FLOW MODELING IN A JET ENGINE

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Abstract

It is possible to monitor effects related to flow in a jet aircraft engine by the three basic approaches – analytical, numerical and experimental. Each approach has undergone changes and has been developed to the stage of its effective use. To efficiently manage the scientific and research work it is appropriate to use effective links among all three basic approaches. An experimental approach requires a test stand on which the characteristics of a usually geometrically reduced object or the actual object itself are verified. The principles of geometric and hydrodynamic similarities are applied. This approach is time and economically demanding and not all aerodynamic processes can be reliably simulated. Other disadvantages can be the occurrence of measurement errors, errors due to changes in the scale, influences of chemical reactions and influence of Reynolds number. Due to a very fast onset, development and challenges of IT, the numerical approach has become mostly used. It can provide sufficient information on an examined phenomenon in a particular object. It does not need any substantial simplifications, it is less financially demanding than the experimental approach, but it needs efficient processors with a huge memory capacity. Its disadvantage is a relatively large dependence of achieved results accuracy on the perfection of numerical models and models of turbulence in the areas with prevailing influence of viscosity. The usage of analytical relations from mathematical and physical analysis of the flow field is the fundamental of the analytical approach of observing the laws related to flowing.

The paper deals with possibilities, procedures, advantages, and disadvantages of the mentioned approaches together with a presentation of some results from research and development activities carried out by the authors.

Keywords: *jet engine, flow, experimental approach, numerical approach, analytical approach*

1. Introduction

The observation of laws and phenomena related to the flowing can be carried out by means of three basic approaches:

- experimental,
- numerical,
- analytical.

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2. Experimental approach

In the next part there is an example of experimental approach to the solution of the problem related to the increase of the aircraft engine combustion chamber life. The experimental verification of flowing was carried out by means of a test stand – Fig. 1, (block diagram and actual conditions – Fig. 2), consisting of a transparent model of part of the combustion chamber (actual size), a centrifugal blower driven by an electromotor, smoke unit, armature and measurement elements (sensors, transmitters and control units).

