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Ambient Effects on Idling Gas Turbine Emissions

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Changes in ambient conditions – pressure, temperature, and humidity – affect the exhaust emissions of a gas turbine engine. Such variations must be compensated for during engine certification. The results of a test program employing a JT8D-17 combustor are presented which quantize the effect of carefully controlled changes in ambient conditions on unburned hydrocarbons, carbon monoxide, and oxides of nitrogen at simulated idle operating conditions. Analytical results are given to explain the observed hydrocarbon and carbon monoxide behavior. It is shown that for a complete range of possible ambient variations, significant changes do occur in the amount of pollutants emitted by an idling gas turbine.

Introduction

ENVIRONMENTAL Protection Agency regulations pertaining to emission standards for gas turbine engines specify maximum quantities of the pollutant species which may be exhausted during a landing and takeoff cycle for engine inlet conditions corresponding to those of a standard day. Only occasionally, however, are ambient conditions those of a standard day, and it is necessary to develop correction techniques in order to be able to relate emission measurements as actually made from an engine or combustor to those which would have occurred on a standard day.

The effect of inlet pressure, temperature, and humidity on the oxides of nitrogen produced by an engine when operating at takeoff power settings was noted quite early by Lipfert,[1] and subsequently numerous correction factors were formulated. A compilation and evaluation of these has been recently given by Rubins and Marchionna.[2] For smoke, which is also a pollutant of concern at high-thrust conditions, recently reported results[3] indicate that the smoke number variability can be decreased by correcting for changes in the ambient temperature. For a combustor operating at idle conditions, additional corrections were developed by Marzeski and Blazowski[5] to account for the effects of nonstandard inlet pressure and temperature on all gaseous emissions. For production samples of a given engine, the effect of ambient temperature and pressure on all gaseous emissions over the complete thrust range has been correlated by Sarli et al.[6] With the exception of some limited engine test results given by Nelson et al[7] and Mosier and Roberts[8] and the work reported by Allen and Slusher,[9] the effect of humidity on idle emissions apparently has received little attention although the extreme sensitivity of CO oxidation to the presence of water vapor is well known.

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In order to ascertain the effect of ambient conditions on gas turbine idle emissions, a research effort was initiated encompassing both experimental and analytical work. Results generated during the program are reported in this paper. Experimentally, a nonvitiating combustor rig was employed to simulate changing combustor inlet conditions as generated by changing ambient conditions. Emissions measurements were made at the combustor exit. Analytically, for the carbon monoxide emissions, a kinetic reaction scheme was applied within each zone of the combustor where temperatures and initial species concentrations not only reflected local combustor characteristics but also changing ambient conditions. For the hydrocarbon emissions, the vaporization of fuel drops passing through temperature profiles determined by local combustor conditions and changing ambient conditions was examined.

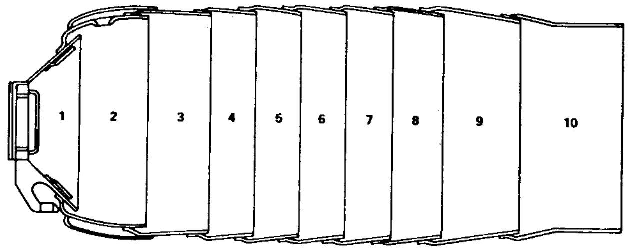
Experimental Program

Test Apparatus

The experimental program was conducted in a closed-duct test facility, described in detail by Fear,[10] located in the Engine Research Building of the NASA Lewis Research Center. A single JT8D-17 combustor can, shown in cross section in Fig. 1, was supplied with the appropriate quantity of Jet A fuel and nonvitiated air to simulate combustor inlet conditions corresponding to specified engine inlet pressure, temperature, and humidity. The combustor installation and instrumentation are shown in Fig. 2. The water content of the inlet air was controlled by injecting demineralized water through a spray nozzle into the hot air supplied by the preheater, approximately 5 m upstream of the combustor, thereby assuring complete vaporization. The water content of the air supplied by the preheater was continually monitored and nominally quite small (dew point of approximately 239 K). The combustor emissions were measured according to SAE specifications.[11]

Test Conditions

The idle operating conditions, both nominal[12] and as tested, are given in Table 1. In relating the ambient variables to combustor inlet variables, compressor pressure ratios of 2, 3, 4, and 5 were chosen and T_I was calculated for a com-



FUEL INJECTOR AND PRIMARY SWIRLER EQUIVALENT METERING AREA 7.61%

Equivalent Metering Area

Louver Cooling Air		Combustion Air	
Panel	%	Panel	%
1	1.53	2	7.93
2	5.62	3	1.92
3	7.56	5	8.00
4	5.69	8	15.85
5	4.24	9	18.09
6	3.41		
7	3.42		
8	3.43		
9	2.78		
10	1.81		

Fig. 1 JT8D-17 combustor.

