



THE USE OF SYNTHETIC JP-8 FUELS IN MILITARY ENGINES



TECHNOLOGY DRIVEN. WARFIGHTER FOCUSED.

By Laura Hoogterp-Decker* and Dr. Peter Schihl

27th Army Science Conference

2 December 2010

Report Documentation Page			Form Approved OMB No. 0704-0188		
Public reporting burden for the collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden, to Washington Headquarters Services, Directorate for Information Operations and Reports, 1215 Jefferson Davis Highway, Suite 1204, Arlington VA 22202-4302. Respondents should be aware that notwithstanding any other provision of law, no person shall be subject to a penalty for failing to comply with a collection of information if it does not display a currently valid OMB control number.					
1. REPORT DATE 02 DEC 2010		2. REPORT TYPE N/A		3. DATES COVERED -	
4. TITLE AND SUBTITLE The Use of Synthetic JP-8 Fuels in Military Engines			5a. CONTRACT NUMBER		
			5b. GRANT NUMBER		
			5c. PROGRAM ELEMENT NUMBER		
6. AUTHOR(S) Laura Hoogterp-Decker; Dr. Peter Schihl			5d. PROJECT NUMBER		
			5e. TASK NUMBER		
			5f. WORK UNIT NUMBER		
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) US Army RDECOM-TARDEC 6501 E 11 Mile Rd Warren, MI 48397-5000, USA			8. PERFORMING ORGANIZATION REPORT NUMBER 21343		
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES) US Army RDECOM-TARDEC 6501 E 11 Mile Rd Warren, MI 48397-5000, USA			10. SPONSOR/MONITOR'S ACRONYM(S) TACOM/TARDEC		
			11. SPONSOR/MONITOR'S REPORT NUMBER(S) 21343		
12. DISTRIBUTION/AVAILABILITY STATEMENT Approved for public release, distribution unlimited					
13. SUPPLEMENTARY NOTES Presented at the 27th Army Science conference (ASC), 29 November 2 December 2010 Orlando, Florida, USA, The original document contains color images.					
14. ABSTRACT					
15. SUBJECT TERMS					
16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT SAR	18. NUMBER OF PAGES 21	19a. NAME OF RESPONSIBLE PERSON
a. REPORT unclassified	b. ABSTRACT unclassified	c. THIS PAGE unclassified			

- **Introduction**
- **Engine Testing**
 - Engine Specifications
 - Test Conditions
 - Fuel Analysis
- **Experimental Results**
 - Overview of Results
 - Fuel Composition Effects
 - Heat Release Analysis
 - Exhaust Temperatures
- **Conclusions**

Introduction

- **Study the impact of alternative jet fuels on military engines**
 - Evaluate multi-cylinder production engines
 - Obtain information on large scale issues such as performance, component wear and possible failure modes
 - Use research engine to support production engine results
 - Use data to quantify the differences seen in the multi-cylinder testing
 - Allows for precise control over intake conditions and injection event
 - Obtain detailed engine measurements such as in cylinder pressure, temperatures and injection data not possible to obtain on the production engines



- **1988 introduced the single fuel forward initiative**
 - Mandates the use of a single fuel (JP-8) for Army vehicles
- **Push for “green” technologies**
- **2009 ASTM International specification for jet fuel changed**
 - Allows up to a 50-50 % blend by volume of JP-8 and Fischer Tropsch synthetic paraffinic kerosene JP-8 (FT SPK JP-8)
- **Need to know vehicle impact before field use**



Engine Testing

- **Two multi-cylinder production engines tested**
 - HMMWV GEP 6.5L
 - Bradley FIV Cummins VTA903
- **Single cylinder research diesel engine**
 - AVL 521

Engine Parameter	AVL	GEP 6.5	Cummins 903
Injection System	IRI BETA	Pump Line Nozzle (PLN)	Step timing control, Pressure Time (PT)
Peak Injection Pressure [bar]	1600	700	1300
Nozzle Geometry [mm]	7 x 0.191	single hole	7 x 0.190
Bore x Stroke [mm]	120 x 120	103 x 97	140 x 120
Peak Firing Pressure [bar]	200	-	-
Compression Ratio	16	20.2	14.5
Displacement [L]	1.4	6.5	14.8
Swirl Number	Variable	NA	-
Operating Speeds	800-3000	1500-3400	800-2900
Cylinders	1	8	8
Boost System	Shop air	Turbocharger	Turbocharger
Rated Power		190 hp @3400 rpm	600 @ 2600
Rated Torque		375 ft-lbs @ 1800 rpm	1200 @ 2600



