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NUMERICAL AND EXPERIMENTAL INVESTIGATION OF DIFFERENT INTAKE CONFIGURATIONS OF HEXAFLY-INT FACILITY MODULE

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Abstract

The results of computational and experimental study of the air intake characteristics of HEXAFLY-INT high-speed civil aircraft facility module carried out by CIAM in the international cooperative project HEXAFLY-INT of 7th Framework Programme are shown in the paper.

1. Task formulation

In HEXAFLY project a scale model of hypersonic civil aircraft with flight Mach number M = 7,5 was proposed [1-4]. The concept of this model was the basis for HEXAFLY-INT project. Central Institute of Aviation Motors (CIAM) is involved in the project in terms of preparation, conduct and analysis of the facility module ground tests. Ground tests are carried out with the simulation of high-altitude conditions, the total pressure and the total temperature of the incoming flow corresponds to these parameters in flight. The HEXAFLY-INT project provides several series of tests of varying duration. The main purpose of the first series of tests was to demonstrate the positive aeropropulsive balance (excess of thrust over the aerodynamic drag).

In the model proposed by the ESA-ESTEC, flow compression is carried out in a complex three-dimensional top-mounted intake with an isentropic compression surface (Fig. 1). Theoretically, such intake is optimal because in this case the total pressure losses are minimized. The proposed intake has been developed based on the calculation performed with the solution of the Euler equations. Accounting of viscous forces solving Navier-Stokes equations showed the presence of losses in the shockwaves coming from the side compression surfaces that has an impact on the flow structure and integral parameters in the throat [5]. Making such intake requires a lot of time and financial costs, as the intake must be machined from a single piece of material.

For the first phase of testing it was proposed to develop the intake having greater manufacturability, but at the same time providing the same integral parameters in the intake throat and similar flow structure. For this 3-shockwave intake was proposed (fig.1)

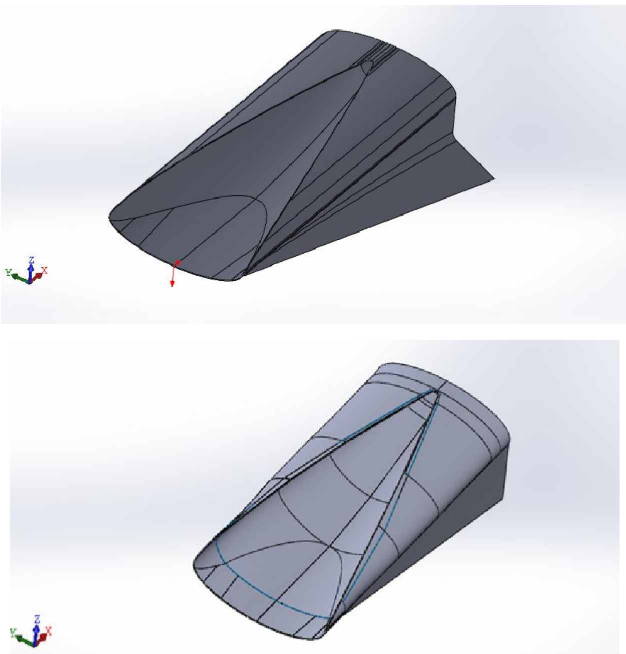


Fig. 1. The intake (top – HEXAFLY intake, bottom – technological intake)

2. Numerical simulation of flow in the technological intake and comparison of integral parameters in the throat of two intake modifications

For the technological intake numerical simulation at the same parameters of the incoming flow as in the case of the original intake was carried out. Mach number of the incoming flow is 7,4. The calculations were carried out in 3D formulation. Favre averaged Navier - Stockes equations supplemented by Spalart-Allmaras turbulence model were solved.

In a series of calculations angles of attack and sideslip angles were varied, estimated angles of attack are α = 0, 2, -2; sideslip angles - γ = 0, 2, 4. Fig. 2 shows the Mach number field in the plane of symmetry. Similar flow structure is observed.

