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COMPARISON OF COMBUSTION EFFICIENCIES FOR RAMJET ENGINES

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The temperature T_{5tot} determined according to equation (5) may be used as estimated value for iteration. This temperature then must be increased in stages until the value of c* determined by caluclation coincides with the one obtained experimentally from the combustion chamber pressure.

If a temperature T_{5tot} is to be deduced from the efficiency η_{λ} or an approximation of the degree of efficiency must be obtained, then a similar consideration as for η_{c*} may be used successfully.

4. Evaluation

The comparative data are obtained assuming ideal conditions for combustion and flow, that is, complete reaction until chemical equilibrium on the basis of the overall mixing ratio on one hand, and single dimensional, isentropic flow on the other. These conditions are naturally not implemented in an engine. But the comparison conducted does not suffer, inasmuch as deviations from the ideal conditions would be considered similarly for all efficiencies. The initial quantities for obtaining the efficiency were specifically the same temperatures T_{5tot} and $T_{5tot,id}$ in all cases.

Strictly speaking, the comparison applies only for the system PE/air. But it can be transferred also to other systems (at least qualitatively). For actual or comparative hydrocarbons, whose combustion gives rise to similar composition of waste gases (for example, kerosene), the condition cannot be much different even under the quantitative aspect.

Naturally, in case of higher deviations, as occur, for example, in cases of considerable formation of soot, or in particular, for other particle fractions, special considerations are needed under certain circumstances.

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COMPARISON OF COMBUSTION EFFICIENCIES FOR RAMJET ENGINES

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1. Principles of Comparison /129*

To evaluate the combustion in ramjet engines, different combustion efficiencies are used. Each of these efficiencies has its specific advantages and drawbacks. Until a standardization of the method of determination of one or several efficiencies is achieved, a comparison of the commonly used methods would be of interest to the experimenter.

Under the aspects of the Joule process generally used for evaluation, the initial temperature for combustion and the maximum process temperature achieved are particularly important. That is why a definition of the efficiency to the increase in temperature of air obtained in the combustion

$$\eta_c = (T_{5\,tot} - T_{2\,tot})/(T_{5\,tot,id} - T_{2\,tot}) \quad (1)$$

is reasonable. In the USA already years ago, a suitable recommendation for standardization was issued [1]. It also established the corresponding measurement cross section (Index 2: combustion temperature input, Index 5: acoustic cross section of the expansion nozzle), as shown schematically in Fig. 1.

This efficiency will now be taken as reference for other commonly used ones. The comparison is based on the following considerations:

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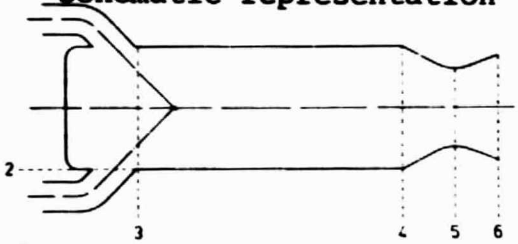
*Numbers in the margin indicate pagination in the foreign text.

The method proposed in the USA for determining the efficiency starts from the measurements of the thrust with a purely converging nozzle and obtains by iterative calculation of the equilibrium, assuming monodimensional, isentropic flow, a temperature T_{5tot} corresponding to the measured momentum and pressure. The method assumes therefore, the reliability of calculation of equilibrium. The other efficiencies used for comparison are treated by the same principle. This allows subsequent comparison. /130

Ramjet combustion chamber in schematic representation



Characteristic cross sections

Figure 1. Definitions of cross section according to [1].

2. Combustion Efficiencies Considered

For the three efficiencies taken for comparison, the equations of definition will now be given:

a) efficiency of the characteristic velocity

$$\eta_{c^*} = c^*/c^*_{id}, \quad (2)$$

b) efficiency of the difference in temperatures η_c' obtained from η_{c^*} by simple conversion

$$\eta_c' = (\eta^2_{c^*} \cdot T_{5tot,id} - T_{2tot})/(T_{5tot,id} - T_{2tot}) \quad (3)$$

and finally

c) efficiency of the mixing ratio

$$\eta_\lambda = (O/F)/[O/F(c^*)]. \quad (4)$$

The determination of the above mentioned efficiency will be discussed further in somewhat greater detail.