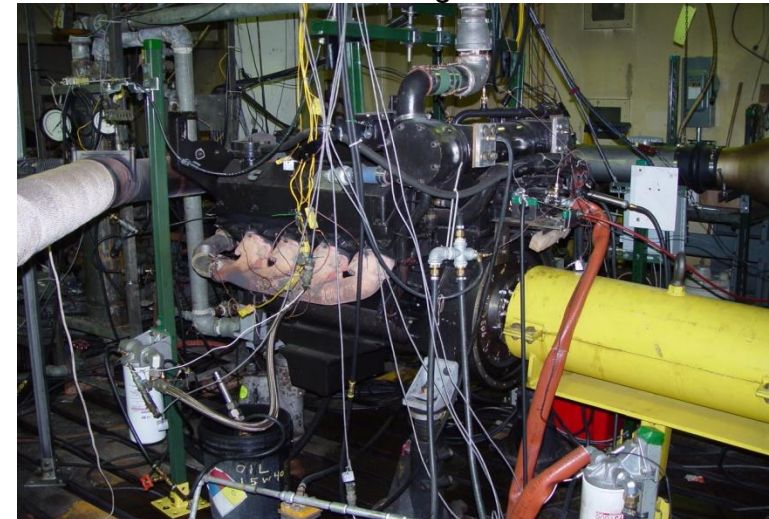
Test Conditions

Multi-cylinder Engine Testing

- **400 hour NATO test**
 - Performed with both the Cummins 903 and GEP 6.5
 - Performance benchmarked on DF-2 then evaluated using JP-8 or the 50-50 blend
 - New engines used for each fuel
 - Intake air set at 77 °F
 - Fuel temperature 86 °F
 - Data recorded at 0, 100, 200, 300 and 400 hours of testing
 - Full load data recorded at 100%, 75% and 60% of the rated speed and max torque speed
 - Part load conditions ran but not studied here
 - Cummins 903 ran elevated temperatures but the results are not included



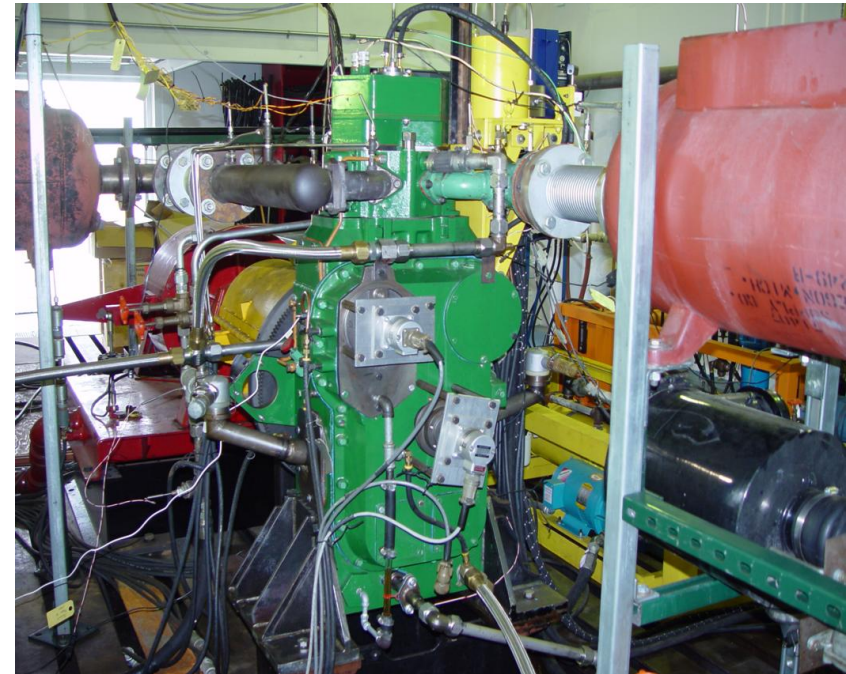
GEP 6.5 L engine



Cummins 903 engine

- **AVL 521 test strategy**
 - Calibrate engine for best fuel consumption using DF2
 - Use only a single injection event
 - Operate full load conditions at six engine speeds
 - Hold fueling and intake air constant
 - Allow air fuel ratio (A/F ratio) and torque to vary
 - Document performance
 - Perform advanced combustion calculations

