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INFRARED RADIATION FROM THE EXHAUST JET OF A J85-GE-5 TURBOJET ENGINE BURNING SIMULATED ALTERNATE FUELS

ENGINE TEST FACILITY
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AIR FORCE SYSTEMS COMMAND
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NOTICES

APPROVAL STATEMENT

This technical report has been reviewed and is approved for publication.

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Spectral measurements were made to compare infrared radiation from the exhaust jet of an engine burning JP-4 and fuel blends which simulate fuels derived from oil shale. A circular variable filter spectroradiometer was used to obtain spectral radiation data from the exhaust of a J85-GE-5 turbojet engine. Xylene was added to JP-4 to simulate the aromatic content of oil shale fuels.

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20. ABSTRACT (Continued)

Radiation data were obtained at each of seven instrument locations with the engine operating at four power levels.

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PREFACE

The work reported herein was conducted by the Arnold Engineering Development Center (AEDC), Air Force Systems Command (AFSC), at the request of the Air Force Aero-Propulsion Laboratory (AFAPL), Wright-Patterson Air Force Base, Ohio, under Program Element 62203F, Project 3048. The results of the research were obtained by ARO, Inc., AEDC Division (a Sverdrup Corporation Company), operating contractor for the AEDC, AFSC, Arnold Air Force Station, Tennessee, under ARO Project Number R34P-D3A. The author of this report was W. T. Bertrand, ARO, Inc. Mr. E. L. Hively, Research Division, Deputy for Operations was the Air Force project manager. The data analysis was completed on April 15, 1977, and the manuscript (ARO Control No. ARO-ETF-TR-77-39) was submitted for publication on May 16, 1977.

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1.0 INTRODUCTION

Recent large price increases for aircraft jet fuels, coupled with difficulties in acquiring required quantities of fuel, have spurred investigations of alternate fuel sources (Ref. 1). Fuels derived from oil shale deposits are being studied by the Air Force Aero-Propulsion Laboratory (AFAPL) at Wright-Patterson Air Force Base, Ohio. These fuels may contain higher concentrations of aromatic hydrocarbons as compared to fuels currently utilized, and they are known to strongly influence carbon particle formation during combustion. Among the possible effects of increased particulates is increased infrared radiation in the exhaust jet. The purpose of the work reported here was to compare infrared radiation from the exhaust of an engine burning JP-4 with radiation from fuels containing different percentages of aromatic hydrocarbons.

A circular variable filter (CVF) spectroradiometer was used to obtain the radiation data from the exhaust of a J85-GE-5 turbojet engine. A description of the engine installation and radiation instrumentation is presented herein. Xylene was added to JP-4 to simulate the aromatic content of oil shale fuels. Two fuel blends, one 25 percent and one 50-percent total aromatics, were used in the test. The nominal value of aromatics in JP-4 is 10 percent. The 25-percent blend was run in the main engine burner during military power operation. All data comparisons were made using JP-4 as a baseline fuel. Engine operation data are presented for all data points. Radiation data were obtained with the engine operating at four power levels at each of seven instrument locations.

2.0 ENGINE INSTALLATION

A J85-GE-5 afterburning turbojet engine was installed in a sea-level engine test stand at AFAPL (Ref. 1). Figure 1 shows the facility with the engine installed. The J85-GE-5 engine has a 7.0/1 maximum compression ratio axial compressor and an annular combustion chamber.

