180	0		8	0.43	0.19	15	1.0493	96/4	GC
55	Flt 427	USAir	Parker	A	Return #3	30 est	Manual	T	322,994	109,470	30,349	851	816	410	12						
55.1	Flt 427	USAir	Parker	A	Return #3	~80	Auto	M	54,380	6,496	2,400	302	44		9	0.38	0.37	11	1.0503	97/3	GC
134	Flt 427	USAir	Parker	A	Main Filter	unk	Nonstd	P													
135	Flt 427	USAir	Parker	B	Link Cavity	unk	Nonstd	P													
136	Flt 427	USAir	Parker	B	Yaw Damper	unk	Nonstd	P													
137	Flt 427	USAir	Parker	B	Main Filter	unk	Nonstd	P													
138	Flt 427	USAir	Parker	Stby	Standby RPCU lines	45	Auto	M	381,128	54,400	15,352	2,384	408			0.5	0.28	25	1.0115	83/17	
139	Flt 427	USAir	Parker	Stby	Standby RPCU lines	10											0.39	625		83/17	
																	Average	**10.3**			
																	Standard Deviation	**1.6**			

Table D Particle Identification on Accident and In-Service Samples

SAMPLE No.	39	40	51	52	53	55	56
AIRLINE	USAir	USAir	USAir	USAir	USAir	USAir	USAir
HYD SYSTEM	B	A	B	A	A	A	B
SAMPLE	Reservoir	Reservoir	Link Cavity	Return #1	Return #2	Return #3	Link Cavity
FILTERED AT	Monsanto	Monsanto	Monsanto	Monsanto	Tinker	Tinker	Monsanto
FTIR 1	[no IRBands,possible carbon or oxide]	Black particle [no IR Bands, possible carbon or oxide]	clear film [poly-butene or -ethylene]	clear film[teflon]	white particle[inorganic & organic carbonates,SH?]	Brown film[teflon wtweak aliphCH]	clear green film[teflon]
FTIR 2	[silicate, or phosphate, or sulfate, carbonyl, C-H]	clear particle [phosphate or silicate or sulfate]	clear fiber [cellulose]	brown clear film[teflon)	white particle [silicate,or sulfate, or phosphate?, IR cannot distinguish]	white particle [teflon w/ weak aliph CH]	Brown particle [teflon] [wk carboxylate H and salt]
FTIR 3			Black particle [no IR Bands, possibly carbon or oxide]	black clear film[teflon]	white particle [monosubstituted amide]	clear film [teflon w/ weak aliph CH]	
FTIR 4			yellow particle [aliph/arom C-H?]	cream-colored particle [metaphosphate, inorganic carbonate]	white particle[aliph/arom C-H,carbonyl?]	white fiber [cellulose]	
FTIR 5				orange particle [hydrated inorganic?]	clear film[teflon]	white particle [monosubstituted amide]	
FTIR 6				red particle [hydrated carboxylate]	white particle[inorganic & organic carbonate,SH?]		
FTIR 7				red particle [hydrated carboxylate]			
EM 1	Fe,0,25-50um	Si,K,Al,O,<50um	Al,K,Si,0,20-100um range	F,many large sheets and chunks >100um	F,many<25um	F,many large sheets, 50-100um	Cu,Zn,<25um
EM 2	Fe	Cd,Sn,Cu,Zn,25um	Na,Si,O,a few,<=25um	F,a lot <50um	Si,O,<25um	F,many particles,25-50um	Ca,<25um
EM 3	Cu		Fe,Cr,Mn,Ni,O,one particle -100um	K,A1,Si,O,several<50um	Fe,several,<10um	Si,O,a few<25um	Fe,<25um
EM 4	Ca w/ Si,Mg		Cd,Zn,Sn, a few, 50-100um range	Cu,Zn,small	Ca,O,many,<50um	Ca,O,many<50um	F,<25um
EM 5	Fe w/ Al,Mg,Si,O		Ca, several<25um	Ca, small	Cu,Zn,a few,<l Oum	Si,Al,O,a few <25um	large F sheet
EM 6				Fe, many small		Cu, Zn, S, one -50um	
EM 7						Cu,Zn,a few<l Oum	
EM Comments	a lot of very small particles	not many particles	numerous particle types				many small particles