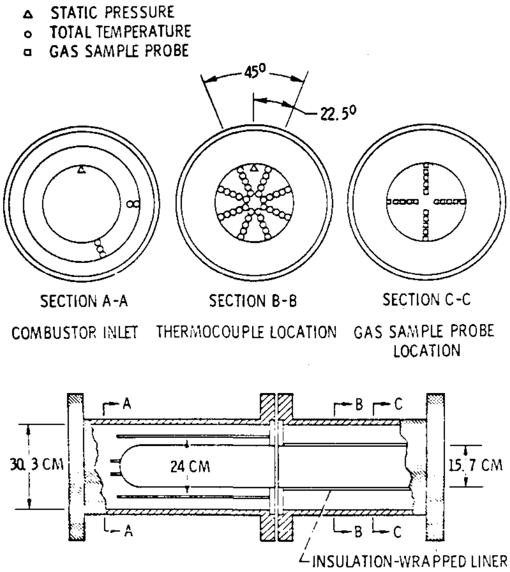


Fig. 2 Combustor assembly and instrumentation section.

pressor efficiency of 80%. The mass flow through the combustor was calculated on the basis of a constant compressor discharge Mach number or a constant reference velocity. Since the mass flow into the combustor consists of both air and water, the combination of which may be considered as an oxidizer, the fuel flow was set to maintain a constant fuel/air ratio and not a constant fuel/oxidizer ratio. Because the combustor was of fixed geometry, three different values of the overall fuel/air ratio were run in order to affect the local fuel/air ratios within the combustor.

Experimental Results

Representative values of the measured emissions from the JT8D-17 combustor are given in Figs. 3-6 in terms of the emission index, EI = g of pollutant/kg of fuel, plotted against the combustor discharge temperature T_4. All figures correspond to one simulated compressor discharge condition—a pressure ratio of four and a constant compressor discharge Mach number. On each figure three separate sets of data are given—one for each of the overall fuel/air ratios. For all other conditions remaining constant, a larger fuel/air ratio gives a higher combustor discharge temperature. Within each of the three fuel/air ratio groupings, two parameters are independently varied—the ambient temperature T_0 and the relative humidity, *RH*. For each of the three ambient temperatures considered, data points are presented for three relative humidities with the exception of $T_0 = 244$ K where an extremely small quantity of water corresponds to saturation, and only one value of relative humidity is given. For a fixed fuel/air ratio and zero relative humidity, increasing ambient temperature increases the combustor discharge temperature. For a fixed fuel/air ratio and ambient temperature, increasing the relative humidity decreases the combustor discharge temperature.

Table 1 Idle JT8D-17 combustor conditions

Nominal operation	
Total inlet pressure	2.47 atm
Total inlet temperature	393 K
Air flow	1.37 kg/s
Fuel flow	0.0161 kg/s
Fuel/air ratio	0.0117
Test operation	
Compressor efficiency	0.8
Compressor pressure ratio	2,3,4,5
Compressor inlet pressure	1 atm
Compressor inlet temperature	244,289,322 K
Compressor inlet relative humidity	0,50,100%
Fuel/air ratio	0.007,0.011,0.015
Constant compressor discharge Mach number or reference velocity	$M_3 = 0.42$, or $V_3 = 15.2$ m/s

For the first two figures, the following trends are recognized. For a fixed set of ambient conditions, an increase in the fuel/air ratio leads to a decrease in the hydrocarbon and carbon monoxide emission index. For a fixed fuel/air ratio and zero humidity, an increase in the ambient temperature causes a decrease in the emission index. For a fixed fuel/air ratio and a given ambient temperature, an increase in the relative humidity causes an increase in the emission index, an effect which is especially noticeable at the highest ambient temperature where saturation corresponds to the presence of 8.12% of mass water vapor.

For regulatory purposes, the combustor discharge temperature T_4 is not a convenient parameter, but it was thought that its use would provide insight with regard to the processes occurring within the combustor. For the hydrocarbons and carbon monoxide, T_4 does not uniquely determine the emissions. Fuel/air ratio, ambient air temperature, and ambient air humidity are all important.

For the third figure, the following well-known trends are evident. For a fixed set of ambient conditions, an increase in the fuel/air ratio leads to an increase in the oxides of nitrogen emission index except at the highest absolute humidity conditions ($T_0 = 322$ K, $RH = 100\%$). For a fixed fuel/air ratio and zero humidity, an increase in the ambient temperature causes an increase in the emission index. For a fixed fuel/air ratio and a given ambient temperature, an increase in the relative humidity causes a decrease in the emission index, again an effect which is quite noticeable when the quantities of water vapor are large. For a given T_4, a wide variation in the emission index is obvious. The combustion efficiency for each point is also indicated, and for similar values there may be large differences in the emission index.

