FUEL CHARACTER EFFECTS ON THE J79 AND F101 ENGINE COMBUSTION SYSTEMS

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Between 1977 and 1978 time period four contractual efforts were initiated to evaluate the effects of select fuel property variations on several major engine classifications. The engines that would be most widely used by the Air Force through the next decade were divided into three categories: low pressure ratio, cannular combustion system; high pressure ratio, annular combustion system; and high pressure ratio, cannular system. The fourth program involved an advanced combustion system.

The first two categories were represented by the J79 and the F101 gas turbine engines, respectively. The third category was represented by the TF41 engine. This system will, however, not be discussed as the evaluation is not finished. The contracts to evaluate fuel effects in the J79 and F101 systems were awarded at about the same time to the same company, General Electric. Both programs were cofunded by the Aero Propulsion Laboratory and the Air Force Engineering Services Center. The efforts were timed to run concurrently. Thus, test fuels used on the program were identical.

All testing within both efforts was conducted on component rigs. The test rigs and the test points were established to evaluate the effects of fuel properties on the static performance, the ignition and stability limitations, the carboning and fuel nozzle fouling tendencies, and the durability of each combustion system. Static performance was measured at four operating conditions: idle, cruise, takeoff, and dash. Partial scaling of inlet air pressure and mass flow was necessary for the J79 dash condition and the F101 takeoff and dash conditions. Ignition properties were evaluated at standard and cold day ground conditions as well as at several points of the altitude windmilling/relight requirement map. Stability was evaluated by determining the fuel lean blowout point and the pressure blowout point at several operating points. Carboning and fuel nozzle fouling tests were conducted in special rigs, operated at special conditions, selected to accelerate these phenomena. In addition, hardware life predictions were made of the combustor liner (based on metal temperature measurements) and of the turbine (based on radial temperature profile and pattern factor measurements).

Thirteen refined and blended fuels were used in these programs. These fuels exhibited significant variations in hydrogen content (12.0 to 14.5 weight percent), aromatic type (monocyclic or bicyclic), initial boiling point (285 to 393 K by gas chromatograph), final boiling point (532 to 679 K also by gas chromatograph), and viscosity (0.83 to 3.25 mm^2/s at 300 K).

The results varied between the two programs. Trends were very similar but the degree of fuel sensitivity was not constant. For both systems the dominant fuel property during high pressure operation was found to be fuel hydrogen content. For the J79 this fuel property strongly affected smoke, carbon deposition, liner temperature (and, therefore, liner life), and flame radiation and moderately affected NO_x emissions. For the F101 system hydrogen content strongly affected smoke emissions, liner temperature (and life), and NO_x emissions.

For operation at low pressure test points the fuel volatility and viscosity became the dominant fuel properties for both systems. The cold day ground starting and altitude relight capabilities of the systems were degraded with reduced volatility and increased viscosity. Typically, the 10% recovery temperatures of the fuels' distillation behavior were used as a measure of fuel volatility. Viscosity was introduced into the correlations through the relative Sauter Mean Diameter (SMD), a parameter characterizing the fuel spray. These values were calculated for each test fuel at each condition of interest and referenced to the SMD of JP-4. The F101 was more sensitive than the J79 to variations in these parameters.

The F101 fuel divider valve indicated a sensitivity to the fuel thermal stability in an accelerated cycle test involving two fuels of widely different thermal stability properties. The tests were not conclusive but did indicate a correlation of laboratory measured fuel thermal stability and the cycles to a discrete degradation in the operation of the F101 fuel divider valve, arbitrarily chosen to be a 10% increase in flow hysteresis at a fuel pressure drop of 1.24 MPa. Related testing of the J79 fuel nozzle indicated no apparent fuel sensitivity over the range tested. This was expected since the J79 fuel nozzle passages are not as critically dimensioned as those of the F101.

Aromatic type and final boiling point do not significantly affect combustion data.

Correlations of other fuel properties with these and other performance parameters were examined. The above relationships, however, were the most dominant. Details of the J79 and F101 fuel effects programs can be found in AFAPL-TR-79-2015 and AFAPL-TR-79-2018, respectively.