Speed	Intake Pressure	Exhaust Pressure	Oil Rail Pressure	Intake Temperature	Pulse Width	Injection Timing bTDC
[RPM]	[psi]	[psi]	[psi]	[F]	[ms]	[deg]
1250	16.5	9.7	3500	145	4	19
1400	27	18.4	4500	177	4.2	18.5
1600	26	21	4000	195	4.2	19.35
1800	26.7	26.7	4000	210	3.5	20.25
2000	28.2	29.3	4800	213	3.3	18.8
2200	30	36	4800	213	3.1	21.35



AVL 521 Single Cylinder

- **Multi-cylinder engine testing**
 - DF-2, JP-8 and 50-50 blend JP-8 and FT SPK JP-8
- **Single Cylinder**
 - DF-2, JP-8, 50-50 blend, Syntroleum 8 (S-8), Sasol FT SPK JP-8 (Sasol)
- **Fuel analysis performed to determine properties**
 - Large cetane number, density and boiling point differences

Fuel	Cetane Number	Density [kg/L] @ 15 C	Viscosity [mm ² /s] 40	Viscosity [mm ² /s] -20	T90 Boiling Point [C]	Lower Heating Value [MJ/kg]	Aromatics % Volume %	Sulfur Content [ppm]
DF2	42.8	0.8655	2.688		317.1	42.6	45.74	390
JP8	44.9	0.8026	1.39	4.96	234.4	43.4	14.69	23
50/50	47.3	0.7923	1.2925	4.397	232.1	43.4	14.05	30
S8	62.4	0.7554	1.2862	4.42	248	44.1	0	1.6
Sasol JP8	25.2	0.7612		3.4775	205.3	44	0.89	-

Experimental Results

- **Multi-cylinder engine tests**

- Loss of torque for both fuels compared to DF-2
- No component failures or excessive wear

- **Single cylinder engine test**

- Reduction in torque for all fuels compared to DF-2

Engine	Engine Speed [RPM]	Torque with DF-2 [ft-lbs]	Torque with JP-8 [ft-lbs]	Torque with 50-50 blend [ft-lbs]	% Decrease for JP8 []	% Decrease for 50-50 []
903	2600	1264.67	1209.67	1197.33	4.36	5.32
903	2400	1300.67	1253.67	1242.67	3.59	4.43
903	2200	1294.33	1254.67	1238.67	3.04	4.30
903	1800	1236.00	1208.33	1189.33	2.24	3.77
903	1600	1164.67	1142.00	1119.67	1.93	3.82
HMMWV	1800	381.76	357.02	336.66	14.18	19.08
HMMWV	2100	376.39	346.32	330.62	8.00	12.17
HMMWV	2400	362.90	333.40	316.31	8.13	12.83
HMMWV	2700	341.82	317.35	300.71	7.16	12.03
HMMWV	3000	325.72	303.07	286.22	6.95	12.13
HMMWV	3200	315.14	292.05	275.75	7.33	12.51
HMMWV	3400	301.80	281.75	263.93	6.64	12.56

Engine Speed	1250	1250	1400	1400	1600	1600
Fuel	Torque [ft-lbs]	% Decrease WRT DF2	Torque [ft-lbs]	% Decrease WRT DF2	Torque [ft-lbs]	% Decrease WRT DF2
DF2	128.67	0.00	159.43	0.00	146.45	0.00
JP8	118.19	8.14	162.28	-1.79	141.12	3.64
50-50	115.62	10.14	149.77	6.06	146.79	-0.23
S8	116.06	9.80	154.71	2.96	144.10	1.60
Sasol	123.73	3.84	137.93	13.49	140.90	3.79
Engine Speed	1800	1800	2000	2000	2200	2200
Fuel	Torque [ft-lbs]	% Decrease WRT DF2	Torque [ft-lbs]	% Decrease WRT DF2	Torque [ft-lbs]	% Decrease WRT DF2
DF2	120.10	0.00	116.73	0.00	108.40	0.00
JP8	112.93	5.97	112.01	4.04	106.64	1.62
50-50	114.55	4.62	113.88	2.44	105.46	2.71
S8	111.32	7.31	122.55	-4.99	99.41	8.29
Sasol	118.19	1.59	116.14	0.51	103.14	4.85