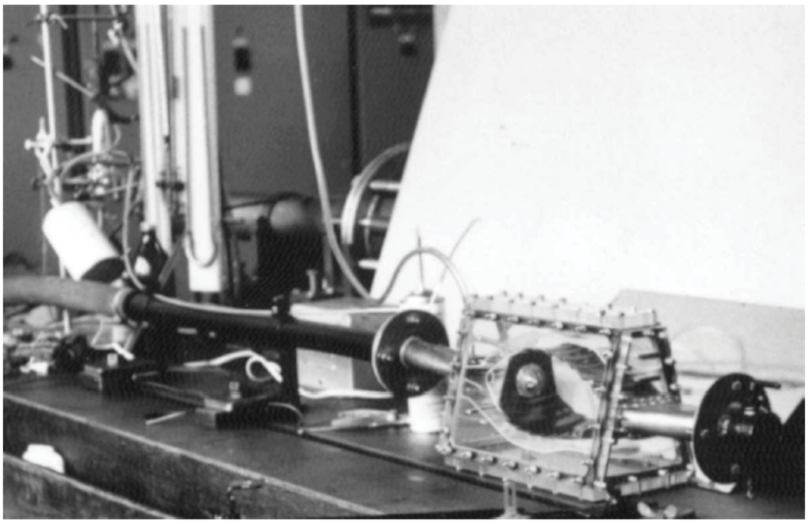

Fig. 1. Real test stand

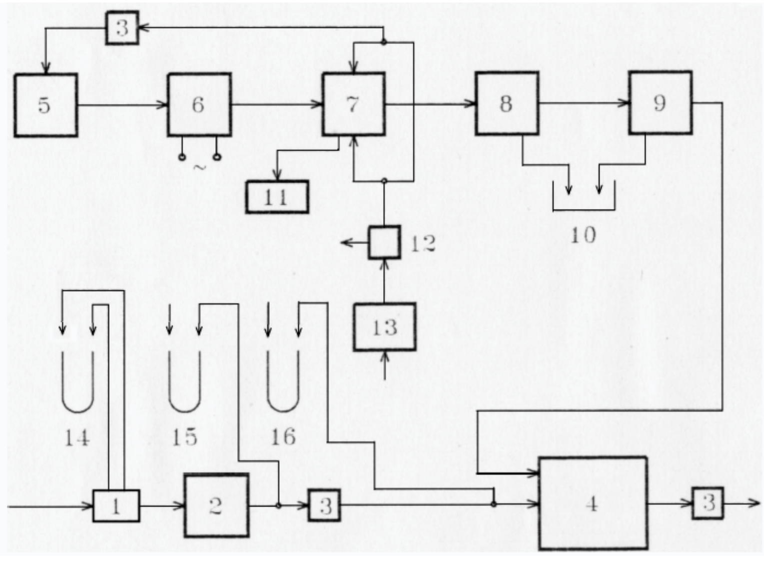

Fig. 2. Block diagram: 1 - orifice plate, 2 - blower, 3 - throttle, 4 - chamber model, 5 - oil container, 6 - smoke unit, 7 - mixing chamber, 8 - separator, 9 - centrifugal separator, 10 - condensate container, 11 - closed condensate tank, 12 - compressed air controller, 13 - compressor, 14 - U - tube to measure air, 15 - U - tube located on the blower exit, 16 -. U - tube on the chamber model entrance

The experiments [1] were carried out for different pressures and air flowing through the chamber. The flowing was observed by visualization – smoke was forced to the swirling unit – Fig. 3. The flowing of secondary air in the chamber was also observed: once the flow was visualized through the outer – Fig. 4 and then through the inner external space of the flame – Fig. 5.

For the purpose of experimental assessment of energetic situation in a small jet engine we are currently building a test stand equipped with a real engine. A total view of the whole test stand can be seen in Fig. 6 (block diagram – Fig. 7). Its detailed solution is shown in Fig. 8.

