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Effect of Paramagnetism and Diamagnetism on Theoretical Rocket Performance

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The impact of an externally applied magnetic field on theoretical rocket performance has been investigated and the results of this investigation are presented and discussed. The application of a magnetic field has been assumed to impact rocket performance as a result of only the paramagnetic and diamagnetic nature of the constituent species in order to isolate the related phenomena. For the results presented in this paper, the impact of an applied magnetic field has been evaluated only for the case of an infinite area combustor. The equilibrium chemical composition produced in the combustor was assumed frozen as the fluid expanded through a supersonic nozzle. The parametric investigation examined a model reaction between kerosene and oxygen. The theoretical model was validated by comparison with existing chemical equilibrium and theoretical rocket performance models for the case of no applied magnetic field. The results indicate that the application of a magnetic field decreases mixture molecular mass, increases specific impulse, decreases the expansion ratio required for isentropic flow, and decreases the thrust coefficient.

Nomenclature

A	=	area
B	=	magnetic induction
C_F	=	thrust coefficient
c_p	=	constant pressure specific heat
c^*	=	characteristic velocity
g	=	acceleration due to gravity
H	=	magnetic field strength
I_s	=	specific impulse
k	=	ratio of specific heats
M_M	=	molecular mass
m	=	mass flow rate
n	=	number of moles
O/F	=	oxygen-to-fuel ratio
p	=	pressure
R_u	=	universal gas constant
T	=	temperature
u	=	fluid speed
V	=	volume
W	=	work
y_i	=	mole fraction of species i
ρ	=	density

Subscripts

e	=	exit conditions
m	=	iteration counter
mix	=	mixture
o	=	stagnation conditions
t	=	throat conditions

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Introduction

MAGNETIC fields are known to influence the performance of propulsion systems as a result of the interaction between the magnetic field and the associated ionized gases, that is, through the Lorentz body force. Many nonconventional propulsion systems employ a magnetic field to accelerate plasma in order to produce thrust.[1–3] For solid rocket motors, the application of an applied magnetic field has been shown to increase the temperature and pressure near the burning surface and thus produce up to a ten-fold increase in the mass burn rate as the result of the interaction between the magnetic field and the ionized combustion gases.[4,5] The interaction between a magnetic field and an ionized gas is not the only way a magnetic field can influence the performance of a chemical rocket. Magnetic fields influence the behavior of all materials as a result of paramagnetism and diamagnetism. Paramagnetism is the weak attraction to a magnetic field experienced by a material composed of atoms with permanent magnetic dipole moments. Because the magnetic dipole moments of a paramagnetic material are randomly oriented, there is an insignificant interaction when no magnetic field is applied. When a magnetic field is applied to such materials, the atoms align with the magnetic field and produce a mild attraction. The strength of this attraction is proportional to the strength of the externally imposed magnetic field. The magnetic behavior associated with the dipole moments in a paramagnetic gas must compete with the randomizing effect of temperature. This behavior is functionally described by the magnetic susceptibility. The magnetic susceptibility is the ratio of the magnetization to the magnetic field strength. In a paramagnetic gas, the magnetic susceptibility is thus a function of temperature. Materials consisting of atoms with no permanent magnetic dipole moments exhibit diamagnetic behavior. When an external magnetic field is applied, the atoms of a diamagnetic material develop a net dipole moment. This induced moment opposes the applied field, and thus a diamagnetic material exhibits a weak repulsion to an applied magnetic field. The repulsion to the magnetic field increases with increasing magnetic field strength. Unlike paramagnetic gases, the magnetic susceptibility of a diamagnetic gas is independent of temperature. For chemical rocket engines, the principal paramagnetic gas is oxygen, whereas most of the other species are diamagnetic.

Although the forces associated with the interaction between magnetic fields and plasmas are orders of magnitude greater than those associated with paramagnetic and diamagnetic interactions, the