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COMPUTATIONAL AND EXPERIMENTAL STUDY OF NOx FORMATION IN HYDROGEN-FUELED PULSE DETONATION ENGINES

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Abstract

The formation of NOx in hydrogen-fueled pulse detonation engines (PDE) is investigated numerically and experimentally. The computations are based on the axisymmetric Euler equations and a detailed combustion model consisting of 12-species and 27 reactions. A multi-level, dynamically adaptive grid is utilized in order to resolve the structure of the detonation front. Computed NO concentrations were in good agreement with experimental measurements obtained at two operating frequencies and two equivalence ratios. Additional computations studied in detail the effects of equivalence ratio and residence time on NOx formation at ambient conditions. The results indicate that NOx formation in PDEs is minimized by operating with lean or rich mixtures, and by utilizing the shortest possible detonation tubes. NOx emissions for very lean or very rich mixtures are fairly insensitive to residence time. Operation of the PDE at near stoichiometric equivalence ratios results in very high NOx levels. However, the NOx emission parameter decreases greatly for lean or rich mixtures reaching values comparable to those obtained with current gas turbine engines.

Nomenclature

C_L	lift coefficient
C_D	drag coefficient
EI	emission index (g/kg-fuel)
g	acceleration of gravity (m/s^2)
I_{sp}	specific impulse (s)
L	length
m_i	initial vehicle mass
m_f	fuel mass
m_{nox}	total mass of NOx
n_s	number of species
p	pressure
R	range
sfc	specific fuel consumption
T	temperature or period
t	time
t_1	detonation wave residence time (see Fig. 9)
V	flight velocity
W_i	initial vehicle weight
x	axial distance

Greek Symbols

Π_0	engine pressure ratio at takeoff
ϕ	equivalence ratio
ϕ_e	engine installation drag
Ψ	emission parameter (g/kN-hr.)

Subscripts

a	ambient
c	charge
$driv$	driver gas
t	tube
0	initial conditions in the detonation tube

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1. Introduction

Pulse detonation combustors have the potential to improve the fuel efficiency of gas turbine engines due to their higher thermodynamic efficiency relative to the conventional near-constant pressure combustors. The NASA Glenn Research Center is currently investigating hybrid Constant Volume Combustion Cycle Engine (CVCCE) concepts in which detonative (or near detonative) combustion replaces constant pressure combustion.

The use of a pulse detonation (or near detonation) combustor in a gas turbine engine poses numerous technical challenges including combustor/turbine compatibility and combustor cooling and durability issues. Reliably detonating at hundreds of cycles per second efficiently in a compact device is a technical challenge in itself. However, not only must reliable, repetitive detonations be obtained, the combustor system must meet the additional constraints imposed by restrictions on the emissions of nitrogen oxides and par-