Test Fuel Chemical and Physical Properties.

Fuel No.	Fuel Components Base Fuel	Fuel Components Blending Agents	Hydrogen Content H Weight %	Heating Value (net) MJ/kg	Density $\rho_{300\ K}$ kg/m^3	$-\frac{\partial \rho}{\partial T} \times 10^4$	Viscosity $\nu_{300\ K}$ mm^2/S	$-\frac{\partial[\ln \ln (\nu + 0.7)]}{\partial[\ln T]}$	Surface Tension $\sigma_{300\ K}$ mN/m	$-\frac{\partial \sigma}{\partial T} \times 10^3$	Vapor Pressure $P_{300\ K}$ kPa	$+\frac{\partial[\ln P]}{\partial[\ln T]}$
1	JP-4	-	14.5	43.603	752.7	7.935	0.924	4.112	23.27	10.01	12.04	9.80
2	JP-8	-	14.0	43.210	799.5	7.363	1.849	4.009	25.85	9.53	2.15	6.19
3	JP-8	Gulf Mineral Seal Oil	13.9	43.189	801.2	7.330	2.071	3.995	25.92	9.78	1.97	5.84
4	JP-8	2040 Solvent	12.0	41.947	852.3	7.455	1.809	4.170	27.62	8.24	1.16	7.78
5	JP-8	Xylene Bottoms	13.0	42.724	813.4	7.525	1.428	4.051	26.38	9.50	1.48	10.86
6	JP-8	Xylene Bottoms	12.0	42.129	827.6	7.775	1.160	4.111	26.66	9.47	1.33	10.77
7	JP-8	2040	13.0	42.556	825.2	7.437	1.804	4.103	26.42	6.20	1.38	7.48
8	JP-4	2040	12.0	42.203	829.7	7.832	1.141	4.179	25.22	7.31	7.38	11.60
9	JP-4	2040	13.0	42.629	796.3	7.758	1.028	4.144	23.75	6.94	8.61	11.41
10	JP-4	Xylene	12.0	42.196	808.0	8.150	0.830	4.237	25.21	7.97	6.17	11.31
11	JP-4	Xylene	13.0	42.682	786.5	8.072	0.835	4.328	24.20	5.40	9.06	10.47
12	JP-4	Xylene & GMSO	14.0	43.366	769.6	7.813	1.057	4.027	23.45	7.20	10.25	10.57
13	2-D	-	13.1	42.691	837.2	7.041	3.245	4.315	27.35	6.35	1.59	6.43
Test Method			D3701 (NMR)	D240 (Bomb)	Dilatometer		D445		Capillary Rise		Micro-vapor Pressure Apparatus	

TEST CONDITIONS/APPARATUS

CONDITION	APPARATUS	
	J79	F101
Performance		
• Idle		
• Cruise	Hi Pressure Single Can Rig	Hi Pressure Full Annular Rig
• Takeoff		
• Dash		
Pattern Factor	Hi Pressure Single Can Rig	Atmospheric Full Annular Rig
Relight/Stability		
• Standard Day Ign	Hi Pressure Single Can Rig	Atmospheric Full Annular Rig
• Idle Stability		
• Cold Day Grd Ign	Lo Pressure Single Can Rig	Lo Pressure 54° Sector Rig
• Altitude Ign/Stability		
Carbon Deposition	Hi Pressure Single Can Rig	Hi Pressure Single Cup Rig
Fuel Nozzle Fouling	Fuel Nozzle Rig	Short Term/Long Term Fuel Metering Valve Rig

