Researcher Links UK-Russia Workshop

Scientific and Technical Grounds of Future Low-Carbon Propulsion

19th - 22nd November 2018, Northumbria University at Newcastle, UK

Combustion Chamber Shaping for Increasing of Effective Parameters of Aviation Wankel Engine

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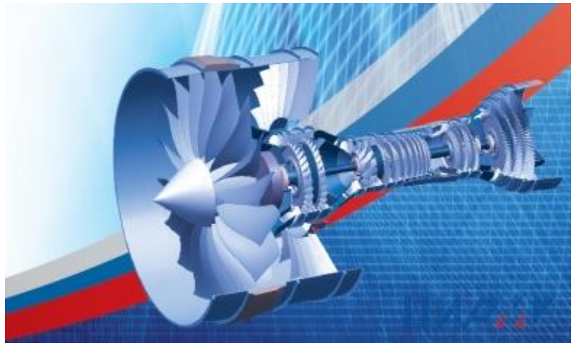
Central Institute of Aviation Motors named after P.I. Baranov

Central Institute of Aviation Motors n.a. P.I. Baranov



Established in 1930, the Institute combines fundamental research activities with participation in the development of future aircraft engines, their systems and components. All the Russian and many foreign engines were developed with the Institute's direct involvement and refined at the Institute's test facilities.

Central Institute of Aviation Motors activity directions

- Fundamental research in gas dynamics, mechanical strength, heat exchange, combustion and acoustics.
- Testing of aircraft engines, their systems and components in real operation conditions.

- Elaboration of the main areas of aircraft engine development forecast based on the world's leading aircraft science and engineering achievements.
- Engine development methodology.
- Applied research in the field of conceptual design of various aircraft engine types; aircraft system and component design, as well as providing reliability and failure-free performance.
- Test facility equipment and measurement instruments' design.
- Design of high-performance gas turbine units for power and gas pumping industries.

Research objective

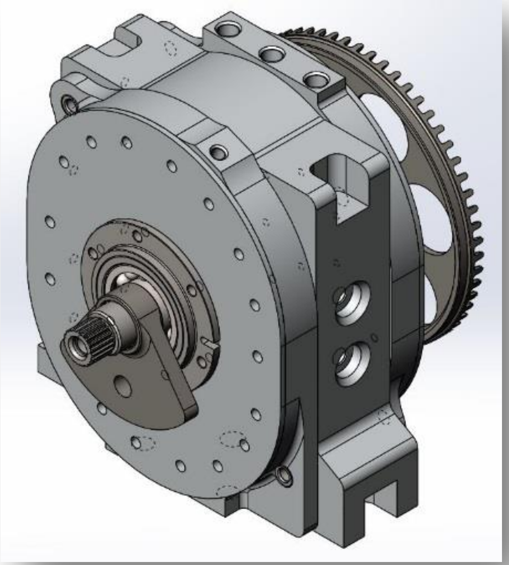
Wankel engines (WE), in comparison with the engines using the crank mechanism, possess smaller weight and dimensions. In this regard, they are well suited for use on aircraft.

The zero-dimensional approach does not allow to correctly take into account the chamber geometry. Also there is no possibility to optimize the position and individual moments of ignition for spark plugs, to evaluate the efficiency of air admission. These features can be taken into account when using a three-dimensional approach.

The research objective is increasing of effective and ecological parameters of aviation Wankel engine by refinement of rotor geometry.

The engine under consideration

Type	Spark-Ignited Wankel engine
Number of sections	1
Power, hp	70…100
Type of fuel	Gasoline
Fuel supply system	Multipoint injection
Engine specific weight, kg/hp	0.42…0.45



Mathematical model

The generalized differential equation of conservation laws (Navier-Stokes, energy conservation, mass conservation, concentration equations):

$$\frac{\partial}{\partial t}(\rho\Phi) + \mathrm{div}\left(\rho\vec{U}\Phi\right) = \mathrm{div}(\Gamma_\Phi \mathrm{grad}\Phi) + S_\Phi \Leftrightarrow \frac{\partial}{\partial t}(\rho\Phi) + \frac{\partial}{\partial x_j}\left(\rho U_j \Phi\right) = \frac{\partial}{\partial x_j}\left(\Gamma_\Phi \frac{\partial\Phi}{\partial x_j}\right) + S_\Phi$$

k-ζ-f turbulence model with Hybrid Wall Function

$$\rho\frac{Dk}{D\tau} = \rho(P_k - \varepsilon) + \frac{\partial}{\partial x_j}\left[\left(\mu + \frac{\mu_t}{\sigma_k}\right)\frac{\partial k}{\partial x_j}\right],$$

$$u^+ = y^+ e^{-\Gamma} + \frac{1}{\kappa\Psi}\ln\left(Ey^+\right)e^{-1/\Gamma} \qquad \Gamma = \frac{0.01\left(y^+\right)^4}{1+5y^+}$$

$$\rho\frac{D\varepsilon}{D\tau} = \rho\frac{c_{\varepsilon1}^* P_k - c_{\varepsilon2}\varepsilon}{T} + \frac{\partial}{\partial x_j}\left[\left(\mu + \frac{\mu_t}{\sigma_\varepsilon}\right)\frac{\partial\varepsilon}{\partial x_j}\right],$$

$$\mu_w = \mu\frac{y_P^+}{u_P^+} \qquad y_P^+ = \frac{\rho u_\tau y}{\mu} \qquad u_\tau = c_\mu^{1/4} k_P^{1/2}\left(\zeta/0.4\right)^{1/4} \qquad \tau_w = \mu_w\frac{u_P}{y_P}$$

$$\rho\frac{D\zeta}{D\tau} = \rho f - \rho\frac{\zeta}{k}P_k + \frac{\partial}{\partial x_j}\left[\left(\mu + \frac{\mu_t}{\sigma_\zeta}\right)\frac{\partial\zeta}{\partial x_j}\right],$$

$$f - l^2\frac{\partial^2 f}{\partial x_j \partial x_j} = \left(c_1 + c_2\frac{P_k}{\zeta}\right)\frac{2/3-\zeta}{T},$$

Here f – is elliptic relaxation function, T – turbulence time scale; l – length scale

