Enhancing the operation of a pulsed combustor with trajectory-correction control

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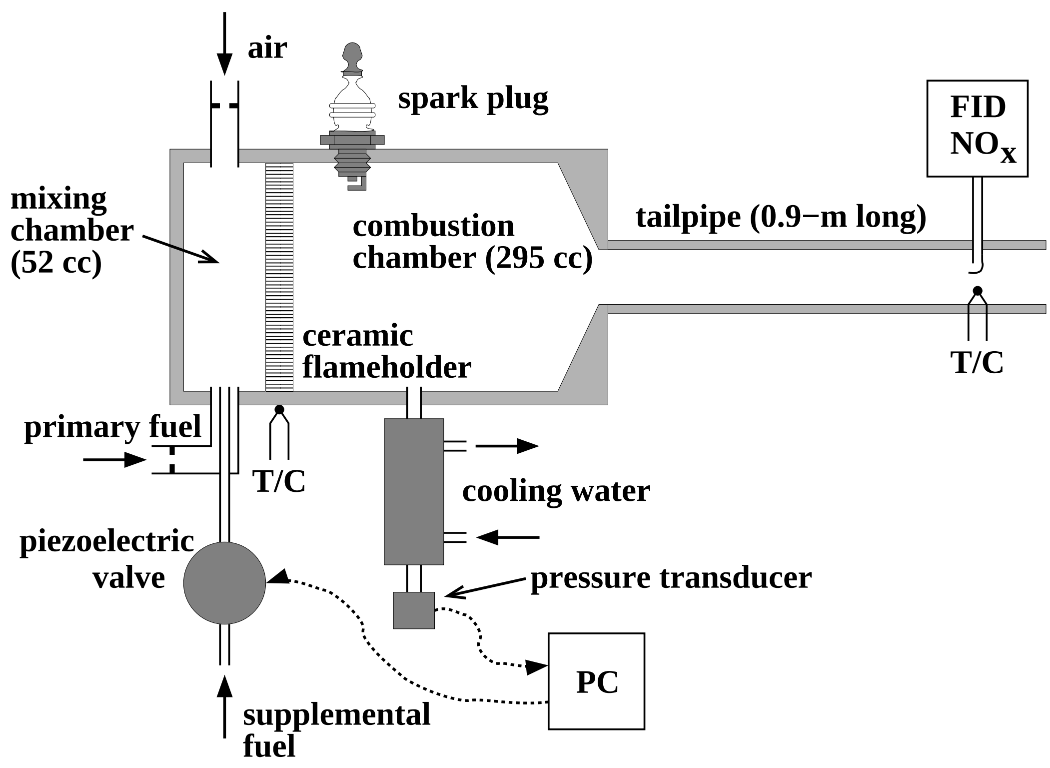
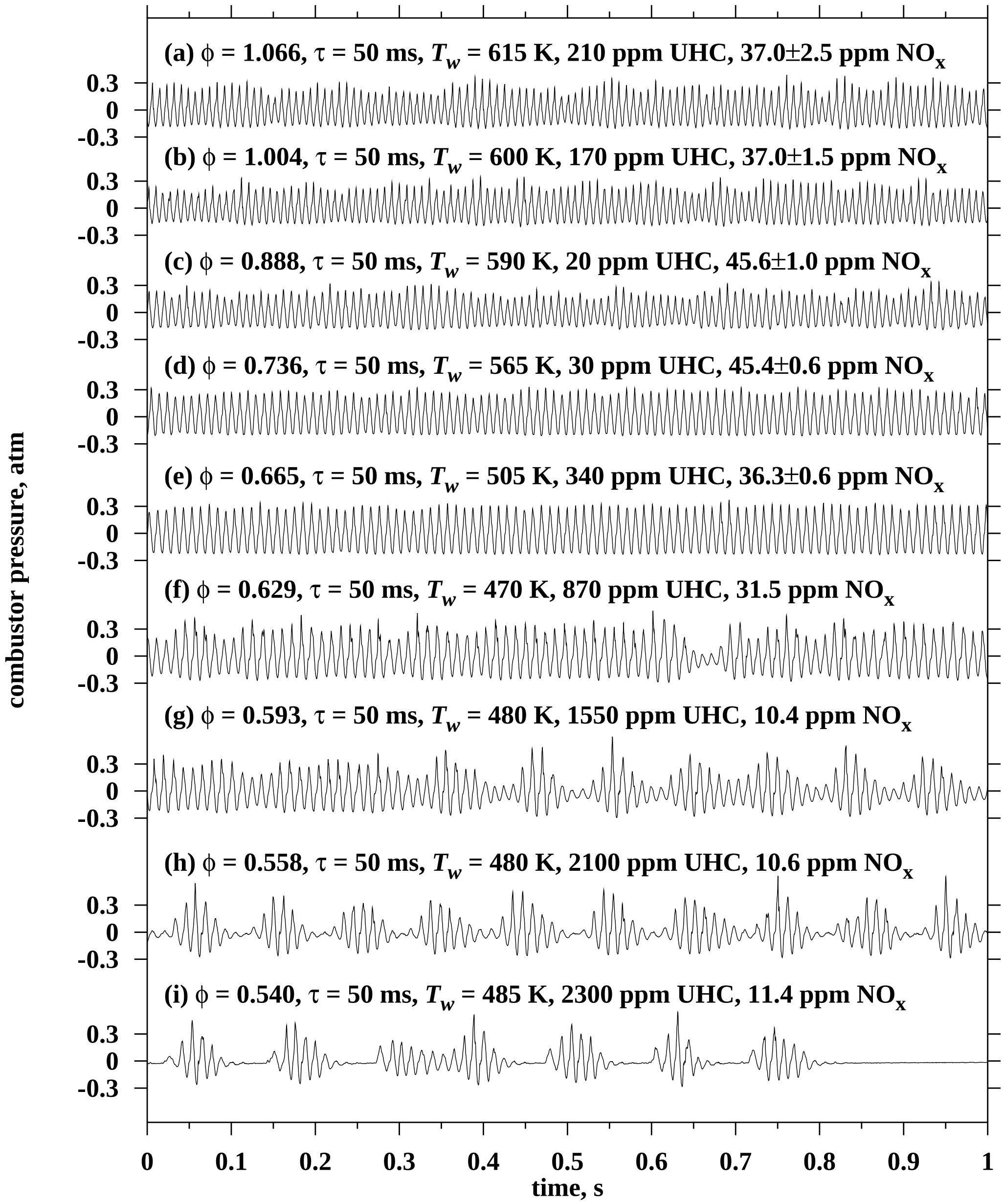
Objective