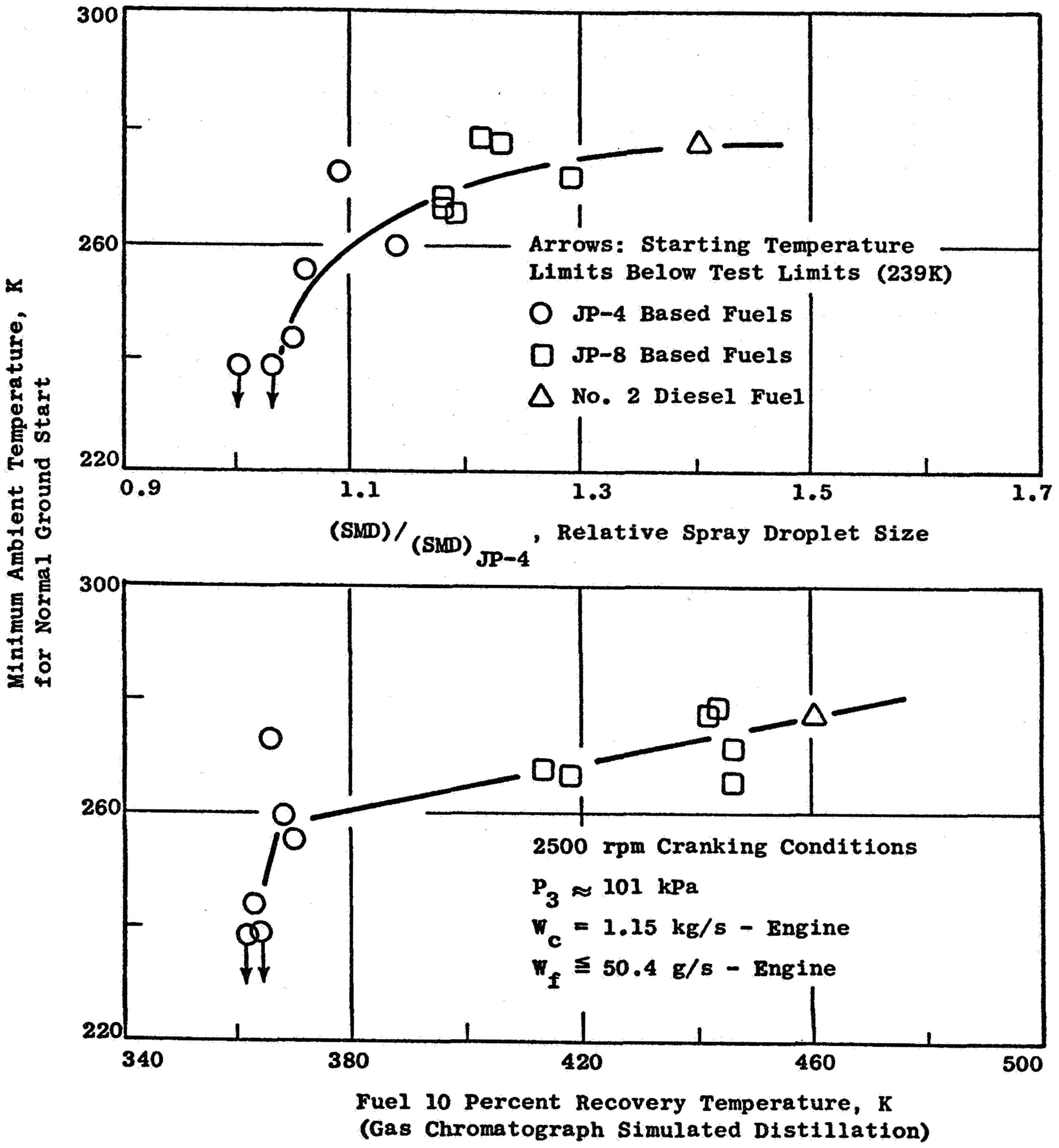

Figure 1 . Effect of Fuel Atomization and Volatility on Cold Day Ground Starting Capability.