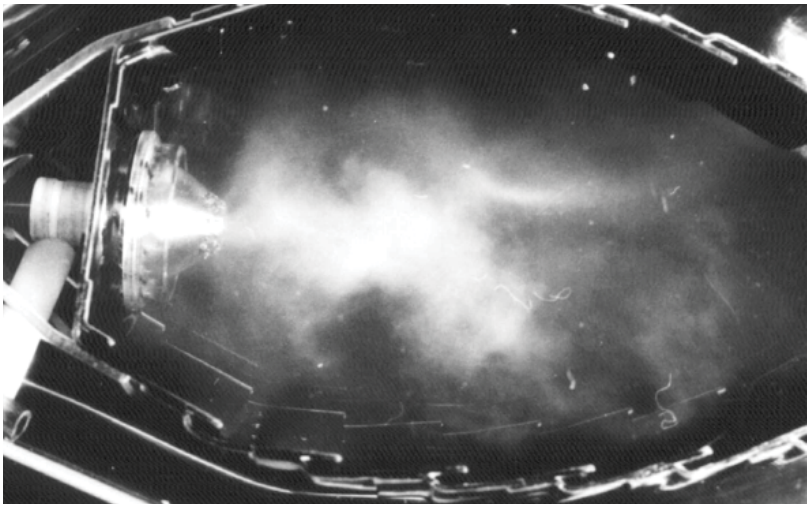

Fig. 3. Flow visualization through the whirling device

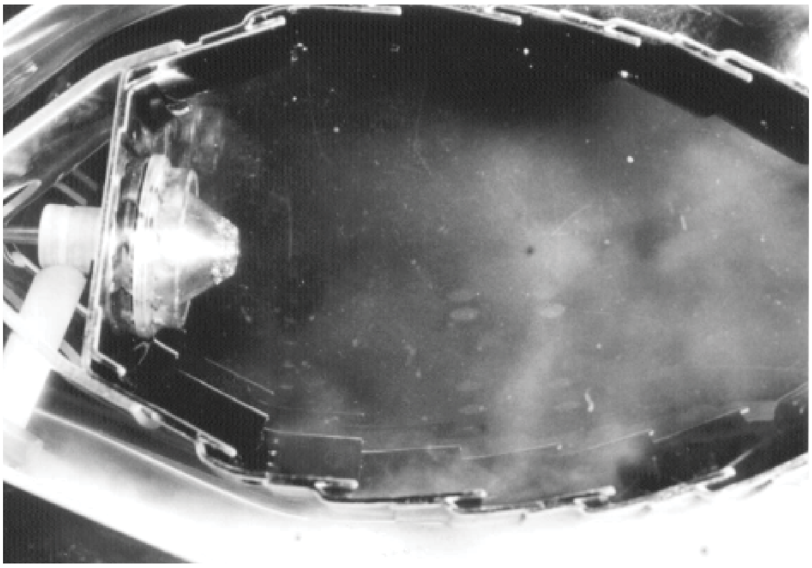

Fig. 4. Visualization of secondary air flow through outer external space of the flame

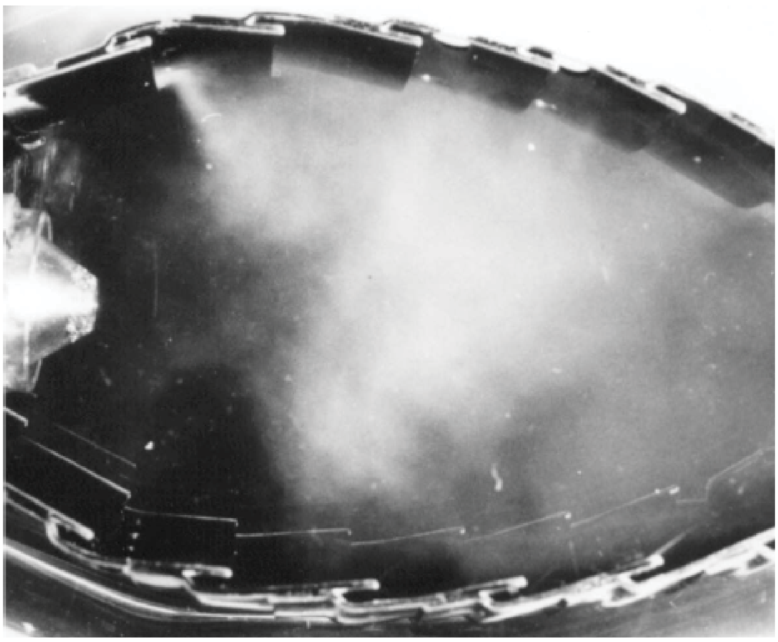

Fig. 5. Visualization of secondary air flowing through the inner external space of the flame