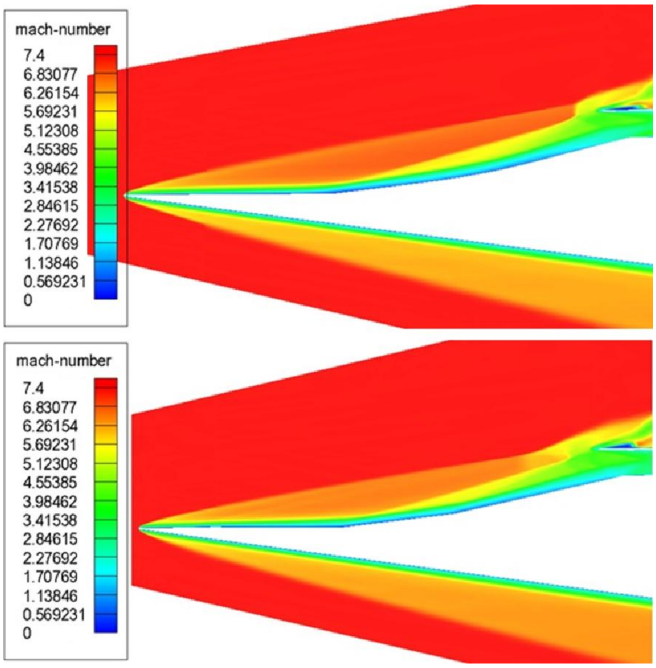


Fig. 2. Mach number field in the plane of symmetry (top – HEXAFLY intake, bottom – technological intake)

Tables 1-3 show the integral parameters in the intake throat. According to the data given in the tables it is seen that the differences in integral parameters in intake throat is within 10% for all calculated cases. Considering the same flow structure, it can be concluded that technological intake can be used in facility module composition for free jet tests while similar to the original intake flow parameters in the combustion chamber inlet are provided.

Tab.1. Mass-flow rate through the model

Model	α =0			α =-2	α =2
	γ =0	γ =2	γ =4	γ =0	γ =0
Original	1,528	1,531	1,529	1,842	1,207
Technological	1,51	1,507	1,497	1,790	1,212
Difference (%)	1.178	1.568	2.093	2.823	0.414

Tab.2. Area-averaged Mach number in the throat

Model	α =0			α =-2	α =2
	γ =0	γ =2	γ =4	γ =0	γ =0
Original	3,00	3,01	2,97	3,01	2,99
Technological	3,29	3,23	3,15	3,18	3,34
Difference (%)	9.667	7.309	6.061	5.648	8.361

Tab.3. Area-averaged static pressure in the throat

Model	α=0			α =-2	α =2
	γ =0	γ =2	γ =4	γ =0	γ =0
Original	47078	46514	48154	56327	37016
Technological	43180	43218	44695	52336	34800
Difference (%)	8.28	7.086	7.183	7.085	5.987

3. Numerical study of technological intake start in flight conditions

Numerical study of technological intake start with flight Mach numbers M = 5…7,5 was the next step. Boundary conditions were chosen for flight altitude H = 35957 m. Angles of attack were varying from 0 to -6. The intake start was determined by the absence of separation which bypasses air and stalls flow in intake. Otherwise, it was considered that the intake is not started. The intake start was simulated by the gradual decrease of Mach number in the inlet of calculated area. Flow parameters in intake throat were determined. Calculations were carried out by means of Favre averaged Navier - Stockes 3D equations with the use of software package developed in CIAM. Flight regimes corresponding to started and unstarted intake were determined.

In figures 3 and 4 Mach number fields in symmetry plane and perpendicular to the throat plane for started and unstarted intake cases are shown.

In table 4 flow parameters in intake throat for different Mach numbers and angles of attack are listed.