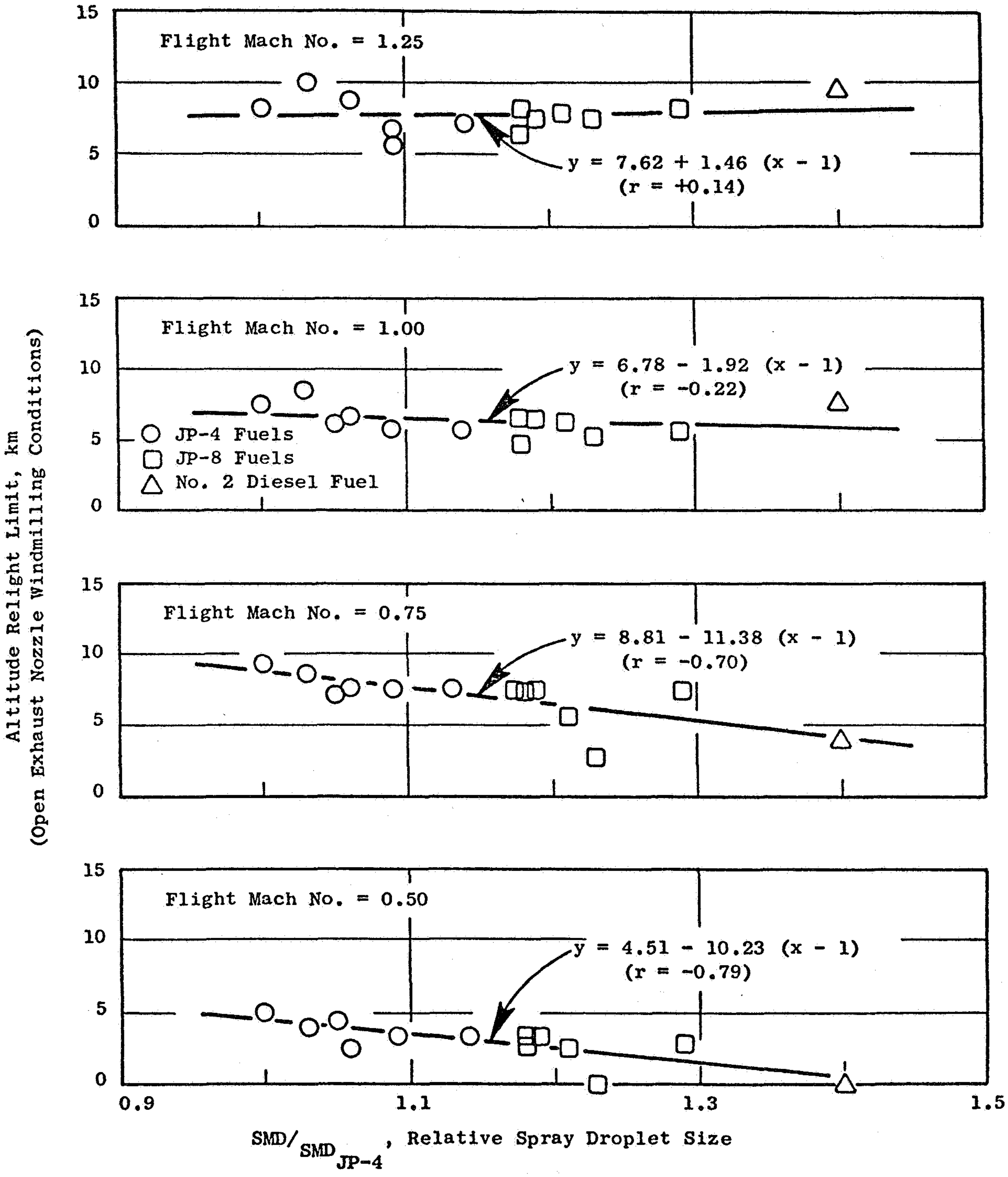

Figure 2 . Effect of Fuel Atomization on Altitude Relight Limits (Open Exhaust Nozzle Windmilling Conditions).

