DOI: 10.13009/EUCASS2017-454

COMPUTATIONAL RESEARCH OF OPERATION PROCESS IN THE COMBUSTION CHAMBER OF HEXAFLY-INT MODEL IN WIDE RANGE OF FREE STREAM CONDITIONS AND EQUIVALENCE RATIOS

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Present work represents results of numerical modeling of hydrogen combustion in combustion chamber of HEXAFLY-INT vehicle. Research of the flow at different free stream conditions was carried out. The effect of different fuel supply strategies to efficiency of combustion processes in combustor was carried out.

Nomenclature

Mach = free steam Mach number
p = static pressure
V = velocity
T = static temperature
ER = equivalence ratio
α = angle of attack
H = flight altitude
η = combustion efficiency

Introduction

In HEXAFLY project the scaled model of hydrogen high-speed civil aircraft with cruise Mach number M = 7,5 was proposed [1-2]. The concept of this model was the basis for HEXAFLY-INT project [3]. External view of the vehicle is shown on fig. 1. CIAM participates in the project in preparation, conducting and analysis of facility module ground tests [4-5].

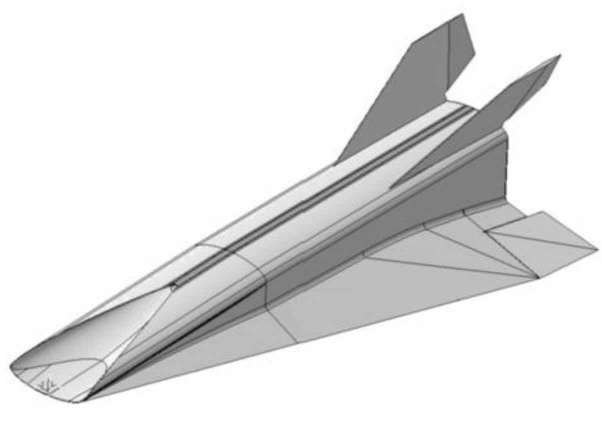

Fig. 1. External view of HEXAFLY-INT vehicle

I. Description of the numerical method

Calculated area was consisted of air intake, combustion chamber and nozzle. In this formulation the problem of choosing of the boundary conditions at the entrance to the

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combustion chamber disappears. Boundary conditions are automatically obtained from the flow calculation in the air intake. The calculation was carried out using a three-dimensional block-structured grid. The calculated area is shown in Fig. 2. The numerical simulation was carried out in computational program FNAS3D [6] developed in CIAM. This program is based on a modified version of Godunov's scheme [7]. The complete Favre averaged Navier-Stokes system of equations for unsteady turbulent flows of a reacting gas is used. A one-parameter turbulence model [8] is used for a closure of system of equations. To describe the combustion of a hydrogen-air mixture the detailed kinetic mechanism of Dimitrov is used [9].

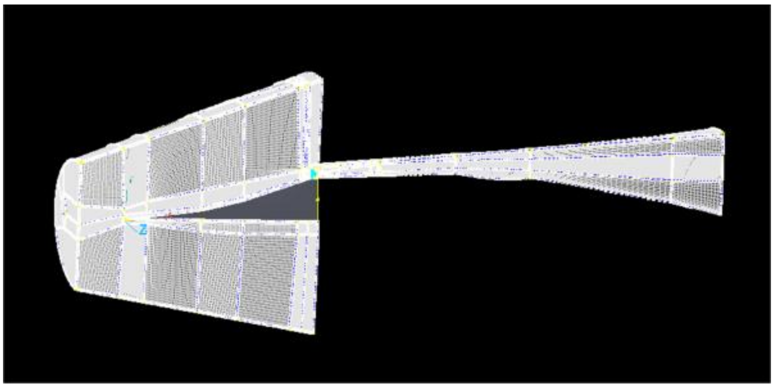

Fig. 2. Calculated area

To evaluate quality of process in the combustion chamber the combustion efficiency coefficient η was used. It should be noted that there are several ways to define it [10]. In the first one η is defined as the ratio of the released heat (result of chemical reactions) to the fuel calorific power. The advantage of this method is that it takes into account the chemical transformations occurring in a multicomponent mixture. In the second method based on molecular hydrogen decreasing it can't be concluded that it will react with the heat release and make a positive contribution to the thrust of the engine. Therefore, in the presence of a detailed kinetic mechanism one should give preference to the first method of combustion efficiency determining. The order of calculation was the same for all variants. First the flow without fuel supply was calculated. After that the pressure in the fuel supply system was defined providing the necessary value of the ER. Further the supply of hydrogen with the specified parameters was activated and steady solution was found.

