Computer Methods in Combustion

Project II

Changes of parameters of reflected shock wave dependent on initial temperature of mixture

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Contents

1. Introduction

During propagation of shock wave are constantly changing in time. We can point out three main stages during the process when parameters can be significant. They are: initiation, incident and reflection. In this paper we will focus only on parameters of shock wave after reflection. They will be discussed in terms of changing the temperature of initial conditions. Discussed mixture is stoichiometric mixture of hydrogen and air. In considered case temperature varies from 300 K to 1400 K. Analysis are made using SDToolbox for Cantera.

1.1 Theory

Pressure, temperature and density are decreasing behind the shock wave. The same is for velocity. Parameters are dependent velocity of the propagating shock wave. Simplest formulas for isentropic perpendicular shock wave are:

$$\frac{P_1}{P_0} = \left[1 + \frac{k-1}{2} M^2\right]^{\frac{k-1}{k}}$$

$$\frac{T_1}{T_0} = \left[1 + \frac{k-1}{2} M^2\right]^{-1}$$

$$\frac{\rho_1}{\rho_2} = \left[1 + \frac{k-1}{2} M^2\right]^{k-1}$$

2. Case study

SDToolbox allows to recursively calculate parameters during the incident and reflection using to predefined functions. Written code calculates parameters of gas in the initiation point, next during the incident with 120% of C-J speed and finally, using earlier calculations, during the reflection. Results of computation are below:

