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ORGANIC COMPOUNDS IN THE EXHAUST OF A J85-5 TURBINE ENGINE

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Information related to exhaust hydrocarbons associated with a J85-5 turbine engine is presented. A comparison of two sampling techniques (cryogenic trapping and sorption tube) is discussed. The collected samples were analyzed by coupled gas chromatograph-mass spectrometer-data system. The number of compounds identified in the samples was 231, with equivalent results from the two sampling techniques. Less than half of the compounds identified were aromatic and oxygenated species.

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ORGANIC COMPOUNDS IN THE EXHAUST OF A J85-5 TURBINE ENGINE

INTRODUCTION

Detailed information of exhaust hydrocarbons related to fuel type, engine type, and engine operating conditions are required to assess the health and environmental impact of aircraft. The U.S. Air Force School of Aerospace Medicine (USAFSAM), the Air Force Aero-Propulsion Laboratory, Wright-Patterson AFB, Ohio, and Monsanto Research Corporation, Dayton Laboratory, Dayton, Ohio, conducted a cooperative study to investigate various techniques for the evaluation of the hydrocarbon constituents associated with J85-5 turbine engine exhaust. Reports of previous studies have been made (1, 2, 3) as well as the Monsanto Research Corporation, Dayton Laboratory, technique of subtractive chromatography (4). This study reports the analysis results of on-line exhaust sampling with the improved version of the USAFSAM cryogenic trapping system (5) and the USAFSAM sorption tube atmospheric sample system (AF Invention No. 12,052; U.S. Patent No. 4,170,901). The collected samples were analyzed with a coupled gas chromatograph-mass spectrometer-data system (6). This report describes a test conducted in January 1978 to identify and quantitate hydrocarbon emissions from a J85-5 turbine engine as a function of fuel type, engine operating conditions, sample acquisition system, and the analytical procedures employed. The J85-5 turbine engine is used on Air Force aircraft such as the T-38 trainer and the F-5.

SAMPLING

The engine exhaust was continously sampled from a single spatial point measurement in the exhaust. The emission profile of the J85-5 is not flat; therefore, a carbon balance between the fuel and the exhaust emission was not accomplished. The probe was located on the exhaust center line, 3.75 ft from the afterburner nozzle exit. Conditioned exhaust was provided to the three sampling techniques as shown in Figure 1. Cryogenic sampling was initiated with the engine operation stable. Sample time was 15 min for the idle (46% rpm), resulting in a collection of 4.5 liters, and 45 min for the cruise (75% rpm), resulting in a collection of 13.5 liters. The sample conditions are reported in Table 1. The cryogenic trapping system is shown schematically in Figure 2. The sample gas was passed through the first trapping cylinder (maintained at 0°C with ice water), through a heated inlet into the second trapping cylinder (maintained at -78°C with pulverized dry ice), and through the final trap (maintained at -175°C with liquid nitrogen), a needle valve for flow control, and a flow meter. The nominal flow was 300 cc/min at 21.1°C and 760 mm Hg. The flow was maintained by the pressure of the exhaust from the combustor. The compounds that will not be trapped and concentrated are those with sufficient vapor pressure at -175°C to remain in the gas being processed by the system (Fig. 3). In addition to the cryogenic trapping system samples, an alternate sample collection was used. Samples were obtained with the USAFSAM sorption tube atmospheric sample system (6). The conditions of sampling are presented in Table 2. The sorption sample tube is stainless steel, 1.27 cm x 15.24 cm, and contains

Tenax-GC (a porous polymer of 2,4-diphenyl-p-phenylene oxide) between double stainless-steel screens at each end of the tube. The sample was obtained at 1 liter/min (Fig. 4).

EXPERIMENTAL TEST PARAMETERS

A J85-5 turbine engine with afterburner was installed in an engine test cell. The engine was provided appropriate support equipment to simulate operation at various conditions. The J85-5 engine was operated at two different power conditions which were idle (46% rpm) and cruise (75% rpm). The 46% and 75% rpm refer to the rpm of the compressor. The cruise condition is a higher power condition than the idle, but the engine operates at a lower fuel to air ratio (F/A). This condition exists because the efficiency of the compressor increases at higher rpm. The air flow increases more than the fuel flow which results in a lower F/A. JP-4 fuel and a blend of JP-4 fuel with sufficient Xylene added to produce a fuel with 25.1% aromatic content was used (Table 3). The higher aromatic content of the fuel would simulate one of the properties that is expected to increase with shale- and coal-derived jet fuels.

ANALYSIS

Hydrocarbons in the cryogenic trapping samples and on the sorption tube sample were analyzed with a coupled gas chromatograph (Varian Model 1400)-mass spectrometer (Dupont Model 21-491)-data system (Dupont Model 21-094) (6). The chromatographic separation was accomplished with Porapak Q (a polyalkylstyrene) of 100-120 mesh in a 3-m x 3-mm OD microbore (0.7 mm ID) stainless-steel column. The column was temperature programmed at 10°C/min from -100°C to 250°C. The effluent from the column was split 25% to a chromatographic flame ionizator detector (FID) and 75% to the mass spectrometer. Compound quantitation was with a Hewlett-Packard 3352B system for integration of the chromatographic FID peak area. Identification was from the data system using a Dupont library search program. The library is based on spectra of 23,879 compounds (7).

RESULTS AND DISCUSSION

The analyses of the 14 cryogenic trapping samples and the 13 sorption tube samples indicated the presence of 231 compounds. The compounds are listed in increasing molecular weight by chemical class in Table 4 for those samples obtained with the cryogenic sampling system and in Table 5 for those samples obtained with the atmospheric sorption tube samples. Table 6 compares the mean values for the samples presented in Tables 4 and 5. Comparison was made between the sets of data on the basis of orders of magnitude difference. If a compound had values in two sets that were zero or within the same order of magnitude the concentration was considered equal. If zero and trace values were evidenced between two sets of data, the concentration was considered as one order of magnitude difference. Using this system, the most comparable sets of data obtained by the cryogenic samples and the sorption tube method was that at the cruise engine power condition. At cruise, 53% of the compounds were zero or equal, 24% were within one order of magnitude, 22% were within two orders of magnitude, and only 1% had more than two orders difference of magnitude. The idle engine power condition, using the JP-4 fuel with added Xylene, has 4% of the compounds with values separated by more than two orders of magnitude. The zero or equal order of magnitude compounds comprised 52% which was similar to the cruise condition. Eight percent of the compounds were separated by more than two orders of magnitude in the idle power setting with neat JP-4 fuel. The compounds zero or equal order of magnitude were reduced to 45%. Idle and cruise engine power conditions with the neat fuel gave 65% and 47% respectively for the cryogenic sampler and tube sampler with compounds equal to order of magnitude or zero. Similar values were obtained in a comparison of idle fueled with JP-4 neat (60%) and idle fueled with JP-4 to which Xylene had been added (45%). The paraffins appeared in 34% of the polymer samples and 36% of the cryogenic samples. A similar pattern appears in the other classes: in the olefins 16% in the cryogenic and 20% in the polymer samples; 8% cryogenic and 67% polymer in the diolefins. For the remaining classes the percent for the cryogenic only is given first and then the polymer: Naphthenes (10,47), aromatic (0,33), acid (0,50), aldehydes (27,40), alcohols (4,48), ketones (29,43), ethers (29,14), esters (25,75), nitrogen containing (20,20), halogen containing (50,17), sulfur containing (100,0), lactone (100,0), and metal containing (0,100).

Table 7 lists the various compounds by chemical class present in a particular sample. The total carbon calculated from the analyses sum is different from that obtained by on-stream analysis at Wright-Patterson AFB, Ohio. This difference is directly related to the manner that summation of area under the curve is derived and will exist until perfect separation of compounds can be accomplished or a more elaborate method of electronic curve resolution is employed.

CONCLUSIONS

Cryogenic sampling and polymer sorption sampling were used to obtain exhaust samples from a J85-5 turbine engine at conditions of idle and cruise. Two fuels were used which differed from each other only by addition of Xylene.

1. Both cryogenic sampling and polymer sampling proved to be effective and reproducible techniques for sampling gaseous hydrocarbons.