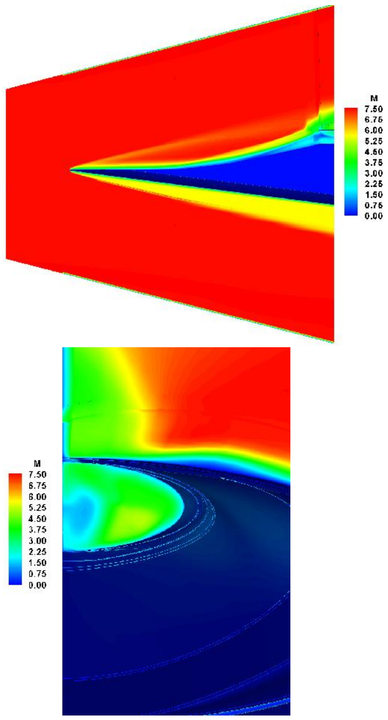


Fig.3 Mach number fields for M_∞=7.5, angle of attack AoA = -2

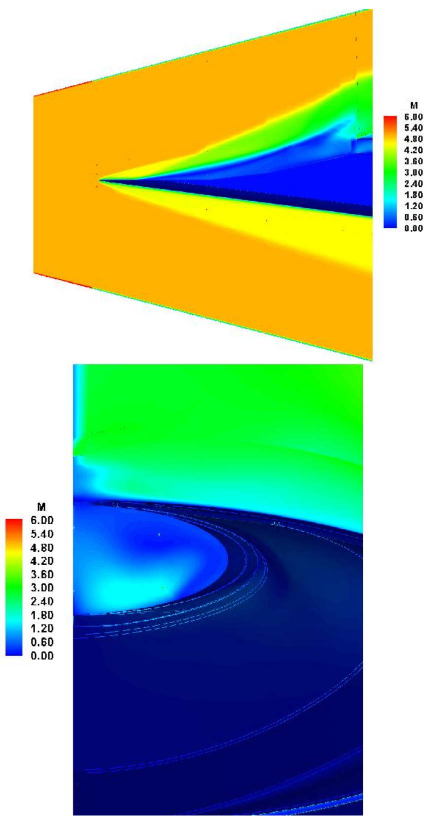


Fig.4 Mach number fields for M_∞=5, angle of attack AoA = -2

Tab. 4. Parameters in the intake throat

α	M∞	M_{th}	σ	G	I
-2	5	3.038	0.1091	0.297	621.3
	6	2.266	0.188	0.317	502.6
	7.5	2.937	0.3506	0.748	1557.6
0	5	2.033	0.1791	0.146	194.5
	6	2.473	0.3120	0.434	705.3
	7.5	2.950	0.2117	0.625	1302.4
2	5	2.096	0.2287	0.175	235.8
	6	2.501	0.2636	0.357	506.8
	7.5	2.941	0.1669	0.498	1036.0
6	5	2.245	0.2860	0.192	262.0
	6	2.635	0.1964	0.235	390.2
	7.5	3.038	0.1091	0.297	621.3

Here α – angle of attack, M∞ - Mach number of incoming flow, M_{th} - averaged Mach number in the throat, σ – total pressure recovery coefficient, G – air mass-flow rate in throat, I – the longitudinal component of momentum in the throat.

4. Numerical study of technological intake start in facility conditions

On the base of 3D computational model received from ESA large-scale facility module was designed and manufactured for high-altitude conditions tests. The facility module is shown in figure 5. In the facility module scramjet is integrated with technological intake.

