Extension of Lighthill's gas model for multi-component air

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In 1957 Lighthill published a pioneering paper [1] in which he proposed a simplified model to determine the degree of dissociation for a single species component gas. It is based on the results of statistical mechanics and valid for equilibrium conditions. In this case of thermal and chemical equilibrium the degree of dissociation depends on two thermodynamic variables of state, where usually the density and temperature are chosen as independent variables. Knowing the degree of dissociation allows to determine the pressure, internal energy, specific enthalpy and other thermodynamic variables of state depending on the gas temperature and density.
Lighthill showed that for a temperature range fom 1000 K to 7000 K the partition functions can be set constant which results in a single expression for the degree of dissociation. Based on Lighthill's ideal dissociating gas model for equilibrium flow, Freeman [2] extended this model for a nonequilibrium dissociating flow. Till today these theoretical models serve for thermochemical modelling of a high tenperature gas in engineering methods.
Despite its wide acceptance, the most significant drawback of Lighthill's model is given by its limitation to a single species gas consisting of atoms and molecules. This necessitates to consider e.g. air only consisting of oxygen or nitrogen. The molecular weight of oxygen and nitrogen is not very different, but a large difference exists for dissociation. Oxygen molecules are almost completely dissociated at temperatures when nitrogen just starts to dissociate. This makes it difficult and questionable to apply Lighthill's ideal dissociating gas model for air, especially for the transitional regime where both oxygen and nitrogen dissociation are important.
The paper describes an extension of Lighthill's model to a more realistic five component air model. It is also based on the approach of statistical mechanics. The total degree of dissociation follows from the sum of the degree of dissociation of oxygen and nitrogen, where NO-molecules are formed as intermediate species. It is shown that as in the original model of Lighthill the final result can significantly be simplified by introducing a constant dissociation density. It is shown that in a temperature range from 1000 K to 10000 K the derived model deviates from exact values for the dissociation degree of air by not more than 6 %.
This new model can be used in any engineering relations to determine the properties of air at reentry-relevant temperatures.

References

[1] M.J. Lighthill, 1957, Dynamics of a Dissociating Gas. Part I. Equilibrium Flow. J. Fluid Mech., Vol. 2, Part 1, pp. 1-32
[2] N.C. Freeman, 1958, Non-equilibrium Flow of an Ideal Dissociating Gas. J. Fluid Mech., Vol. 4, Part 4, pp. 407-425