In the last of this group of figures, the nitrogen dioxide emission index for the smallest value of the fuel/air ratio shows trends identical to those discussed previously for the

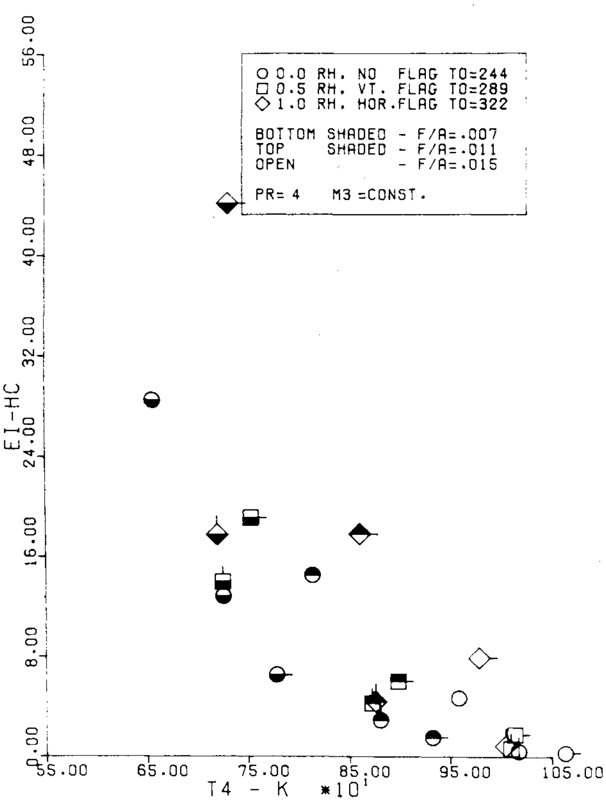


Fig. 3 Hydrocarbon emission index, JT8D-17.

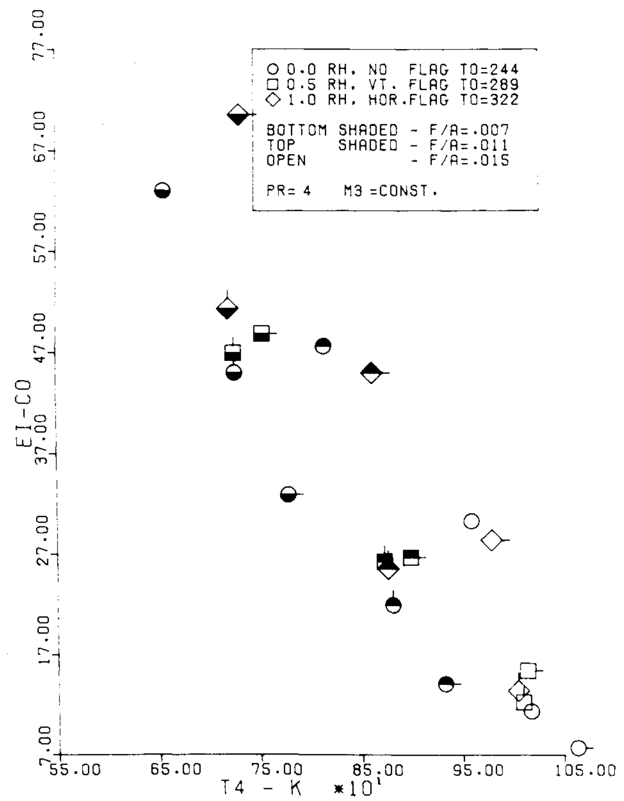


Fig. 4 Carbon monoxide emission index, JT8D-17.

total oxides of nitrogen. It is difficult to recognize a functional dependence of the emission index on ambient conditions for the two higher values of the fuel/air ratio. Consideration of data collected at other simulated idle operating conditions will delineate this problem further.

In these figures only a limited amount of the emission data collected is presented, i.e., a compressor pressure ratio of four

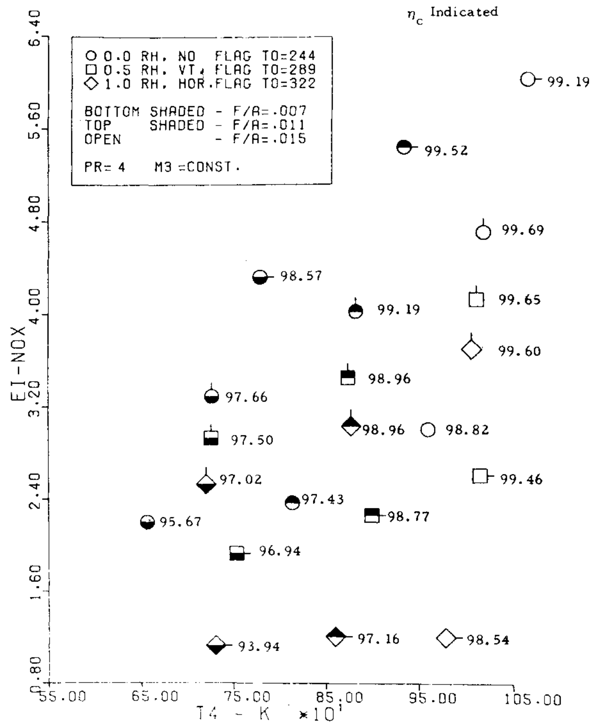


Fig. 5 Oxides of nitrogen emission index, JT8D-17.

