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Flight Velocity Effects on the Compressibility and Heating Occurring in Pulse Detonation Engines

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ABSTRACT

The advantage of the pulse detonation engine (PDE) cycle over the Brayton cycle has usually been attributed to the higher thermodynamic efficiency of the PDE. This advantage is normally depicted as a plot of thermal efficiency versus relative inlet temperature ratio, where the atmospheric temperature is used as the reference. The typical plot, shown in figure 1, assumes that a comparison of the different cycles is performed at a constant value of the temperature ratio, regardless of the type of cycle and the flight conditions. In addition, the heat release for all of the engine cycles is assumed to be equal. The usual result from figure 1, therefore, would show that at a temperature ratio of 2, the cycle efficiency for the PDE is 0.63, while that for a Brayton cycle is only 0.5. There are two fallacies associated with this type of comparison; namely (1) the temperature ratio, T_3/T_0 (where T_0 is the atmospheric temperature), entering the combustor of a pulse detonation engine or a ramjet is lower than that of the gas turbine, and (2) the available heat released in the detonation cycle is lower than that in a Brayton (either gas turbine or ramjet) cycle. In this paper, we shall examine both of these issues, in some detail, in order to establish an improved comparative basis for the propulsion performance of each of the cycles. Some typical flight conditions are assumed in order to demonstrate the effects mentioned above.

In regards to issue (1), the PDE and the ramjet utilize only ram compression and heating to increase the inlet temperature ratio, T_2/T_0, where T_0 is the atmospheric or reference temperature and T_2 is the temperature of the air exiting the inlet and diffuser section of the engine. In the case of the gas turbine, the ram compression is further boosted by the mechanical compressor (and fan) to a temperature T_3 that is higher than that in the PDE or ramjet. In order to compare the relative performances, it is necessary, therefore, to use the value of the temperature, T_2, entering the PDE detonation chamber or into the ramjet combustion chamber as well as the temperature, T_3, entering the gas turbine combustion chamber. ***The effect of using these temperatures is to shift the comparison point between the PDE (and the ramjet) and the gas turbine cycles to different locations on the abscissa of figure 1.***

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Therefore, the previous comparison must be modified so that the PDE value is now compared to the gas turbine efficiency at a higher temperature ratio. The value of the higher temperature ratio depends on the mechanical compression ratio and flight speed. For a specific heat ratio of 1.4, a compression ratio of 4 and zero flight speed, the isentropic temperature ratio value to be used for the turbine becomes 1.5. The paper will present results for the propulsion performance parameters, i.e., specific thrust, impulse and specific fuel consumption, for a range of flight Mach numbers. Some typical results are shown in figure 2.

In regards to issue (2), it has been shown that the ***higher temperatures associated with the detonation process creates a greater amount of dissociated species and lower sensible heat release than does the deflagration process in a ramjet or gas turbine engine***. Use of time accurate CFD code including finite rate chemistry has been used to determine the combined dissociation and recombination occurring in an open-ended PDE tube. The resulting effect on the amount of sensible heat available for creating thrust is significant (shown in figure 1) and, in fact, causes the specific thrust, impulse and fuel consumption values for the PDE to become inferior to the gas turbine at some conditions, as shown in figures 2 and 3. These results will be shown for both ethylene-air and hydrogen-air mixtures for Mach numbers from 0 to 5. Comparison of the CFD impulse calculations with experimental data, as well as analytical results from a cycle analysis will be presented (see figure 4).

The overall significance of these results on the role of PDE's for flight propulsion systems, and their performance relative to the gas turbine cycle, figure 5, will also be presented.

References

Povinelli, Louis A., "Impact of Dissociation and Sensible Heat Release on Pulse Detonation and Gas Turbine Engine Performance", NASA TM-2001-211080, July 2001, also 15th ISABE Symposium Paper 2001-1212, Sept 2002.

Povinelli, Louis A., Lee, Jin-Ho and Anderberg, Michael O., "Role of Air-Breathing Pulse Detonation Engines in High Speed Flight, NASA/TM- 2001-211163, Sept 2001, also 52nd IAF Congress Paper IAF-01-S.5.01, Oct. 2001.

Povinelli, Louis A. and Yungster, Shaye, "Airbreathing Pulse Detonation Engine Performance", NASA TM/-2002-211575, May 2002, 26th Air-breathing Propulsion Subcommittee, JANNAF Conference, Destin, FL, April 8-12, 2002.