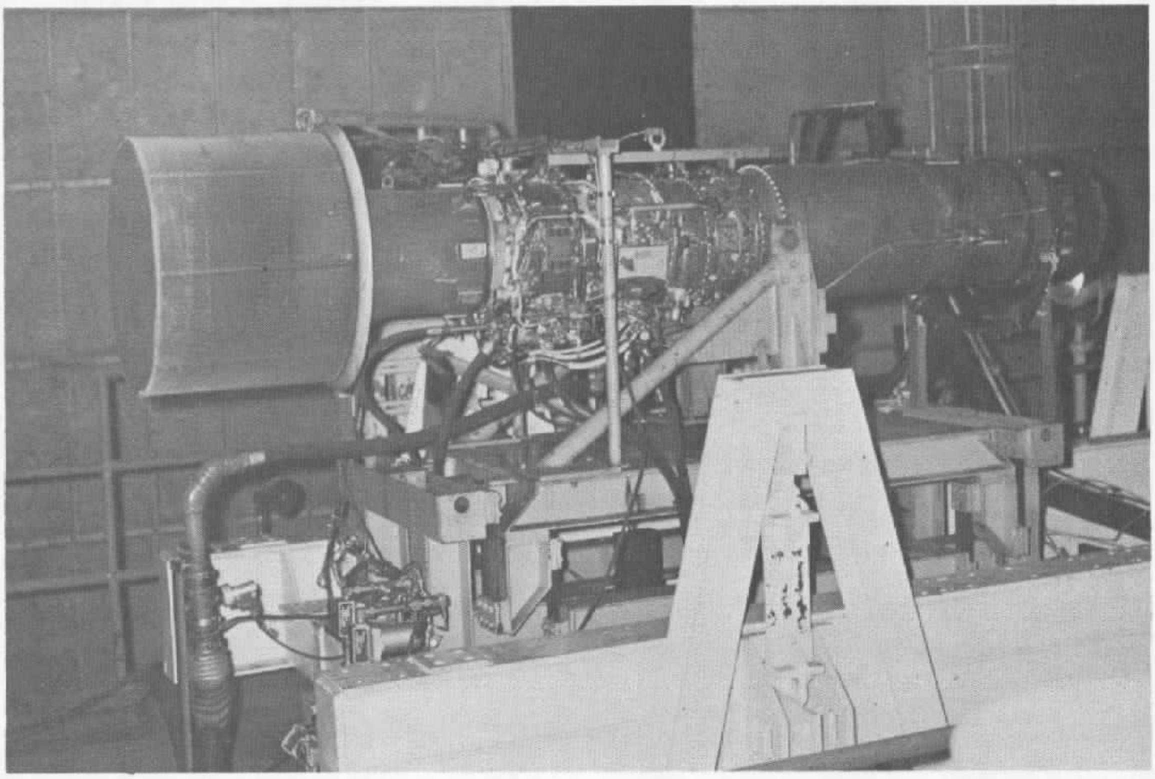

Figure 1. J85-GE-5 engine in ground-level test stand at AFAPL.

The afterburner employs a single flameholder with four pilot modules and a variable area exhaust nozzle. Engine airflow at military operation is 20 kg/sec, and maximum thrust is 17,126 N.

Engine performance parameters measured included engine thrust, airflow, main combustor fuel flow, afterburner fuel flow, turbine exit temperature, compressor discharge pressure, and oil temperature and pressure. Separate fuel systems were provided for the engine main burner and the afterburner to facilitate comparisons between JP-4 and simulated oil shale fuels.

Main burner and afterburner fuel flows are presented in Table 1 for the engine conditions used to obtain radiation data. The main burner fuel flow is set by the main fuel control as a function of compressor inlet total temperature, compressor discharge static pressure, engine rotor speed, and power lever angle. The afterburner fuel flow was set by the engine operator in order to duplicate flow rates for the different types of fuels. Nominal values of afterburner flow rates were 815, 1,590, and 1,815 kg/hr for minimum, mid-range, and maximum afterburning, respectively. Heating values of JP-4, the 25-percent blend, and the 50-percent blend were 10,400, 10,285, and 10,108 kcal/gm, respectively.

Table 1. Engine Fuel Flows for All Test Conditions

Engine Power	AB Fuel Type (JP-4 or Blend, percent)	Wide Field		Station 1*		Station 2		Station 3	
		A	B	A	B	A	B	A	B
Military	JP-4	1,293	---	1,259	---	1,293	---	1,247	---
Military	25	1,259	---	1,259	---	1,270	---	1,259	---
Min AB	JP-4	1,315	817	1,350	817	1,300	817	1,350	817
Min AB	25	1,247	817	1,247	817	1,270	817	1,247	817
Min AB	50	1,315	817	1,315	817	1,281	812	1,315	817
Mid AB	JP-4	1,315	1,597	1,350	1,579	1,293	1,588	1,259	1,588
Mid AB	25	1,247	1,588	1,259	1,588	1,270	1,588	1,247	1,588
Mid AB	50	1,315	1,597	1,315	1,570	1,281	1,588	1,315	1,588
Max AB	JP-4	1,315	1,814	1,338	1,814	1,297	1,814	1,259	1,792
Max AB	25	1,236	1,814	1,259	1,805	1,270	1,814	1,247	1,814
Max AB	50	1,315	1,814	1,315	1,814	1,281	1,814	1,315	1,814