2. The hydrocarbon content of the engine exhaust was directly related to the F/A mixture.

3. The number of compounds identified were 231; of these less than half were aromatic and oxygenated species.

4. There is an equivalence between the cryogenic and polymer samples; however, it appears that the lighter molecular weight materials are trapped more efficiently by the cryogenic system.

5. Since equivalent results were obtained by the polymer samples and its logistics support is considerably less, it is more efficient to use the polymer samplers.

6. No appreciable difference was observed in the neat versus the Xylene additive fuel with the exception of concentrations of Xylene and substitut-

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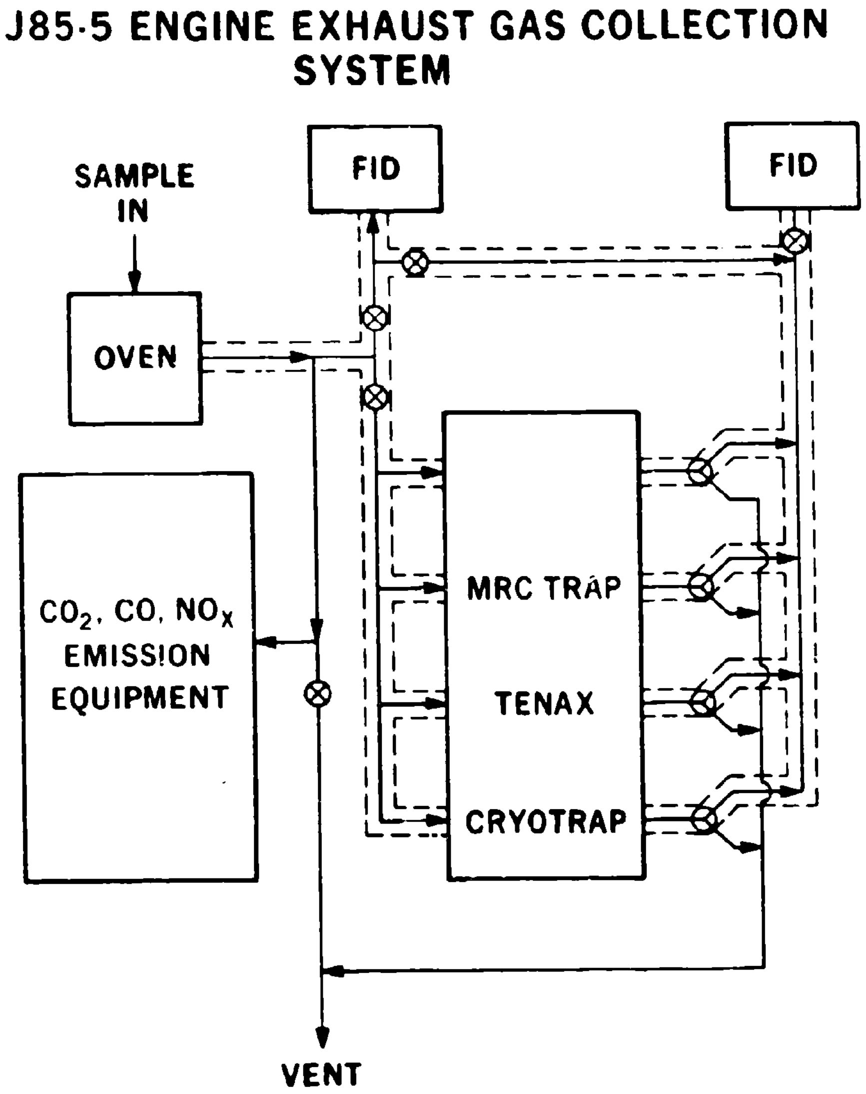

Figure 1. J85-5 exhaust gas collection system.

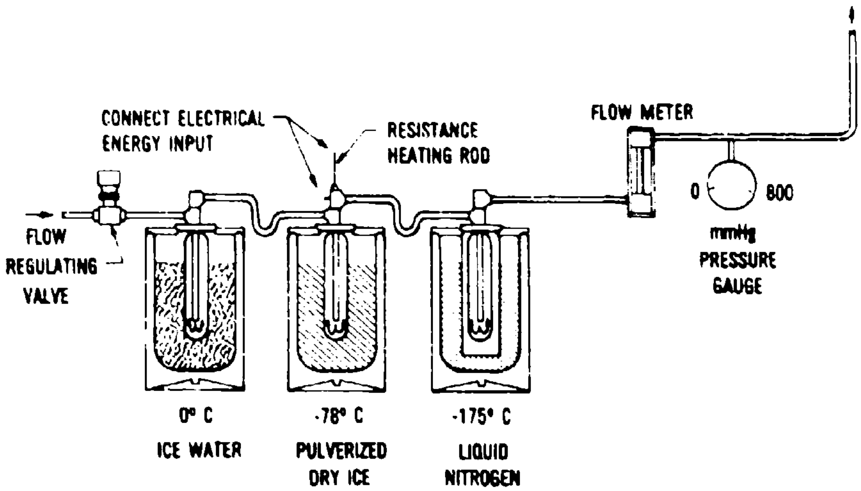

Figure 2. The USAFSAM cryosampler gas flow path.

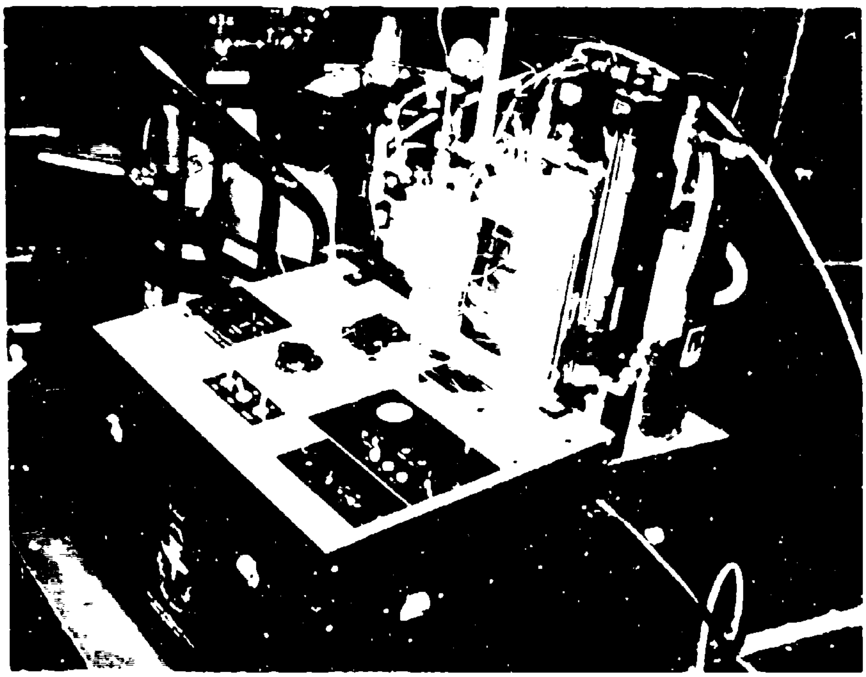

Figure 3. USAFSAM cryosampler.