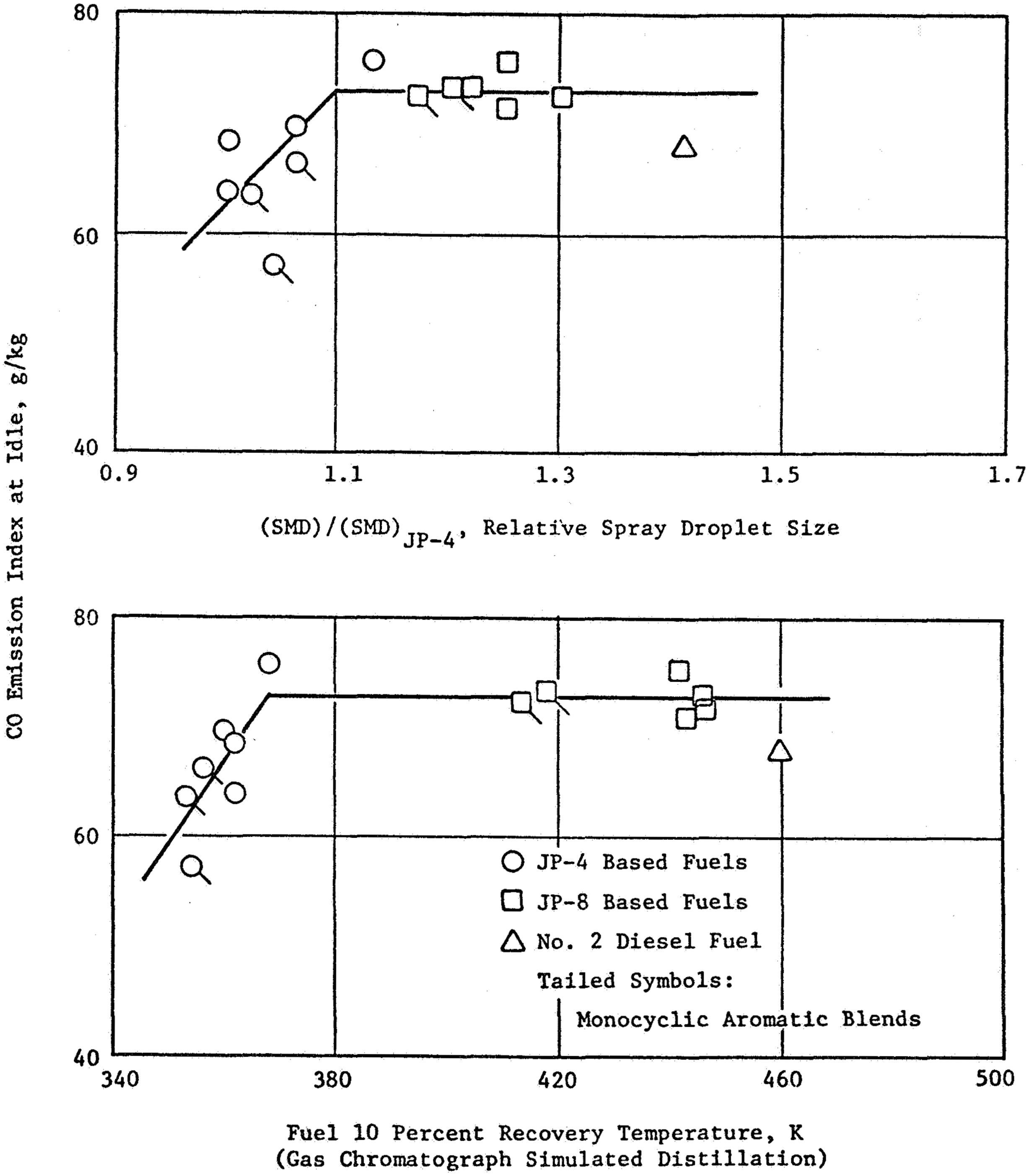

Figure 3 . Effect of Fuel Atomization and Volatility on Idle CO Emission Levels.