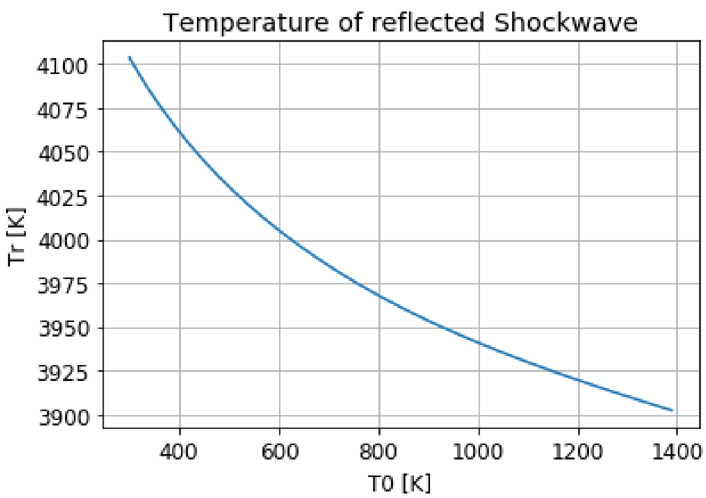

***Figure 1**: Temperature after reflection in terms of changing initial temperature*

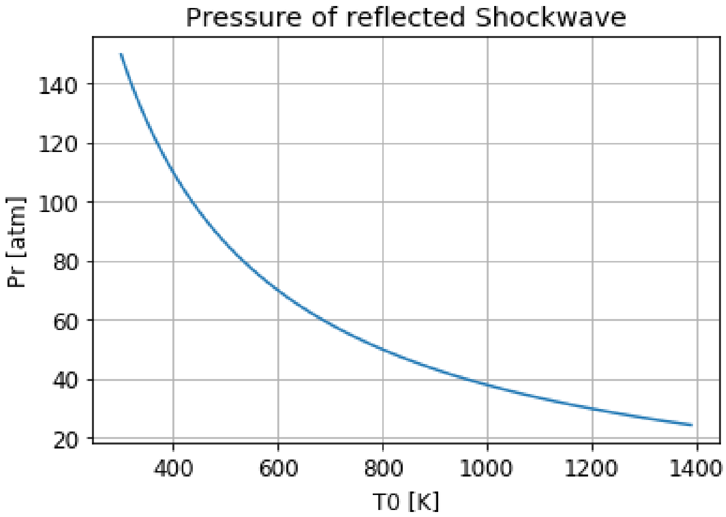

Figure 2: *Pressure after reflection in terms of changing initial temperature*

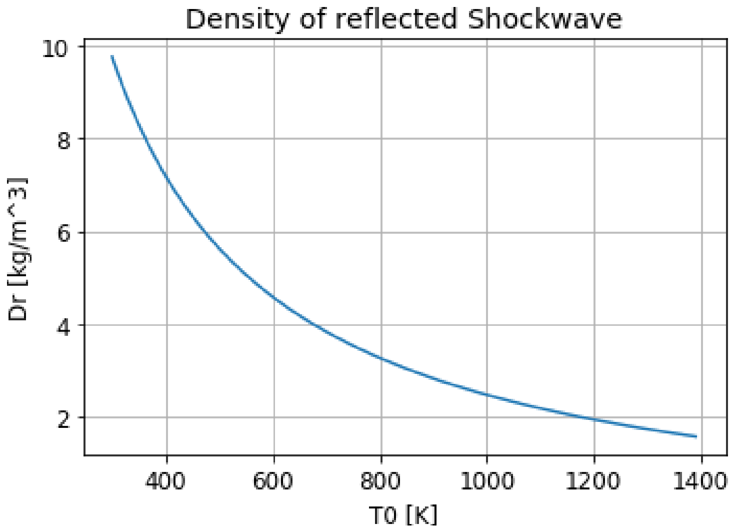

Figure 3: *Density after reflection in terms of changing initial temperature*

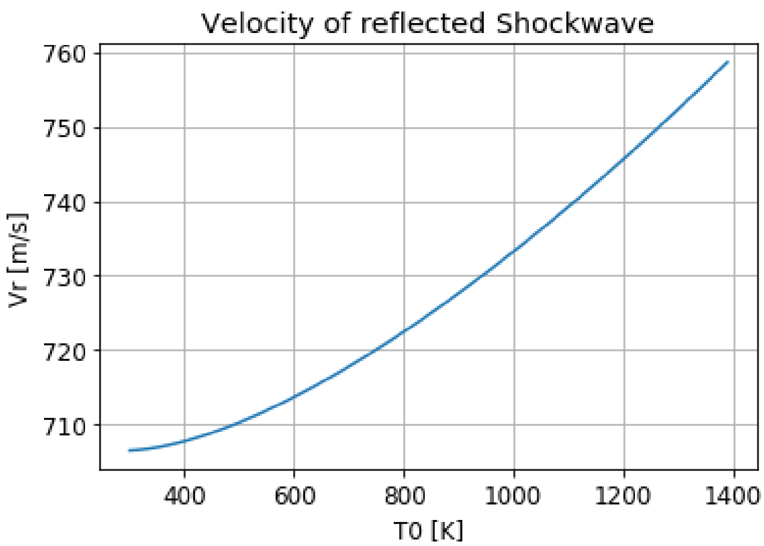

Figure 4: *Velocity after reflection in terms of changing initial temperature*

3. Conclusions

In case when initial temperature is constant, pressure, temperature and density are bigger after reflection in contrast to velocity which decreases. When temperature of starting point raises, pressure, temperature and density of reflected shock wave decrease nonlinearly. Velocity raises from about 705 m/s to 760 m/s in the considered range of initial temperature.

Watching gained results we can say that this study may be applied to developing and designing RamJet or ScramJet engines. They are using shock wave phenomenon. Air on the inlet to engine is pressurized and heated up. Choosing right temperature of gases on the inlet we can achieve better performance due to studied example. In higher temperature reflected shock waves are propagating faster what can adjust performance of the engine.

4. Code

Below code using SDToolbox functions:

```
import cantera as ct

import numpy as np

import matplotlib.pyplot as plt

from sdtoolbox.postshock import CJspeed, PostShock_eq

from sdtoolbox.reflections import reflected_eq


# Initial state specification:

# P1 = Initial Pressure

# T1 = Initial Temperature

# U = Shock Speed

# q = Initial Composition

# mech = Cantera mechanism File name

# Tmax = maximal temperature


P1 = 100000

T1 = 300

Tmax = 1400

tab_T=[]
```

```
tab_P=[]
tab_D=[]
tab_U=[]

for T1 in range(300,Tmax,10):
    q = 'H2:2 O2:1 N2:3.56'
    mech = 'Mevel2017.cti'
    gas1 = ct.Solution(mech)
    gas1.TPX = T1, P1, q

    # create gas objects for other states
    gas2 = ct.Solution(mech)
    gas3 = ct.Solution(mech)

    # compute minimum incident wave speed
    cj_speed = CJspeed(P1, T1, q, mech)

    # incident wave must be greater than or equal to cj_speed for
    # equilibrium computations
    UI = 1.2*cj_speed

    # compute postshock gas state object gas2
    gas2 = PostShock_eq(UI, P1, T1, q, mech);

    # compute reflected shock post-shock state gas3
    [p3,UR,gas3]= reflected_eq(gas1,gas2,gas3,UI);

    # Outputs:
    # p3 - pressure behind reflected wave
```

```
    # UR = Reflected shock speed relative to reflecting surface
    # gas3 = gas object with properties of postshock state

    # gas3 states stored in tables
    tab_T.append(gas3.T)
    tab_P.append(gas3.P/ct.one_atm)
    tab_D.append(gas3.density)
    tab_U.append(UR)

#generating plots
x = np.arange(300,Tmax,10)

fig, ax_T = plt.subplots()
ax_T.plot(x,tab_T)
ax_T.set(xlabel='T0 [K]', ylabel='Tr [K]', title='Temperature of reflected
Shockwave')
ax_T.grid()
fig.savefig('C:/Users/user/Desktop/Temperature.png', bbox_inches='tight',
pad_inches=0.3)

fig, ax_P = plt.subplots()
ax_P.plot(x,tab_P)
ax_P.set(xlabel='T0 [K]', ylabel='Pr [atm]', title='Pressure of reflected
Shockwave')
ax_P.grid()
fig.savefig('C:/Users/user/Desktop/Pressure.png', bbox_inches='tight',
pad_inches=0.3)

fig, ax_D = plt.subplots()
ax_D.plot(x,tab_D)
```

```
ax_D.set(xlabel='T0 [K]', ylabel='Dr [kg/m^3]', title='Density of reflected Shockwave')

ax_D.grid()

fig.savefig('C:/Users/user/Desktop/Density.png', bbox_inches='tight', pad_inches=0.3)


fig, ax_U = plt.subplots()

ax_U.plot(x,tab_U)

ax_U.set(xlabel='T0 [K]', ylabel='Vr [m/s]', title='Velocity of reflected Shockwave')

ax_U.grid()
fig.savefig('C:/Users/user/Desktop/Velocity.png', bbox_inches='tight', pad_inches=0.3)
```