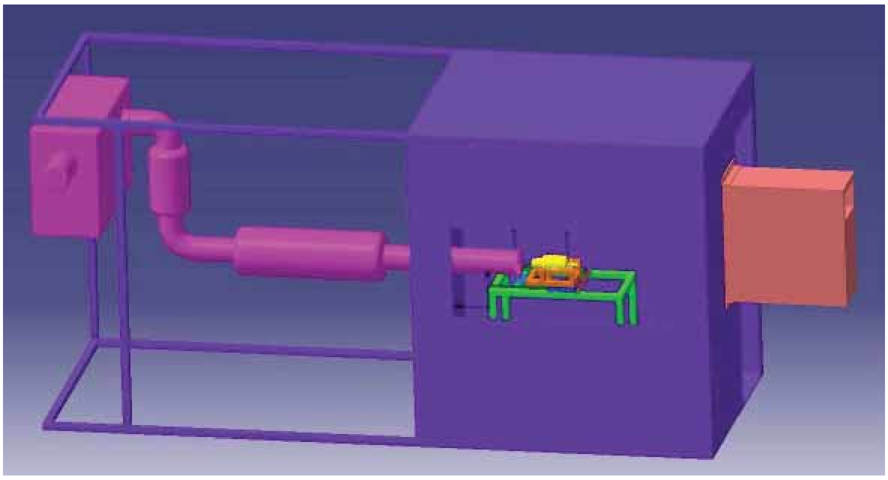

Fig. 6. A total view of the test stand of a small aircraft engine JetCat

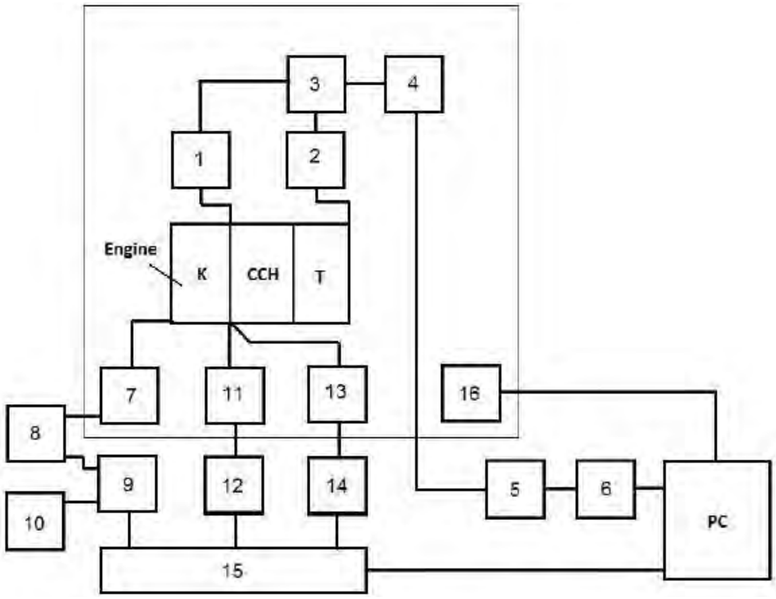

Fig. 7. Block diagram of the test stand of a small aircraft engine JetCat : 1 - speed, 2 - exhaust gases temperature, 3 - ECU, 4 - LED board, 5 - GSU, 6 - RS 232 interface, 7 - thrust, 8 - EMS 168 converter, 9 - A/D converter, 10 - power supply, 11 - temperature after the compressor, 12 - A/D converter, 13 - pressure after the compressor, 14 - A/D converter, 15 - measuring card, 16 - environment parameters, K - compressor, CCH - combustion chamber, T - turbine

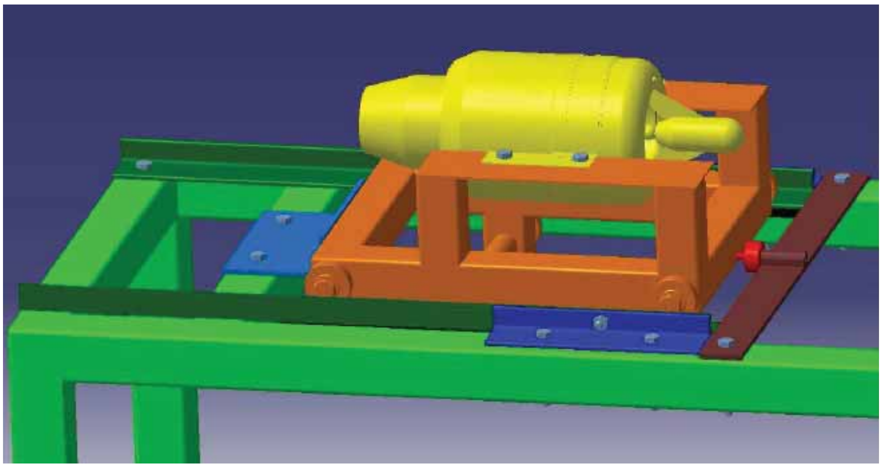

Fig. 8. A detailed solution of the engine fastening to the frame

3. Numerical approach

The numerical approach application prevails over the application of both experimental and analytical approaches.

