Diffusion flame ignition by a recirculating flow

M. Konczalla, DFVLR, Institute for chemical propulsion, D-7101 Hardthausen

Abstract
The ignition of a diffusion flame results from the interaction of transport processes and an exothermic chemical reaction. Diffusion flame ignition by a recirculating flow downstream of a backward-facing step is investigated. Special features of this flow are taken into account. The reaction rate is given by an Arrhenius expression, which introduces a nonlinear contribution to the conservation equations. The activation energy of the chemical reaction is used as large parameter in a singular perturbation approach. A well-defined singularity determines an ignition point $y_{ig}$ on the dividing streamline. The influence of the inlet conditions on $y_{ig}$ is investigated. It is shown, that $y_{ig}$ is a decreasing function of the entrance velocity. This behaviour is experimentally observed.

1. Model
A diffusion flame close to a recirculating flow is ignited due to the strong exchange of heat and mass between the wake and the surrounding flow. A fraction of the heat released from the flame is transported by the reverse flow in regions upstream of the flame, where it heats the entering cold flow. Thus a continuous process is maintained.

![Physical situation](image)

Fig. 1.1 Physical situation
A cold and fast flow (temperature $T=T_E$, oxidator mass fraction $Y_{Ox}=Y_{Ox,E}$, vanishing fuel mass fraction $Y_F=0$, characteristic velocity $U_o$) separates at the step and a wake of well-defined length is established. Fuel is supplied through the chamber-walls (sintermetal). The entering gas mixes with the hot, fuel-rich gas from the re-
circulation zone in the vicinity of the dividing streamline. In this region ignition occurs. Downstream of the ignition point a stationary flame is observed. A fraction of the flames hot waste gases is entrained into the wake. Inside the stagnant wake conditions are homogenous \((T' = T_R', \; Y_{Ox} = 0, \; Y_F = Y_{F,R})\). \(T_R\) approximately coincides with the flame temperature. By heat and mass exchange an ignitable mixture is established in the surrounding flow. Further details are given in \([1,4,5,11]\).

This description shows, that several processes effect ignition. In the surrounding flow we have to take into account convective transport of heat and species along the streamlines, crosswise diffusion and an exothermic, reactant consuming chemical reaction. Using several assumptions \([6]\) a closed equation for a nondimensional temperature \(T\) is obtained:

\[
\frac{\partial T}{\partial y} - \frac{\partial^2 T}{\partial y^2} = \frac{1}{x} f(y) (S_F - T)(S_{Ox} - T) \exp(-T_a/T),
\]

(1.2) \[
\frac{\partial T}{\partial \eta} \bigg|_0 = \chi (T-1), \quad T(y=0,\eta) = \lim_{\eta \to \infty} T(y,\eta) = 1 - \delta
\]

\(T\) is given by

(1.3) \(T = T'/T_R\).

The normalized mass fractions \(Y_i\) \((i = F, \; Ox)\)

(1.4) \(Y_i = \frac{m_F Q}{m_i c_p T_R} Y_i'\)

are expressed in terms of \(T\) and coupling functions \(S_i\) \([10]\)

(1.5) \(S_i = T + Y_i\),

which are solutions of homogenous transient heat equations

(1.6) \[
\frac{\partial}{\partial y} \left( \frac{\partial S_i}{\partial y} - \frac{\partial^2 S_i}{\partial y^2} \right) = 0
\]

with appropriate linear boundary conditions. In (1.2) the nondimensional temperature difference \(\delta\) is introduced. \(\Gamma\) is a Damköhler number and \(\chi\) describes the exchange between the wake and its surrounding. \(f(y)\) is defined in (1.8). Further \(m_i\) \((i=F, \; Ox)\) refers to the molecular mass of fuel and oxidizer, \(Q\) is the specific heat of