To develop a feedback control strategy which dampens combustion instabilities near the lean flammability limit allowing NO_x emission levels to be reduced without incurring an increase in UHC emission levels.

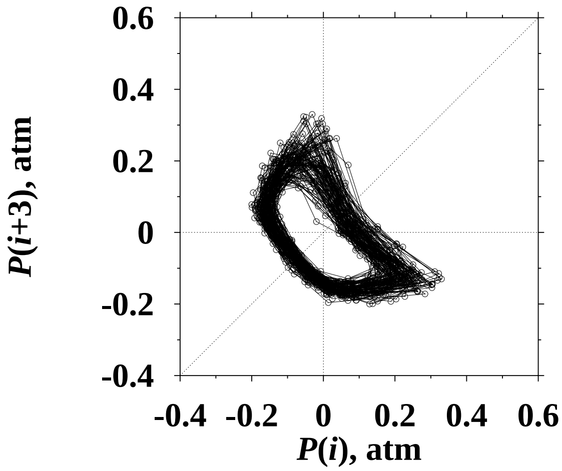
Experimental apparatus: pulsed combustor



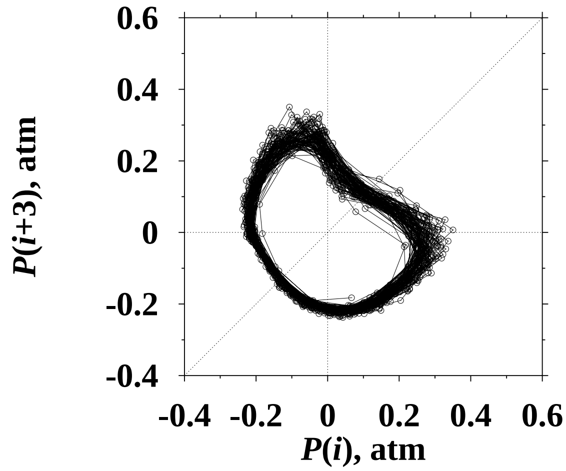
Onset of combustion instabilities



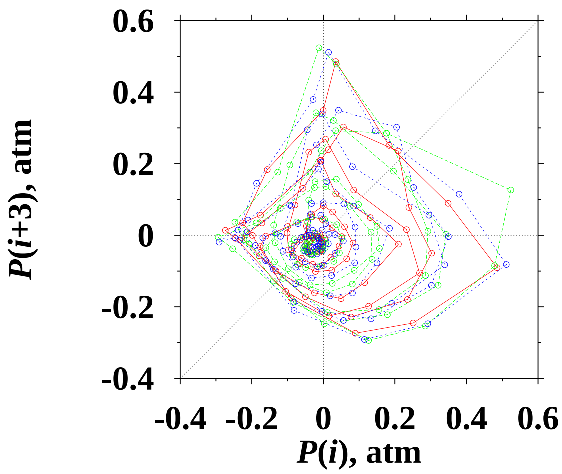
Pressure return maps



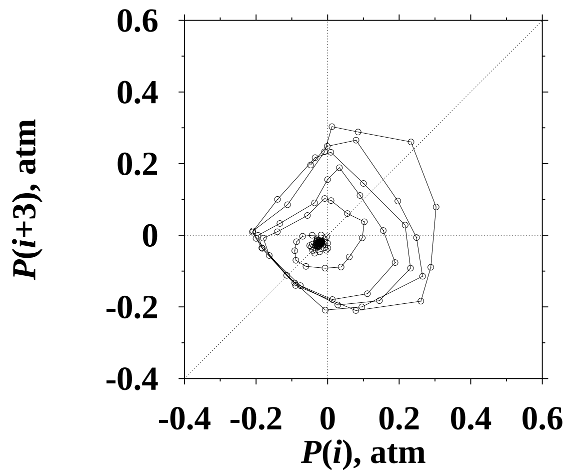
(a) $\phi = 1.004$, $\tau = 50$ ms



(b) $\phi = 0.665$, $\tau = 50$ ms

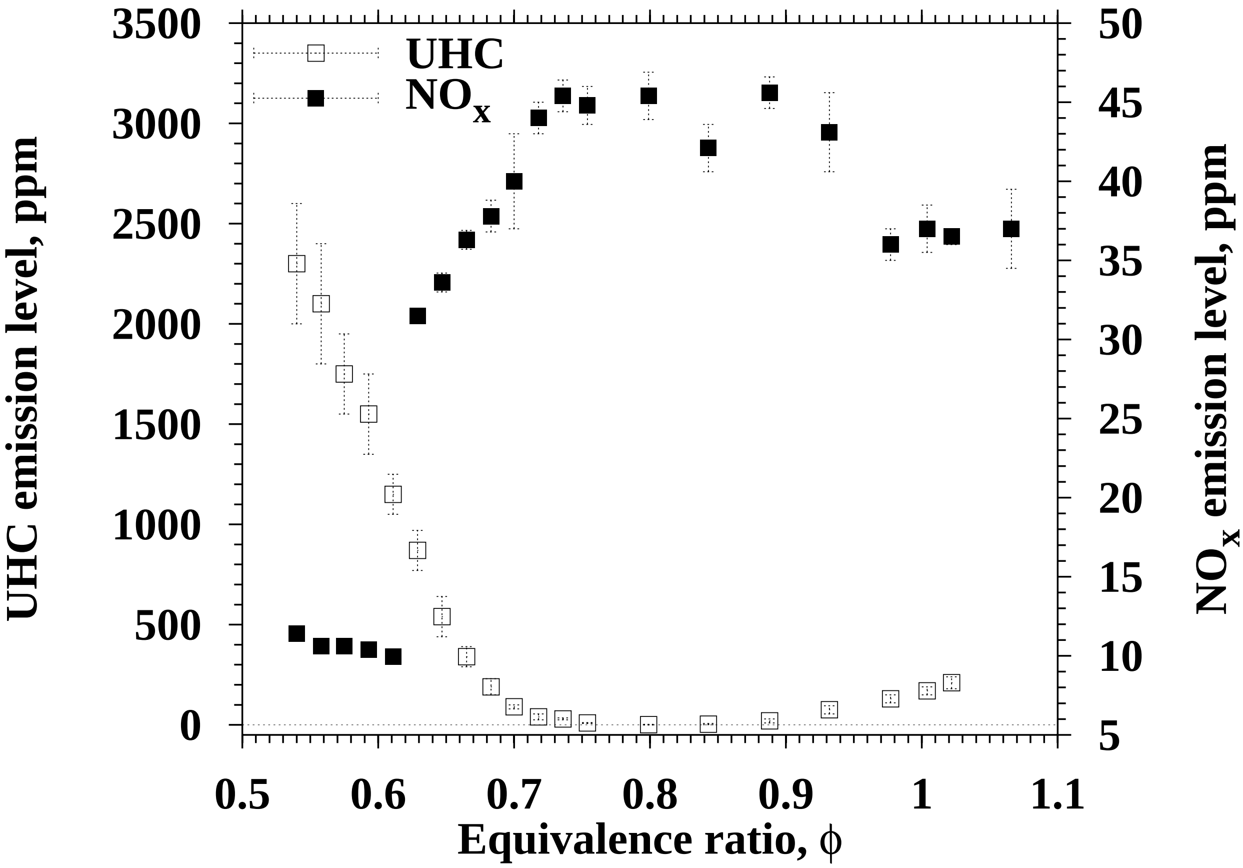


(c) $\phi = 0.558$, $\tau = 50$ ms