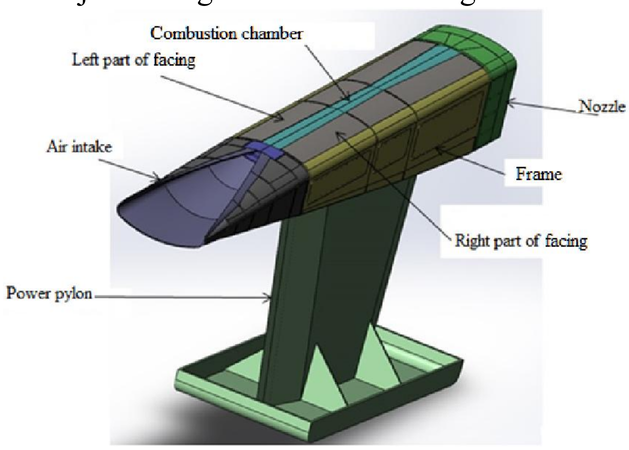
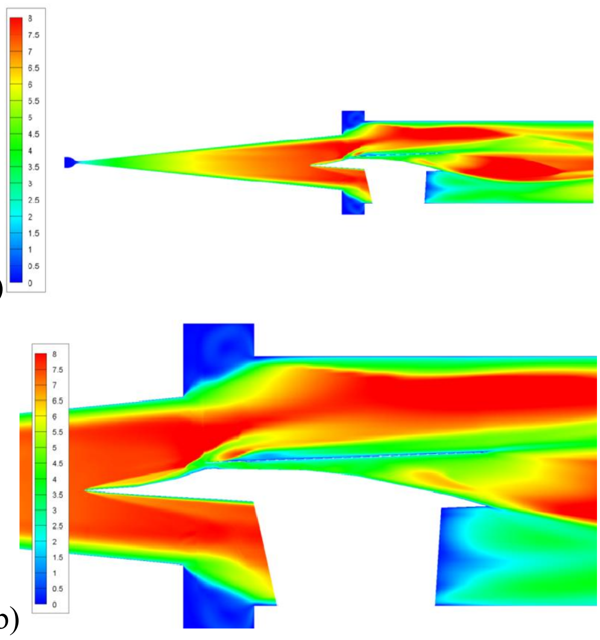


Fig. 5. Facility module assembled with power pylon

In preparation for the tests computational studies to determine facility regimes for which flight conditions will be simulated and the intake of facility module will be started were carried out. The regime test parameters were defined by means of software package developed in CIAM.

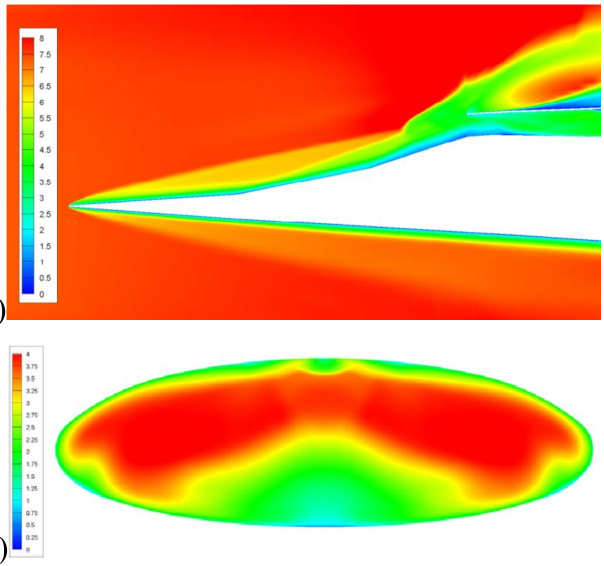
The calculations were carried out in 3D formulation. Favre averaged Navier - Stockes equations supplemented by Spalart-Allmaras turbulence model were solved. Thermal properties are variable depending on the temperature and correspond to the properties of the gas mixture entering the facility test chamber from combustion heater. Flows at the cell boundaries are calculated by the AUSM scheme. The boundary conditions for the numerical simulation were selected based on the facility conditions. On the inlet total temperature and total pressure corresponded to combustion heater parameters were set. The constant temperature was set on the walls. In calculations various wall temperatures were set. Thus its effect on the intake start was studied. In the experiment the wall temperature depends on the time elapsed since the beginning of test. During the test wall heating occurs which affects the boundary layer structure and integral parameters, in particular on the aerodynamic drag.

Fig. 6 shows flowfields for one of the calculation regimes corresponding to those upcoming flow parameters for which positive aeropropulsive balance was recorded.



a)

b)



c)

d)

FIg. 6. Mach number fields for total parameters p* = 64 bar, T*=2310 K; a) the module in the facility; b) the module in the facility (zoom); c) flowfield in the intake; d) flowfield in the throat

Conducted a three-dimensional numerical simulation of facility module flow allowed to define operating parameters of the facility in which the module intake is started. Calculated forces acting on the whole object and on the separate parts can be used to validate the computational methods on test results and to analyze the experimental data.