Povinelli, Louis A. and Yungster, Shaye, "Thermodynamic Cycle and CFD Analyses for Hydrogen Fueled Air-Breathing Pulse Detonation Engines", NASA TM/-2002-211698, June 2002, also AIAA Paper 2002-3629, 38th AIAA/ASME/SAE/ASEE Joint Propulsion Conference, Indianapolis, Indiana, July 7-10, 2002.

Povinelli, Louis A., "Pulse Detonation Engines for High Speed Flight", Paper 17_5169, 11th International Conference of the AIAA/AAAF Hypersonics Conference, Orleans, France, Sept 29-Oct. $, 2002. Also NASA/TM-2002-211908, Sept. 2002.

Povinelli, Louis. A. and Yungster, Shaye, “Real Gas Effects on the Performance of Hydrocarbon-Fueled Pulse Detonation Engines”, AIAA Paper 2003-0712, 41st Aerospace Sciences Mtg & Exhibit, 6-9 January 2003, Reno, NV.

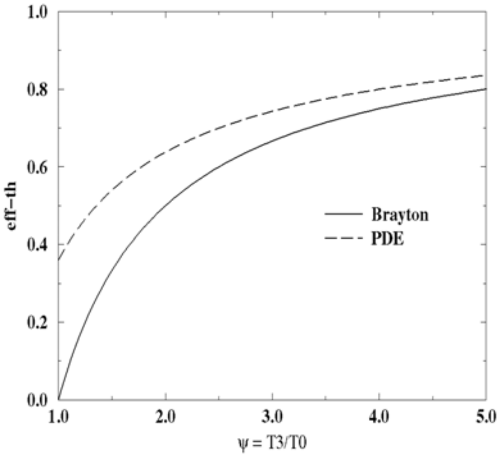

Fig. 1 Thermal efficiency for unequal values of heat release (12% difference), stoichiometric propane-air.

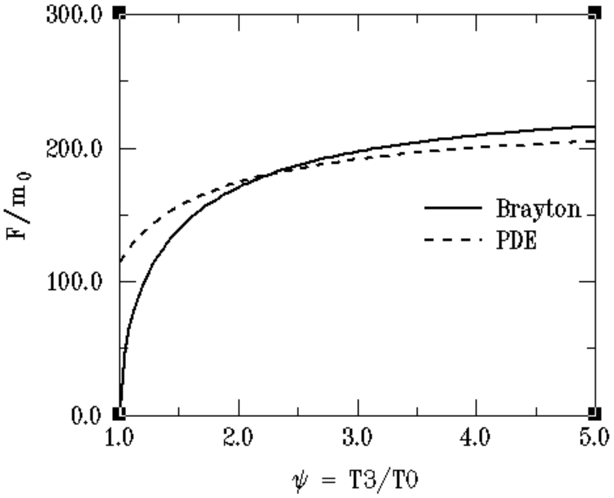

Fig 3 Specific thrust for the PDE and Brayton Cycles, stoichiometric Propane-air.

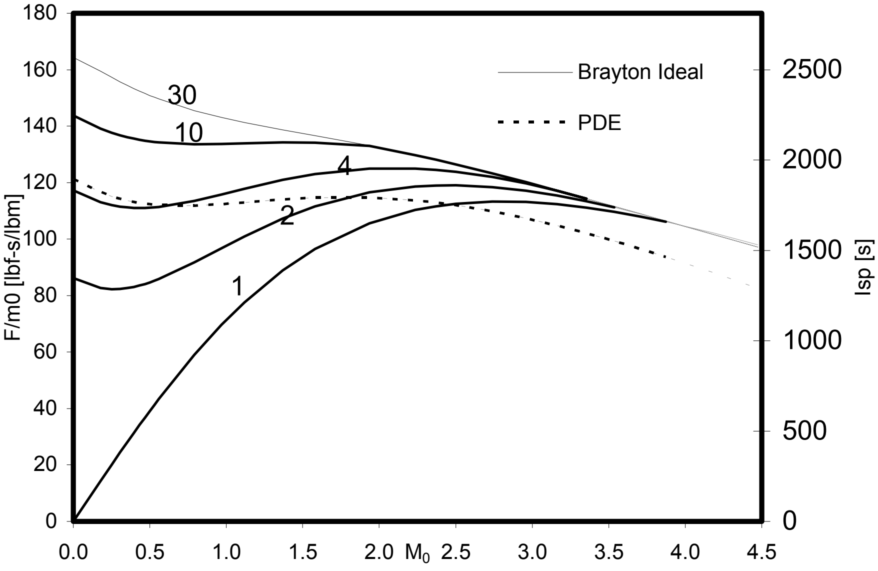

Fig. 2 Specific thrust versus Mach number for Brayton and PDE cycles, stoichiometric propane-air, numbers on plot represent the Brayton mechanical compression ratio.