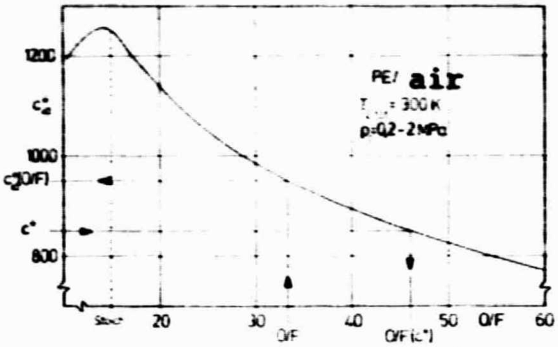


Figure 2. Variation of the characteristic velocity to determine the efficiency η_λ.

The determination of the temperature T_{5tot} from $T_{5tot,id}$ according to

$$T_{5tot} = \eta_\lambda^{2} \cdot T_{5tot,id} \tag{5}$$

assumes a uniform composition and properties of the waste gases. On the other hand, the determination of η_λ also assumes the knowledge of the total range of the variation of c* corresponding to complete conversion as a function of the mixing ratio. A mixing ratio O/F obtained from the characteristic speed calculated by measurement of pressure

$$c^* = p_c A_t / \dot{m} \tag{6}$$

is compared with the mixing ration O/F(c*) obtained by measuring the fuel flows (Fig. 2).

At a sufficient distance from stoichiometric operation, the determination of the efficiency η_λ represents basically an expansion as compared with the efficiency η_{c*}.

3. Comparison of Efficiency

All efficiencies are determined assuming known temperature T_{5tot} by calculation of equilibrium [2]. They are obtained for the pair of fuels polyethylene(PE)/air for different inflow temperatures (T_{2tot}=300/500/700/900K) and are represented in twelve diagrams, each time as a function of the mixing ratio in the form of the equivalency ratio $\Phi = (F/O)/(F/O)_{stoich}$ in an η_c ordinate division.

The comparative representation is given in Figures 3 to 5.

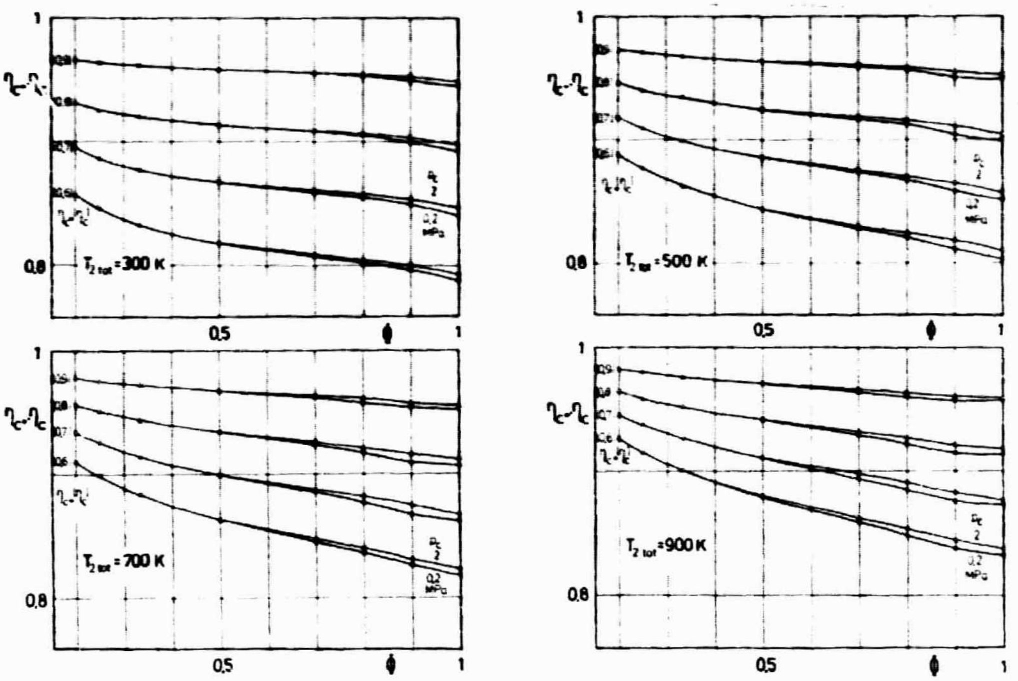


Figure 3. Comparison of η_{c*} with η_c as reference.