5. Experimental study of intake flow

The main test series was conducted with total parameters in combustion heater p* = 64 bar, T*=2310 K. 8 pressure sensors were mounted in the inner intake surface. Experimental and calculated pressure distributions are shown in Fig. 7. Numerical simulation allows to predict the overall pressure level in the intake but locally experimental data may differ from calculated values. This is due primarily to the fact that large-scale real experimental object differs from a mathematical 3D model. Thus, compression waves are moving from the side intake compression surfaces towards the center and the differences between these surfaces and theoretical one can cause the compression wave can be caught in sensors points sooner than in calculation (see. Fig. 8).

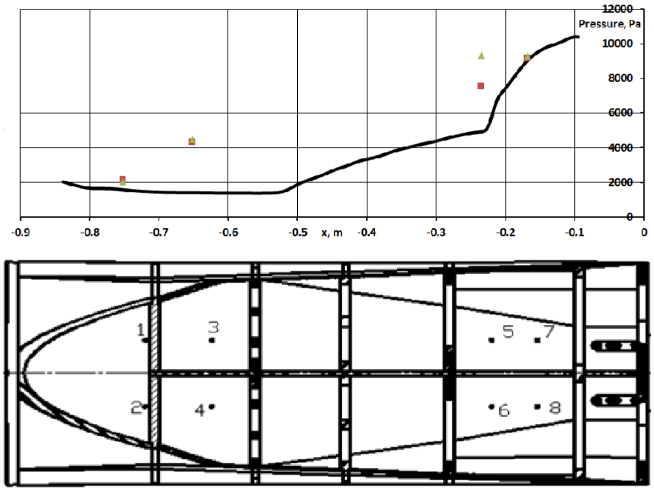


Fig. 7. Pressure distribution on the inner intake surfaces (black line – calculation distribution, red dots – left side (sensors 1,3,5,7), green dots – right side (sensors 2,4,6,8))

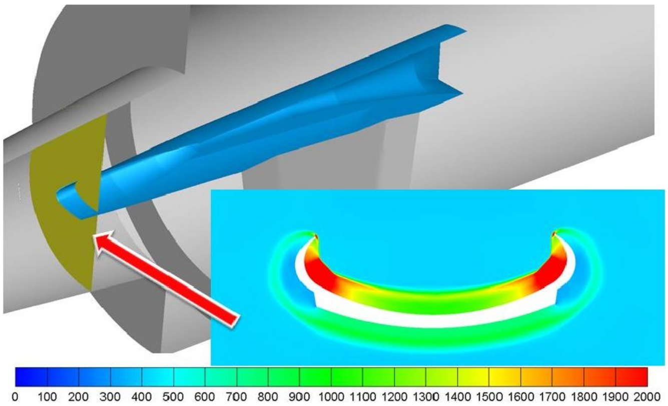


Fig. 8. Shockwaves system in the intake cross-section

It should be noted that the main purpose of the tests was to demonstrate the positive aeropropulsive balance of the facility module and detailed study of intake flow structure was not put on an experimental purpose. However the obtained results allow to conclude that used calculation methods correctly predict pressure levels in the intake.

6. Conclusions

For aeropropulsive balance tests of HEXAFLY-INT facility module technological intake with 3 compression ramps was proposed. Through numerical simulation it has been demonstrated that the proposed intake provides the same parameters at the inlet of the facility module combustor as the original intake with isentropic compression surface (the maximum difference between area-averaged pressure is less than 10%). Proposed intake was checked numerically on start in the range of Mach number M = 5 – 7,5 and in the range of angles of attack AoA = -2 – 6. Numerical simulation of facility module tests was carried out. The possibility of intake start with facility conditions was demonstrated. Tests of the facility module with the simulation of high-altitude conditions and flight Mach number M = 7,5 were conducted. The correspondence of calculated and experimental pressure distributions are shown.

Acknowldgements

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