Engine Power	AB Fuel Type (JP-4 or Blend, percent)	Station 4		Station 5		Station 6	
		A	B	A	B	A	B
Military	JP-4	1,293	---	1,247	---	1,281	---
Military	25	1,275	---	1,259	---	1,275	---
Min AB	JP-4	1,291	817	1,338	817	1,288	817
Min AB	25	1,270	812	1,281	817	1,286	821
Min AB	50	1,286	817	1,315	817	1,281	817
Mid AB	JP-4	1,270	1,588	1,247	1,588	1,284	1,588
Mid AB	25	1,281	1,588	1,247	1,588	1,284	1,588
Mid AB	50	1,281	1,588	1,315	1,588	1,281	1,588
Max AB	JP-4	1,291	1,814	1,247	1,769	1,284	1,814
Max AB	25	1,281	1,814	1,247	1,810	1,284	1,814
Max AB	50	1,281	1,814	1,315	1,814	1,284	1,814

Legend

A - Main Fuel Flow, kgm/hr

B - AB Fuel Flow, kgm/hr

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*See Fig. 3 for station locations.

3.0 RADIATION INSTRUMENTATION AND TEST PROCEDURE

A Barnes Model 12-550 CVF spectroradiometer was used to obtain low resolution ($\approx 40\ \mathrm{cm}^{-1}$) spectral data in the 2.0- to 6.0-μm IR region. In the sensing head, shown in Fig. 2, radiation from the selected target is collected by a lens and focused onto a plane that includes a field-defining aperture and a radiation chopper. Transfer mirrors refocus the expanding radiation beam onto the plane of a spectral filter assembly, and a relay lens refocuses the energy upon an indium antimonide (InSb) detector, which transduces the radiation signal into an electrical signal. A preamplifier conditions this signal to a level and impedance suitable for transmission through a cable to the remote electronics unit. A digital signal proportional to the filter wheel position is also generated by an optical encoder in the CVF head and transmitted to the electronics unit. In the electronics unit, solid-state electronics amplify, demodulate, and filter the detector signals. The result is an output voltage proportional to the target radiation, which is then digitized and recorded on magnetic tape for further processing.

An instrument position schematic is shown in Fig. 3. The CVF was mounted on a remotely controlled traversing cart to obtain radiation

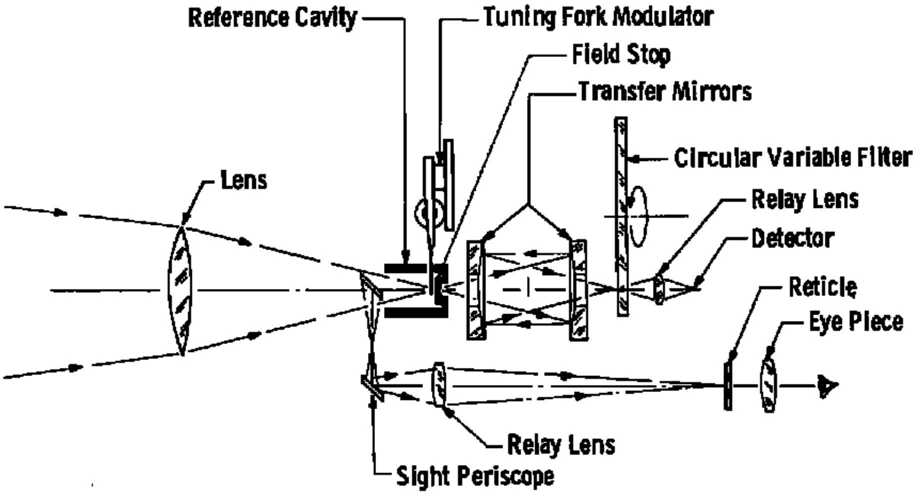
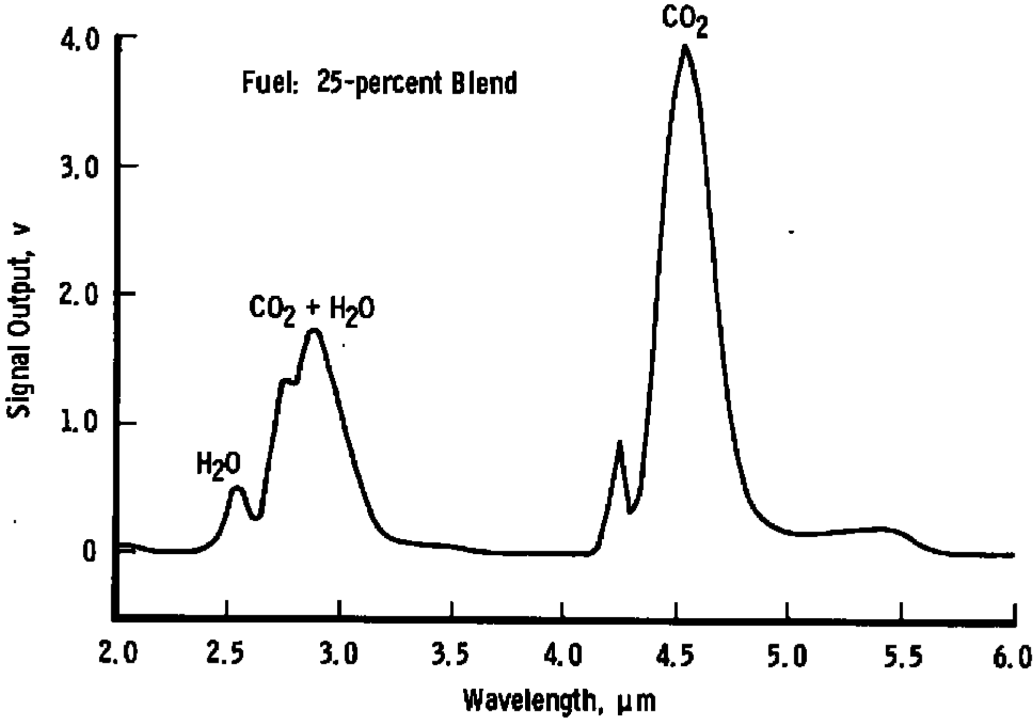


