A SEMI-ANALYTICAL FINITE RATE TWO-REACTOR MODEL FOR GAS TURBINE COMBUSTORS

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ABSTRACT

A gas turbine combustor is modeled using a two-reactor, finite-rate mixing and chemistry gas particle approach. The first reactor, used to simulate combustion in the primary zone, permits independent definition of the rates of macromixing and micromixing within the reactor, and the amount of premixing of fuel and air entering the reactor. Finite-rate macromixing is simulated by consideration of the fluid particle residence time distribution frequency function and the ages of the particles in the reactor. Finite-rate micromixing is simulated using a modified Coalescence-Dispersion (C-D) model. The second reactor model simulates combustion in the dilution zone of the combustor, and is modeled as a plug flow reactor with cross-flowing jets of dilution air and co-flowing streams of cooling film air. The primary zone reactor model predicts physically reasonable trends in mean temperature, and CO and NOx emissions as the macromixing and micromixing parameters are varied with respect to the perfectly-stirred reactor limit. The model also has shown to predict the correct trends in modeling NOx and CO emissions from aircraft engine gas turbine combustors.

NOMENCLATURE

- $a$, $b$: PDF coefficients
- $c_x$: Constant of proportionality relating the C-D mixing frequency to $\varepsilon$ and $k$
- $f, \bar{f}$: Mixture fraction, mean mixture fraction
- $f(t)$: Residence time distribution frequency function
- $l_m$: Number of C-D mixing events per feed (particle entering reactor) event
- $k$: Turbulent kinetic energy
- $L$: Length of the primary zone
- $m$: Total mass in the reactor
- $m_{total}$: Total mass flow rate through reactor
- $N$: Total number of particles in the reactor
- $P(f)$: Inlet mixture fraction probability density function
- $P_{bulk}$: Probability for a bulk flow particle to be selected for a C-D event
- $P_{dil}$: Probability for a dilution air particle to be selected for a C-D event
- $P_V$: Inlet mixture fraction variance parameter
- $t$: Time
- $t_0$: Residence time in the plug flow reactor component of a PSR/PFR
- $t_{cycle}$: Cycle time
- $t_{PSR}$: Residence time in perfectly-stirred reactor
- $t_r$: Mean residence time
- $t_{dil}$: Dilution air hole transit time
- $V_{swirler}$: Velocity of the gases exiting from the swirler inlet
- $x_{dil}$: Mixing bias factor for the C-D mixing probability of a dilution air particle
- $\beta$: C-D mixing frequency
- $\Delta t$: Timestep
- $\varepsilon$: Turbulent dissipation rate

INTRODUCTION

A numerical model of a gas turbine combustor that incorporates finite-rate mixing and chemical processes is presented in this study. This model is based on the population balance chemical reactor modeling approach (Pratt, 1975). Population balance modeling defines the steady-state flow through the
combustor as a stream of particles which are born as they enter the combustor, age as they reside in the combustor, and die as they exit. The time that a particle spends in the combustor is its residence time (Danckwerts, 1957; Zweitering, 1959).

Mixing of the fluid particles is defined in terms of "macromixing" and "micromixing." Macromixing is the gross convective recirculation or backmixing in the combustor that brings thermally hot fluid particles into physical proximity with the unignited cold fluid particles. Micromixing is the molecular diffusion among particles that allows the hot particles to ignite the cold particles through the diffusion of heat and mass. Typically, reactor network simulations of gas turbine combustors have utilized perfectly-stirred reactor (PSR) models, which neglect both these effects. In addition, PSR models cannot account for the imperfect premixing of fuel and air before entering the combustor. In the present model, finite-rate macromixing and variable premixedness of the fuel and air are considered.

This model is similar to a finite-rate macromixing and micromixing model that was used to model lean-premixed combustion of CH₄/Air within a high-intensity jet-stirred reactor (Tonouchi and Pratt, 1995). Finite-rate macromixing was varied by the flow of fluid particles among the control volumes based on an assumed entrainment model for the jet. Finite-rate micromixing was applied using Curl's Coalescence-Dispersion (C-D) model (Curl, 1963).

