ONE-DIMENSIONAL, FINITE-RATE MODEL FOR GAS-TURBINE COMBUSTORS

by

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Dissertation submitted to the Faculty of the Virginia
Polytechnic Institute and State University in partial
fulfillment of the requirements for the degree of

DOCTOR OF PHILOSOPHY

in

Mechanical Engineering

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July 11, 1997

Blacksburg, Virginia

Key Words: Numerical-Methods, Control-Volume, Unsteady-Flow, Blow-out

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Abstract

An unsteady, finite-rate, one-dimensional model has been developed for the analysis for gas-turbine combustors. The basis of the model is the one-dimensional, integral form of the conservation equations for multi-species, non-equilibrium, reacting mixtures. Special procedures were devised for the flow-division of the inlet flow into primary- and annular-flows, for both straight- and reverse-flow combustors. This allows the model to handle complete combustor configurations, which at present are beyond the reach of more sophisticated CFD tools. The model was validated with a steady-state analytical solution for a basic problem, and with steady-state results from a production code applied to a production combustor. Additional calculations show the ability of the code to predict blow-out due to rich and lean mixtures, and to predict the response of a combustor to perturbations in operating and boundary conditions.

ACKNOWLEDGMENTS

The author wishes to express sincere gratitude to Dr. Walter F. O'Brien, head of the Mechanical Engineering Department at Virginia Polytechnic Institute and State University, for providing the funding, opportunity and resources to conduct the present research. The author also wishes to thank Drs. Uri Vandsburger, Balakrishnan Ganeshan, John Moore and Wing-fai. Ng, for serving on my committee and for their suggestions for the validation of the model presented here and improvement of this work. Special acknowledgment goes to Rolls-Royce for their support in providing data for this research. Finally the author wishes to thank William T. Cousins at AlliedSignal Engines, Inc., for providing the financial support that made the present research possible.

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Nomenclature

Note: In this work all units are in SI (metric).

a	Frozen speed of sound
A	Arrhenius pre-exponential factor
$\mathbf{A}$	Jacobian matrix of flux vector
A(i)	Flow-area of face i
$A_{wall}(i)$	Wall or wetted area of CV i
C_D	Discharge coefficient
C_f	Friction coefficient
C_{Vj}	Constant-volume specific-heat of specie j
E_a	Arrhenius activation energy
E_i	i-th eigenvector of system of governing equations
e_t	Absolute total energy
$\vec{F}$	Vector of fluxes
f/a	Fuel/air ratio
$\left(h_f^0\right)_j$	Enthalpy of formation of specie j
F_{wall}	Axial component of wall force
h_t	Absolute total enthalpy
M	Mach number
MW_j	Molecular weight of specie j
N	Total number of CVs
N_S	Total number of species in the system
p	Static pressure

p_t	Total pressure
$\vec{Q}$	Vector of conservative variables
$\vec{q}$	Vector of primitive variables
$\vec{R}$	Residual vector
R	Mixture gas-constant
R_j	Gas-constant for specie j
R_u	Universal gas constant
T	Matrix of right eigenvectors of matrix A
T	Temperature
T_t	Total temperature
t	Time
Δt	Time-step
u	Axial velocity
$\Delta V(i)$	Volume of CV i
w	Mass flow-rate
$\vec{W}$	Vector of source terms
w_{fuel}	Fuel flow-rate
Δx	Spatial-discretization step
y_j	Mass-fraction of specie j

Greek Symbols

α_i	Wave strength associated with eigenvalue i
$\alpha_{u\,(l)}$	Fraction of total mass flow-rate into the upper (lower) annular path
$\beta_{u\,(l)}$	Ratio of central-path to upper-(lower-)path total pressure
$\gamma_{u\,(l)}$	Ratio of central-path to upper-(lower-)path total temperature
Λ	Diagonal matrix of eigenvalues of matrix A
λ_i	i-th eigenvalue of system of governing equations
υ	Stoichiometric fuel/air ratio
$\dot{\omega}_j$	Mass production rate per unit volume of specie j
$\hat{\dot{\omega}}_j$	Molar production rate per unit volume of specie j
ϕ	Equivalence ratio
ρ	Total density of the mixture
ρ_j	Density of specie j

Subscripts/superscripts

$( )_{dil}$	Dilution property
$( )_{exit}$	Exit value
$( )_{inlet}$	Inlet value
$( )_{L\,(R)}$	Left (right) values at an interface
$( )_{pz}$	Primary-zone value
$( )_{u\,(c,\,l)}$	Upper-(center-, lower-)path value
$( )^{\pm}$	Values associated with right-/left-running waves
$( )^{n}$	Value at time-step n