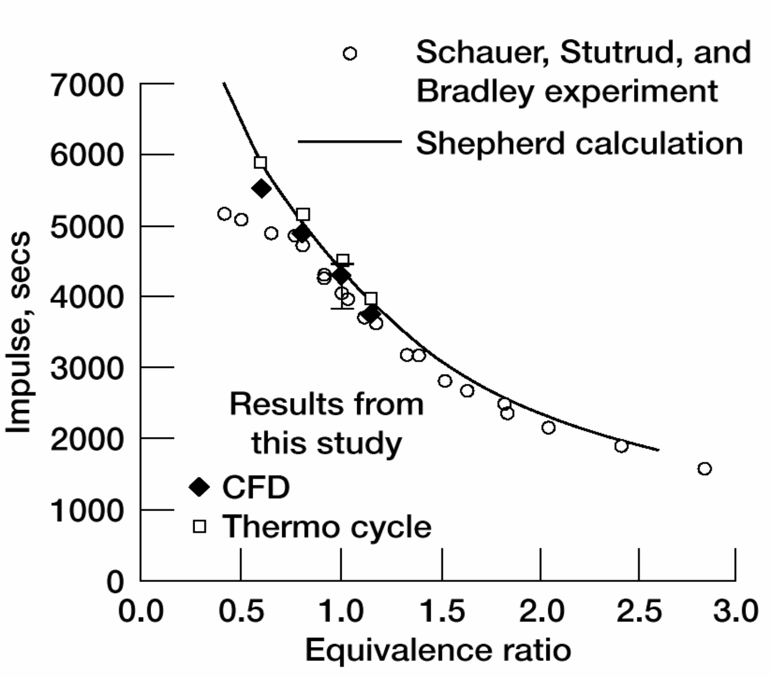

Fig. 4 Comparison of analyses with Wright Labs data, hydrogen-air.

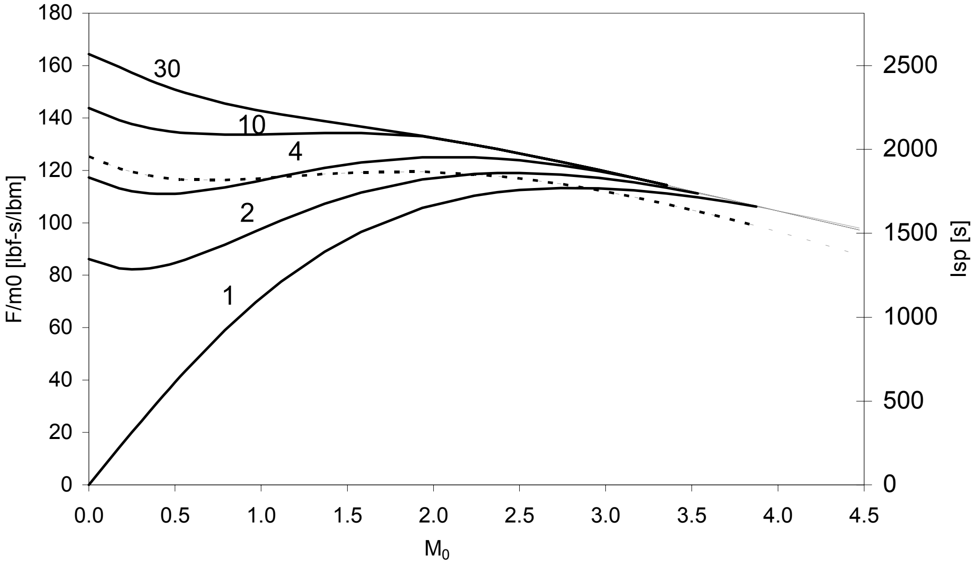

Fig. 5. Specific thrust versus Mach number including real gas effects, stoichiometric propane-air.