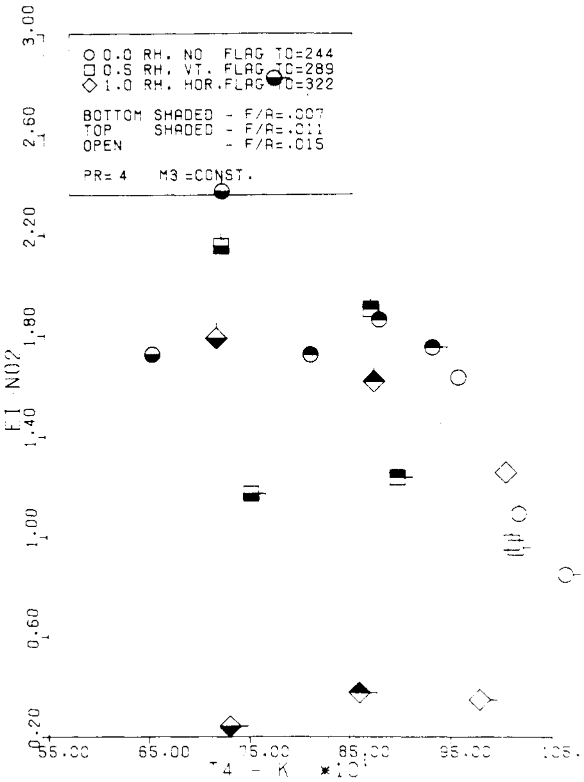


Fig. 6 Nitrogen dioxide emission index, JT8D-17.

and a constant compressor discharge Mach number. A complete reporting of all data is given elsewhere.[4] A comparison of all emission data shows that for a given pressure ratio, considerable similarity exists between the emission levels and trends for the case of a constant reference velocity as compared to the case of a constant compressor discharge Mach number. An increase in the pressure ratio, however, does cause a decrease in hydrocarbon and carbon monoxide emission indices and an increase in the oxides of nitrogen and nitrogen dioxide emission indices. An examination of this additional data shows that the functional dependence of the nitrogen dioxide emission index is identical to that of the total oxides of nitrogen emission index as long as the combustor discharge temperature is less than approximately 900 K. Above this temperature the expected quantities of nitrogen dioxide do not appear. For all data, the range in ambient conditions considered certainly produce large variations in the emission indices.

Other combustor emission data is surprisingly similar to that collected for the JT8D-17. The emission data of Marzeski and Blazowski[5] was collected using a T-56 combustor employing two different fuels and differing primary zone fuel/air ratios for a constant overall fuel/air ratio. The relative humidity of the inlet air was close to zero. The absolute values of the emission indices vary slightly for identical compressor ratios. However, for the same pollutant gaseous species, the sensitivity of the emission index to changes in the combustor discharge temperature of the two combustors is nearly identical. A similarity among combustors would ease the regulatory task of developing corrections for nonstandard inlet conditions.

Correlation Factors

For regulatory purposes, the convenient independent variables in a correlation equation are those at the compressor discharge plane—p_3, T_3, and humidity (HUM)—in addition to the fuel/air ratio (FAR). The data collected in this study were employed to generate such an equation for the emission index of each pollutant species. Because of the similarity between the constant velocity and constant Mach number data, separate correlations were not developed. The emission data was fit employing a stepwise multiple linear regression program to determine the coefficients in an equation of the following form:

$$\mathrm{EI}=\left(\frac{p_s}{6894}\right)^a \exp\left[b+\frac{\mathrm{FAR}}{c}+\frac{9}{5}\frac{T_s}{\mathrm{d}}+\frac{\mathrm{HUM}}{e}\right]$$

where the respective dimensions are EI (g/kg), p_3 (Pa), T_3 (K), and HUM (g water/kg air). The coefficients, as determined by the program, are given in Table 2 for two extremes—all data collected and various subcases selected to maximize correlation. In the latter case for the hydrocarbons (HC) and the carbon monoxide (CO), the data collected at a compressor discharge pressure of 2 atmospheres was not included in that combustion is most marginal under these circumstances. For the case of oxides of nitrogen (NO_x), only the data for a fuel/air ratio of 0.015 was included in that production of oxides of nitrogen is highest under these conditions. In the case of the selected data, the near unity value of the square of multiple correlation coefficient indicates the relationship between the emissions and the ambient variables to be adequately established.

Table 2 Coefficients of regression analysis

Emission index coefficient	HC	CO	NO_x
All data			
a	−1.2833	−0.9468	0.2547
b	15.806	11.552	−2.916
c	−0.00400	−0.00981	0.02074
d	−128.93	−243.48	324.67
e	43.30	76.39	−59.88
Multiple correlation coefficient squared	0.934	0.929	0.824
Selected data			
a	−1.9130	−1.1214	0.2552
b	20.135	13.411	−2.090
c	−0.00341	−0.00763	0.0
d	−107.35	−196.11	334.44
e	34.61	77.04	−54.31
Multiple correlation coefficient squared	0.953	0.940	0.955

Analytical Effort

Model

The experimental results indicate that the HC and CO emissions are decreased by an increasing fuel/air ratio, pressure ratio, and ambient temperature, while they are increased by an increasing ambient humidity. For the NO_x emissions, the situation is just the reverse. The behavior of the NO_x emissions has been modeled to account for all effects.[13] Some details of the modeling process relevant to the production of carbon monoxide in the gas turbine combustor have been previously given by Morr et al.,[14] and a less detailed model, but one which includes limited ambient effects, has been presented by Sarli.[6] In attempting to define a tractable but yet accurate model of the combustion process occurring within a gas turbine combustor conflicts will arise. In the model considered here,[15] it is suggested that the combustor may be treated as a plug flow reactor in which there is a homogeneous reaction between the perfectly mixed fuel and oxidizer under isothermal conditions corresponding to the adiabatic flame temperature. Additionally, since the kinetics representing the oxidation of a complex hydrocarbon fuel such as Jet A are only poorly understood, methane is chosen as the fuel for employment in the analytical effort. It is relevant to observe, however, that much of the emissions result from the escape of raw fuel. Hence, here it is necessary to consider the vaporization of fuel droplets as they pass in a plug flow fashion through the combustor.