**MODEL DESCRIPTION**

Most gas turbine combustors have a primary zone characterized by a high rate of backmixing followed by intermediate and dilution zones where the burned and partially burned gases mix with crossflowing jets of air (Lefebvre, 1983). Figure 1 shows a schematic drawing of the flow within these zones. The gases in the primary zone recirculate axially inward due to the high swirl component of the flow. The gases in the intermediate and dilution zones, which will be referred to collectively as the dilution zone, are essentially in plug flow with crossflows of air jets. Because their flowfields are fundamentally different, the modeling approach uses separate reactors to simulate combustion in these two zones. Both reactor models assume adiabatic conditions.

**Primary Zone Reactor**

The primary zone reactor model is a variation of the work by Kattan and Adler (1972). Finite-rate macromixing is described in terms of the residence time distribution of particles flowing through the reactor and the ages of the particles in the reactor. Finite-rate micromixing is incorporated using a modified C-D model.

**Finite-Rate Macromixing.** For an ensemble of particles which flow through the reactor, the distribution of particle residence times can be described by the residence time distribution (RTD) frequency function, \( f(t) \). The RTD frequency function is defined such that \( f(t) \) represents the fraction of particles which exit the reactor during a certain residence time interval of \( t \) to \( t + dt \). The function \( f(t) \) can also be viewed as the probability that a particle, upon reaching an age between \( t \) and \( t + dt \), will exit the reactor (Pratt, 1975). Thus \( f(t) \) describes the flow within the combustor volume in terms of particles moving in 'age space.'

One of the two extremes of macromixing include infinitely effective backmixing, such as in a perfectly-stirred reactor (PSR). The RTD frequency function for a PSR is a decaying exponential, Eq. (1) (Pratt, 1975),

\[
\frac{1}{t_{PSR}} \exp\left(-\frac{t}{t_{PSR}}\right)
\]

where \( t_{PSR} \) is the mean residence time of the PSR. Equation (1) is derived by considering a step input of a tracer fluid in the PSR. By performing a mass balance of the tracer fluid in the PSR, an expression is obtained for the concentration of the tracer fluid as a function of time at the reactor exit. The derivative of this expression gives Eq. (1) (Levenspiel, 1972).

The other macromixing extreme is zero backmixing, as in the case of a plug flow reactor (PFR). In a PFR, particles which enter together at time \( t = 0 \) will exit together at time \( t_{PFR} \). The PFR has an RTD frequency function of a Dirac delta function centered at \( t_{PFR} \),

\[
f(t)_{PFR} = \delta(t - t_{PFR})
\]

Finite-rate macromixing within the primary zone reactor is modeled by defining the RTD frequency function \( f(t) \) for fluid...
particles entering from each reactor inlet. These inlets include fuel/air particles from the swirlers and air particles from dilution and cooling holes. For this work, it is assumed that \( f(t) \) for particles entering from the swirler inlet has a shape which approaches the form of Eq. (1) as the rate of macromixing is increased to the infinite macromixing PSR limit and the form of Eq. (2) as the macromixing rate is decreased to the zero macromixing PFR limit. More specifically, \( f(t) \) is assumed to have the form of a PSR in series with a PFR,

\[
f(t) = \frac{H(t - t_0)}{t_e - t_0} \exp\left(\frac{t - t_0}{t_e - t_0}\right)
\]

where \( t_0 \) is the time the fluid particles reside in the PFR, \( t_e \) is the mean residence time for the PSR/PFR arrangement, and \( H(t - t_0) \) is the Heaviside unit function. The derivation of Eq. (3) is similar to the derivation of Eq. (1), with the exception that the time-variation of the tracer concentration at the PSR/PFR exit is delayed by the PFR time, \( t_0 \) (Levenspiel, 1972).

For the combustor modeled as a PSR in series with a PFR, the minimum time that a fluid particle resides in this reactor arrangement is \( t_0 \), the PFR time; since the minimum time that a fluid particle spends in a PSR is zero. In applying Eq. (3) to the primary zone reactor, \( t_0 \) is associated with the minimum time a fluid particle spends in the combustor primary zone. This time is one-half the fluid particle cycle time, or one-half the time a fluid particle takes to make one round trip in the primary zone of the combustor (see Fig. 1). As \( t_0 \) approaches zero, implying a high rate of recirculation, Eq. (3) approaches the form of Eq. (1). For \( t_0 \) approaching the mean residence time \( t_e \), implying little backmixing, Eq. (3) approaches the form of Eq. (2). For the primary zone reactor model, \( t_{p,0} \) is defined as the characteristic macromixing time for fuel/air particles entering the reactor from the swirler inlet, and can be estimated as \( V_{swirler} L \), where \( V_{swirler} \) is the velocity of the swirler inlet gases and \( L \) is the length of the primary zone.