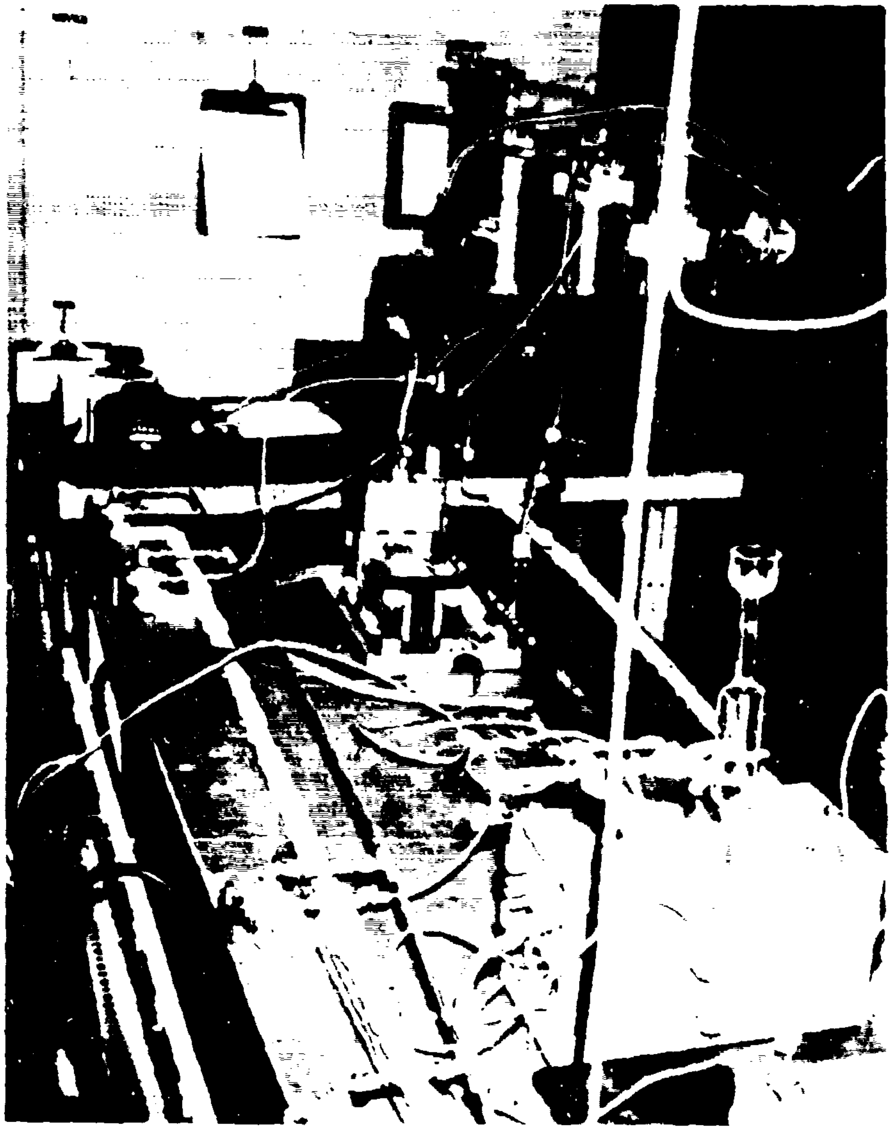

Figure 4. Sampling manifold with USAFSAM sorption tube atmospheric sample system.

TABLE 1. CONDITIONS WHILE SAMPLING WITH USAFSAM CRYOGENIC SAMPLING SYSTEM

Date/time	Sample size (liters)	Fuel	Engine condition	Sample set no.
18 Jan 1978:				
1400-1415	4.5	JP-4	Idle	112
1440-1455	4.5	JP-4	Idle	30
1520-1535	4.5	JP-4	Idle	106
0945-1000	4.5	JP-4	Idle	102
1041-1054	4.6	JP-4	Idle	104
19 Jan 1978:				
1242-1326	13.5	JP-4	Cruise	19
1344-1429	13.5	JP-4	Cruise	110
1446-1530	13.5	JP-4	Cruise	25
20 Jan 1978:				
1054-1109	4.5	JP-4 + Xylene	Idle	9
1136-1151	4.5	JP-4 + Xylene	Idle	109
1215-1230	4.5	JP-4 + Xylene	Idle	27
1303-1318	4.5	JP-4 + Xylene	Idle	28
1334-1349	4.5	JP-4 + Xylene	Idle	11
1403-1418	4.5	JP-4 + Xylene	Idle	101

TABLE 2. CONDITIONS WHILE SAMPLING WITH USAFSAM ATMOSPHERIC SAMPLING SYSTEM

Date/time	Sample size (liters)	Fuel	Engine condition	Sample tube A	Sample tube B
18 Jan 1978:					
1401-1416	15	JP-4	Idle	14	70
1520-1535	15	JP-4	Idle	67	39
1041-1046	15	JP-4	Idle	2	5
19 Jan 1978:					
1242-1252	21	JP-4	Cruise	47	56
1344-1359	15	JP-4	Cruise	17	19
1414-1419	5	JP-4	Cruise	18	46
1446-1451	5	JP-4	Cruise	32	61
20 Jan 1978:					
1054-1059	5	JP-4 + Xylene	Idle	55	57
1136-1144	5	JP-4 + Xylene	Idle	33	37
1215-1220	5	JP-4 + Xylene	Idle	64	62
1303-1308	5	JP-4 + Xylene	Idle	35	43
1334-1339	5	JP-4 + Xylene	Idle	10	58
1403-1408	5	JP-4 + Xylene	Idle	68	20

TABLE 3. FUEL PROPERTIES

Property	JP-4	Alternate fuel blend
Vapor pressure @ 38°C	2.7	---
Initial boiling point (°F)	140.0	140.000
End point	475.0	475.000
Aromatic content (% vol)	10.0	25.100
Olefinic content (% vol)	1.2	
Saturates content (% vol)	8.8	
Net heat of combustion (Btu)	18,730.0	18,512.000
Specific gravity @ 16°C	0.762	0.773

TABLE 4. ANALYSIS OF SAMPLES OBTAINED FROM THE EXHAUST OF A J85-5 ENGINE BY CRYOGENIC SAMPLING REPORTED IN MICROGRAMS PER CUBIC METER AS HEXANE BY CHEMICAL CLASS

Compound	JP-4 fuel at low idle Sample					JP-4 fuel at mid idle sample			JP-4 fuel with Xylene at mid idle sample					
	1	2	3	4	5	1	2	3	1	2	3	4	5	6
Paraffins										.4				
Ethane	.1									.4				
Propane	.7	.2	.6		.1		.1		.8		.7	T		.1
2-Methylpropane			.1	.3						.1				T
n-Butane			.1	.1	.3					.2		.3		T
2-Methylbutane	.8	1.5	1.9	.1	3.2	.6	.1	.4	.7	.9	1.7	.8	1.6	1.2
n-Pentane				.2	.2	.1	T	.1	T		1.3		T	
2,2-Dimethylbutane														
2,3-Dimethylbutane	4.6	1.2	2.5	2.3	1.1		.3		1.8	1.0	.8	1.4	.6	.9
2-Methylpentane			.2											
3-Methylpentane	8.8	.9	.1	1.6	.5	.4	.2	.8	2.9	2.0		.1		.1
n-Hexane		.5		1.2			T		.2					
2,2,3-Trimethylbutane	3.7		1.4		.3	.5						.1		
2,2-Dimethylpentane										.8			4.9	
2,3-Dimethylpentane		.5					.1			.6	.4			.4
2,4-Dimethylpentane	21.3	8.1	10.6	40.7	12.1	3.8	1.2	1.8	2.2		4.0	5.4		2.7
3-Methylhexane	11.1	4.7	6.0	5.1	7.0	2.2	.6	1.6	.2	2.8	2.8	.1	4.2	1.6
n-Heptane														
2,3,3-Trimethylpentane														
2-Methyl-3-Ethylpentane	5.6	1.5	2.8	10.0	3.0	.4	.6	2.2		4.6				.5
2,4-Dimethylhexane	8.7		12.4						1.0			2.9		
3,3-Dimethylhexane				.9										
3,4-Dimethylhexane				.9										
3-Ethylhexane					13.8				2.9	1.2		.9		1.7
2-Methylheptane														
3-Methylheptane						3.0		1.0						
4-Methylheptane		.9	.6	.9		2.4	T						5.2	
n-Octane						.8								
2,2,3,4-Tetramethylpentane	10.2	5.7	8.6	7.2		.6		2.2			.7			
2,3,4-Trimethylhexane								.3						
2,3,5-Trimethylhexane		8.0			3.2						2.5	.2		
2-Methyl-4-Ethylhexane	7.1	7.6			8.5	T	.1							
2,4-Dimethylheptane														
2,5-Dimethylheptane	8.5	4.6					.6					.3		
3,4-Dimethylheptane														
4-Ethylheptane														
2-Methyloctane												.5		
3-Methyloctane														
4-Methyloctane														

T=trace, less than 0.05 $\mu g/m^3$.