This somewhat unusual form of representation is purposely chosen, to allow a quantitative comparison at a first glance. In the selected lattice networks, the efficiencies considered each time η_{c*}, η_c' and η_λ are plotted each time with the corresponding reference efficiency η_c as parameter. For example, they have to compare with each other (Figure 3) $\eta_{c*}(0.6)$ and η_c=0.6. For an arrival temperature T_{2tot}=700K and an equivalency ratio Φ=0.5, we read in the diagram $\eta_{c*}(0.6)$=0.864. In other words: if taking as basis a certain temperature T_{2tot} (and a certain pressure) for the system PE/air, we determine η_c=0.6, for the corresponding temperature T_{5tot}, on the other hand, we would determine for the corresponding temperature T_{5tot} an η_{c*}=0.863 and accordingly an η_c'=0.585 (Figure 4) and η_λ=0.566 (Figure 5).

The diagrams show that the comparable values of the different efficiencies differ greatly from each other under certain

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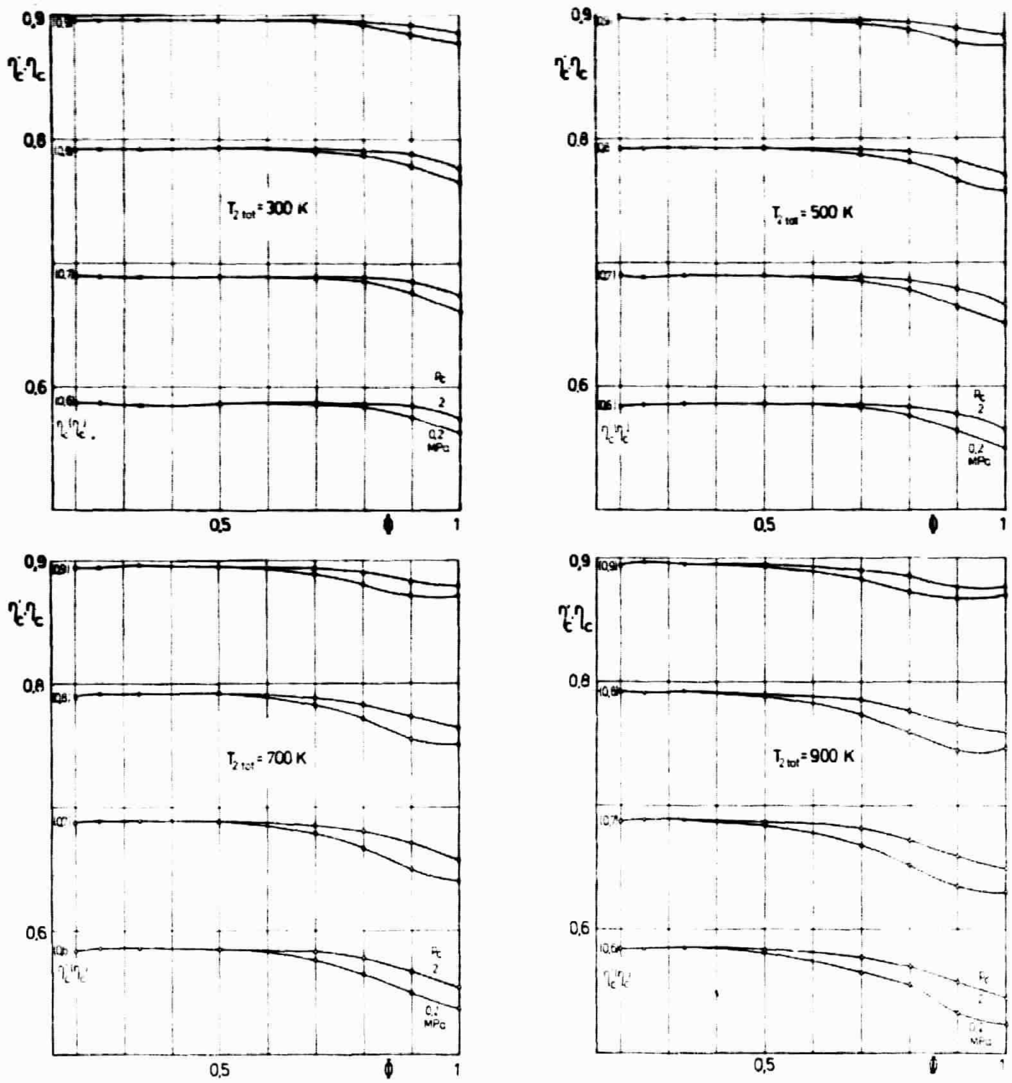

Figure 4. Comparison of η_c' with η_c as reference.