Air from the dilution hole inlets is typically used to promote recirculation of the fuel and air from the swirlers (see Fig. 1). Although most of this air flows into the dilution zone, some is entrained into the recirculation zone. For air particles entering from the dilution hole inlets, the RTD function is assumed to have the following form,

\[
f(t) = \frac{H(t - t_0)}{t_r - t_0} \exp\left(\frac{t - t_0}{t_r - t_0}\right)
\]

where \( t_0 \) is defined as the transit time or the minimum time that a fluid particle spends in the primary zone and \( H(t - t_0) \) is the Heaviside function. The factor of \( \tau \) is a normalization constant. The fundamental basis for Eq. (4) is derived from consideration of contact times between the air jet and the edge of the recirculation zone.

With RTD frequency functions defined for particles flowing from each inlet, the \( f(t) \) for particles which exit the primary zone is assumed to be a mass average of the frequency functions for each inlet,

\[
f(t)_{\text{primary}} = \frac{\sum \dot{m}_i f_i(t)}{\dot{m}_{\text{total}}}
\]

where \( \dot{m}_{\text{total}} \) is the total mass flow rate through the reactor. Equation (5) is used to prescribe the amount of macromixing in the primary zone by serving as a weighting function for particles to exit the reactor. In earlier formulations of particle models (Butler and Pratt, 1986; Correa, 1995; Chen, 1997; Chen, 1993) the reactor volume was assumed to have infinite macromixing rates or to have an RTD frequency function resembling Eq. (1). Thus particles of any age were randomly selected from the ensemble to exit the reactor. In this model, since finite-rate macromixing is assumed, Eq. (5) is used to specify that only particles close to an age of \( t \) may be randomly selected to exit.

**Finite-Rate Micromixing.** Variable-rate micromixing is simulated using a modified form of the C-D model, where micromixing is simulated by randomly pairing particles and allowing them to mix (coalesce) before being dispersed and allowed to react as individual batch, or closed system, reactors. In this work, the C-D model is modified in two ways. First, unlike the original Curl model, which assumes that the reactor is infinitely macromixed and thus any two particles can be paired, only particle pairs which are likely to be physically near each other are randomly selected to mix. This model does not track the location of each particle in the reactor, but assumes that two particles are likely to be near each other if their ages are nearly the same or their ages differ by a multiple of the fluid particle cycle time.

The second modification to the Curl model is the way in which two paired particles mix. In the original approach, the extensive properties (enthalpy and chemical species masses) of the particles are averaged and each particle assumes the averaged properties. In the present model, a randomly selected fraction of their extensive properties are exchanged (Dopazo, 1979; Janika et al., 1978). After mixing, each of the particles undergoes batch reaction until it is selected again for a mixing event or exits the reactor. The number of C-D events is prescribed by the micromixing parameter \( \tau_{\text{mic}} \), which is defined as the number of C-D events per feed (particle entering reactor) event, or as the ratio of the C-D mixing frequency \( \beta \) to the reciprocal mean residence time \( 1/t_r \). The mixing frequency is typically estimated as

\[
\beta = c_p \frac{\epsilon}{k}
\]

where \( \epsilon \) is the turbulent dissipation rate and \( k \) is the turbulent kinetic energy, and \( c_p \) is a proportionality constant (Pratt, 1975). For this work, an averaged \( \epsilon/k \) was determined for the entire
The process of inflow, outflow, and micromixing is repeated until a stationary state in the temperature and species concentrations is achieved, usually in 5 mean residence times. Typically, the convergence rate is limited by the NO mass fraction. Runtimes using 500 particles for the conditions examined in this work required 20 to 25 hours on a Pentium Pro 200 computer.

**Numerical Approach.** Initially, the primary zone reactor consists of a user-defined number of equal-mass fluid particles. Each of these particles is assigned the temperature and composition of a PSR with the same volume and inlet conditions as the primary zone.