TABLE 4 (Continued)

Compound	JP-4 fuel at low idle sample 1	2	3	4	5	JP-4 fuel at mid idle sample 1	2	3	JP-4 fuel with Xylene at mid idle sample 1	2	3	4	5	6
Paraffins (Continued)														
n-Nonane	2.7	5.0	4.7	6.8	7.6	2.4	.2	.8	3.6	4.1	3.6	4.5	3.5	1.3
2-Methyl-5-Ethylheptane												T		
3,3,5-Trimethylheptane														
2,3-Dimethyloctane														
2-Methylnonane														
3-Methylnonane				.2					1.5					
n-Decane	1.3	1.8		2.4		.9				4.2		.4	2.9	
4,5-Dimethylnonane						T								
2-Methyldecane		.1	4.0											
n-Undecane														
2-Methylundecane														
4-Methylundecane														
5-Methylundecane			4.0											
2-Methyldodecane														
Olefins														
Ethene										.9				
Propene	43.0	13.4	17.2	19.4	26.4	3.9	T	1.5	9.9	10.9	6.2	8.5	8.2	7.1
Propyne	1.6			.3	T	.5	.1	.2	.8	.9	.7		1.0	
2-Methylpropene	.	.3	.3	.5	T	1.9	T			2.8				
1-Butene	3.0	5.1	6.8	6.1	9.4	.3	.1	.7	.6	.9	2.8	.8	3.4	1.3
2-Butene	16.2	.8	1.3	1.4	.7		1.0		3.2	.3	.4	2.8	.4	
1-Butyne	.2									.2				
2-Butyne		T	.3	.2	.2			.1	.2		T	T	T	.1
3-Methyl-1-Butene									.3		.5		.8	
1-Pentene	10.1	.5	2.7	1.1	2.6	.9	.1		.4	1.7	.1	.1		.7
2-Pentene		.4			.3		.5	.5	.2	.2	1.2	.6	.6	
1-Pentyne														
2,2-Dimethyl-1-Butene				.7										
2-Ethyl-1-Butene								.1						
2-Methyl-1-Pentene		3.1		.1	2.3		.4		1.5	1.8				
4-Methyl-1-Pentene	2.3		.6	.7	.6	.2		.2	.3	.4	.5	.8	.2	
4-Methyl-2-Pentene					T									
1-Hexene				3.2	3.5									
3,4-Dimethyl-1-Pentene										2.6				
4,4-Dimethyl-2-Pentene										2.8				
4-Methyl-1-Hexene				3.4										
2-Heptyne														
3-Methyl-4-Ethylhexene														
1-Nonene														
1-Decyne														

T=trace, less than 0.05 $\mu g/m^3$.

TABLE 4 (Continued)

Compound	JP-4 fuel at low idle sample 1	2	3	4	5	JP-4 fuel at mid idle sample 1	2	3	JP-4 fuel with Xylene at mid idle sample 1	2	3	4	5	6
Diolefins														
Propadiene	1.3	.7	1.4	1 6	2.2	.2	.3	.1	.3		.3	.5	.4	.9
1,2-Butadiene	.5													
1,3-Butadiene	3.7	3.4	3.6	4.1	5.5	1.1	.7	.5	2.6	2.6	2.0	.6	2.8	1.7
1-Buten-3-yne														
1,3-Butadiyne														
2-Methyl-1,3-Butadiene														
3-Methyl-3-Buten-1-yne														
1,2-Pentadiene														
1,3-Pentadiene														
1,4-Pentadiene					.3		T							
2,3-Pentadiene														
3-Penten-1-yne														
Naphthenes														
Cyclopropane			1.2	.9										
Cyclobutane					T			.1						
1,1-Dimethylcyclopropane	2.2	2.4	.7		1.5				1.5			.2		.1
1,2-Dimethylcyclopropane									.2	1.0			1.3	
Ethylcyclopropane														
Methylcyclobutane														
Cyclopentane		.1		.5	.1	T	.1		.2	T	.2	.5	.2	
Cyclopentene											.2			
1,3-Cyclopentadiene														
Dimethylcyclobutane														
Ethylcyclobutane								.3		.2	.7		2.0	
Methylcyclopentane		.8	1.6	.3	.5	.5			.1	1.4			.6	.2
Methylcyclopentadiene														
Cyclohexane	3.0								.8					.6
1,3-Cyclohexadiene														
1,2-Dimethylcyclopentane														
1,2-Dimethylcyclopentadiene														
Methylcyclohexane	2.0	1.9	2.5	2.4	2.8	.9	.2	.7	2.6	.3	2.6	3.2	1.2	1.8
1-Methyl-1-Ethylcyclopentane			.7						.1			.1	.8	
1-Methyl-2-Ethylcyclopentane														
1-Methyl-3-Ethylcyclopentane							T				.2			
1,2-Dimethylcyclohexane									.2					
1,4-Dimethylcyclohexane														.3
Ethylcyclohexane									.1	1.1		T		.2
1,1,2-Trimethylcyclohexane														
1,1,3-Trimethylcyclohexane														

T=trace, less than 0.05 μg/m^3.

TABLE 4 (Continued)

Compound	JP-4 fuel at low idle sample 1	2	3	4	5	JP-4 fuel at mid idle sample 1	2	3	JP-4 fuel with Xylene at mid idle sample 1	2	3	4	5	6
Naphthenes (Continued)														
1,2,3-Trimethylcyclohexane														
1,2,4-Trimethylcyclohexane														
n-Propylcyclohexane														
Butylcyclohexane										.2				
Aromatics														
Benzene	11.8	3.8	5.8	5.3	6.3	2.1	.8	1.1	4.8	5.4	4.0	4.2	4.8	3.7
Methylbenzene	6.5	2.8	3.8	3.2	4.0	1.4	.4	.9	5.0	6.7	4.5	4.4	10.5	3.3
Dimethylbenzene	7.8	.5		6.3	7.6	5.4	.3	1.7	10.7	17.1	14.9	8.1	15.6	4.0
Ethylbenzene			7.1					.2						
1,2,3-Trimethylbenzene														
1,2,4-Trimethylbenzene				3.3		1.1		.8	6.3					
1,3,5-Trimethylbenzene	.4				1.0									
1-Methyl-2-Ethylbenzene	.5		3.7					.7		.9	.8		1.4	5.0
n-Propylbenzene									11.1	7.3	6.3	4.9	6.3	.2
Isopropylbenzene									5.5		4.5	14.2	6.5	1.7
Diethylbenzene		1.7												
Naphthalene														
1-Methylnaphthalene														
2-Methylnaphthalene														
Dimethylnaphthalene														
Acids														
Acetic					2.1									
Propanoic														
Aldehydes														
Methanal														
Ethanal	2.4	1.8	.4	1.1	2.3	2.1			2.5	1.4	2.5	2.1	2.6	.4
Propanal		.5			.2	.6	T	.1	.2		.4	.6	.4	
Propenal														
2-Methylpropanal									1.4					
n-Butanal	.8	.1				.7		.9			1.1		.5	
2-Butenal									.4		.3			
3-Butanolal														.4
2,2-Dimethylpropanal			2.6		4.1									
2-Methylbutanal												.4	.7	1.2
2-Ethylbutanal														
2-Methylpentanal											.3	2.1		

T=trace, less than 0.05 μg/m3.

TABLE 4 (Continued)

Compound	JP-4 fuel at low idle sample 1	2	3	4	5	JP-4 fuel at mid idle sample 1	2	3	JP-4 fuel with Xylene at mid idle sample 1	2	3	4	5	6
Aldehydes (Continued)														
Benzaldehyde														
n-Heptanal														
n-Decanal														
Alcohols														
Methanol	T	.6	.1	.1	.1	T	T	.1	.9	.1	T	.9	T	.1
Ethanol	.2	.3	.4	T	.3	.1	T	T	.3	.4	.1	.1		
1-Propen-3-ol														
2-Propen-1-ol	.1	.4	.1			T		.1			T	.1		
2-Buten-1-ol							T							
3-Butyn-2-ol											.1			
3-Buten-1,2-diol														
3-Methyl-1-Butanol														
1-Pentanol														
1-Penten-3-ol														
1-Penten-1-ol	3.1		.2	2.3	.5	.2			.3			T	.2	
2-Ethyl-1-Butanol									2.4		1.2			
2-Methyl-1-Pentanol														
3-Methyl-1-Pentanol	4.4	1.6			.5		T				.6	.1		
2,2-Dimethyl-1-Pentanol										.2				
Methylcyclohexanol														
Cyclohexymethanol														
2-Methylheptanol														
6-Methylheptanol														
1-Nonanol														
n-Propylheptanol							.2	.5						
2-Propylheptanol		2.7							.8	4.2	4.0	.2	5.6	2.8
2,7-Dimethyloctanol													1.5	
Butyloctanol											2.5			
2-Butyl-1-Octanol														
Ketones														
2-Propanone	1.5	.5	2.1	1.0	2.3	1.0	.2	.3	2.7	1.1	.3	.9	.8	1.0
2-Butanone		.2			.3	1.4	.1	.4		.3			2.0	
Cyclobutanone														
3-Butene-2-one							T							
2-Pentanone					.9				.1					
3-Pentanone						1.0								
3,3-Bis(Hydroxymethyl)-2-butanone														

T=trace, less than 0.05 $\mu g/m^3$.

