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Cylindrical shock waves in rotational axisymmetric non-ideal dusty gas with increasing energy in presence of conductive and radiative heat fluxes

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Rotating medium

Abstract The propagation of a cylindrical shock wave in a rotational axisymmetric non-ideal dusty gas in the presence of conductive and radiative heat fluxes with increasing energy, which has variable azimuthal and axial fluid velocities, is investigated. The dusty gas is assumed to be a mixture of non-ideal (or perfect) gas and small solid particles, in which solid particles are continuously distributed. Similarity solutions are obtained and the effects of the variation of the heat transfer parameters, the parameter of non-idealness of the gas, the mass concentration of solid particles in the mixture and the ratio of the density of solid particles to the initial density of the gas are investigated. It is shown that the heat transfer parameters and the parameter of non-idealness of the gas, both, decrease the compressibility of the gas and hence there is a decrease in the shock strength.

1. Introduction

Marshak [1] studied the effect of radiation on the shock propagation by introducing the radiation diffusion approximation. He solved both the cases of constant density and constant pressure fields without invoking conditions of self similarity. Using the same mode of radiation, Elliott [2] discussed the conditions leading to self-similarity with a specified functional form of the mean free path of radiation and obtained a solution for self-similar spherical explosion. Wang [3], Helliwell [4] and Nicastro [5] treated the problems of radiating walls, either stationary or moving, generating shocks at the head of self-similar flow fields. Ghoneium et al. [6] obtained the self-similar solution for spherical explosions taking into account the effects of both conduction and radiation in the two limits of Rosseland radiative diffusion and Planck radiative emission.

The formation of self-similar problems and examples describing the adiabatic motion of non-rotating gas models of stars, is considered by Sedov [7], Zel'dovich and Raizer [8], Lee and Chen [9], and Summers [10]. The experimental studies and astrophysical observations show that the outer atmosphere of the planets rotates due to rotation of the planets. Macroscopic motion with super-sonic speed occurs in an interplanetary atmosphere and shock waves are generated. Shock waves often arise in nature because of a balance between wave breaking non-linear and wave damping dissipative forces [8]. Collisional and Collisionless shock waves can

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Nomenclature

A	angular velocity
A_a	initial angular velocity
a_m	speed of sound in the mixture
a_{iso}	isothermal speed of sound in the mixture
B	constant
b	internal volume of the molecules of the gas
$\overline{b}$	parameter of non-idealness of the gas
C_p	specific heat of the perfect gas at constant pressure
C_v	specific heat of the perfect gas at constant volume
C_{sp}	specific heat of solid particles
C_{pm}	specific heat of the mixture at constant pressure
C_{vm}	specific heat of the mixture at constant volume
D	non-dimensional density
E	total energy of the flow between shock and the inner contact surface or piston
E_0	constant
E^*	constant
F	total heat flux
F_c	conductive heat flux
F_R	radiative heat flux
f	reduced total heat flux
G	ratio of the density of solid particles to that of the perfect gas
G_a	ratio of the density of solid particles to that of the perfect gas at initial state
g	reduced density
h	reduced azimuthal velocity
J	abbreviation
K	thermal conductivity
K_p	mass fraction (concentration) of the solid particles in the mixture
L	abbreviation
l_r	non-dimensional radial component of vorticity
l_θ	non-dimensional axial component of vorticity
l_{z^*}	non-dimensional azimuthal component of vorticity
M	shock-Mach number
M_e	effective shock-Mach number
m	total mass of the mixture
m_{sp}	mass of solid particles
N	abbreviation
P	non-dimensional pressure
p	fluid pressure
p_g	partial pressure of the gas in the mixture
Q	non-dimensional total heat flux
$\vec{q}$	fluid velocity
R	shock radius
R^*	gas constant
r	space coordinate
r_p	radius of inner expanding surface
S	abbreviation
s	total energy variation index
T	absolute temperature of the mixture
t	time coordinate
U	non-dimensional radial component of fluid velocity
U_m	internal energy per unit mass of the mixture
u	radial component of fluid velocity
V	shock velocity
V^*_{sp}	volume of solid particles
V^*	total volume of the mixture
v	azimuthal component of velocity
W	non-dimensional axial component of fluid velocity
w	axial component of fluid velocity
X	similarity variable
X_p	value of X at inner expanding surface
Y	reduced pressure
Z	volume fraction of solid particles in the mixture
Z_a	initial volume fraction of solid particles in the mixture
α_R	Rosseland mean absorption coefficient
β	density ratio across the shock
β'	ratio of specific heat of the solid particles to that of perfect gas at constant volume
β_c	density variation index in thermal conductivity
β_R	temperature variation index in absorption coefficient
Γ	ratio of specific heat of the mixture
Γ_c	non-dimensional conduction heat transfer parameter
Γ_R	non-dimensional radiation heat transfer parameter
γ	ratio of the specific heat of the perfect gas
δ_c	density variation index in thermal conductivity
δ_R	density variation index in absorption coefficient
λ	ambient azimuthal velocity variation index
μ	ambient axial velocity variation index
π	ratio
ρ	density of the mixture
ρ_{sp}	density of solid particles
ρ_{g_a}	density of the perfect gas in the initial state
$\overline{\rho}_g$	partial density of the gas in the mixture
σ	Stefan–Boltzman constant
ϕ	reduced radial velocity
ψ	reduced axial velocity
ξ	non-dimensional azimuthal component of fluid velocity
$\vec{\zeta}$	vorticity vector
ς_r	radial component of vorticity vector
ς_θ	axial component of vorticity vector
ς_{z^*}	azimuthal component of vorticity vector

Subscripts

a	immediately ahead of the shock
n	immediately behind the shock
S	at constant entropy
T	at constant temperature
0	reference state