circumstances. In particular, the incompatability of the efficiency /130 η_{c*} based on the characteristic velocity is obvious. The simple correction η_c' according to equation (5) leads, however, already to relatively good results in combustion with high excess of air. But in air breathing drives, in spite of the great attraction of maximum pulse operation with high excess of air, in general because of the thrust density, an operation under stoichiometric combustion is inevitable up to double the proportion of air. In this region,

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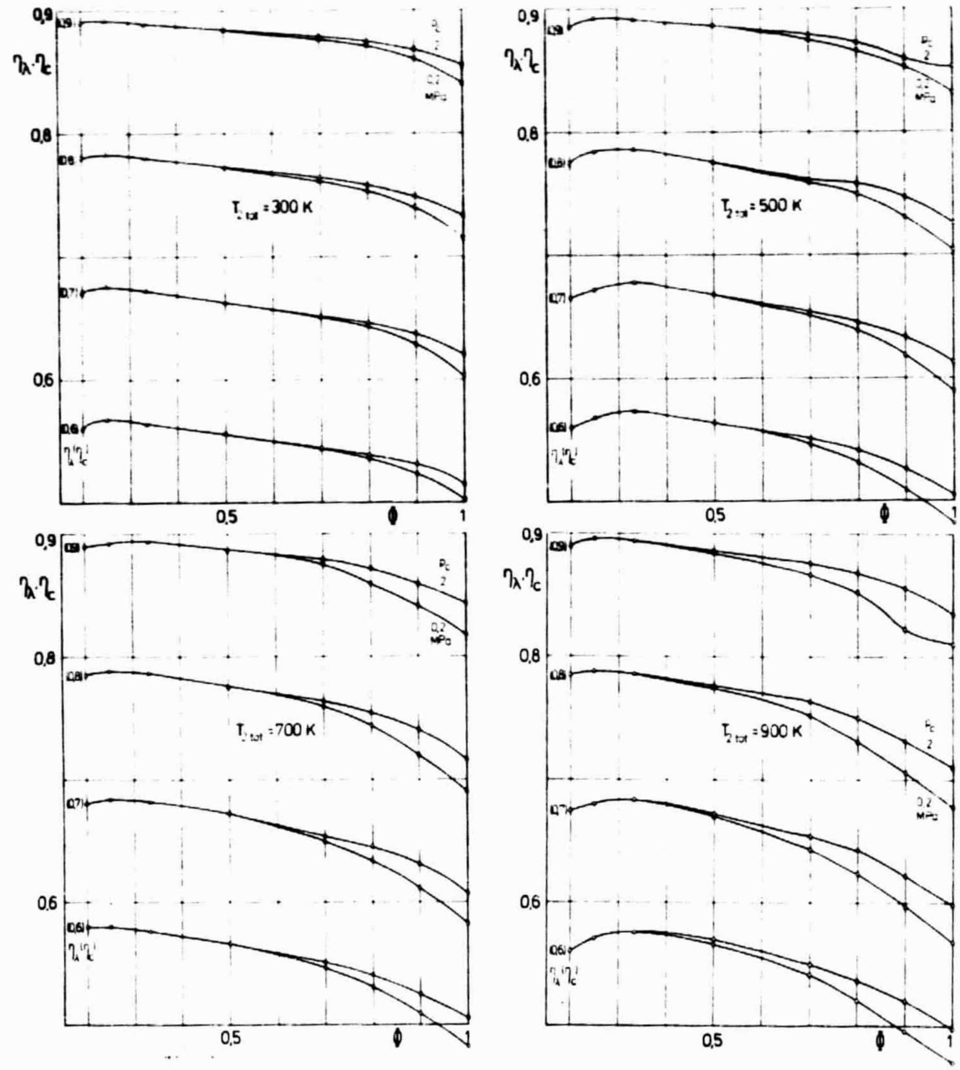

Figure 5. Comparison of η_λ with η_c as reference.

the simple conversion is inadequate. In this case it is recommended, whenever possible, to measure the thrust, to carry out /130 an iterative correction of the composition and properties of the waste gases by means of repeated calculation of equilibrium up to the desired precision. /132 For this iteration, a method similar to the one used to determine the thrust according to [1] may be used in which, instead of specific momentum, the characteristic velocity c* obtained experimentally from the combustion chamber pressure is used according to equation (6).

The temperature T_{5tot} determined according to equation (5) may be used as estimated value for iteration. This temperature then must be increased in stages until the value of c* determined by caluclation coincides with the one obtained experimentally from the combustion chamber pressure.

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