Eddy viscosity: $\nu_t = c_\mu \zeta \frac{k^2}{\varepsilon}$

Model constant: $c_{\varepsilon1}^* = c_{\varepsilon1}\left(1 + 0,045\sqrt{1/\zeta}\right)$

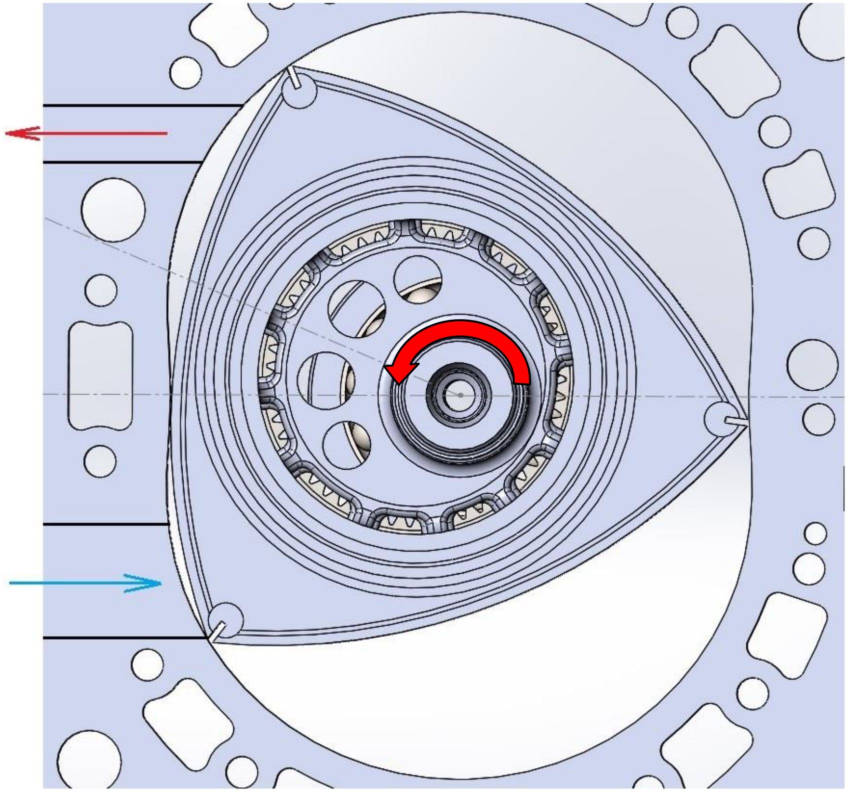
Combustion model – Extended Coherent Flame Model (ECFM)

$$\frac{\partial\Sigma}{\partial\tau} + \frac{\partial}{\partial x_j}\left(\bar{W}_j\Sigma\right) = \frac{\partial}{\partial x_j}\left(\frac{\nu_t}{Pr_{tD}}\frac{\partial\Sigma}{\partial x_j}\right) + S_\Sigma$$

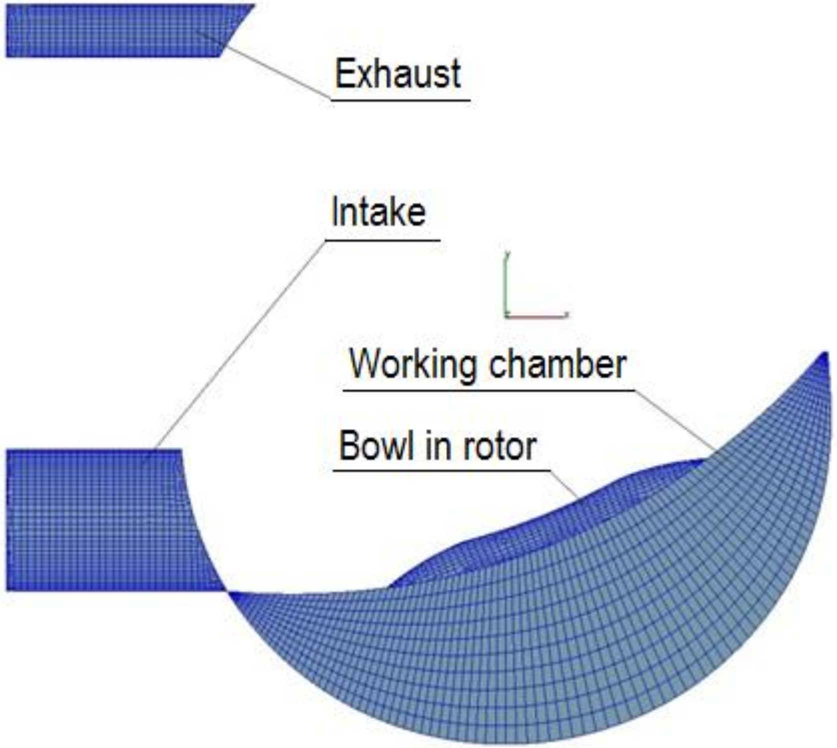
here Σ is a flame front surface area per volume unit; Pr_{tD} is turbulent Prandtl number; S_Σ is an source term.

Average combustion reaction rate: $\bar{w}_r = -\rho_{Tp} w_l \Sigma$ $\quad\rho_{Tp}$ – partial fuel density; w_l – laminar flame velocity

Meshing procedure



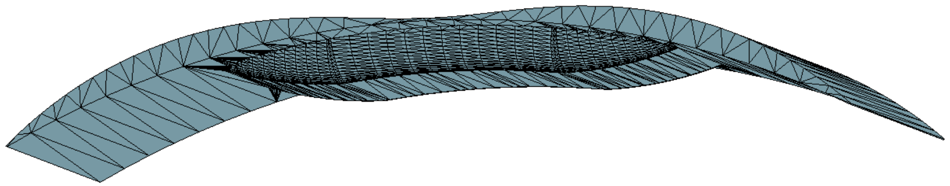
Three-dimensional solid-state model of the WE at the position of rotor at the time of closing the intake window



