FAST LAGRANGIAN ANALYSIS OF THREE DIMENSIONAL UNSTEADY REACTING FLOW WITH HEAT RELEASE

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Abstract

This paper summarizes the major features of a fast Lagrangian analysis of 3D, unsteady, reacting flow. In its most general form, the analysis includes the effects of moderate heat release, flow confinement, and turbulence and builds on recent advances in fast hierarchical algorithms for vortex-dominated flows. A description of the technical approaches adopted in the implementation of this capability is presented, including the development of a 3D vortex particle formulation that incorporates the effect of heat release on dilatation and the baroclinic generation of vorticity; and the application of a fast hierarchical methodology to reduce the asymptotic time complexity of the Lagrangian method from $O(N^2)$ to O(NlogN), thus rendering large scale calculations computationally feasible. A range of demonstration problems are described, including basic studies of non-reacting and reacting flows as well as flows more representative of combustor applications, including temporally evolving shear layers. A particular focus of this work was to quantify the effect of heat release on the dynamics of shear flows, and the computations undertaken reflect realistic behavior of reacting flows with heat release.

Nomenclature

A_F	frequency factor
c_p	specific heat at constant pressure
D	mass diffusion coefficient
$\frac{D'f}{Dt}$	$\frac{\partial f}{\partial t}+\nabla\cdot(\underline{u}\,f)=\frac{Df}{Dt}+f(\nabla\cdot u)$
h	enthalpy of formation; also, particle spacing
k_F	reaction rate
m	molecular weight of fuel and oxidizer
N	number of particles
Pr	Prandtl number, $\mu c_p/\lambda$
p	pressure
Q	heat of reaction
Re	Reynolds number, $\rho\Delta U\delta/\mu$
Sc	Schmidt number, $\mu/\rho D$
T	temperature
T_a	activation temperature
U	axial velocity distribution
$\underline{u}$	velocity vector
$\tilde{V}$	scaled particle volume, $h^3/4\pi$
$\underline{x}$	position vector
Y_α	mass fraction of species
Γ	circulation
ΔU	characteristic velocity difference across a shear layer
δ	shear layer thickness
ε	amplitude of shear layer disturbances
η	shear layer coordinate, z/δ; also, smoothing function used in diffusion approximation
λ	thermal conductivity; also, wavelength of shear layer disturbances
μ	viscosity
ρ	density
σ	vortex smoothing core
τ	nondimensional time, $t\,\Delta U/\lambda_x$
$\underline{\omega}$	vorticity vector
$\dot{\omega}_\alpha$	production rate of species α
ξ	particle smoothing function; in this work, $\xi(r)=(15/2)/(r^2+1)^{7/2}$
$()^p$	property of p-th vortex particle
$()^0$	property at standard conditions
$()_F$	property of the fuel
$()_O$	property of the oxidizer
$()_P$	property of the combustion product

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