(d) $\phi = 0.540$, $\tau = 50$ ms

Emission levels without control (τ = 50 ms)



Summary of behavior

At stoichiometric and slightly lean conditions, the combustor pressure follows a noisy limit cycle. Fluctuations in cycle magnitude are the result of random fluctuations in the equivalence ratio due to turbulent mixing.

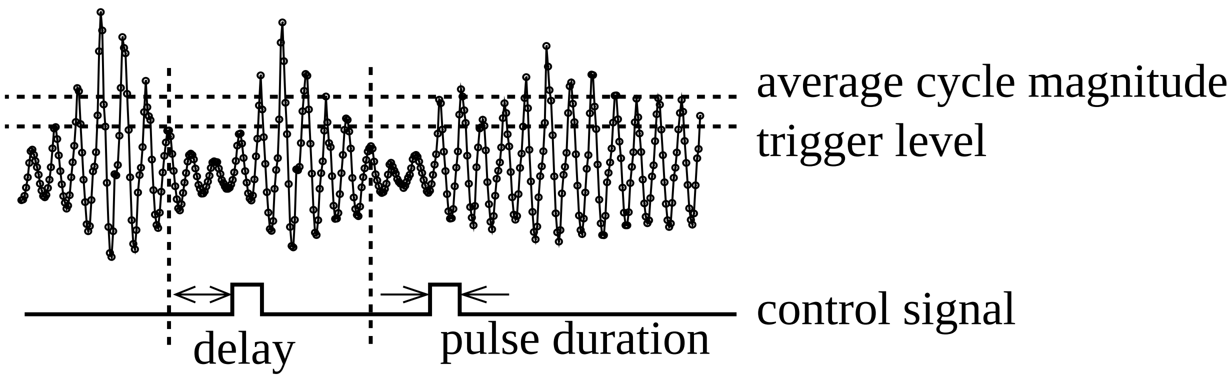
As the equivalence ratio is lowered, the system dynamics undergo a global bifurcation. The combustor behavior becomes unstable. Combustion instabilities develop in the form of low-frequency oscillations as the available fuel is consumed and restocked.