- **Some power loss can be explained by the reduced energy content of the alternative fuels**
 - $E_f = \rho_f \times \text{LHV}$
 - E_f = Energy input of the fuel
 - ρ_f = density of the fuel
 - LHV = lower heating value of the fuel
- **DF-2 has the highest energy input**
 - Means if injection parameters are held constant it is expected that DF-2 would create more power

Fuel	Energy Input	Ratio to DF2
	[J/m ³]	
DF2	36870.3	1.00
JP8	34832.84	0.94
50/50	34385.82	0.93
S8	33304.32	0.90
GTL	34177.5	0.93
Sasol	33492.8	0.91

• Fuel density

- Shown previously can cause a reduction in the energy content
- Causes a change in fuel consumption
 - Higher density causes a larger quantity of fuel to be injected during the same duration

• Viscosity

- Has a minimal effect on injection and spray parameters

• Lubricity

- Low lubricity can negatively affect the fuel injection pump and injector life

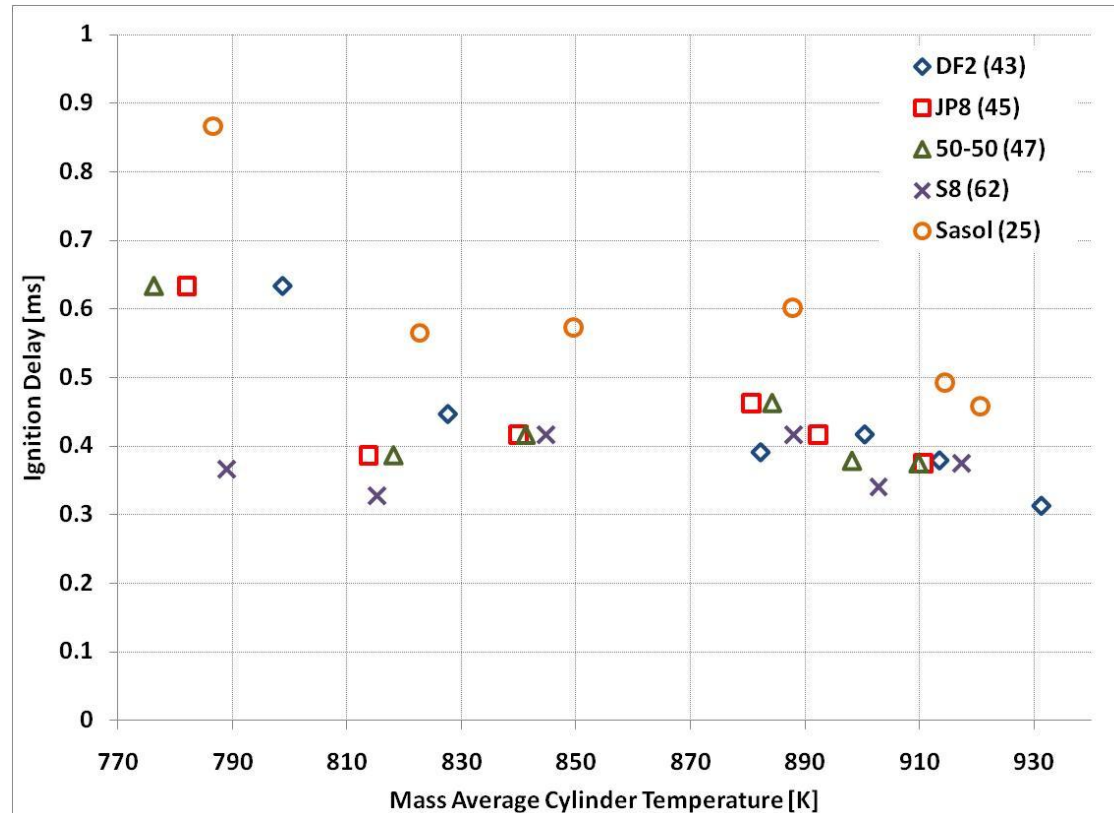
Engine Speed	2600	2600	2400	2400	2200	2200
Fuel	Fuel Consumption [lb/hr]	Ratio to DF2	Fuel Consumption [lb/hr]	Ratio to DF2	Fuel Consumption [lb/hr]	Ratio to DF2
DF2	222.07	1.00	205.23	1.00	187.25	1.00
JP8	209.74	0.94	197.71	0.96	178.77	0.95
50-50	208.01	0.94	194.07	0.95	174.42	0.93
Engine Speed	1800	1800	1600	1600		
Fuel	Fuel Consumption [lb/hr]	Ratio to DF2	Fuel Consumption [lb/hr]	Ratio to DF2		
DF2	149.32	1.00	130.24	1.00		
JP8	145.73	0.98	126.01	0.97		
50-50	142.44	0.95	124.16	0.95		