TABLE 4 (Continued)

Compound	JP-4 fuel at low idle sample 1	2	3	4	5	JP-4 fuel at mid idle sample 1	2	3	JP-4 fuel with Xylene at mid idle sample 1	2	3	4	5	6
Ketones (Continued)														
3-Methyl-2-Pentanone														
3-Hexanone									3.0	.5				
Cyclohexanone														
2-Methyl-3-Heptanone								2.0						
Acetophenone														
Cyclononanone														
Propyl Benzyl Ketone														.6
Ethers														
Methyl Ether	.2													
2,3-Epoxybutane							.8							
1,3-Dioxolane		.7	.4		.7	.8				.1				
Furan	1.1	.3		.3	.2	.1	.1	.1	.1	.2		.9	.2	.1
2,5-Dihydrofuran		.2				.2				.3	.2		.8	
Ethyl Vinyl Ether					1.0						.2			
Benzyl Ether														
Esters														
Ethyl Formate														
Ethyl Acetate														
Allyl Formate														
Isopropyl Propionate														
Allyl Acetate											.1			
Isoamyl Acetate														
Octyl Acrylate												.1		.3
Decyl Acetate														
[illegible]														
Ammonia									.2					
Nitromethane	1.7	.2	3.0											
Diazoethane														
2-Nitroethylpropionate														
Neopentyl Nitrate											1.2			

T=trace, less than 0.05 $\mu g/m^3$.

TABLE 4 (Continued)

Compound	JP-4 fuel at low idle sample 1	2	3	4	5	JP-4 fuel at mid idle sample 1	2	3	JP-4 fuel with Xylene at mid idle sample 1	2	3	4	5	6
Halogen containing														
Chloromethane										.1				
Dichlorodifluoromethane (R-12)														
Trifluorotrichloroethane(R-113)	2.9	.1	.1											
1-Chloro-3-Methylbutane	5.5		.4	.3	1.1	.2	.3					.1	.2	.1
2-Chloro-3-Methylbutane								.4			.1			
2-Iodo-2-Methylbutane													.6	
1-Chloropentane										.2				
2-Chloropentane												.7		
Isoamyl Chloride														.1
3-Chloro-3-Methylpentane									T				.9	
1-Fluorohexane														
1-Fluoroheptane														
Sulfur containing														
Octyl Mercaptan									4.7					.6
Lactones														
β,β-Dimethylpropiolactone			T											
Metal containing														
Nickel Carbonyl														
Unknown	46.0	28.2	29.6	48.5	66.6	7.5	4.6	5.3	28.0	32.3	18.3	26.3	22.2	29.7

T=trace, less than 0.05 μg/m³.

TABLE 5. ANALYSIS OF SAMPLES OBTAINED FROM THE EXHAUST OF A J85-5 ENGINE BY POLYMER TRAPPING REPORTED IN MICROGRAMS PER CUBIC METER AS HEXANE BY CHEMICAL CLASS

Compound	JP-4 fuel at low idle sample 1	2	3	4	5	JP-4 fuel at mid idle sample 1	2A	2	3	JP-4 fuel with Xylene at mid idle sample 1	2	3	4	5	6
Paraffins															
Ethane							T				T				
Propane								T	T						
2-Methylpropane														.4	
n-Butane					T					.9					
2-Methylbutane										3.1		.1			
n-Pentane	.1					T	.4	.4			.2	2.3	.2		.4
2,2-Dimethylbutane						.2			T						
2,3-Dimethylbutane							.2								
2-Methylpentane			1.2				.7	.6			.6	2.8	.4	2.3	.5
3-Methylpentane						2.0									
n-Hexane	2.3		.8		9.1	.1	2.2	1.7	1.9		3.1	2.6		2.6	
2,2,3-Trimethylbutane															
2,2-Dimethylpentane							.1	.2				.1			.1
2,3-Dimethylpentane	2.8					1.4					.6	.4		4.0	.5
2,4-Dimethylpentane			.5										.1		
3,3-Dimethylpentane													4.4		
2-Methylhexane			1.4												
3-Methylhexane	3.9		3.5		2.6	.8	4.1	2.7	3.7			3.3	3.7		3.0
n-Heptane	1.5		5.2		5.5	1.3		1.8	2.4	3.8	3.7	2.9			
2,3,3-Trimethylpentane								.8							
2-Methyl-3-Ethylpentane										.3			.1	.2	.2
2,4-Dimethylhexane	1.6		4.6		1.1	1.5	4.3	T	.6						3.1
3,3-Dimethylhexane					T	.4		1.9				2.8			2.6
3,4-Dimethylhexane															
3-Ethylhexane															
2-Methylheptane	.6				1.5	1.9	.6		3.6		5.2	4.0	4.0	3.5	
3-Methylheptane			3.2		4.5										
4-Methylheptane															
n-Octane	.6		5.4		4.4	2.1	.2	1.9	2.3	1.2	5.3	4.1		5.1	4.3
2,2,3,4-Tetramethylpentane	.3								.7						
2,3,4-Trimethylhexane	.3				1.3	.5	1.7	1.0					.1		
2,3,5-Trimethylhexane															
2-Methyl-4-Ethylhexane			T												
2,4-Dimethylheptane	.8	1.0	.9												
2,5-Dimethylheptane								.1							
3,4-Dimethylheptane	.8				1.3		.3								
4-Ethylheptane			6.4		2.7										
2-Methyloctane						.3									
3-Methyloctane															

T=trace, less than 0.05 μg/m^3.

TABLE 5 (Continued)

Compound	JP-4 fuel at low idle sample 1	2	3	4	5	JP-4 fuel at mid idle sample 1	2A	2	3	JP-4 fuel with Xylene at mid idle sample 1	2	3	4	5	6
Paraffins (Continued)															
4-Methyloctane					.9				T			T			
n-Nonane	6.7		6.3		3.6	1.7		.4	2.6		3.7	8.9			
2-Methyl-5-Ethylheptane			6.7		.9		.5		1.3		5.7				
3,3,5-Trimethylheptane			2.5												
2,3-Dimethyloctane					.4									15.4	
2-Methylnonane			.6												
3-Methylnonane							1.4		1.9		17.0				
n-Decane	.3		1.4		.4	1.1					6.6	5.8	5.0		
4,5-Dimethylnonane							3.0								
2-Methyldecane					1.1										
n-Undecane	.2		2.3		3.9	2.7	.5		.3		3.2	1.1		4.8	4.2
2-Methylundecane	1.														
4-Methylundecane											.4				
5-Methylundecane														3.3	
n-Dodecane					2.6	8.5			.4					.7	
2,6-Dimethy[illegible]decane			4.1		1.4						1.0			2.2	2.9
2-Methyldodecane	.1														
n-Trimethyldecane	8.6		.1												
n-Tridecane						1.0									
Olefins															
Ethene															
Propene	.1		T		.1	.1	.7	.2	T	T	T	.1	.1	.2	.2
Propyne	T		T			T							T	.1	.1
2-Methylpropene	T					T									
1-Butene			.6		1.0	.4	1.7	8.5	.9				1.5	1.9	1.7
2-Butene	.7		T				T	.1	.1		1.5	1.8			
1-Butyne															
2-Butyne						T		T		1.5	T	T		1.1	
3-Methyl-1-Butene									.1				.8		
1-Pentene	1.1		2.9		1.8	1.4	1.4	3.4	1.3		.5		1.6	.6	
2-Pentene			1.0		T					.6				.6	2.3
1-Pentyne			.2												
2,2-Dimethyl-1-Butene															
2-Ethyl-1-Butene															
2-Methyl-1-Pentene							1.2				2.1	1.8	1.9		
4-Methyl-1-Pentene								.7							
4-Methyl-2-Pentene															
1-Hexene	T							1.1							

T=trace, less than 0.05 μg/m^3.