Figure 2. Optical schematic of Barnes 12-550 spectroradiometer.



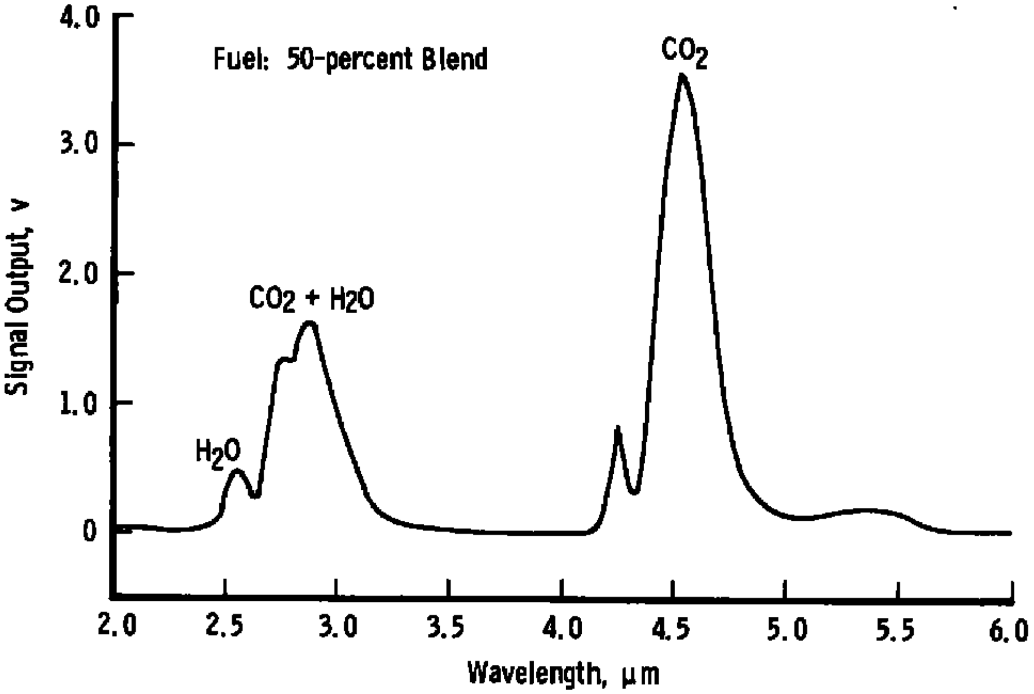


Figure 4. Concluded.