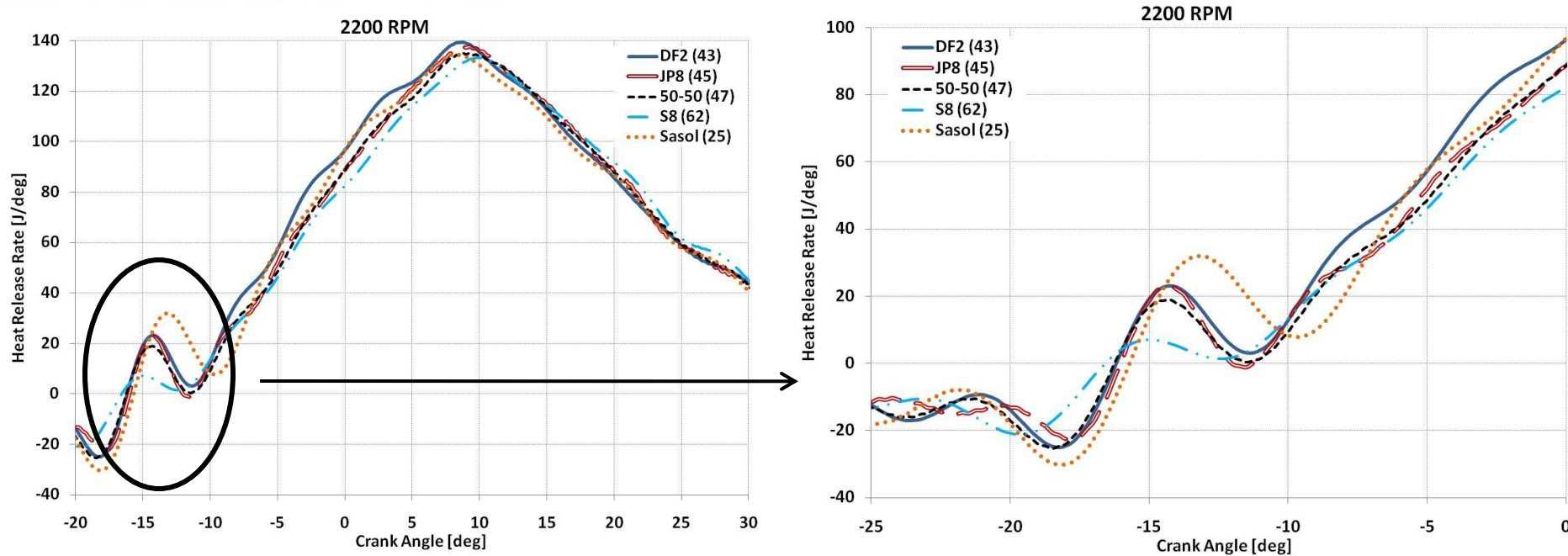
903 Data ^

Engine Speed	1250	1250	1400	1400	1600	1600
Fuel	Fueling Rate [lbs/hr]	Ratio to DF2	Fueling Rate [lbs/hr]	Ratio to DF2	Fueling Rate [lbs/hr]	Ratio to DF2
DF2	10.67	1.00	14.54	1.00	16.09	1.00
JP8	9.32	0.87	13.43	0.92	14.83	0.92
50-50	8.97	0.84	12.99	0.89	14.86	0.92
S8	8.85	0.83	12.56	0.86	14.40	0.90
GTL	9.52	0.89	13.13	0.90	14.47	0.90
Sasol	8.88	0.83	11.63	0.80	13.67	0.85
Engine Speed	1800	1800	2000	2000	2200	2200
Fuel	Fueling Rate [lbs/hr]	Ratio to DF2	Fueling Rate [lbs/hr]	Ratio to DF2	Fueling Rate [lbs/hr]	Ratio to DF2
DF2	14.08	1.00	15.69	1.00	16.07	1.00
JP8	12.81	0.91	14.90	0.95	15.04	0.94
50-50	13.03	0.93	14.65	0.93	14.86	0.92
S8	11.93	0.85	14.26	0.91	14.45	0.90
GTL	12.23	0.87	14.34		14.46	0.90
Sasol	12.62	0.90	14.20	0.91	14.73	0.92

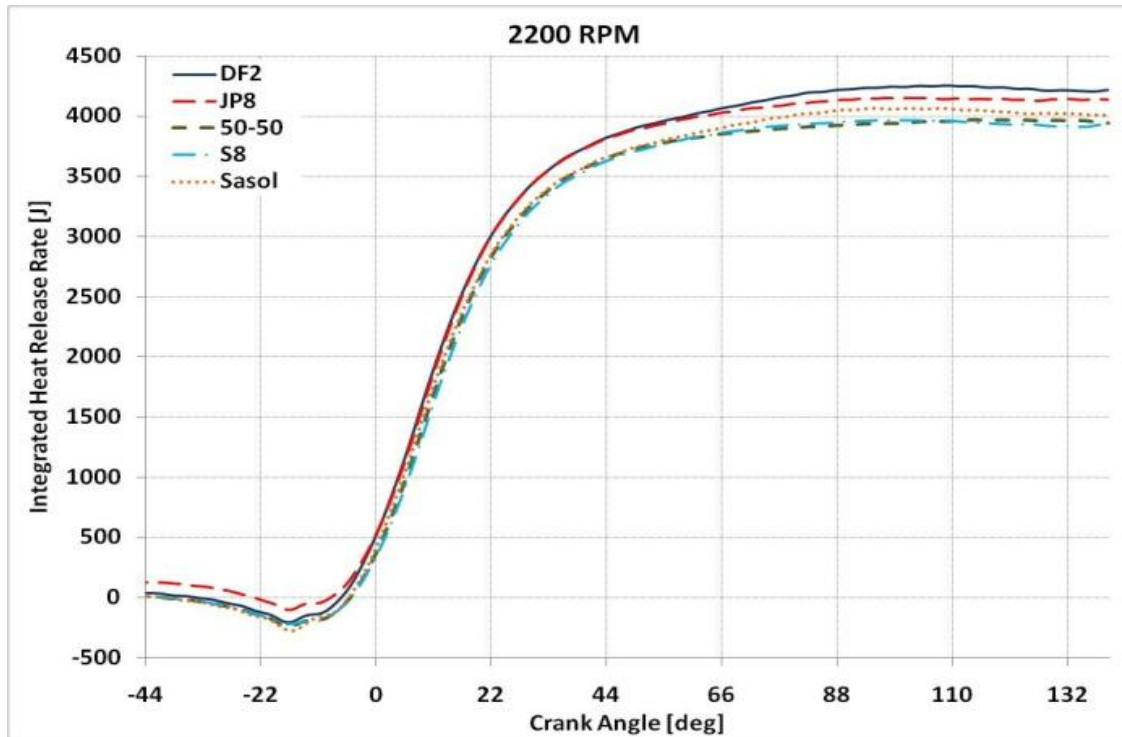
AVL Data ^

- **Cetane number (CN) is the fuel property with the largest effect on ignition and combustion**
 - Ignition delay (ID) is the amount of time it takes for the fuel to ignite
 - High CN result in shorter ID times
 - Long ID can lead to high pressure rise rates which can damage engines
 - Low CN has poor ignitibility
 - Would not be able to cold start





- Premix region
 - JP-8 and DF-2 very close
 - 50-50 slightly lower
 - S-8 ignites quick and small premix burn
 - Low pressure rise rate
 - Runs quiet
 - Sasol large premix spike
 - High pressure rise rate
- Diffusion burn
 - JP-8 and DF-2 very close
 - 50-50 slightly lower
 - S-8 has lower magnitude peak and peaks later
 - Lower HR results in less power produced
 - Sasol declines quicker
- Sasol and S-8 variances
 - S-8 has a high CN and low volatility (T90 = 248 C)
 - Ignites quick
 - Takes more time to evaporate
 - Sasol has low CN and high volatility (T90 = 205 C)
 - Long ignition time but evaporates quick