TABLE 5 (Continued)

Compound	JP-4 fuel at low idle sample 1	2	3	4	5	JP-4 fuel at mid idle sample 1	2A	2	3	JP-4 fuel with Xylene at mid idle sample 1	2	3	4	5	6
Olefins (Continued)															
3,4-Dimethyl-1-Pentene						.3									
4,4-Dimethyl-2-Pentene															
4-Methyl-1-Hexene						.3				3.9					
2-Heptyne			.6		.6										
3-Methyl-4-Ethylhexene							.1								
1-Nonene			T												
1-Decyne			T												
Diolefins															
Propadiene	T				T	T		T		.1	T	.1	.1	T	T
1,2-Butadiene															
1,3-Butadiene	.5		.7		.9	.4	1.6	1.9	.9	1.9	1.8	2.2	1.9	1.4	2.1
1-Buten-3-yne	.1					.1									
1,3-Butadiyne													.2	.1	
2-Methyl-1,3-Butadiene			.6		.8			T			.9	.9	.8		
3-Methyl-3-Buten-1-yne								.2							
1,2-Pentadiene							.1								
1,3-Pentadiene					T										
1,4-Pentadiene														.4	.8
2,3-Pentadiene								.2							
3-Penten-1-yne			T												
Naphthenes															
Cyclopropane															
Cyclobutane	T		1.0		2.0		1.5					2.7			
1,1-Dimethylcyclopropane								.1				1.8	2.4		
1,2-Dimethylcyclopropane					1.3										
Ethylcyclopropane											1.9				
Methylcyclobutane										.1					
Cyclopentane							1.1	.1			T	T	T		T
Cyclopentene															
1,3-Cyclopentadiene	.1		.3		.1	.1	T		.1						
Dimethylcyclobutane						T									
Ethylcyclobutane			2.8											2.8	1.4
Methylcyclopentane					.5		.1			.2	.2	.1	.1	.3	.2
Methylcyclopentadiene						T									
Cyclohexane					.2	.8				.8	.2	.1	.2	5.4	.2
1,3-Cyclohexadiene	T		.2												

T=trace, less than 0.05 μg/m^3.

TABLE 5 (Continued)

Compound	JP-4 fuel at low idle sample 1	2	3	4	5	JP-4 fuel at mid idle sample 1	2A	2	3	JP-4 fuel with Xylene at mid idle sample 1	2	3	4	5	6
Naphthenes (Continued)															
1,2-Dimethylcyclopentane					2.5										
1,2-Dimethylcyclopentadiene					2.4										
Methylcyclohexane			.5		.3	.1		.6		.5	2.3	2.0	2.0	2.2	2.0
1-Methyl-1-Ethylcyclopentane											T				
1-Methyl-2-Ethylcyclopentane															T
1-Methyl-3-Ethylcyclopentane					1.3										
1,2-Dimethylcyclohexane								.1							.4
1,4-Dimethylcyclohexane														.3	
Ethylcyclohexane					.1			.1		.1					
1,1,2-Trimethylcyclohexane										.2					
1,1,3-Trimethylcyclohexane											5.9	.1			.1
1,2,3-Trimethylcyclohexane	4.6		2.8												
1,2,4-Trimethylcyclohexane														.2	
n-Propylcyclohexane					1.9									14.7	
Butylcyclohexane															
Aromatics															
Benzene	2.9		4.3		5.7	3.6	3.3	2.0	2.7	4.8	5.8	4.8	4.9	5.4	4.7
Methylbenzene	.5		3.2		7.7	1.5	1.2	.9	1.6	4.1	4.7	3.9	4.0	4.7	4.3
Dimethylbenzene	1.3		.3		4.5	2.1	2.9	.9	2.3	19.4	11.0	8.6	8.5	9.9	8.6
Ethylbenzene															
1,2,3-Trimethylbenzene			1.4												
1,2,4-Trimethylbenzene												8.6			
1,3,5-Trimethylbenzene	1.0								.4						
1-Methyl-2-Ethylbenzene	3.6						.5		2.2	5.0					
n-Propylbenzene						.6	2.0								4.5
Isopropylbenzene													8.7		
Diethylbenzene			2.9				.7				12.6			10.5	
Naphthalene	1.4					.9									
1-Methylnaphthalene						.1									
2-Methylnaphthalene						.2									
Dimethylnaphthalene						.1									
Acids															
Acetic	2.1		2.2		.1	.9				1.2		1.4	1.4	T	1.5
Propanoic											.5	.5	.5	.2	.6

T=trace, less than 0.05 $\mu g/m^3$.

TABLE 5 (Continued)

Compound	JP-4 fuel at low idle sample 1	2	3	4	5	JP-4 fuel at mid idle sample 1	2A	2	3	JP-4 fuel with Xylene at mid idle sample 1	2	3	4	5	6
Aldehydes															
Methanal											T				
Ethanal	.1		.2		.4	.2	1.0	T	.3	.5	.5	.8	.7	.8	.7
Propanal										2.4					
Propenal	.1		1.6		.1	T	.4				.2	.1			2.5
2-Methylpropanal						T		.5							
n-Butanal						2.1	2.8				2.8				
2-Butenal							.1			2.0					
3-Butanolal															
2,2-Dimethylpropanal															
2-Methylbutanal															
2-Ethylbutanal															2.6
2-Methylpentanal															
Benzaldehyde						T			.3	.1	T	T		.1	13.3
n-Heptanal					.2	.2									
n-Decanal					5.4										
Alcohols															
Methanol	T		T		T		.1		T	T	T	T	T	.1	T
Ethanol	T		.1		.1		.1		T	.2	.2	.2	.1	.1	.2
1-Propen-3-ol			.1												
2-Propen-1-ol			.3		1.2	.4	1.0		1.1		.8			2.2	.5
2-Buten-1-ol					T										
3-Butyn-2-ol						T									
3-Buten-1,2-diol					.3										
3-Methyl-1-Butanol						.2							.8		
1-Pentanol									T						
1-Penten-3-ol										1.0					
4-Penten-1-ol			.4		.8	.5		.1							
2-Ethyl-1-Butanol	.1														
2-Methyl-1-Pentanol								T							
3-Methyl-1-Pentanol															
2,2-Dimethyl-1-Pentanol															
Methylcyclohexanol			.1		.3										
Cyclohexylmethanol	.1														
2-Methylheptanol										6.0					
6-Methylheptanol											11.5	.1		9.9	
1-Nonanol					2.3										
n-Propylheptanol								.1							
2-Propylheptanol			.4		6.3	.3	.4		2.0			4.8	4.6	5.2	

T=trace, less than 0.05 $\mu g/m^3$.

TABLE 5 (Continued)

Compound	JP-4 fuel at low idle sample 1	2	3	4	5	JP-4 fuel at mid idle sample 1	2A	2	3	JP-4 fuel With Xylene at mid idle sample 1	2	3	4	5	6
Alcohols (Continued)															
2,7-Dimethyloctanol					4.9										
Butyloctanol															
2-Butyl-1-Octanol	.7		3.7		.4										
Ketones															
2-Propanone	.2		.2		.5	1.5	.8	.1	.7		.9	.8			
2-Butanone	.4		3.3												
Cyclobutanone					T										
3-Butene-2-one															
2-Pentanone														2.7	
3-Pentanone															
3,3-Bis(Hydroxymethyl)-2-Butanone							.4								
3-Methyl-2-Pentanone									2.5						
3-Hexanone			.4		.7		2.5						3.9	3.2	3.8
Cyclohexanone										1.6				.1	
2-Methyl-3-Heptanone															
Acetophenone	T					T									T
Cyclononanone					.1						1.2				
Propyl Benzyl Ketone															
Ethers															
Methyl Ether															
2,3-Epoxybutane			.1		.4										
1,3-Dioxolane								.1							
Furan															
2,5-Dihydrofuran							.1							.2	
Ethyl Vinyl Ether	1.0					.2									
Benzyl Ether					2.1										
Esters															
Ethyl Formate							T								
Ethyl Acetate			1.4				1.2		1.1			1.4			
Allyl Formate			.5												
Isopropyl Propionate					T										
Allyl Acetate															
Isoamyl Acetate	.7														
Octyl Acrylate															
Decyl Acetate								.9							

T=trace, less than 0.05 µg/m³.