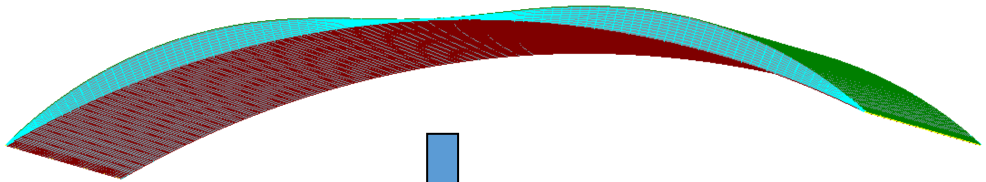
Discretization of the computational domain into control volumes

Meshing procedure

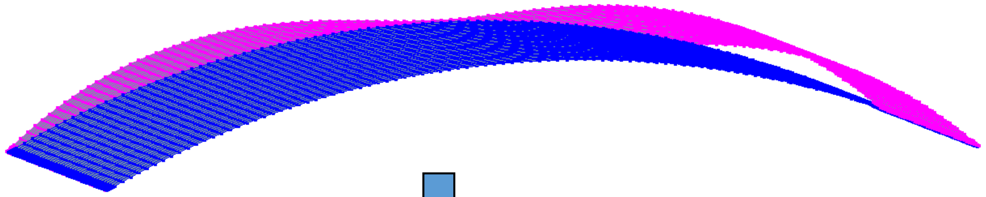
1. Base surface mesh

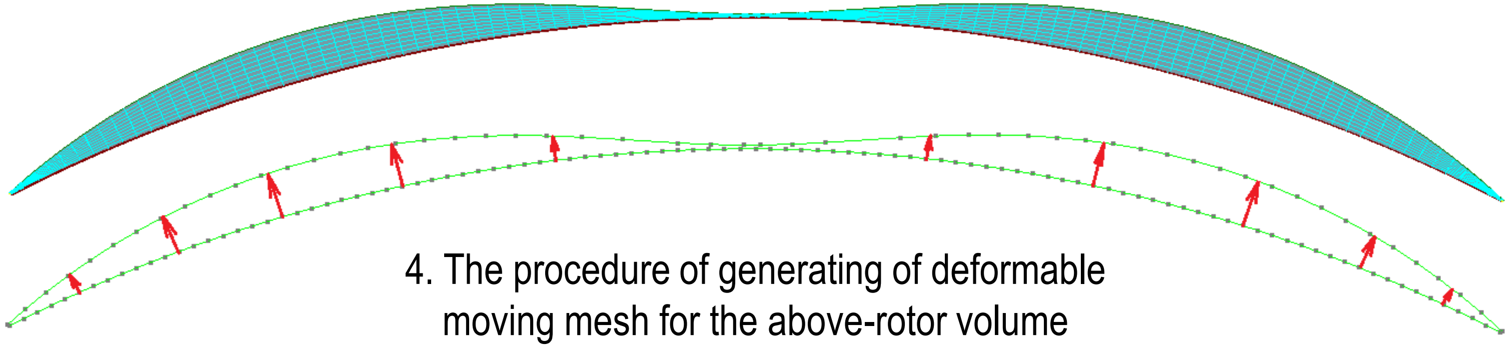


2. Discretization of the above-rotor volume into control volumes (CV) (source stationary mesh)

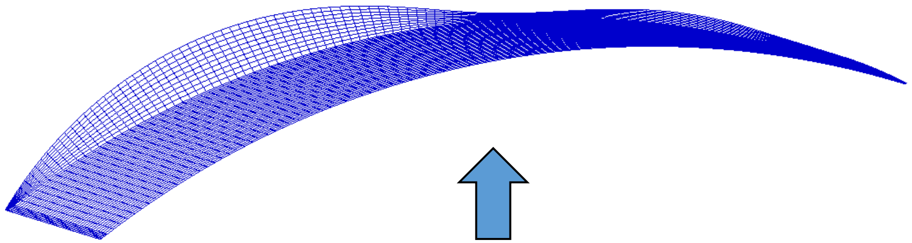


3. Allocation of the deformation boundaries of moving mesh (stator and rotor surfaces)



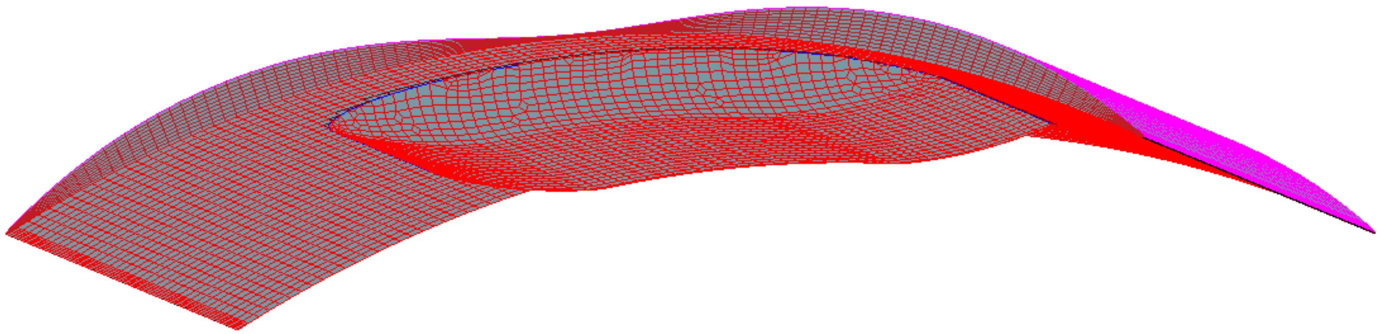


4. The procedure of generating of deformable moving mesh for the above-rotor volume



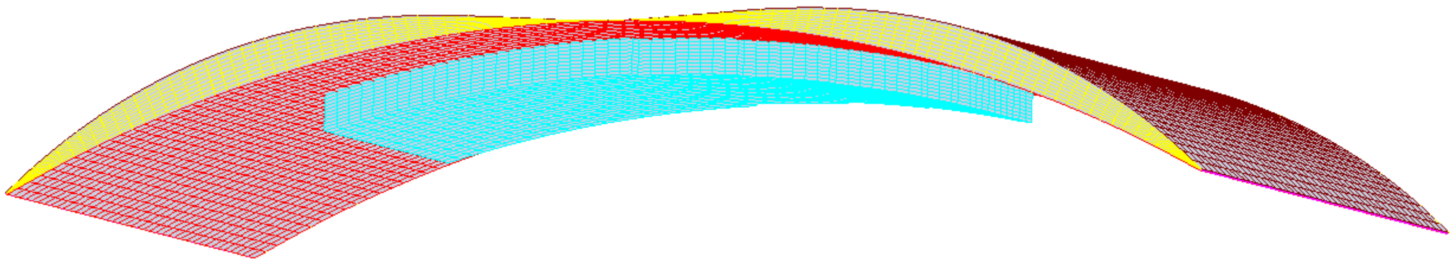
5. Final deformable moving mesh (intermediate position of the rotor)