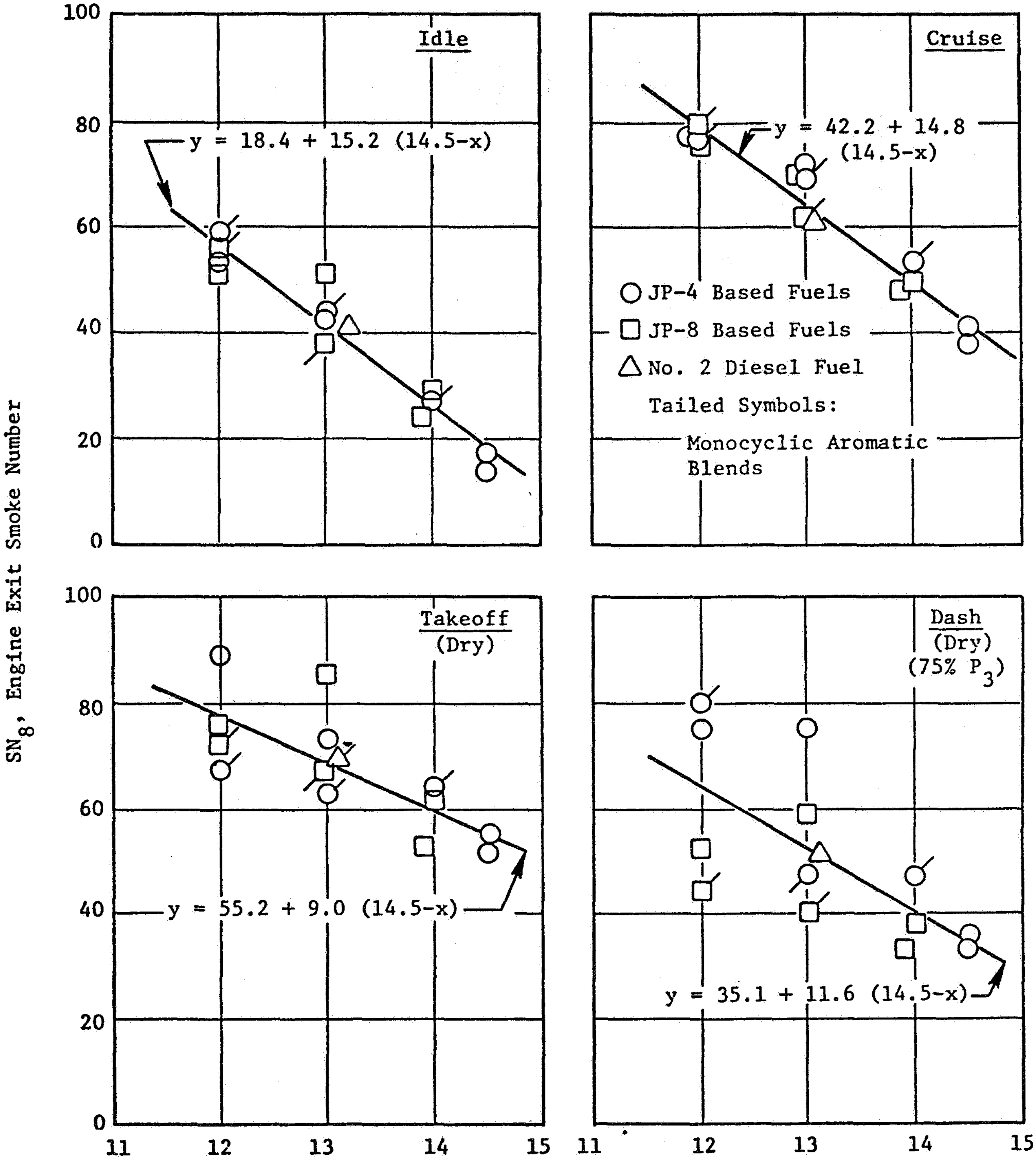

Figure 4 . Effect of Fuel Hydrogen Content on Smoke Emission Levels.