The combustor inlet conditions corresponding to the temperature, pressure, and water content of the compressor discharge mass flow are identical to those in the experimental measurements. In the situation for the modeling of the carbon monoxide, the methane is instantaneously mixed with the air and water vapor mixture in the primary zone to obtain the desired equivalence ratio. The mixture is then allowed to react for a period of time corresponding to an appropriate primary zone residence time at a temperature which corresponds to the adiabatic flame temperature. The primary zone combustion products are then instantaneously mixed again with a quantity of additional air to simulate entrance into the secondary combustion zone. The mixture is again allowed to react at a temperature representing the new adiabatic flame temperature for a period of time representing an appropriate residence time. This process is again repeated in the dilution zone. With respect to the hydrocarbons, a size distribution of JP-4 droplets is passed in a plug flow fashion through the respective zones of the combustor where the amount of vaporization is determined by the local adiabatic flame temperature and the local residence time.

For both models, the calculation process is initiated by determining the adiabatic flame temperature for each simulated compressor discharge condition and a variety of fuel/air ratios using the NASA CEC-71 Computer Program.[17] Each fuel/air ratio, of course, could correspond to a different location within the combustor where the local value is indeed affected by the overall fuel/air ratio. In the case of the carbon monoxide, the methane/air kinetic scheme employed is that given by Ay and Sichel[18] with the following exceptions. For the reaction $M+CH_4=M+CH_3+H$, the rate constant $k_f=0.20$ E18 exp(−88332/RT) was used while for the reaction $CO+OH=CO_2+H$ two rate constants were employed: $k_f=0.56$ E12 exp(−600/RT) and $k_f=0.85$ E14 exp (13895/RT). The second rate constant is similar in nature to that developed by Kollrack,[19] and it is found that the analytical model is much more successful in reproducing the magnitude of the experimental results when this smaller value is used. It may be worthwhile to note that the species HO_2 and NO_2 are not included in the reaction scheme. Simultaneous solution of the rate equation for each species is obtained using

Table 3 Typical local fuel/air ratios and average residence times

	Primary		Secondary		Dilution	
	High	Low	High	Low	High	Low
f/a	0.071	0.048	0.034	0.019	0.012	0.011
τ(ms)	1.90	1.60	4.47	3.54	2.62	2.45

the NASA GCKP-72 Computer Program.[20] The initial species composition utilized in this program differs for each ambient condition and for each combustor region. The integration routine is carried out for a period corresponding to the residence time for each combustor region. Representative fuel/air ratios and residence times employed for the regions within the combustor are given in Table 3. In the case of the hydrocarbons, limited atomization data exists for the JT8D-17 fuel nozzle. A Rosin-Rammler droplet size distribution function was assumed which gives the weight fraction of particles R having a diameter larger than a given diameter x, $R=\exp[-bx^q]$. The value of the parameter indicating the non-monodisperse nature of the spray q was assumed to be similar to those determined for airblast atomizers.[16] The value of the parameter relating to the mean size b, was obtained by fitting experimentally measured emission data for a reference case. To calculate the amount of fuel evaporating, the drop distribution was divided into small segments, and the usual diameter squared vaporization law was applied including corrections for convective enhancement of the vaporization as given by $(1+0.276\ Re^{0.5}\ Pr^{0.33})$. The Reynolds number Re and the Prandtl number Pr as well as other pertinent vaporization parameters, were determined by the local conditions in each zone of the combustor where the droplets were allowed to remain for the appropriate residence time.

Analytical Results

All results presented here are for a compressor pressure ratio of four.

Values of the adiabatic flame temperature are first to reflect the effects of the different ambient conditions. Humid and cold air are quite effective in causing its reduction. Because water is replacing oxygen, at the different humidities for each temperature, lines of constant fuel/air ratio correspond to different equivalence ratios.

The effect of ambient conditions on the amount of CO at the end of the primary zone is shown in a normalized fashion in Fig. 7 for a primary zone residence time of 5 ms. Here, CF_{CO} is defined as the mole fraction of carbon monoxide at standard ambient conditions ($T_0=289$, $RH=0\%$) divided by

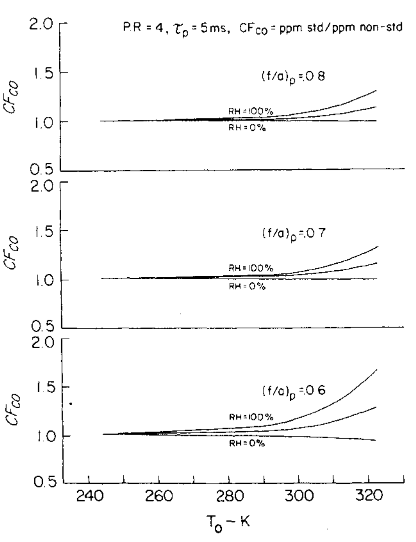


Fig. 7 Normalized primary zone carbon monoxide emissions.