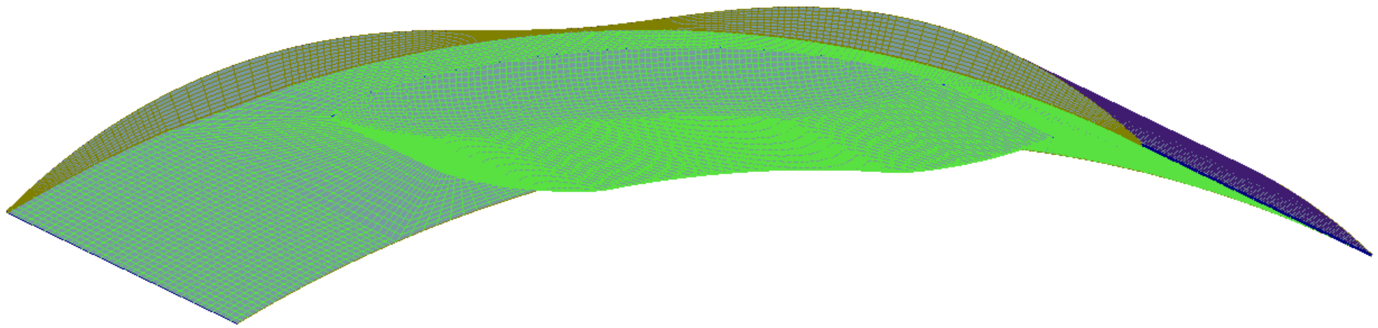
Meshing procedure



1. Separate mesh discretization procedure for above-rotor volume and bowl-in-rotor, followed by their combination

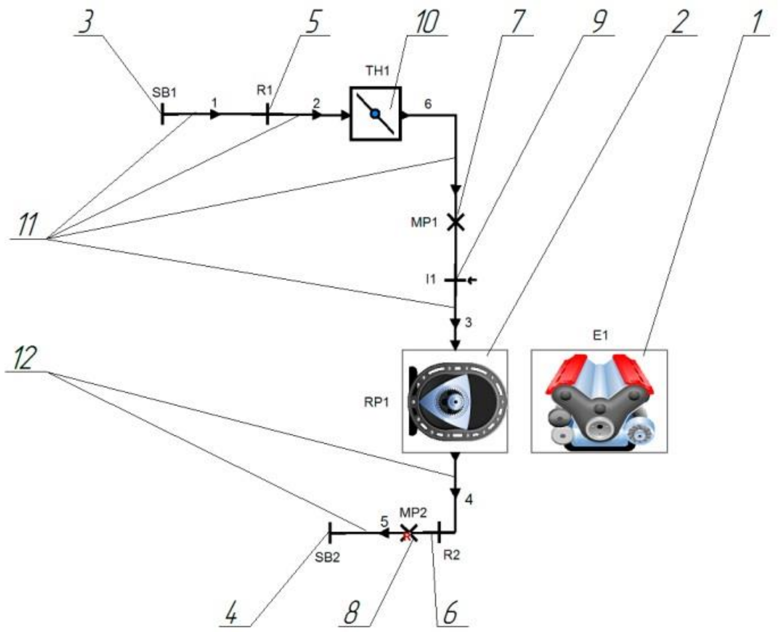
2. "Growing" the bowl-in-rotor mesh based on the above-rotor mesh





3. Above-rotor volume discretization based on the bowl-in-rotor mesh

Definition of boundary conditions. Model verification



Design model for the single-section Wankel engine :

1 – unit that sets operating parameters of the engine;

2 – block simulating the WE section,

3 и 4 – boundary conditions definition;