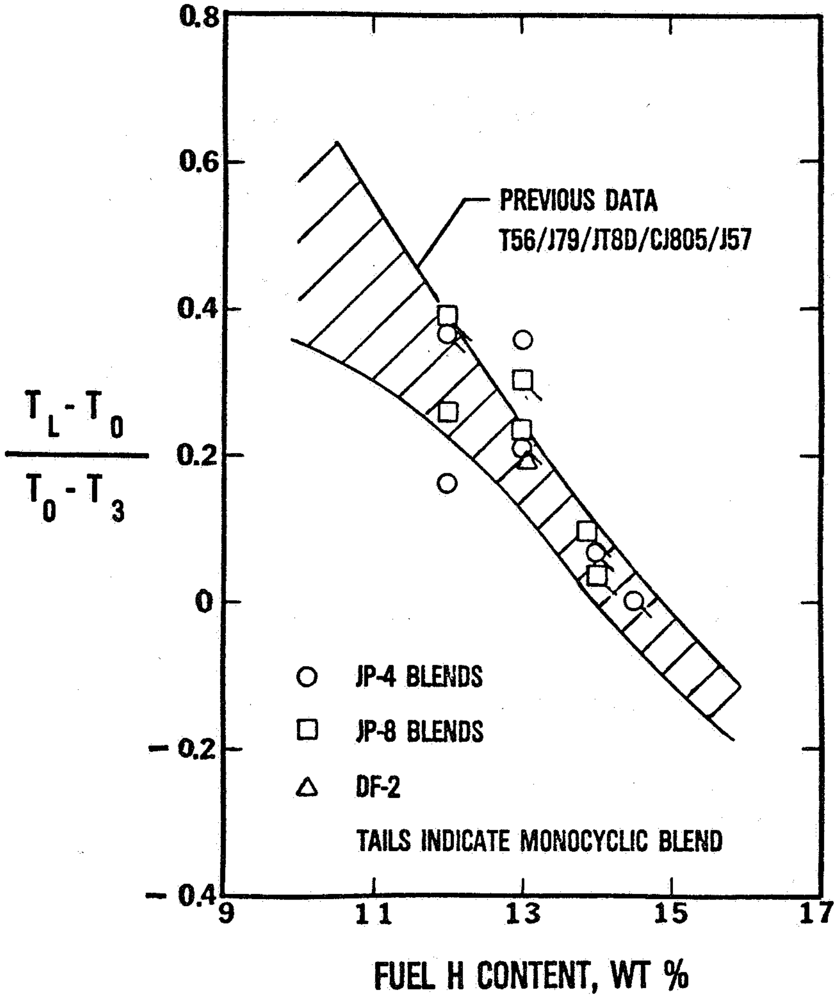

Figure 5. Effect of Fuel Hydrogen Content on Liner Temperature Parameter at Cruise Operating Conditions.

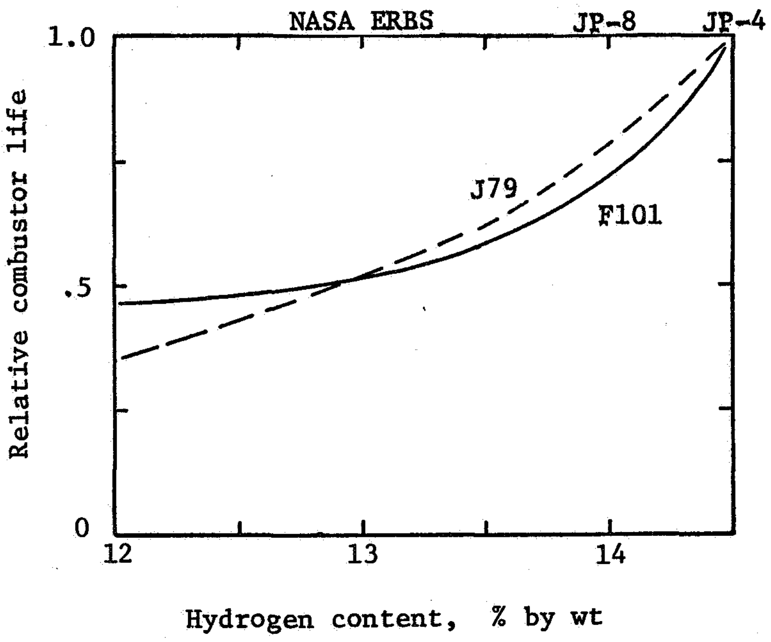

Figure 6. Effect of fuel hydrogen content on combustor durability.