the mole fraction of carbon monoxide at nonstandard ambient conditions. Three different primary zone fuel/air ratios are considered, but the effects of ambient temperature and humidity changes are the same for each. An increase in the ambient temperature causes an increase in the carbon monoxide mole fraction, and an increase in the ambient humidity causes a decrease in the carbon monoxide mole fraction. These effects are precisely opposite to that observed for the gas turbine, but agrees well with the flame results of Muller-Dethlefs and Schlader.[21] These results may be simply explained by considering the effect of flame temperature on dissociation. Miles[22] also finds the same inverse ambient effects when the primary zone is treated as a perfectly stirred reactor employing a global hydrocarbon kinetic scheme.

In view of the stated results, changing ambient conditions must indeed have an effect on the kinetics in the secondary and dilution zones. The calculated mole fraction of carbon monoxide X_{CO} exiting the combustor is given in Figs. 8-10. On each figure one primary zone fuel/air ratio is considered, and this is diluted to lower fuel/air ratios in the secondary and dilution zones. Differing dilution sequences are denoted by the differently shaded symbols in the figures. For each sequence, changes in both the ambient temperature and ambient humidity are considered. The residence time for each of the three combustor regions is individually taken as 5 ms.

The importance of the secondary zone on carbon monoxide emissions is illustrated in Fig. 8, where the products of combustion from a primary zone having a fuel/air ratio of

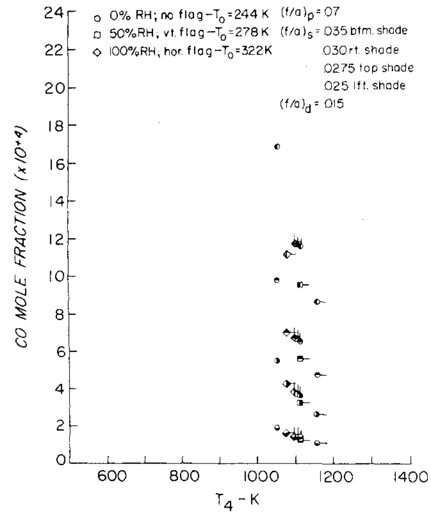


Fig. 8 Carbon monoxide emission, secondary zone effects.

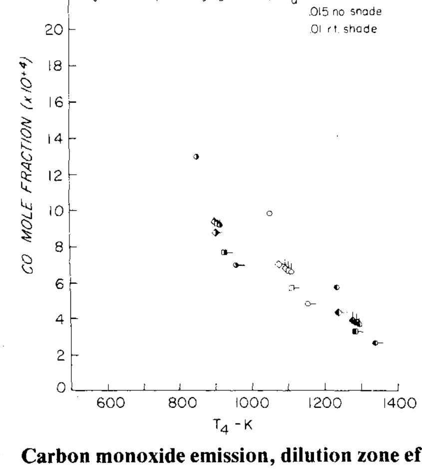


Fig. 9 Carbon monoxide emission, dilution zone effects.

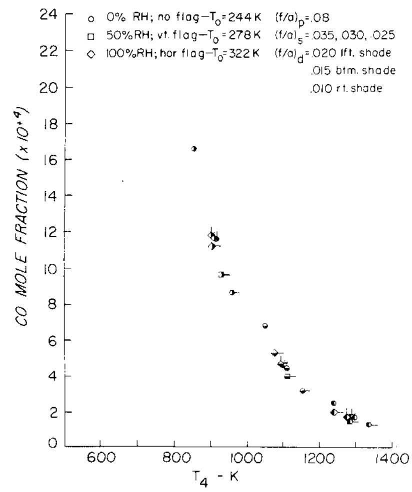


Fig. 10 Carbon monoxide emission, secondary and dilution zone effects.

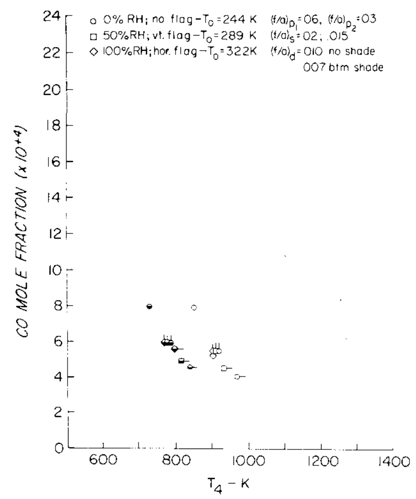


Fig. 11 Carbon monoxide emission, lean primary zone.

0.070 are exhausted at a dilution zone fuel/air ratio of 0.015. The largest levels of carbon monoxide emission occur for the smallest values of the secondary zone fuel/air ratio, i.e., the carbon monoxide oxidation reaction is quenched. Examining the results for any one of the secondary zone fuel/air ratios, the effect of changing ambient conditions on the carbon monoxide is evident. For zero ambient humidity an increase in the ambient temperature decreases the emissions, while for a given ambient temperature an increase in the ambient humidity increases the emissions.