The development of numerical approach is limited by the need for efficient and accessible IT as very fast processors with a huge memory capacity for continuous data storage is required. An important factor is the choice of an operational system as it conditions the choice of programming language for the programming of so called CFD code and graphical processing of computational results. The mentioned factors have a decisive influence on the efficiency of computations.

An objective of computational methodology is minimization of time losses occurring during operations of the computer system processor. The following three methods are used:
- zonal,
- hybrid ,
- adaptive meshes.

Numerical solution begins with the generating of the computational mesh. It is necessary to choose a mesh type – from the following basic classification: simple, and multiblock (with further sub-classification) and the method of its generating – algebraic and differential. Differential methods have a wider use. They lead to the systems of partial differential equations solved numerically. Elliptical, hyperbolic and parabolic methods of mesh generating are being used.

If turbulent flowing is to be modelled, one of possible approaches to the turbulence description can be used – either turbulent viscosity or Reynolds stress. The choice of a suitable model of turbulence depends on a concrete problem of turbulent flowing. For simpler cases standard models suffice (algebraic models of turbulent viscosity, one- or two-equation models). Two equation models are more natural than algebraic and one-equation models. Turbulent viscosity in a two-equation model for turbulent kinetic energy – turbulent dissipation rate, referred to as k - ε model, is presented by the relation

$$\mu_t = c_\mu p \frac{k^2}{\varepsilon} \tag{1}$$

and in a turbulent kinetic energy – specific dissipation rate model referred to as k-ω model for the turbulent viscosity is presented by the relation:

$$\mu_t = \gamma^* p \frac{k}{w}. \tag{2}$$

The method of the Reynolds Stress Transport Equations or some of its modification can be used for the solution of complex flows. Currently, CFD (Computational Fluid Dynamics) codes are used as they are advantageous.

Zonal methods divide the computational area into three zones (a thin layer of the viscous flow, a thicker layer of the non-viscous flow and a zone of non-viscous non-swirl flow). The flow in the first zone is solved by means of Navier-Stokes equations, in the second zone by Euler equations and in the third zone by means of a complete potential equation.

The multimesh method ranks among widely used hybrid methods. It makes use of fine and coarse meshes alternation.

The methods of adaptive meshes are popular as they enable optimization of the mesh density and line - area orthogonality through the gradient of the chosen flow field parameter.

From the point of view of the used numerical method, the mostly used have been the methods of finite:
- differences,
- volumes,
- elements.

To illustrate the use of numerical methods we present the results of solution of the flow in the jet engine flame. Fig. 9 - 11 shows the computational result.