II. Task formulation

In the study the free stream parameters corresponds to the two trajectory points presented in Table 1. These parameters are presented in Table 1. In order to take into account the different paths along the trajectory, calculations at each altitude were made at different angles of attack. The angles -2 °, 0 °, 2 ° and 6 ° were considered. In addition during the study the ER was changed (ER = 1, ER = 0.8, ER = 1.2).

H (km)	V (m/s)	T (K)	p (Pa)	Mach
36	2325,39	239,13	502,25	7,50
27.8	2102,05	224,38	1651,94	7,00

Table 1. Free stream parameters

III. Results

In Fig. 3 and 4 the fields of temperature and Mach number are shown in the plane of symmetry for the variant M = 7.5, α = -2 °, ER = 1. This picture is typical in the considered limits of the Mach number (7 - 7,5). The general character of the flow is supersonic. One can

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note a tendency to gas temperature decrease as the angle of attack increases and the flight Mach number increases. This process is due to the fact that the air mass-flow rate decreases which leads to a lower hydrogen mass-flow rate and a decreasing of the total heat release in the combustion chamber. In Fig. 5 and 6 the flow parameters fields in perpendicular to the plane of symmetry sections are shown. Under these flight conditions the influence of the separation zones is insignificant. Subsonic zones are observed only in the the main fuel strut area. In the main core of the stream the velocity greatly exceeds the speed of sound.

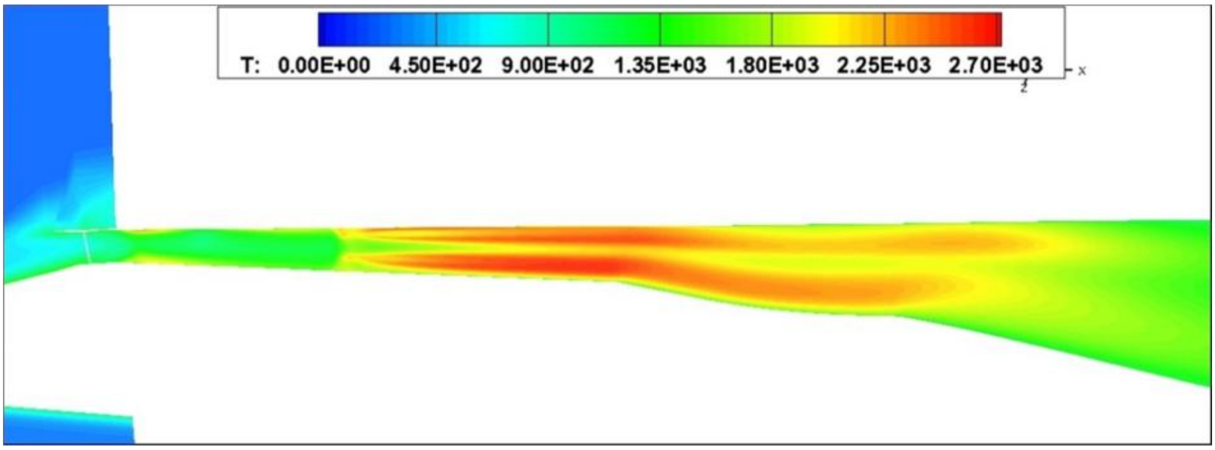

Fig 3. Temperature field in the symmetry plane (M=7.5 , α= -2°, ER=1)