TABLE 5 (Continued)

Compound	JP-4 fuel at low idle sample 1	2	3	4	5	JP-4 fuel at mid idle sample 1	2A	2	3	JP-4 fuel With Xylene at mid idle sample 1	2	3	4	5	6
Nitrogen Containing															
Ammonia															
Nitromethane				T											
Diazoethane	3.4						.5		1.7		.4		2.5	2.5	.3
2-Nitroethylpropionate		T													
Neopentyl Nitrate															
Halogen Containing															
Chloromethane	T							T						T	T
Dichlorodifluoromethane (R-12)															
Trifluorotrichloroethane (R-113)									T						
1-Chloro-3-Methylbutane															
2-Chloro-3-Methylbutane										1.8	2.2				2.3
2-Iodo-2-Methylbutane	T						T								
1-Chloropentane	.1														
2-Chloropentane															
Isoamyl Chloride															
3-Chloro-3-Methylpentane															
1-Fluorohexane															
1-Fluoroheptane			3.0												
Sulfur Containing															
Octyl Mercaptan															
Lactones															
β,β-Dimethylpropiolactone															
Metal Containing															
Nickel Carbonyl							T								
Unknown	21.0		25.4		40.3	12.7	7.7	.9	5.3	54.0	21.5	33.5	58.0	15.3	41.9

T=trace, less than 0.05 μg/m³.

TABLE 6. A COMPARISON OF THE MEAN CONCENTRATION IN MICROGRAMS PER CUBIC METER BETWEEN POLYMER-TRAPPED AND CRYOGENIC-TRAPPED J85-5 ENGINE EXHAUST

Compound	Cryotrap			Polymer		
	JP-4 low idle	JP-4 mid idle	JP-4 with Xylene mid idle	JP-4 low idle	JP-4 mid idle	JP-4 with Xylene mid idle
Paraffins	68.0	11.2	18.7	46.3	20.9	31.7
Ethane			.1		T	T
Propane	T		.1		T	
2-Methylpropane	.3	T	.6			.1
n-Butane	.1		T	T		.2
2-Methylbutane	.1		.1			.5
n-Pentane	1.5	.4	1.2	T	.2	.5
2,2-Dimethylbutane	.1	.1	.2		.1	
2,3-Dimethylbutane					.1	
2-Methylpentane	2.3	.1	1.1	.4	.3	1.1
3-Methylpentane	T				.5	
n-Hexane	2.4	.5	.8	4.1	1.5	1.4
2,2,3-Trimethylbutane	.3	T	T			
2,2-Dimethylpentane	1.1	.2	T		.1	T
2,3-Dimethylpentane			1.0	.9	.4	.9
2,4-Dimethylpentane	.1	T	.2	.2		T
3,3-Dimethylpentane						.7
2-Methylhexane				.5		
3-Methylhexane	18.6	2.3	2.4	3.3	2.8	1.7
n-Heptane	6.8	1.5	2.0	4.1	1.4	1.7
2,3,3-Trimethylpentane					.2	
2-Methyl-3-Ethylpentane						.1
2,4-Dimethylhexane	4.6	1.1	.8	2.4	1.6	.5
3,3-Dimethylhexane	4.2		.6	T	.6	.9
3,4-Dimethylhexane	.2					
3-Ethylhexane	.2					
2-Methylheptane	2.8		1.1	.7	1.5	2.8
3-Methylheptane				2.6		
4-Methylheptane		1.3				
n-Octane	.5	.8	.9	3.5	1.6	3.3
2,2,3,4-Tetramethylpentane		.3		.1	.2	
2,3,4-Trimethylhexane	6.3	.9	.1	.1	.8	T
2,3,5-Trimethylhexane		.1				
2-Methyl-4-Ethylhexane	.2		.4	T		

T=trace, less than 0.05 μg/m^3.

TABLE 6 (Continued)

Compound	Cryotrap JP-4 low idle	Cryotrap JP-4 mid idle	Cryotrap JP-4 with Xylene mid idle	Polymer JP-4 low idle	Polymer JP-4 mid idle	Polymer JP-4 with Xylene mid idle
Paraffins (Continued)						
2,4-Dimethylheptane	4.6	T		.9		
2,5-Dimethylheptane					T	
3,4-Dimethylheptane	2.6	.2	.1	.7	.1	
4-Ethylheptane				3.0		
2-Methyloctane					.1	
3-Methyloctane			.1			
4-Methyloctane				.3	T	T
n-Nonane	5.4	1.1	3.4	5.5	1.2	2.1
2-Methyl-5-Ethylheptane			T	2.5	.4	1.0
3,3,5-Trimethylheptane				.8		
2,3-Dimethyloctane				.1		2.6
2-Methylnonane	T			.2		
3-Methylnonane	T		.2		.8	2.8
n-Decane	1.1	.3	1.2	.7	.3	2.9
4,5-Dimethylnonane		T			.8	
2-Methyldecane	.8			.4		
n-Undecane				2.1	.9	2.2
2-Methylundecane				.3		
4-Methylundecane						
5-Methylundecane						.6
n-Dodecane				.9	2.2	.1
2,6-Dimethylundecane				1.8		1.0
2-Methyldodecane	.8			.3		
n-Trimethyldecane				2.9		
n-Tridecane					.2	
Olefins	42.3	4.2	15.9	3.6	6.1	4.6
Ethene			.2			
Propene	23.9	1.8	8.5	.1	.2	.1
Propyne	.4	.3	.6	T	T	T
2-Methylpropene	.2	.6	.5	T	T	
1-Butene	6.1	.4	1.6	.5	2.9	.8
2-Butene	4.1	.3	1.2	.2	.1	.6
1-Butyne	T		T			

T=trace, less than 0.05 $\mu g/m^3$.

TABLE 6 (Continued)

Compound	Cryotrap JP-4 low idle	Cryotrap JP-4 mid idle	Cryotrap JP-4 with Xylene mid idle	Polymer JP-4 low idle	Polymer JP-4 mid idle	Polymer JP-4 with Xylene mid idle
Olefins (Continued)						
2-Butyne	.1	T	.1		T	.4
3-Methyl-1-Butene			.3		T	.1
1-Pentene	3.4	.3	.5	2.0	1.9	.4
2-Pentene	.1	.3	.5	.3		.6
1-Pentyne				.1		
2,2-Dimethyl-1-Butene	.1					
2-Ethyl-1-Butene		T				
2-Methyl-1-Pentene	1.1	.1	.6		.3	1.0
4-Methyl-1-Pentene	.8	.1	.4		.2	
4-Methyl-2-Pentene	T				.3	
1-Hexene	1.3			T		
3,4-Dimethyl-1-Pentene			.4		.1	
4,4-Dimethyl-2-Pentene			.5			
4-Methyl-1-Hexene	.7				.1	.6
2-Heptyne				.4		
3-Methyl-4-Ethylhexene					T	
1-Nonene				T		
1-Decyne				T		
	5.7	1.0	2.4	1.2	1.4	2.7
Diolefins						
Propadiene	1.4	.2	.4	T	T	.1
1,2-Butadiene	.1					
1,3-Butadiene	4.1	.8	2.0	.7	1.2	1.9
1-Buten-3-yne				T	T	
1,3-Butadiyne						
2-Methyl-1,3-Butadiene				.5	T	
3-Methyl-3-Buten-1-yne					.1	.4
1,2-Pentadiene					T	
1,3-Pentadiene				T		
1,4-Pentadiene	.2	T				.2
2,3-Pentadiene					.1	
3-Penten-1-yne				T		
	5.5	.9	4.5	8.3	1.2	8.8
Naphthenes						
Cyclopropane	.4					
Cyclobutane	T	T		1.0	.4	.4

T=trace, less than 0.05 μg/m^3.