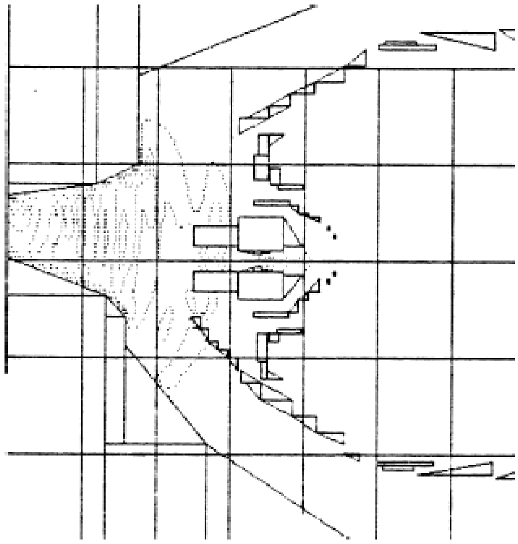

Fig. 9. Isotachs of entering air

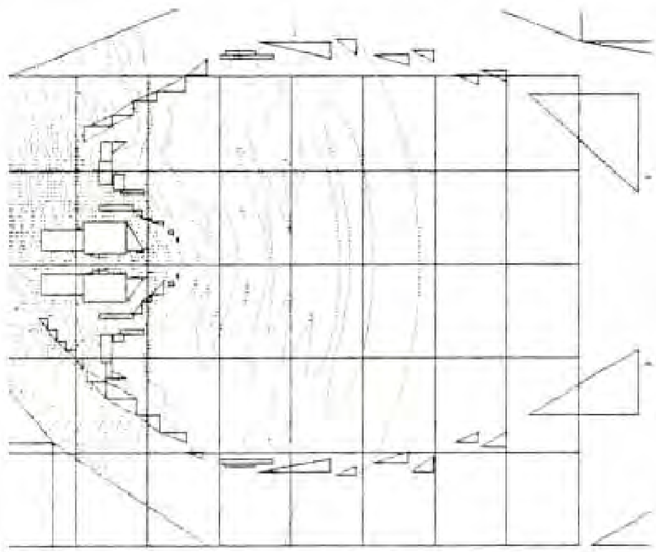

Fig. 10. Pressure field in the vicinity of the swirl device

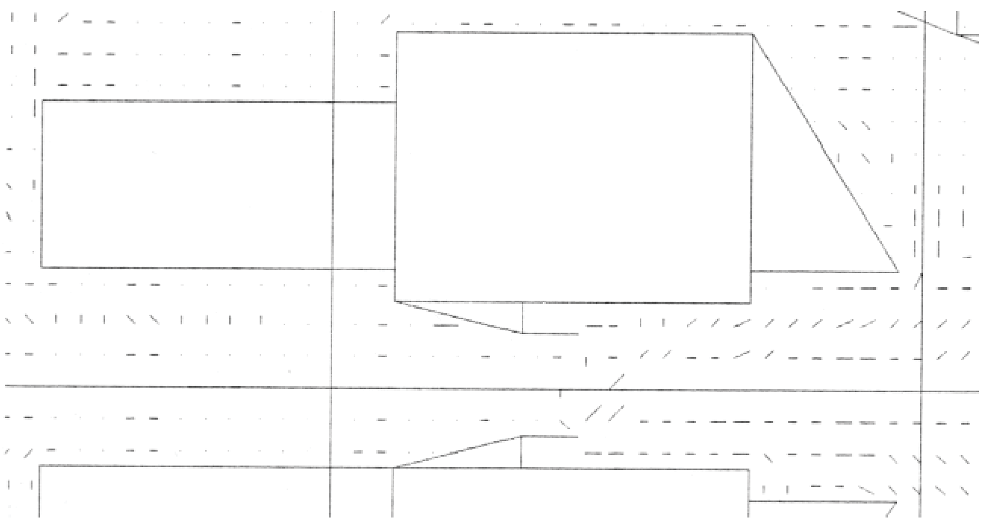

Fig. 11. Velocity vectors in particular elements of the disperser

4. Analytical approach

The analytical approach makes use of relations from mathematical and physical analysis of the flow field. It needs a relatively large simplification of the observed object which is manifested as an idealization of expectations. The results are characteristics for idealized conditions. The object geometry is usually simplified too and a limited range of computational characteristics of flowing is achieved. The results of solution are in a conservative form, losses of computational times are minimal, laws of similarities are used. The analytical approach is more efficient for solution of simpler tasks than the numerical approach.

The final solution can be achieved only when a large simplification – idealization of expectation is used. That is why the approach is used mostly when solving the flow in objects featuring simple geometrical shapes. The solution is achieved in a conservative form.

5. Conclusion

The paper deals with possible methods for solution of the flow in the jet engine and their brief characteristics. Advantages and disadvantages of the methods are outlined. Individual methods are presented and illustrated with real results gathered from experimental and theoretical work of the team of researchers.

Acknowledgements

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