In an actual combustor, however, each secondary zone will have a unique, corresponding dilution zone. In Fig. 9, leaner secondary zones are paired with leaner dilution zones. Not surprisingly, the least carbon monoxide is produced by the sequence with the richest secondary and dilution zones. The effect of differing ambient temperature and humidity is the same as discussed with regard to the previous figure.

For a fixed geometry combustor operating at constant reference velocity or constant inlet Mach number, an increase in the primary zone fuel/air ratio will also increase the secondary and dilution fuel/air ratios. This situation is illustrated by the flow sequences in Fig. 10. Here again, the secondary and dilution zones are paired, and the effect of changing ambient conditions is again obvious.

A comparison between the last two flow sequences in Fig. 9 and the first two flow sequences in Fig. 10, thereby eliminating the possibility of creating a rich dilution zone from a lean primary zone and vice versa, shows that the richer

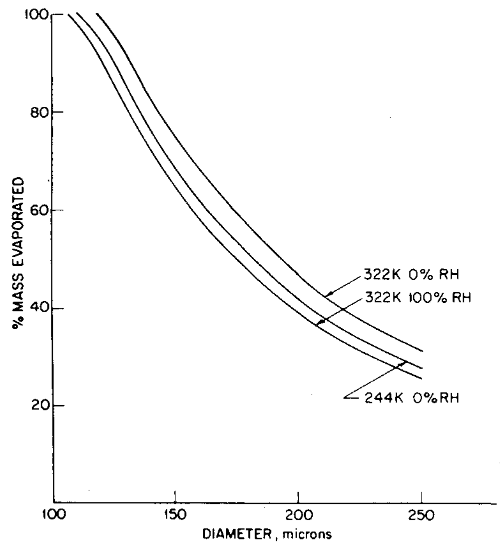


Fig. 12 Fuel drop evaporation.

Table 4 Hydrocarbon emissions

Ambient Conditions	Hydrocarbon emission index		
	Static	Convective	Experimental
322 K, 0% *RH*	1.5	1.5	1.5
244 K, 0% *RH*	3.19	2.80	14.4
322 K, 100% *RH*	4.35	3.74	17.6

primary and subsequent zones give lower carbon monoxide emissions.

For lean idle operating conditions corresponding to a combustor exit fuel/air ratio of 0.007, a slight modification of the modeling scheme became necessary. Consideration of only three combustor zones, as done previously, produced very little carbon monoxide at the combustor exit plane. An analysis of this problem indicated that too small of a quantity was being produced in the lean primary zone—fuel/air ratios varying between 0.30 and 0.45. In a lean actual combustor with a fuel spray, combustion will occur at approximately stoichiometric in the droplet diffusion flame, and these products of combustion will then be further diluted by the excess air present. Indeed, experimental evidence given by Sullivan[23] indicates that this type of primary zone quenching does occur. He found that under lean combustion conditions the exact placement of air holes in the secondary zone had very little effect on the carbon monoxide emission levels. This suggests that the carbon monoxide reactions are quenched by primary zone air. A similar approach was employed in the current homogeneous combustion model. The methane and oxidizer were allowed to react stoichiometrically for a short period of time (0.5 ms) chosen so as to produce large amounts of carbon monoxide. Then, an initial dilution was allowed to occur within the primary zone to some lower equivalence ratio where reactions were allowed to continue for the usual 5 ms. These products were then exhausted into the usual secondary and dilution zones. The results of such a calculation are shown in Fig. 11, and the usual ambient effects may be recognized.

For the hydrocarbon emissions, calculations were performed at one overall fuel/air ratio of 0.011. The effect of three different ambient conditions on the fraction of a drop evaporated at the combustor exit plane for different diameter drops is presented in Fig. 12. Because of the effect on flame temperature, cold and wet ambient air is effective in suppressing vaporization. Through a combination of those results and the previously discussed droplet distribution function, the total quantity of hydrocarbon emission may be

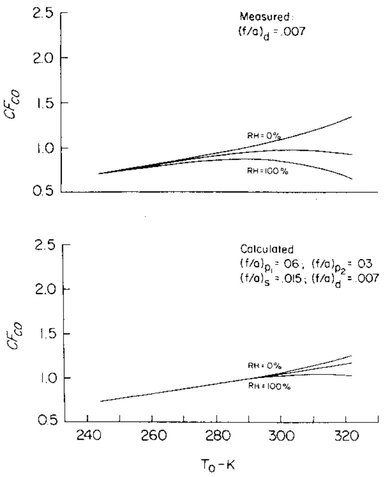


Fig. 13 Ambient temperature and humidity correction factors, lean primary zone.

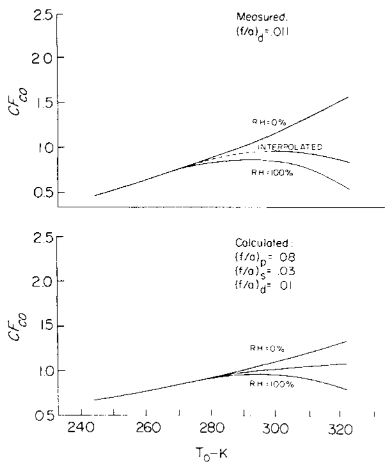


Fig. 14 Ambient temperature and humidity correction factors, intermediate primary zone.