At each timestep, discrete fluid particles enter the reactor from the swirler inlet and dilution holes. The rate of particles entering from an inlet \( i \) is \( N = m_i N_i \), where \( m_i \) is the mass flow rate of inlet \( i \), \( N \) is the total number of particles in the reactor, and \( m \) is the total mass in the reactor. Particles entering from the swirler inlet have a composition and temperature representative of the inlet stream of fuel and air. The composition of each entering particle is randomly weighted from an assumed beta-PDF of the mixture fraction (\( P(f) \)) and a user-defined mixture fraction variance (PV), as defined by the following equations:

\[
P(f) = f^{a+1} (1-f)^{b+1} \frac{\Gamma(a+b)}{\Gamma(a)\Gamma(b)}
\]

\[
a = \frac{1 - \bar{f}}{PV} \quad b = \frac{\bar{f}}{PV} + (\bar{f} - 1)
\]

The limit of \( PV=0 \) corresponds to a perfectly premixed inlet, while \( PV=1 \) gives completely non-premixed inlet particles. Particles entering from dilution and cooling inlets are assigned the composition and temperature of the inlet air stream.

Since the flow through the reactor is steady, the rate of particles exiting the reactor is equal to the rate of particles entering the reactor. Because finite-rate macromixing is assumed, the selection of particles to exit the reactor is random but weighted by Eq. (5). Thus finite-rate macromixing is implicitly applied in the selection of particles to exit the reactor.

After the flow of particles into and out of the reactor, micromixing is simulated by applying the C-D model to the ensemble of particles. The number of C-D events per timestep, defined as the time between a feed (particle entering from the swirler inlet) event, is given by the mixing parameter \( L_m \). It is assumed that \( L_m \) is an averaged value for the entire primary zone. As explained earlier, the probability that a given particle pair will mix is weighted by their relative ages. The batch kinetics of the particles are calculated using a modified form of the SENKIN package in Chemkin-II (Kee, et al., 1989). The chemical kinetic mechanism used is the semi-empirical n-heptane oxidation scheme of Held, et al. (1996), which consists of 255 reactions among 41 species. The formation mechanism for NOx is taken from GRI-Mech 2.11 (Bowman et al., 1996), and accounts for an additional 97 reactions and 17 species.

The combustor primary zone is characterized by a significant amount of backmixing: downstream in the dilution zone, the gas is essentially in plug flow with cross streams of dilution air and co-flowing streams of combustor wall cooling film air. The dilution zone reactor simulates the plug flow of particles which have exited the primary zone reactor. It is assumed that there is no backmixing in the dilution zone, thus the mixing of particles in the axial direction is not permitted. Without backmixing, a Lagrangian approach can be used for this reactor model, where a plug of fluid particles is followed as it flows through the dilution zone. Dilution and cooling air particles are introduced as the plug passes the axial location of these inlets.

The number of air particles entering the plug depends on the inlet's mass flow rate relative to the mass flow rate entering the dilution flow reactor.

For each user-defined timestep \( \Delta t \), the C-D model is applied to the ensemble of particles. The number of C-D events per timestep is prescribed by \( L_m \) for the dilution flow reactor model. Particles selected to undergo C-D events are chosen at random, but each particle probability of selection is weighted by an empirical biasing factor related to its cross-flowing momentum. A nominal mixing frequency is assigned to the main inlet (the primary zone reactor exit), which is related to the bulk turbulence properties as described in Eq. (6). Cooling film particles are assumed to have the same mixing frequency since these particles are co-flowing within the dilution flow reactor. An entering dilution air particle, because it is cross-flowing and has a higher momentum than the bulk flow, is assumed to have a higher mixing frequency (i.e., probability of selection for a mixing event) since it has greater opportunity to interact with the other particles in the plug. The probability for a dilution air particle to be selected for a C-D event, \( P_{\text{diff}} \), is given as follows,

\[
P_{\text{diff}} = x_{\text{diff}} P_{\text{bulk}}
\]

where \( P_{\text{bulk}} \) is the probability for a bulk flow particle to be selected for a C-D event and \( x_{\text{diff}} \) is defined as the mixing bias factor. The mixing bias factor is assumed to be proportional to the ratio of the dilution air jet momentum to the bulk flow momentum. For the purposes of this work, \( x_{\text{diff}} \) was set to 10, based on order-of-magnitude estimates of the relative dilution jet and bulk flow momenta. As the dilution air particle mixes with other particles, it transfers its momentum to those particles, thus eventually approaching a uniform mixing bias with the bulk flow. In other words, the dilution air particle's probability for a C-D event decreases to that of the co-flowing particles. To
simulate this effect, a C-D encounter also exchanges momentum (and hence, probability for micromixing) between two particles. The momentum transfer between paired particles is assumed to be proportional to their mass exchange.