Near the bifurcation point, the pulsed combustor intermittently transitions between the stable and unstable modes of operation.

Flameout occurs when the combustor walls and ceramic flameholder cool to the point where they cannot provide enough energy to ignite the fresh mixture.

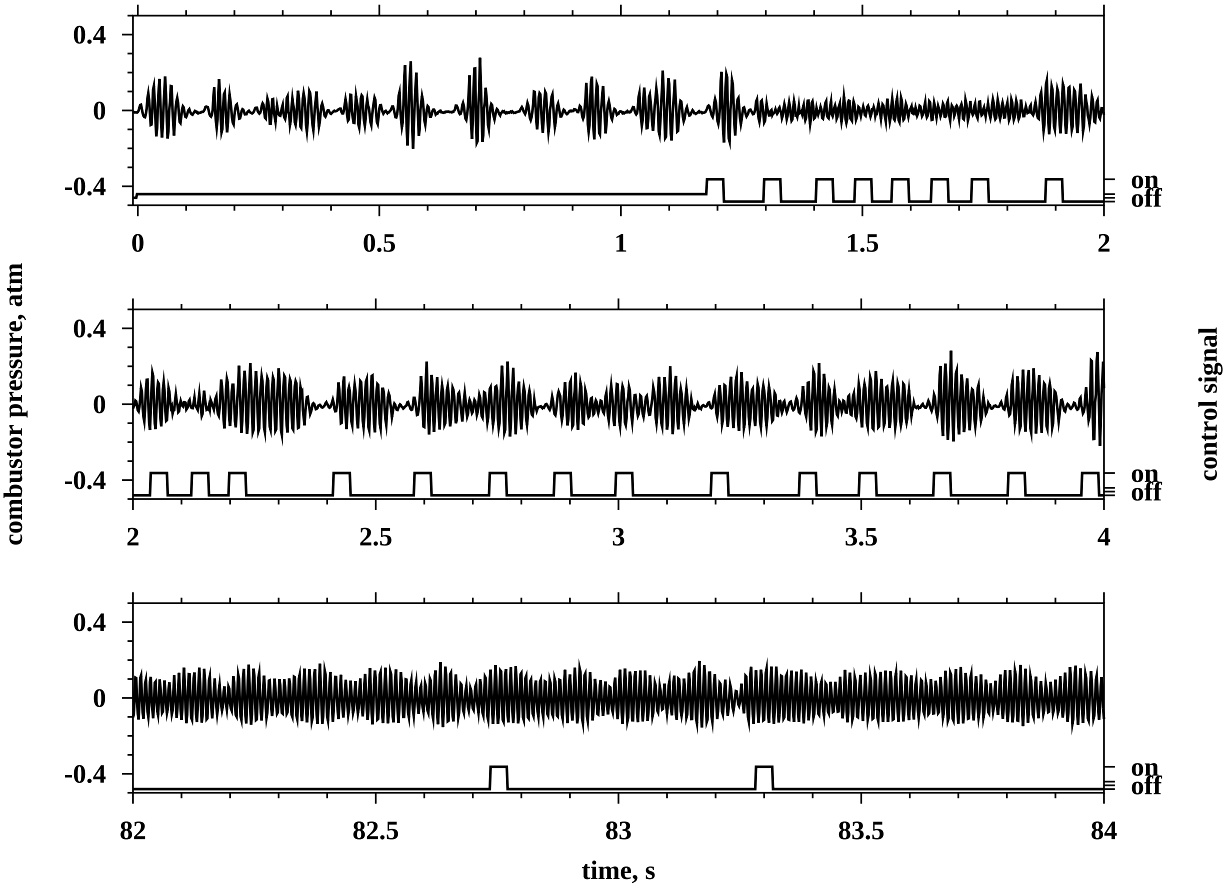
The combustion instabilities are nonlinear in nature and are due to the nonlinearity of the combustion process.