SAMPLE No.	57	58	59	60	61	62	63
AIRLINE	USAir	USAir	USAir	USAir	USAir	USAir	USAir
HYD SYSTEM	B	B	B	B	B	B	B
SAMPLE	Yaw Damper Filter	Large Filter	Link Cavity	Yaw Damper Filter	Large Filter	Large Filter	Yaw Damper Filter
FILTERED AT	Tinker	Tinker	Monsanto	Tinker	Tinker	Tinker	Tinker
FTIR 1	white film[teflon]	[silicon rubber]	Black particle [teflon]	yellow film [C-H aliph/arom, amine?]	clear fiber[cellulose]	clear flim[teflon]	white rubberlike[silicone] clear flim[teflon]
FTIR 2	Brown particle [polyester]	white film [cellulose]	clear particle [teflon]	white particle [inorganic?]	white film[teflon]	Black particle[teflon, mixed w/silicate or polyol?]	white film [teflon] Black particle [teflon]
FTIR 3	clear flim [teflon]	yellow particle, white particle, white film [?]			yellow particle [aliph/arom CH, carbonyl]	clear particle[aliph/arom polyester]	white particle[polyol or salt?]
FTIR 4		Brown Black particle [residual Skydrol]			white particle [carbonate, inorganic and organic?, S-H?]	gray particle [aliph polyester]	red particle[?]
FTIR 5							red-brown particle[?]
FTIR 6							
FTIR 7							
EM 1	Al,Si,O,20-70um	Cd,Sn,Cu,200um particle	F,>50um	F,25-50um	F,>100um	F, >50um	F,mostly 25-50um
EM 2	F,50um	Fe,Cr,Ni,Mn,25-50um	Ca,O, lots of 25 um	Al,Mg,Na,25-50um	Cd,Zn,Sn,Ni,Mn,>100um	Al,Mg,Na,S,>50um	Cd,Ca,P,>50um
EM 3	Cu,Zn,Ni,75-100um	Ca,Si,O,long needle	Al	Fe,<25um	Si,O,Na,one particle	Si,Mg,O,>50um	Cu,Zn,S,>50um
EM 4			Cu		Fe,Cr,Mn,>100um	Cu,Cd,Zn,P,S,	
EM 5			Fe		Al,Mg,S,Cl,>100um	Fe,very small particles	
EM 6							
EM 7							
EM Comments	not many particles	majority>50um	majority ~25um	not many particles	a lot >100um	>50um and larger	majority 25-50um

SAMPLE No.	64	65	68	71	134	135	136	137
AIRLINE	USAir	CHINAAIR	QANTAS	BOEING	USAir	USAir	USAir	USAir
HYD SYSTEM	B	B	B	B	A	B	B	B
SAMPLE	Link Cavity	Link Cavity	Link Cavity	Link Cavity	Main Filter	Link Cavity	Yaw Damper	Main Filter
FILTERED AT	Monsanto	Monsanto	Monsanto	Monsanto	Parker	Parker	Parker	Parker
FTIR 1	clear film [teflon]	gray particle [teflon]	green fiber [cellulose]	Brown particle[?]	Black particle [phosphate]	clear Black particle[teflon]	Black particle [teflon]	BlackBrown particle[Viton]
FTIR 2	black particle [teflon]	clear film [teflon]	red fiber [cellulose]	Brown particle [no IRBands]	Black particle [aliph CH?]	orange particle [hydrated inorganic?]	white film [monosubstituted polyamide?]	clear particle [monosubstituted amide?)
FTIR 3	Brown Black particle [teflon]			Black Brown particle [no IRBands]	Black particle[teflon]	Black particle [organic?]	Black particle [no IRBands?]	fiber [cellulose,weak carboxyl?]
FTIR 4				Black Brown particle [no IRBands]	Black particle [no IR Bands?]			Black and white particle [filter pad mat'l?]
FTIR 5					yellow fiber [cellulose]			turquoise particle [aliph/arom ester w/ 2095cm Band?]
FTIR 6					Brown Black spongy particle[Viton?]			
FTIR 7								
EM 1	Cu,small particles	F,>100um	C,O,>100um fiber	F, wide size range	F,>50um	F,several particles	F,many,<50um	F,several,100um
EM 2	Al,small particles	Cu,Zn,Ni,<25um	F,75-100um	Ca,O,<25um	Cd,Zn,P,Cl, rectangular crystal	Cd,Sn,<25um	Fe,many,<10um	Al,O,<50um
EM 3	Si,O, small particles	Cd,Sn,<25um	Cr,O,<25um	Cu,Zn,Fe,Al,O, <25um	Ca,S,P,Mg,0,50um cube	Al,<25um	Cd,Sn,Ca,P,O,Cu,3-4 particle,<25um	Si,K,Al,O,<50um
EM 4	Ca,O, small particles	Fe,<10um	Si,Mg,O,<25um		Fe, very small	Si,<25um	Ca,Si,O,one 25um particle	Cd,Sn,P,<50um
EM 5	Fe,finely divided	Si,<10um	Al,O,<25um		Cu,very small	Fe,Ca,P,K,O,<25um		Fe,very small particles
EM 6	F,>100um sheets	Al,O,<10um	Ca,O,<25um					
EM 7		Ca,<10um	Cu,<25um					
EM Comments	many small particles	majority<25um	majority<25um	wide range of sizes	many cubic rectangular particles	majority <25um	many F-containing <50um	majority<50um