5 и 6 – restrictions,

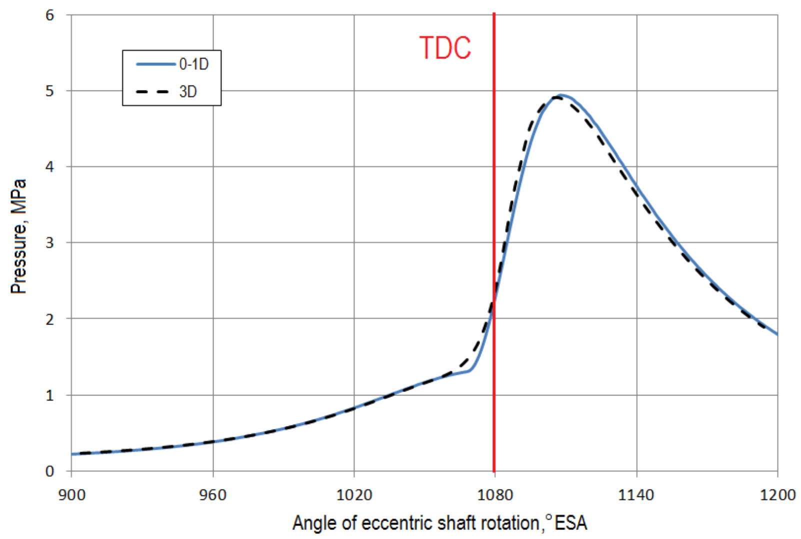
7 и 8 – measuring points,

9 – injector,

10 – throttle,

11 – intake pipes,

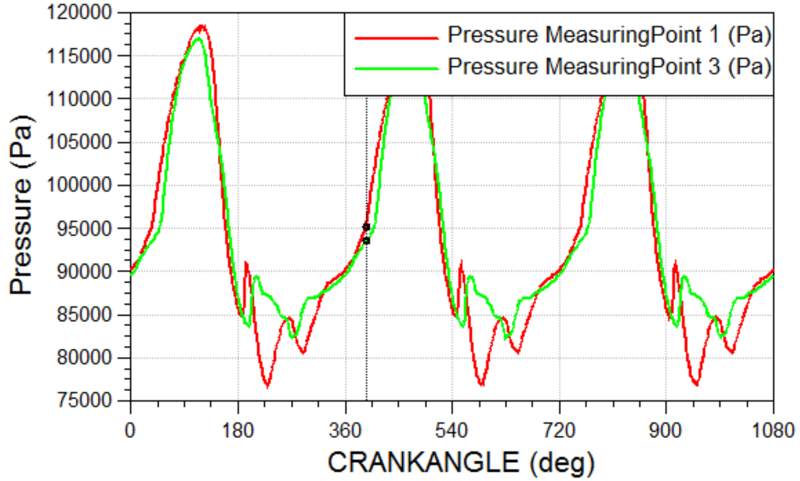
12 – exhaust pipes

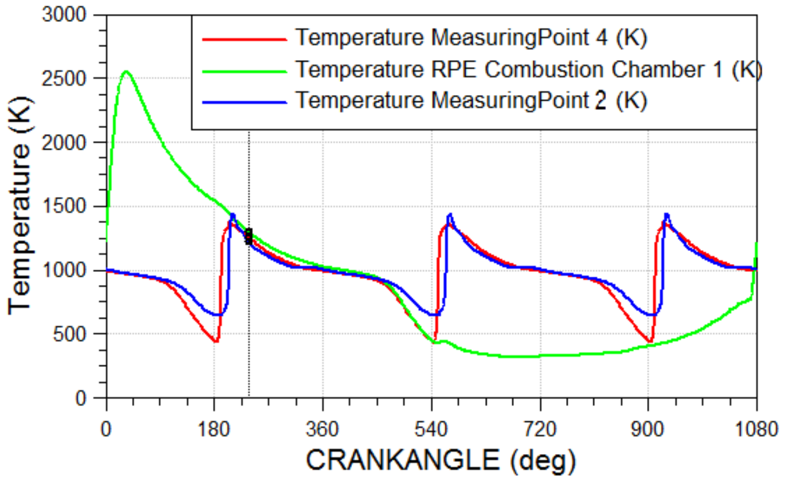


Model verification

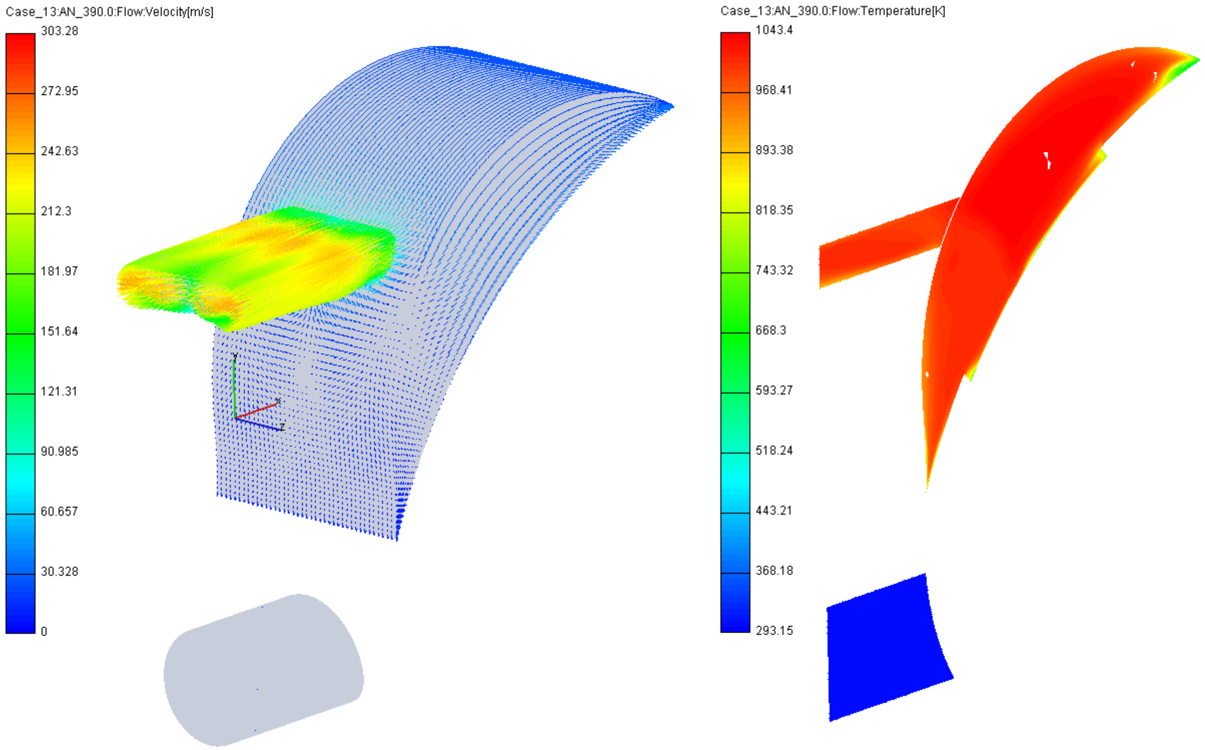
The maximum pressure p_z error is less than 0.5%, and in the angle of its achievement – at least 1%

Boundary conditions for the subsequent three-dimensional calculation of the working process