TABLE 6 (Continued)

Compound	Cryotrap JP-4 low idle	Cryotrap JP-4 mid idle	Cryotrap JP-4 with Xylene mid idle	Polymer JP-4 low idle	Polymer JP-4 mid idle	Polymer JP4 with Xylene mid idle
Naphthenes (Continued)						
1,1-Dimethylcyclopropane	1.4		.3		T	.7
1,2-Dimethylcyclopropane			.4	.4		
Ethylcyclopropane						.3
Methylcyclobutane						T
Cyclopentane	.1	T	.2		.3	T
Cyclopentene			T			
1,3-Cyclopentadiene				.2	.1	
Dimethylcyclobutane					T	
Ethylcyclobutane		.1	.5	.9		.7
Methylcyclopentane	.6	.2	.4	.2	T	.2
Methylcyclopentadiene					T	
Cyclohexane	.6		.2	.1	.2	1.1
1,3-Cyclohexadiene				.1		
1,2-Dimethylcyclopentane				.8		
1,2-Dimethylcyclopentadiene				.8		
Methylcyclohexane	2.3	.6	2.0	.3	.2	1.8
1-Methyl-1-Ethylcyclopentane	.1		.2			T
1-Methyl-2-Ethylcyclopentane						T
1-Methyl-3-Ethylcyclopentane		T	T	.4		
1,2-Dimethylcyclohexane			T		T	.1
1,4-Dimethylcyclohexane			.1			.1
Ethylcyclohexane			.2	T	T	T
1,1,2-Trimethylcyclohexane						T
1,1,3-Trimethylcyclohexane						1.0
1,2,3-Trimethylcyclohexane				2.5		
1,2,4-Trimethylcyclohexane						T
n-Propylcyclohexane				.6		2.4
Butylcyclohexane			T			
Aromatics	18.6	5.6	35.7	13.6	8.1	28.6
Benzene	6.6	1.3	4.5	4.3	2.9	5.1
Methylbenzene	4.1	.9	5.7	3.8	1.3	4.3
Dimethylbenzene	4.4	2.5	11.7	2.0	2.0	11.0
Ethylbenzene	1.4	.1				
1,2,3-Trimethylbenzene				.5		
1,2,4-Trimethylbenzene	.7	.6	1.0			1.4
1,3,5-Trimethylbenzene	.3			.3	.1	

T=trace, less than 0.05 $\mu g/m^3$.

TABLE 6 (Continued)

	Cryotrap			Polymer		
Compound	JP-4 low idle	JP-4 mid idle	JP-4 with Xylene mid idle	JP-4 low idle	JP-4 mid idle	JP-4 with Xylene mid idle
Aromatics (Continued)						
1-Methyl-2-Ethylbenzene	.8	.2	1.4	1.2	.7	.8
n-Propylbenzene			6.0		.6	.8
Isopropylbenzene			5.4			1.4
Diethylbenzene	.3			1.0	.2	3.8
Naphthalene				.5	.2	
1-Methylnaphthalene					T	
2-Methylnaphthalene					.1	
Dimethylnaphthalene					T	
Acids	.4			1.5	.2	1.3
Acetic	.4			1.5	.2	.9
Propanoic						.4
Aldehydes	3.2	1.4	3.7	.8	1.8	5.0
Methanal						T
Ethanal	1.6	.7	1.9	.2	.4	.7
Propanal	.1	.2	.3			.4
Propenal				.6	.1	.5
2-Methylpropanal			.2		.1	
n-Butanal	.2	.5	.3		1.2	.5
2-Butenal			.1		T	.3
3-Butanolal			.1			
2,2-Dimethylpropanal	1.3					
2-Methylbutanal			.4			
2-Ethylbutanal						.4
2-Methylpentanal			.4			
Benzaldehyde					.1	2.2
n-Heptanal				.1	.1	
n-Decanal				1.8		
Alcohols	3.6	.3	4.8	7.4	1.6	8.1
Methanol	.2	T	.3	T	T	T
Ethanol	.2	T	.2	.1	T	.2
1-Propen-3-ol				T		
2-Propen-1-ol	.2	T	T	.5	.6	.6
2-Buten-1-ol		T		T		

T=trace, less than 0.05 $\mu g/m^3$.

TABLE 6 (Continued)

Compound	Cryotrap JP-4 low idle	Cryotrap JP-4 mid idle	Cryotrap JP-4 with Xylene mid idle	Polymer JP-4 low idle	Polymer JP-4 mid idle	Polymer JP-4 with Xylene mid idle
Alcohols (Continued)						
3-Butyn-2-ol			T		T	
3-Buten-1,2-diol				.1		
3-Methyl-1-Butanol					.1	.1
1-Pentanol					T	
1-Penten-3-ol						.2
4-Penten-1-ol	1.2	.1	.1	.4	.2	
2-Ethyl-1-Butanol			.6	T		
2-Methyl-1-Pentanol					T	
3-Methyl-1-Pentanol	1.3	T	.1			
2,2-Dimethyl-1-Pentanol			T			
Methylcyclohexanol				.1		
Cyclohexymethanol				T		
2-Methylheptanol						1.0
6-Methylheptanol						3.6
1-Nonanol				.8		
n-Propylheptanol		.2		T		
2-Propylheptanol	.5		2.9	2.2	.7	2.4
2,7-Dimethyloctanol			.2	1.6		
Butyloctanol			.4			
2-Butyl-1-Octanol				1.6		
Ketones	.8	2.1	2.2	1.9	2.1	2.8
2-Propanone	.5	.5	1.1	.3	.8	.3
2-Butanone	.1	.6	.4	1.2		
Cyclobutanone				T		
3-Butene-2-one		T				
2-Pentanone	.2		T			.4
3-Pentanone		.3				
3,3-Bis(Hydroxymethyl)-2-Butanone					.1	
3-Methyl-2-Pentanone					.6	
3-Hexanone			.6	.4	.6	1.5
Cyclohexanone						.3
2-Methyl-3-Heptanone		.7				
Acetophenone				T		T
Cyclononanone				T	T	.3
Propyl Benzyl Ketone			.1			

T=trace, less than 0.05 $\mu g/m^3$.

TABLE 6 (Continued)

Compound	Cryotrap JP-4 low idle	Cryotrap JP-4 mid idle	Cryotrap JP-4 with Xylene mid idle	Polymer JP-4 low idle	Polymer JP-4 mid idle	Polymer JP-4 with Xylene mid idle
Ethers	1.0	.8	.4	1.2	.1	.1
Methyl Ether	T					
2,3-Epoxybutane		.3		.2		
1,3-Dioxolane	.4	.3	T		T	
Furan	.4	.1	.2			
2,5-Dihydrofuran	T	.1	.2		T	.1
Ethyl Vinyl Ether	.2		T	.3	.1	
Benzyl Ether				.7		
Esters			.1	.9	.8	.2
Ethyl Formate					T	
Ethyl Acetate				.5	.6	.2
Allyl Formate				.2		
Isopropyl Propionate				T		
Allyl Acetate			T			
Isoamyl Acetate				.2		
Octyl Acrylate			.1			
Decyl Acetate					.2	
Nitrogen Containing	1.0	T	.2	1.1	.6	1.0
Ammonia			T			
Nitromethane	1.0			T		
Diazoethane					.6	1.0
2-Nitroethylpropionate		T		1.1		
Neopentyl Nitrate			.2	T		
Halogen Containing	2.1	.3	.4	1.0	T	1.0
Chloromethane			T	T	T	T
Dichlorodifluoromethane (R-12)			T			
Trifluorotrichloroethane	.6				T	
1-Chloro-3-Methylbutane	1.5	.2	.1			
2-Chloro-3-Methylbutane		.1	T			1.0
2-Iodo-2-Methylbutane				T	T	
1-Chloropentane			.1	T		
2-Chloropentane			T			
Isoamyl Chloride			.1			

T=trace, less than 0.05 $\mu g/m^3$.

TABLE 6 (Continued)

Compound	Cryotrap JP-4 low idle	Cryotrap JP-4 mid idle	Cryotrap JP-4 with Xylene mid idle	Polymer JP-4 low idle	Polymer JP-4 mid idle	Polymer JP-4 with Xylene mid idle
Halogen Containing (Continued)						
3-Chloro-3-Methylpentane			T			
1-Fluorohexane			.1			
1-Fluoroheptane				1.0		
Sulfur Containing			.9			
Octyl Mercaptan			.9			
Lactones	T					
β,β-Dimethylpropiolactone	T					
Metal Containing					T	
Nickel Carbonyl					T	
Unknown	43.8	5.8	26.2	28.9	6.7	37.4

T=trace, less than 0.05 μg/m^3.