Control algorithm

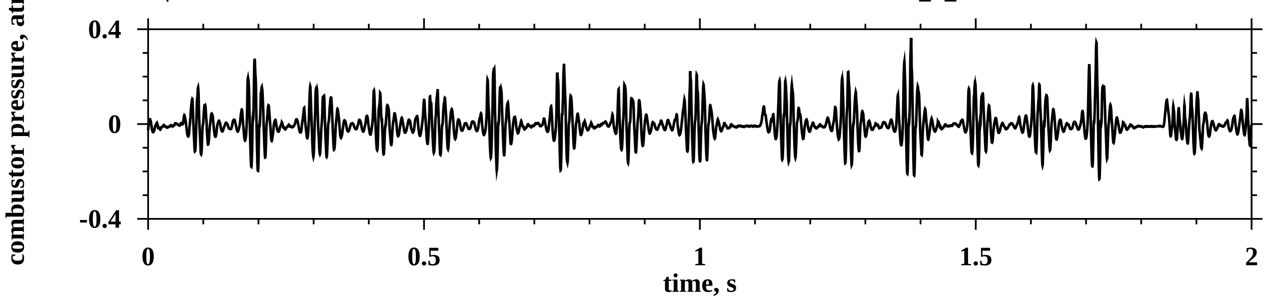


- The average cycle maximum is tallied from the peak pressure value for each cycle.
- Control perturbations are initiated when a peak falls below the trigger level (defined as a percentage of the average cycle maximum) following a specified triggering delay interval.
- The amount of supplemental fuel injected with each perturbation is controlled by the pulse duration and the preset through-put of the piezoelectric valve.
- The control variables are selected by trial-and-error.

$\bar{\phi}$ = 0.45 (ϕ = 0.427), τ = 75 ms, T_w = 520 K, ~80 ppm UHC



ϕ = 0.45, τ = 75 ms, T_w = 450 K, ~1600 ppm UHC



Reduction in UHC emission levels with control

$\tau = 50$ ms			
ϕ	UHC w/o control (ppm)	ϕ	UHC w/ control (ppm)
0.665	340±50	0.687	100±20
0.647	540±100	0.669	100±20
0.629	870±100	0.663	125±10
0.611	1150±100	0.656	130±10
0.593	1550±200	0.672	130±20
0.575	1750±200	0.688	160±30
0.558	2100±300	0.670	190±40
0.540	2300±300	0.653	220±50
0.522	—	0.635	400±150

$\tau = 75$ ms			
ϕ	UHC w/o control (ppm)	ϕ	UHC w/ control (ppm)
0.487	105±20	0.487	60±20
0.469	980±200	0.469	60±10
0.452	1600±300	0.452	160±30
0.435	1600±300	0.450	125±25
0.418	—	0.435	250±200
0.400	—	0.430	500±200
0.382	—	0.425	700±100
0.366	—	0.410	850±100

NO_x emission levels with control

$\tau = 50$ ms			
ϕ	NO_x w/o control (ppm)	$\bar{\phi}$	NO_x w/ control (ppm)
0.593	10.6	0.672	10.3±0.7
0.575	10.6	0.688	10.0±0.8
0.558	10.6	0.670	10.1±0.7
0.540	11.4	0.653	10.1±0.7

Summary

- Control is achieved with a relatively small perturbation in equivalence ratio to hasten restocking of the fuel inventory.
- Once the controller has stabilized, control perturbations are only occasionally required to keep the pulsed combustor entrained in the stable mode of operation.
- The practical operating range of the pulsed combustor has been extended towards the lower flammability limit allowing NO_x emission levels to be lowered without incurring an increase in UHC emission levels.