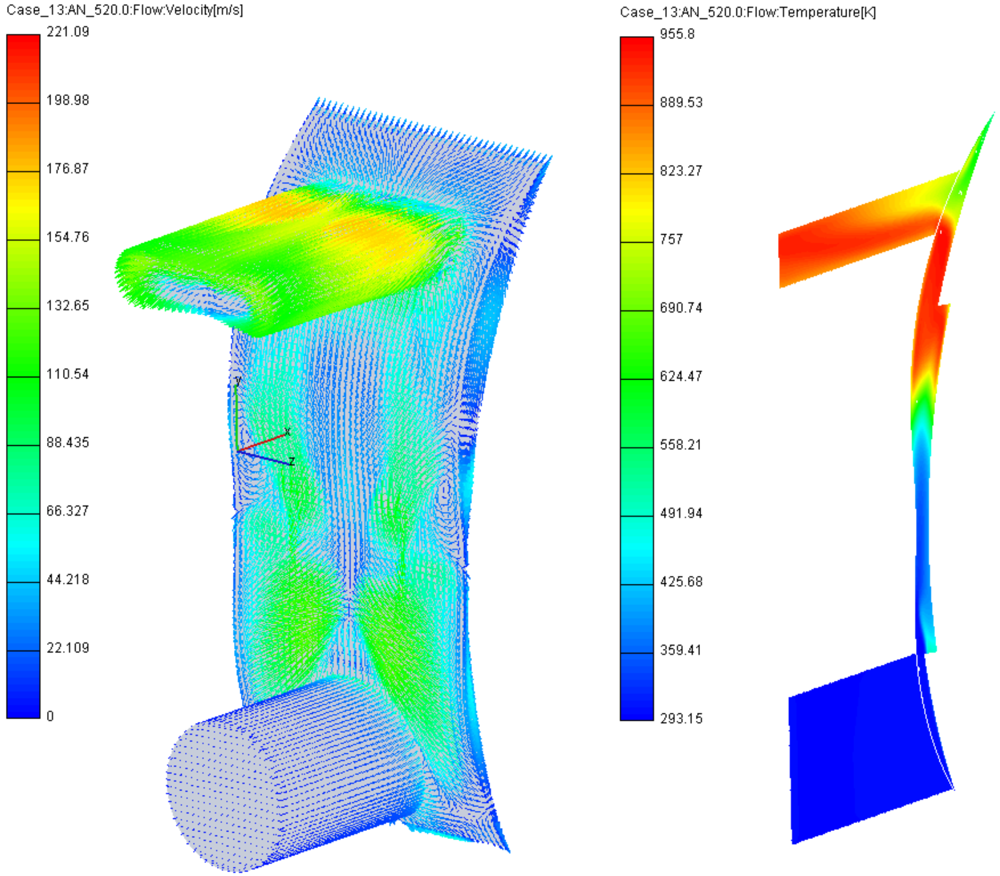




Simulation results

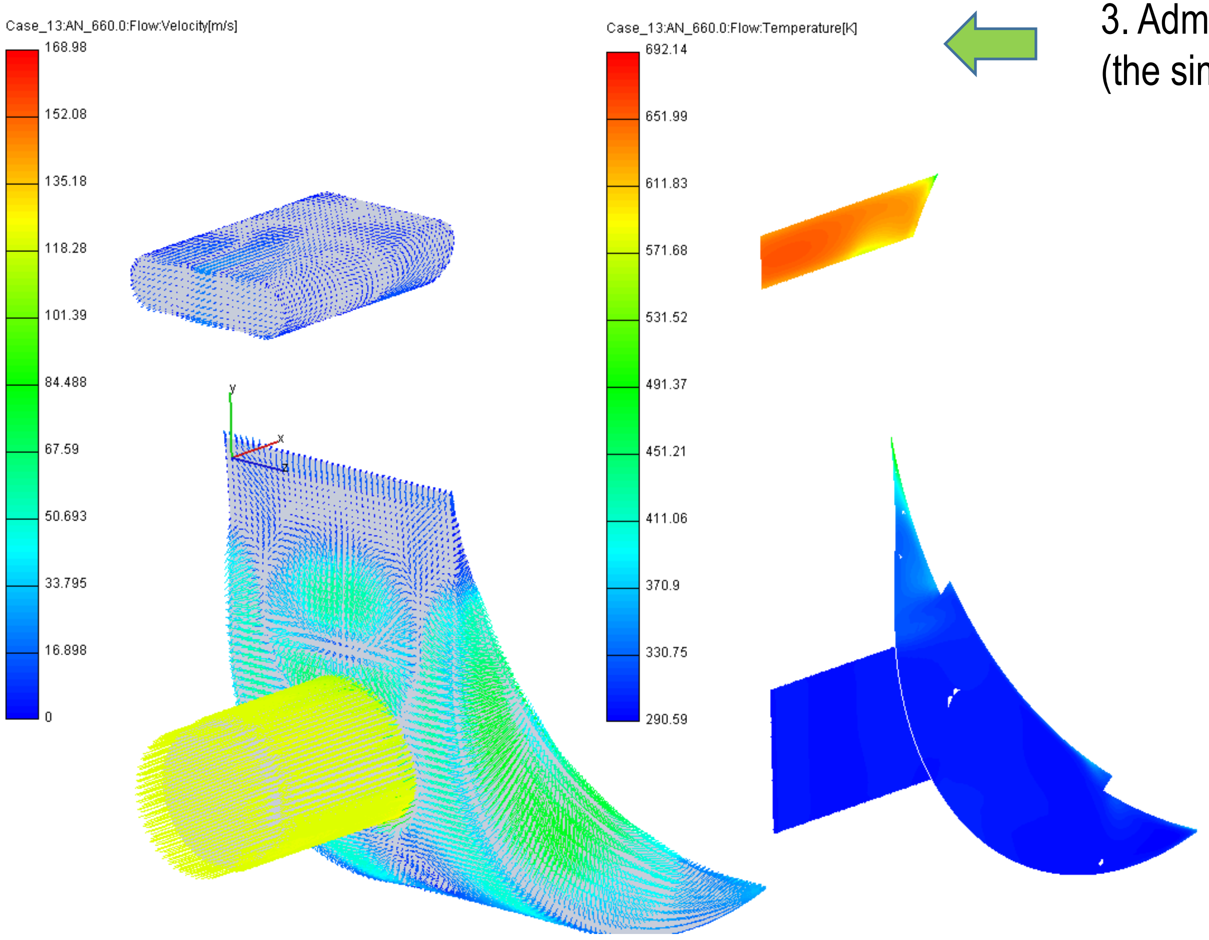


1. Exhaust process in the WE with radial intake and exhaust ports (the simplified combustion bowl in rotor)

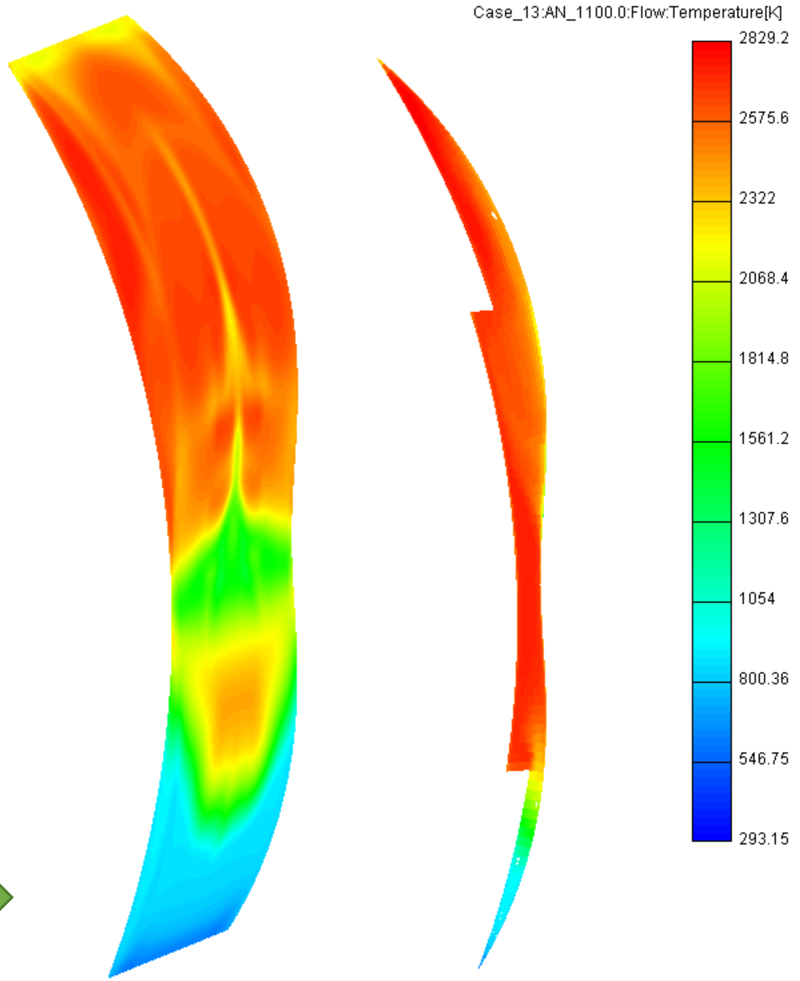