- Integrated rate of heat release (IRHR) at exhaust valve close (140° aTDC) gives the total energy released during combustion
 - Data confirms observations made in torque and fuel energy input
 - S-8 and 50-50 blend very similar explaining lack of clear trend in data

- Exhaust temperatures affect emission formation, turbocharger performance and the thermal signature of a vehicle
 - Alternative fuels had lower exhaust temperatures
 - Higher fuel energy input leads to higher IRHR and higher exhaust temperatures
 - Higher fuel consumption leads to higher A/F ratios and higher exhaust temps
 - Variations of combustion phasing seen in the HR profiles will affect the temperatures
 - HMMWV engine has more pronounced differences
 - Due to more pronounced fueling rate changes with this engine

Engine	Engine Speed [RPM]	Exhaust Temperature DF-2 [F]	Exhaust Temperature JP-8 [F]	Exhaust Temperature 50-50 [F]	JP-8 ratio to DF2	50-50 ratio to DF-2
903	2600	1171.90	1158.73	1155.73	0.99	0.99
903	2400	1178.13	1169.70	1167.30	0.99	0.99
903	2200	1200.70	1190.00	1189.73	0.99	0.99
903	1800	1301.37	1287.50	1288.87	0.99	0.99
903	1600	1365.47	1354.30	1350.60	0.99	0.99
HMMWV	1800	1033.68	963.54	930.82	0.93	0.90
HMMWV	2100	1094.94	1002.99	977.67	0.92	0.89
HMMWV	2400	1172.89	1080.44	1046.54	0.92	0.89
HMMWV	2700	1222.37	1141.51	1106.21	0.93	0.90
HMMWV	3000	1303.29	1222.80	1193.50	0.94	0.92
HMMWV	3200	1355.40	1272.72	1235.78	0.94	0.91
HMMWV	3400	1397.15	1320.35	1277.87	0.95	0.91

Engine Speed	1250	1250	1400	1400	1600	1600
Fuel	Exhaust Temperature [F]	Ratio to DF2	Exhaust Temperature [F]	Ratio to DF2	Exhaust Temperature [F]	Ratio to DF2
DF2	1042.11	1.000	1112.94	1.000	1267.08	1.000
JP8	1047.04	1.005	1105.77	0.994	1262.61	0.996
50-50	953.49	0.915	1079.89	0.970	1181.12	0.932
S8	973.13	0.934	1037.91	0.933	1165.6	0.920
Sasol	993.7	0.954	964.88	0.867	1077.65	0.850
Engine Speed	1800	1800	2000	2000	2200	2200
Fuel	Exhaust Temperature [F]	Ratio to DF2	Exhaust Temperature [F]	Ratio to DF2	Exhaust Temperature [F]	Ratio to DF2
DF2	1073.28	1.000	1087.72	1.000	1001.08	1.000
JP8	1066.76	0.994	1102.39	1.013	980.78	0.980
50-50	1047.64	0.976	1069.24	0.983	970.42	0.969
S8	1005.67	0.937	1054.91	0.970	951.37	0.950
Sasol	1022.37	0.953	1005.25	0.924	940.47	0.939

Conclusions

- **Production engine tests were completed using the blended fuel with no component failures**
- **Power loss for alternative fuels tested**
 - Could possibly mitigate with timing changes
 - Not feasible with out knowing precise fuel properties
 - Not easily performed in a field environment
- **Lack of JP-8 specifications combined with possible low quality synthetic fuels could have disastrous results if unknowingly blended**
 - Low lubricity
 - Low cetane
 - Combustion phasing and spray targeting
- **Desert conditions could result in greater power loss**
- **Part load conditions still have to be investigated**
- **Cold start may be an issue**



ACKNOWLEDGEMENTS

The authors would like to thank Mr. Mike Radic and Ms. Kayla Pence for their efforts in conducting the AVL 521 experiments and post processing in-cylinder pressure measurements. Adria Socks and John Hubble performed the military engine testing and provided results while the National Automotive Center funded the production engine testing.