Table 2. Normalized Radiance Levels for All Engine Power Settings and Instrument Locations

Engine Power	AB Fuel Type (JP-4 or Blend, percent)	Wide Field Radiance Level, μ 2.54	2.86	4.51	Station 1 Radiance Level, μ 2.54	2.86	4.51	Station 2 Radiance Level, μ 2.54	2.86	4.51	Station 3 Radiance Level, μ 2.54	2.86	4.51
Military	JP-4	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Military	25	1.00	0.88	1.05	1.00	1.00	1.01	1.00	1.00	1.03	1.00	1.00	1.03
Min AB	JP-4	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Min AB	25	1.00	1.00	1.07	1.00	1.00	1.04	0.94	1.05	1.01	1.00	1.00	1.07
Min AB	50	0.92	0.99	0.96	0.90	0.93	0.97	0.90	1.00	1.00	1.00	0.94	1.02
Mid AB	JP-4	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Mid AB	25	1.00	1.00	1.06	1.00	0.95	1.01	0.92	1.00	0.99	1.00	0.97	0.98
Mid AB	50	0.93	0.89	0.95	0.93	0.89	0.96	0.92	0.94	0.96	0.91	0.89	0.88
Max AB	JP-4	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Max AB	25	0.94	1.00	1.04	0.95	0.98	1.00	0.94	0.98	1.01	1.00	0.94	0.99
Max AB	50	0.89	0.92	0.96	0.89	0.96	1.00	0.88	0.92	0.99	0.85	0.91	0.93

Engine Power	AB Fuel Type (JP-4 or Blend, percent)	Station 4 Radiance Level, μ 2.54	2.86	4.51	Station 5 Radiance Level, μ 2.54	2.86	4.51	Station 6 Radiance Level, μ 2.54	2.86	4.51
Military	JP-4	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Military	25	1.00	1.00	0.99	1.00	1.00	1.02	1.00	1.00	1.02
Min AB	JP-4	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Min AB	25	0.93	1.00	0.99	0.97	0.85	0.99	0.87	1.00	0.98
Min AB	50	0.93	0.93	1.06	1.00	0.92	0.99	0.87	1.00	0.95
Mid AB	JP-4	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Mid AB	25	1.00	1.00	1.00	1.00	0.99	1.01	1.00	0.89	0.98
Mid AB	50	0.92	0.99	0.96	1.00	0.87	0.84	1.00	0.95	0.97
Max AB	JP-4	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Max AB	25	0.90	0.94	1.04	1.00	0.99	1.01	1.00	0.93	1.03
Max AB	50	0.95	0.93	1.04	0.89	0.83	0.88	1.00	0.93	1.04

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*See Fig. 3 for station locations.

valid only between fuels at one particular combination of instrument location, engine power, and wavelength because no corrections were made for different fields of view and exhaust jet size.

In interpreting the results, one must consider the change in radiation values caused by time-varying exhaust jet fluctuations. Typical fluctuation percentages as determined experimentally are presented in Table 3. These values were obtained from measurements of the CVF output with the filter wheel stopped at the 4.51-μm wavelength position.

Table 3. Typical Jet Exhaust Radiation Fluctuation Percentages at $\lambda = 4.51\ \mu m$

Engine Power	Wide Field, percent	Narrow Field, percent
Military	±2.7	±4.2
Min AB	±2.5	±5.6
Mid AB	±2.0	±6.1
Max AB	±2.0	±6.1

Variations in the measured radiation values as a function of fuel type were less than exhaust jet fluctuations in 96 percent of the data points presented. No correlation between radiation and fuel type could be determined.

5.0 SUMMARY

Spectral measurements were made to compare infrared radiation from the exhaust jet of a turbojet engine burning JP-4 and fuel blends simulating oil shale derivatives. Xylene was added to JP-4 to simulate the aromatic content of oil shale fuels. Two blends, one 25-percent and one 50-percent total aromatics, were used in the test. A circular variable filter spectroradiometer was used to obtain radiation data in the 2.0- to 6.0-μm spectral range from the exhaust of a J85-GE-5 turbojet engine. Radiation data were obtained with the engine operating at four power levels at each of seven instrument locations. An analysis of the data and the fluctuations in the radiation intensity with time showed no discernible differences in radiation values with the blend fuels as compared to JP-4.

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1. Blazowski, W. S., Farenbruch, F. S., and Tacket, L. P. "Combustion Characteristics of Oil Shale Derived Jet Fuels." Presented at the Western States Section of the Combustion Institute, 1975 Fall Meeting, Palo Alto, California, October 1975.