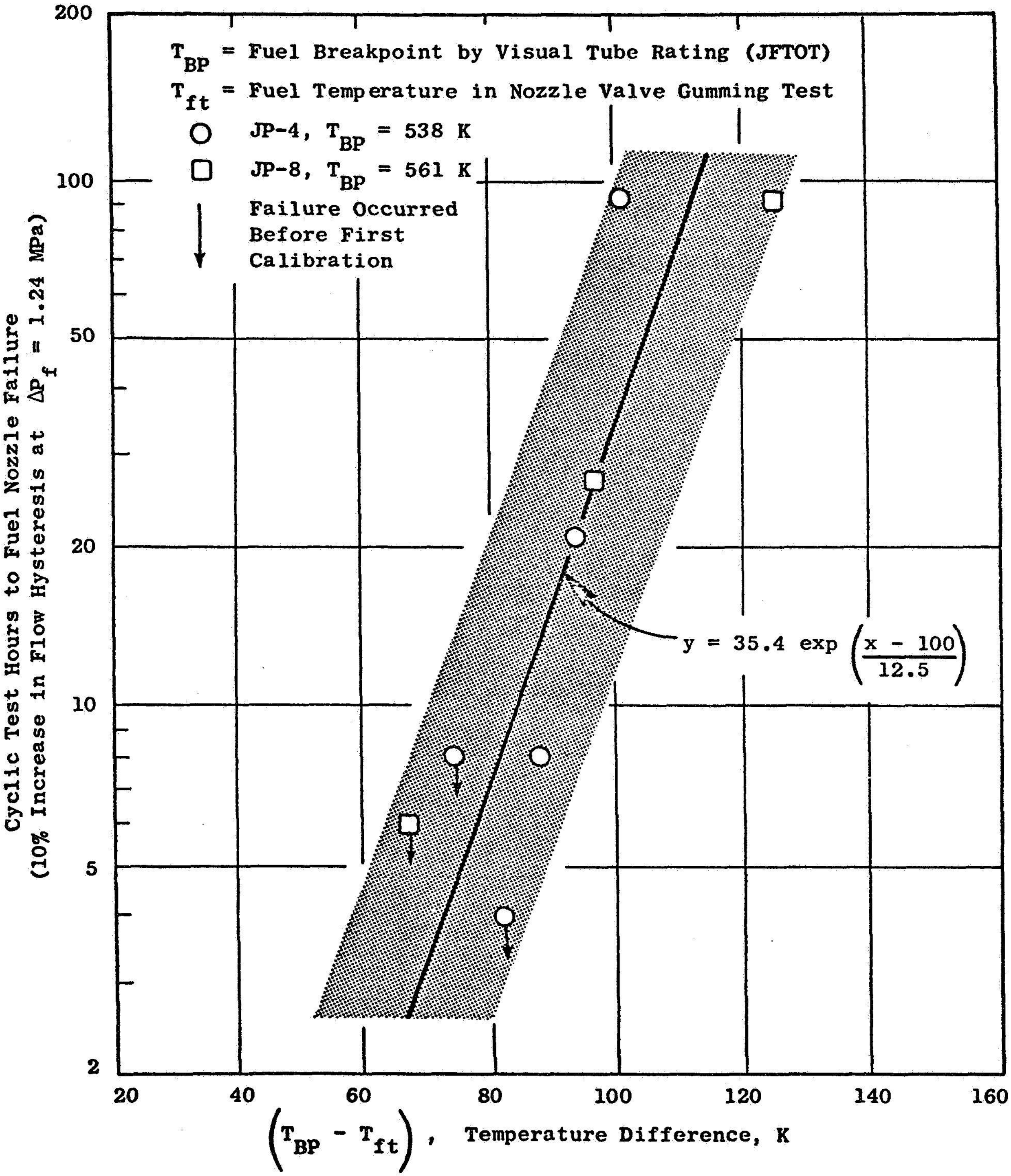

Figure 7. Effect of Fuel Temperature and Type on Fuel Nozzle Valve Life.