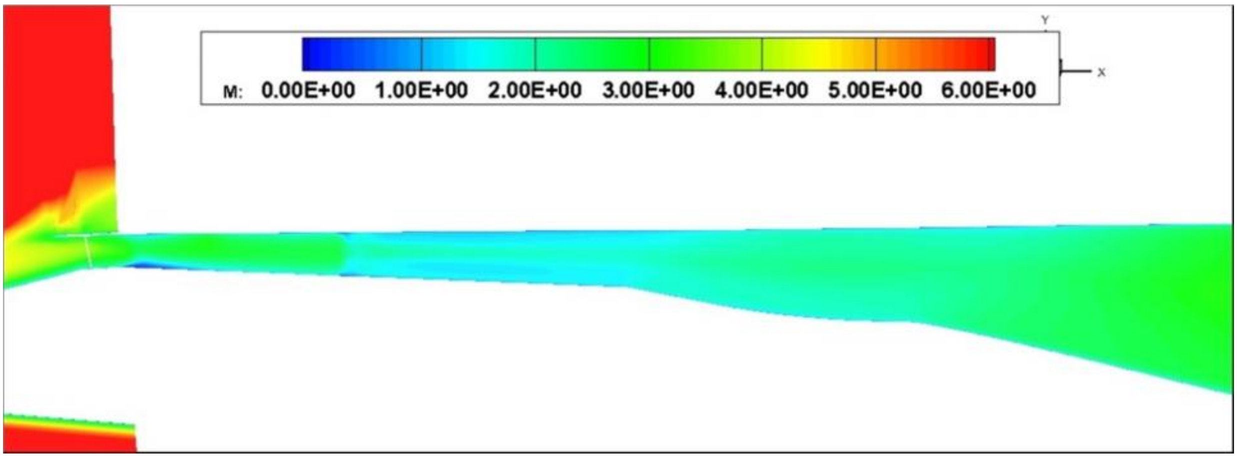

Fig 4. Mach number field in the symmetry plane (M=7,5 , α=-2°, ER=1)

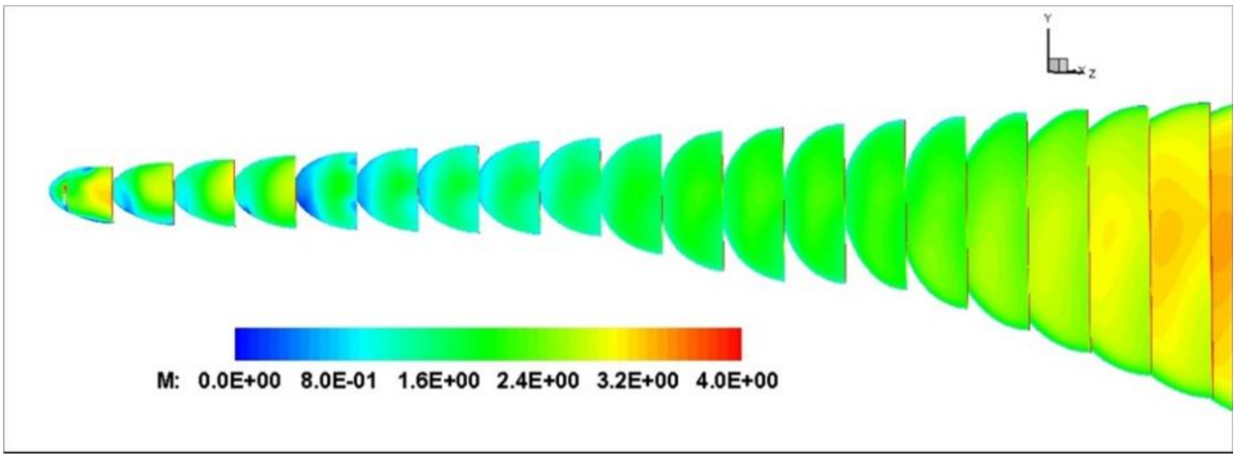

Fig 5. Mach number fields in cross-sections (M=7,5 , α=-2°, ER=1)