2. Scavenging of the combustion chamber of WE with radial intake and exhaust ports (the simplified combustion bowl in rotor)

Simulation results



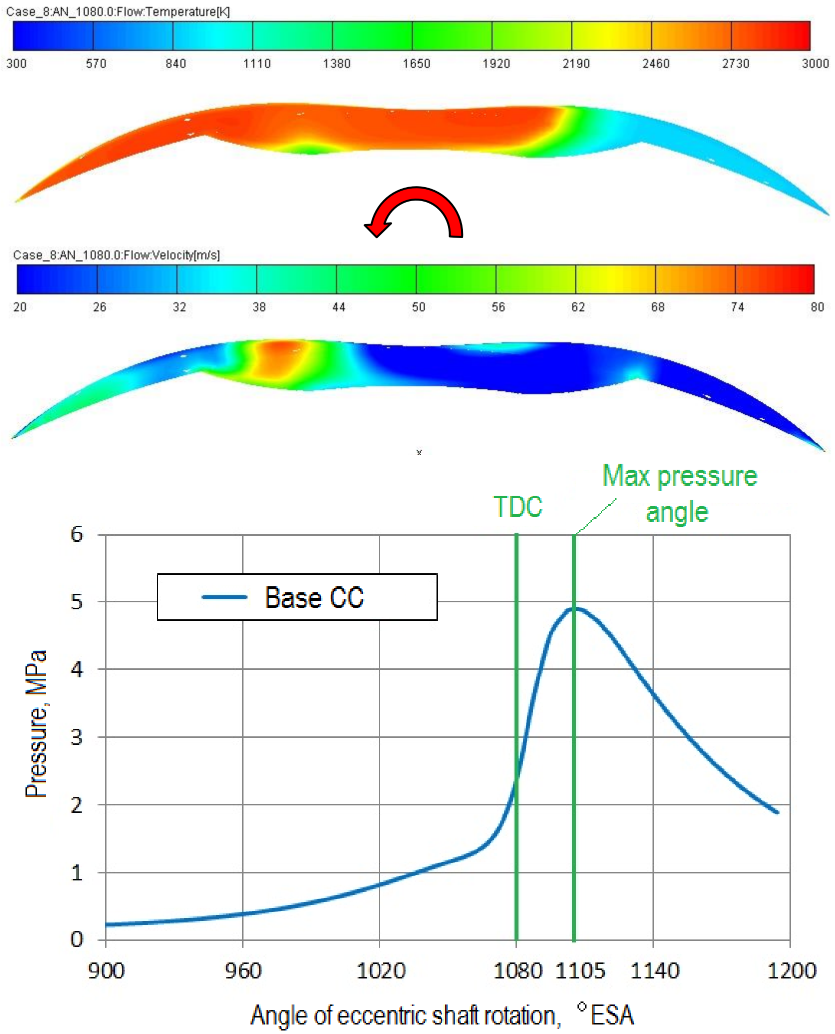
3. Admission of working chamber of WE with intake and exhaust ports (the simplified combustion bowl in rotor)