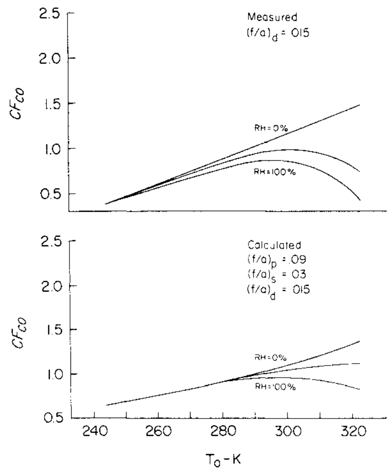


Fig. 15 Ambient temperature and humidity correction factors, rich primary zone.

calculated, and the results are presented in Table 4. For both the static and convective vaporization cases, emissions are increased with respect to the base level—322 K, 0% *RH*—through either cooling of the ambient air or through an increase in the humidity of the ambient air. The emissions are more sensitive to wide humidity variations than to wide temperature changes.

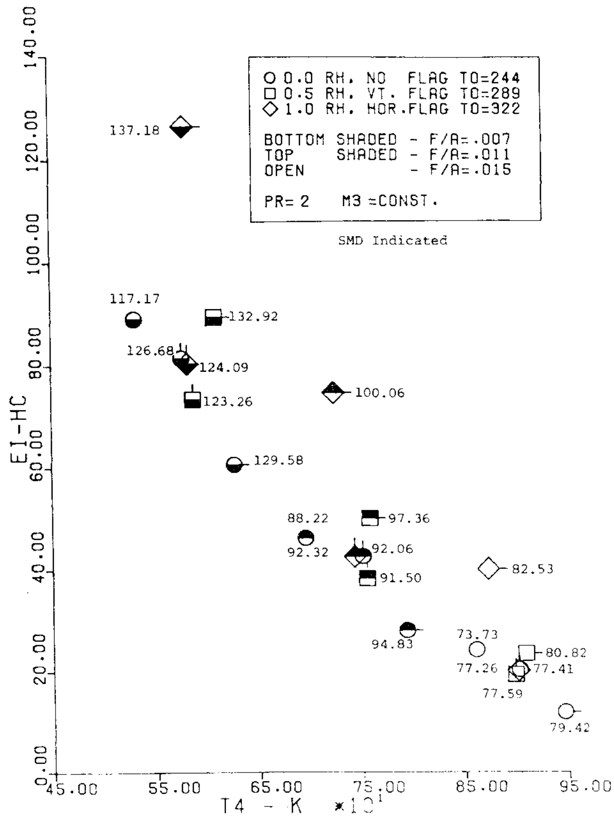


Fig. 16 Hydrocarbon emission, SMD effect.

Experimental and Analytical Comparisons

Both collected and calculated results show that for zero ambient relative humidity an increasing ambient temperature decreases hydrocarbon and carbon monoxide emissions, and that for a given ambient temperature an increasing ambient relative humidity increases hydrocarbon and carbon monoxide emissions. Analytically, for the carbon monoxide, the latter effect could only be obtained employing the modified CO/OH rate constant. A direct comparison is given in Figs. 13-15, where the emissions at standard conditions are divided by those at nonstandard conditions and plotted as a function of ambient temperature with relative humidity as a parameter. The agreement in the magnitude of the emission changes is reasonable; however, the kinetic calculations are unable to predict a sufficiently large increase in the carbon monoxide emissions with increasing humidity. At present the reason for this disagreement is not known, but any comparison is affected by the path chosen in the kinetic model by which the primary zone combustion products are diluted down to the exit conditions. As already indicated by Morr et al.,[14] a Gaussian distribution should be considered for the local residence times as well as for the local fuel/air ratios. For the hydrocarbon emissions as given in Table 4, the predicted effect of changing ambient conditions is much less severe than those actually observed. However, this disagreement is believed in part due to the changing character of the fuel spray as ambient conditions vary. In that the data was run at a constant fuel/air ratio, as the water replaced the air with increasing humidity, it was necessary to decrease the fuel flow which caused poorer fuel atomization. At run conditions for a pressure ratio of two, the entire combustor fuel flow is supplied only by the primary portion of the duplex fuel nozzle. The Sauter mean diameter (SMD) of the spray is directly proportional to the fuel mass flow and inversely proportional to the nozzle pressure drop. Calculated SMD's are superimposed upon the emission data in Fig. 16, where for a given combustor discharge temperature the highest values of emission are seen to correspond to the largest value of the SMD.

Conclusions

Changing ambient conditions are observed and predicted to significantly affect idle emissions from a gas turbine engine. The combustor discharge temperature or adiabatic flame temperature does not uniquely determine the emissions, thereby allowing a mechanism for the normalization of emissions under differing ambient conditions. However, changes may be calculated employing compressor discharge parameters. Fuel/air ratio changes, which may result from engine control systems, reacting to changing ambient conditions while attempting to maintain a constant T_4 may significantly affect emissions.

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