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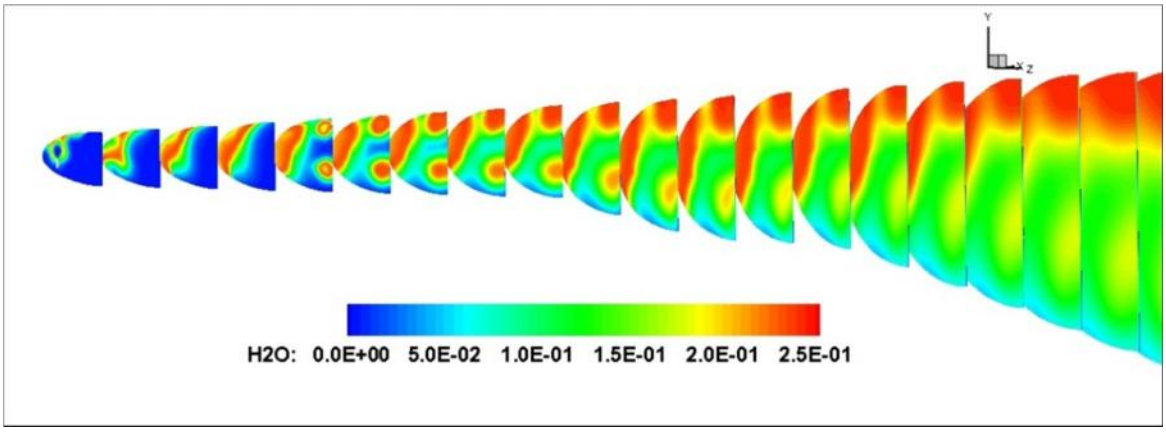

Fig.6. H_2O mass concentration fields in cross-sections

Figure 7 represents the distribution of average value of Mach number along the combustion chamber for two variants: M=7,5 , α=-2°, ER=1 и M=7, α=-2°, ER=1. For main part of combustor Mach number is lays in the limits of 1,5 … 2,3. And even in the main strut area Mach number is still higher than 1.

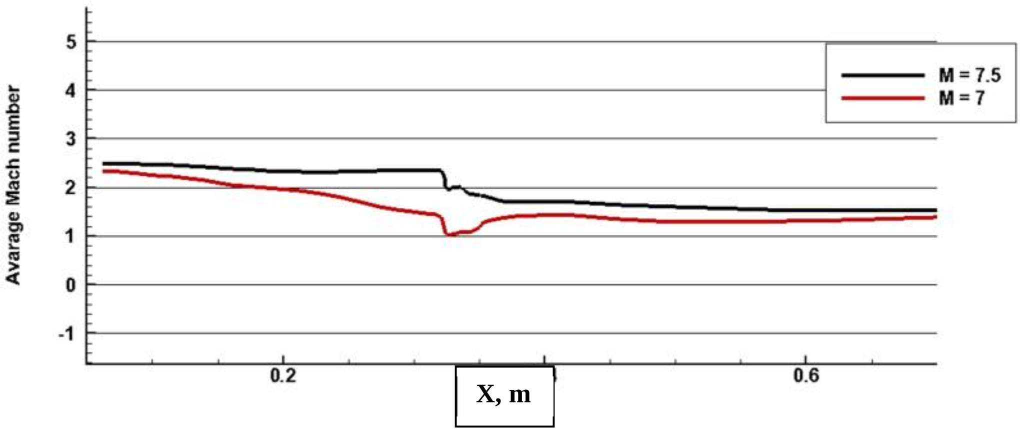

Fig. 7. Average Mach number along the combustor

The distribution of the combustion efficiency along the length of the combustion chamber for different ER values is shown in Fig. 8. In this case the combustion efficiency was calculated in relation to the actual fuel supplied to the flow in the considered section. Because of this way of determining a leap is observed on the graph it corresponds to the location of the main fuel supply strut. Combustion efficiency values for all cases are presented in Table. 2.

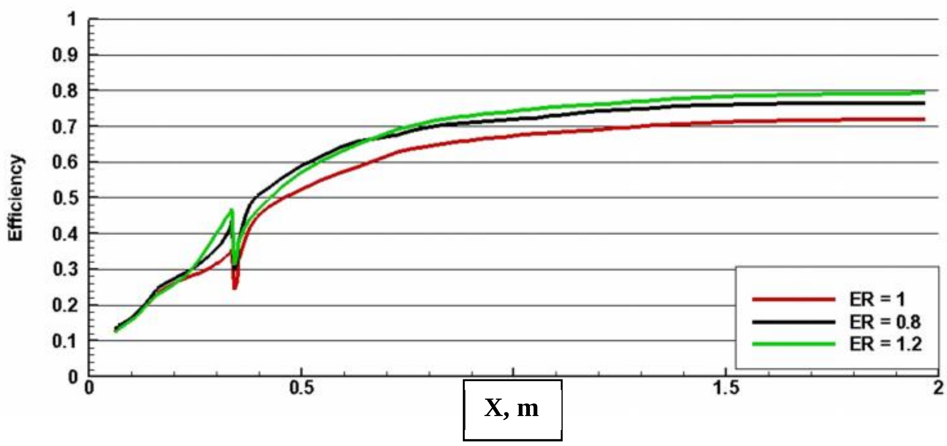

Fig. 8. Combustion efficiency along the combustor (M=7,5 ; α=0°)