The plug of particles that exits the reactor gives the properties of the fluid for one combination of inlet particles and random mixing processes. In order to achieve a statistical sample of particles, it is necessary to pass a number of particle groups through the reactor. For the results presented in this work, 2 or 3 passes of 500 particles were used, limited due to computer runtime considerations. Further investigation is needed to assess the number of passes required and the number of particles per pass to achieve a stationary state for a range of operating conditions.

VARIATION OF PRIMARY ZONE REACTOR MODEL PARAMETERS

There are four mixing parameters in the primary zone reactor model. The fluid particle cycle time and the transit time of dilution air particles, \( t_{cyc} \) and \( t_r \), respectively, determine the rate of macromixing. The rate of micromixing is specified by \( l_m \). The fourth parameter is the mixture fraction variance, which specifies the premixedness of the fuel and air before it enters the reactor. A parametric study was performed to verify that the primary zone reactor predicts the correct trends with respect to the PSR limit and to investigate the sensitivities of the model parameters.

The primary zone modeled was for a combustor with a swirler inlet and three dilution holes. The nominal conditions modeled were heptane fuel, an overall mass fuel/air ratio of 0.0301, at 30.4 atm. The fuel and air entering from the swirler are assumed to be perfectly premixed and enter at a temperature of 855 K; the mass fuel/air ratio for this stream was 0.07 (corresponding to an equivalence ratio of 1.1). The volume of the primary zone was estimated at 7500 cm³, and the mean residence time about 1.3 ms.

The macromixing times were estimated from the geometry of the combustor and the mass flow rates through the swirler and dilution holes. For the baseline condition, the cycle time was estimated to be one-fourth the mean residence time. The transit times for the air particles entering from the dilution holes were estimated from estimates of the particles trajectories from the holes to the primary zone exit. The dilution hole transit times were fixed for all the conditions examined in this study. The micromixing parameter \( l_m \) was determined from Eq. (6) to be about 6. About 500 to 600 particles were used in this study.

Figure 2 shows the results of varying only the mixing parameter \( l_m \) from the conditions given above. The points plotted represent the mean properties of the particle ensemble. The figure shows that as the micromixing rate parameter \( l_m \) is increased, the predicted temperature, CO, and NOx approach the PSR limit, calculated independently using the PSR code of Glarborg et al. (1986). Increasing \( l_m \) gives the hot particles more opportunities to mix and ignite the cold particles. This leads to an overall increase in the reactor temperature, CO, and NOx because of the greater number of burned and partially burned particles relative to the number of unignited cold particles, which have an inlet temperature of 855 K and zero concentrations of CO and NOx.
Figure 3. Temperature, CO, and NOx predictions versus the ratio of the fluid particle cycle time to the mean residence time using the primary zone reactor. The dashed lines represent the PSR limit, assuming the primary zone reactor is a PSR.

Figure 4. Temperature, CO, and NOx predictions versus mixture fraction variance (Eq. (6)). The dashed lines represent the results for premixed (zero mixture fraction variance) conditions. The solid lines represent the PSR results, assuming the primary zone reactor is a PSR.
For an $I_m$ of 2, combustion could not be sustained in the reactor. The rate of micromixing among the particles is too low, thus allowing little opportunity for the hot particles to ignite the inflowing cold particles. Because the conditions preclude the possibility of autoignition, a minimum amount of micromixing is required for sustained combustion within the reactor.

Figure 3 presents the results of varying the fluid particle cycle time, $t_{cyc}$, with the other model parameters held fixed at the conditions specified earlier. The results indicate that the cycle time does not significantly influence the ensemble mean temperature, CO, or NOx, despite a variation of $t_{cyc}$ from a condition of high recirculation (small cycle time) to a macromixing condition approaching plug flow (large cycle time). It appears that for the conditions chosen for this parametric study, the micromixing effects (variation of $I_m$) are more significant than macromixing effects. Further study is required to examine under what conditions the macromixing parameters of cycle time and dilution hole transit times, which were fixed for this study, would play a more significant role.

The results of varying the initial mixing state of the fuel and air are shown in Figure 4. Increasingly poor premixing (increasing variance), results in a lower ensemble mean temperature and lower CO, as an increasing number of unreacted fuel particles exit the reactor. For a relatively small amount of non-premixedness (PV=0.001), NOx emissions increase by 24% over the perfectly premixed inlet case, even though the mean temperature has slightly decreased. Under perfectly premixed conditions, the maximum possible temperature is the equilibrium temperature of the mixture (i.e., all the fluid particles have the same mixture fraction). With imperfect premixing, some particles achieve a mixture fraction closer to stoichiometric than the mean, which has the effect of adding a high-temperature "tail" to the particle temperature distribution. Because of the high sensitivity of NOx formation rate to temperature, this change has the effect of increasing NOx emission levels. As the variance increases, the lower mean temperature eventually causes the observed decrease in NOx emissions.

MODELING GAS TURBINE COMBUSTOR DATA

Three combustors, referred to as Combustors 1, 3, and 4 (numbering identical to Danis et al. (1996)), are modeled for this study, at four operating conditions varying from idle to sea level takeoff power. The combustors are all production single-annular, rich dome designs, and the emissions data are from certification tests. To limit the number of free input parameters to the two-reactor approach, several assumptions are made in modeling the data.

- For a given combustor, the volumes of the primary and dilution zones, as well as the flow splits of fuel and air flows through inlets, dilution holes, and cooling film are held fixed for the range of power conditions modeled.
- The micromixing frequency $\beta$ is assumed to be independent of operating condition. The micromixing frequency is estimated from Eq. (6) to be from 3000 to 5000 Hz, corresponding to an $I_m$ of about 5 to 10.
- The fluid particle cycle time in the primary zone is assumed to be one-fourth the mean residence time. The transit times for the dilution particles introduced into the primary zone reactor are estimated from the location of these holes.
- The fuel and air entering from the swirler inlet are assumed to be premixed (zero mixture fraction variance).
- The fuel (heptane) mass flow rate is adjusted to match the equivalence ratio of the Jet-A data.
- About 500 to 600 particles are used in the primary zone reactor; the number of particles exiting the dilution flow reactor after one pass is about 1000 to 1300. The results given in the modeling are for one pass.
Figures 5 through 7 present the calculated and measured CO and NOx emissions from the three combustors. The modeled results are the particle ensemble mean properties exiting the dilution flow reactor. The data in brackets next to the modeled results are the root mean square (rms) of the particle properties exiting the dilution flow reactor.

The two-reactor model gives the correct trends for all three combustors over the modeled conditions. The agreement with the measured data is reasonable, considering the assumptions and lack of optimization used in modeling these data. The comparisons with combustor 1 are good, while for Combustors 3 and 4, the model tends to overpredict NO at high power conditions and overpredict CO at low power conditions. Better agreement with the measurements can be expected by considering the variation of the primary model parameters, particularly \( I_a \), which is probably not constant over the range of power conditions examined.

Two general observations can be made based on informal variation of the modeling parameters. The first is that the NOx emissions level primarily depends on conditions in the primary zone reactor, consistent with the high temperature dependence of the thermal NOx formation rate. The particle ensemble NOx does continue to increase in the dilution flow reactor; however, varying \( I_a \) in the dilution reactor does not significantly influence the NOx production rate. The second observation is that the dilution flow reactor plays a predominant role in determining the CO emissions level. The micromixing parameter \( I_a \) significantly affects the CO oxidation rate in the dilution zone.

Further study is required to understand the sensitivities of the two-reactor model parameters. Additional work is required to determine the minimum number of particles to achieve a 'particle number independent' solution. Similar work must be performed to assess the number of particles and passes through the dilution zone reacto.
CONCLUSIONS

A two-reactor model incorporating finite-rate chemistry and mixing has been described, and early parametric studies and comparisons to emissions data reported. Qualitative success has been obtained by varying only the micromixing parameters in the primary zone reactor and dilution flow reactor. Further investigation is required to assess the relative sensitivities and interactions of the model parameters, particularly the effects of inlet mixture fraction variance. From the parametric studies and data modeled to this point, the micromixing parameter $I_m$ appears to play a more significant role in determining CO and NOx emissions than the macromixing parameters.

REFERENCES


Chen, J.-Y., 1993, Paper No. 93-071, Fall Meeting, Western States Section/The Combustion Institute.