Mach	α	ER	η
7.5	-2	0,8	0.81
7.5	-2	1	0.71
7.5	-2	1.2	0.66
7.5	0	0,8	0.76
7.5	0	1	0.72
7.5	0	1,2	0.79
7.5	2	1	0.67
7.5	6	0,8	0.81
7.5	6	1	0.68
7.5	6	1,2	0.66
7	-2	0,8	0.78
7	-2	1	0.81
7	0	0,8	0.86
7	0	1	0.70
7	0	1,2	0.83
7	2	0,8	0.79
7	2	1	0.74
7	2	1.2	0.73
7	6	0.8	0.81
7	6	1	0.71
7	6	1.2	0.72

Table 2. Combustion efficiency

Despite the rather scattered results it is possible to note that higher values of the combustion efficiency are observed at M = 7, which is due to lower velocities in the combustion chamber. In all the modes considered, the combustion efficiency lies in the range 0.65-0.8, which is a rather high values for supersonic combustion. For a variant with Mach number M = 7.5, α =-2 °, ER = 1, a comparison with experiment was made. In Fig. 9 pressure distributions along the side wall of the combustor obtained in the experiment and as a result of numerical simulation are shown.

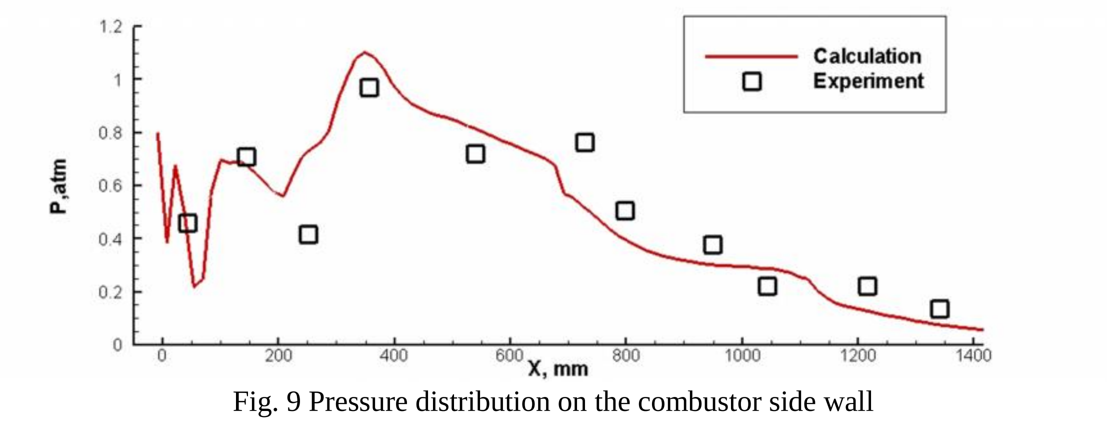

Fig. 9 Pressure distribution on the combustor side wall

IV. Conclusion

A large series of calculations of flow in the flowpath of the HEXAFLY-INT model was carried out. With the free stream Mach number 7; 7.5 stable supersonic flow with combustion is realized. The combustion efficiency for these options lies in the range 0,65 - 0,8. The calculated pressure distributions are compared with the results of the experiment, a satisfactory agreement is shown.

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Acknowledgments

This work was performed within the 'High Speed Experimental Fly Vehicles - International' project fostering International Cooperation on Civil High-Speed Air Transport Research. HEXAFLY-INT, coordinated by ESA-ESTEC, is supported by the EU within the 7th Framework Programme Theme 7 Transport, Contract no.: ACP3-GA-2014-620327 with additional support of the Ministry of Trade and Industry RF. Further info on HEXAFLY-INT can be found on http://www.esa.int/techresources/hexafly_int.

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