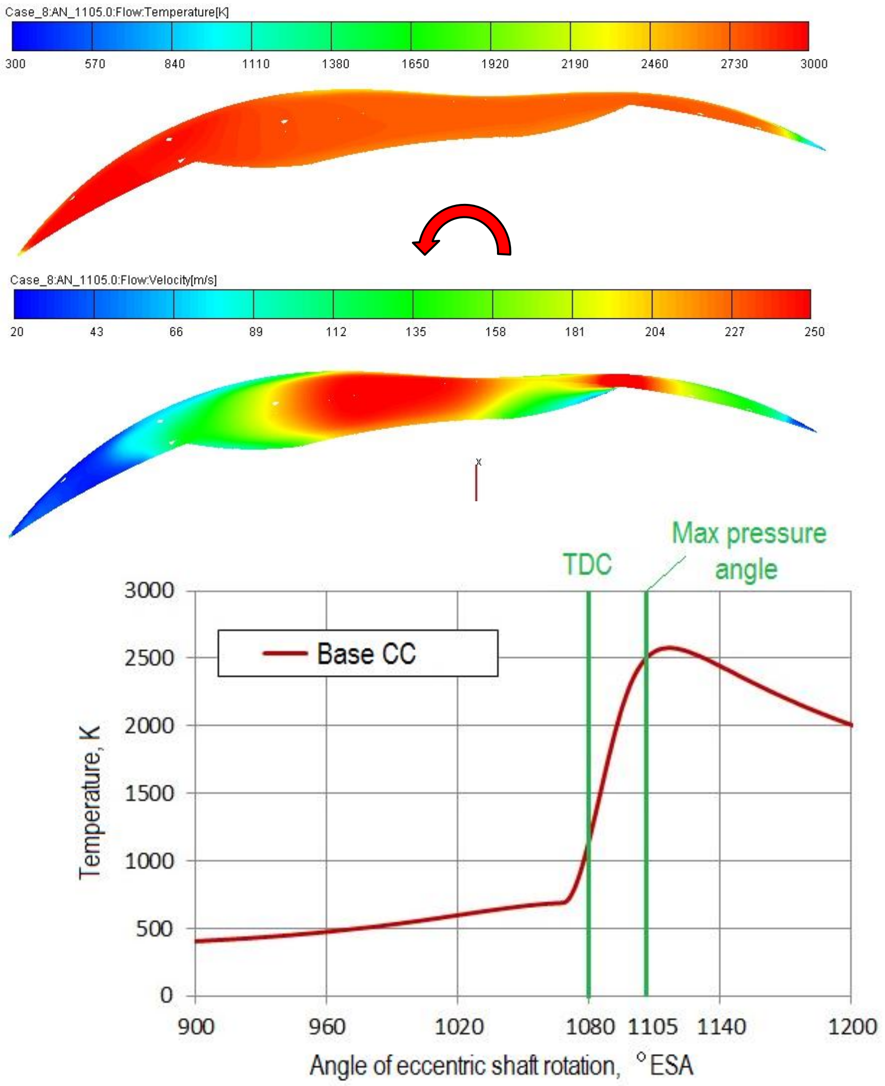
4. Combustion process in the working chamber of WE (the simplified combustion bowl in rotor)

Simulation results

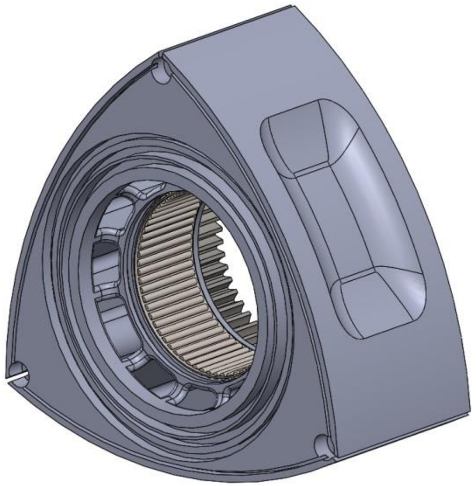
Temperature and velocity values in cross-section of WE combustion chamber (rotor position in Top Dead Center)

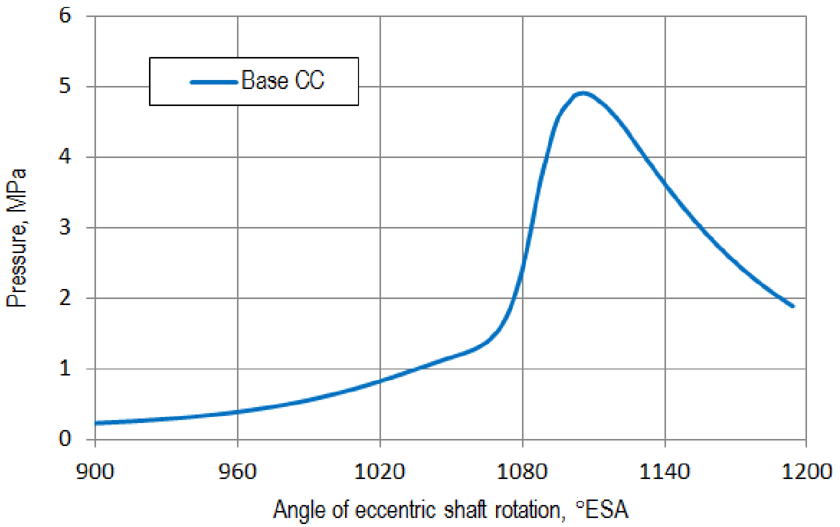


Temperature and velocity values in cross-section of WE combustion chamber (max pressure angle position of rotor)

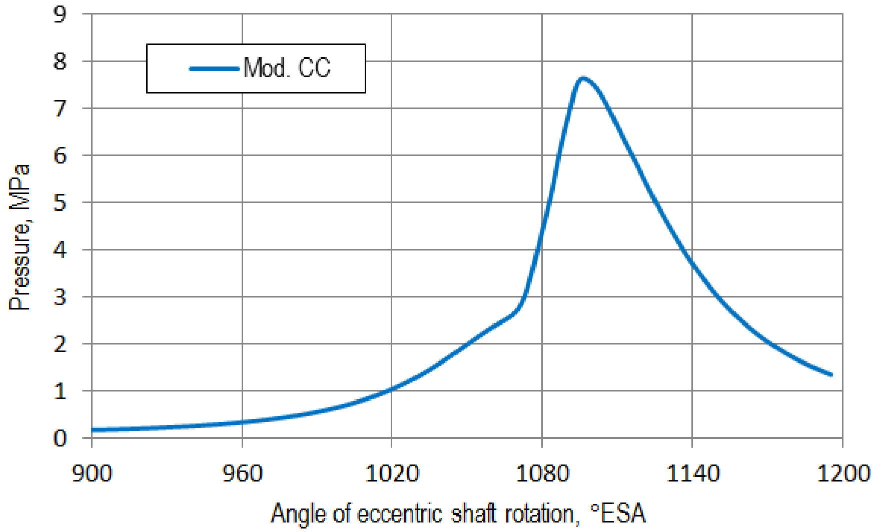


Shaping of combustion chamber





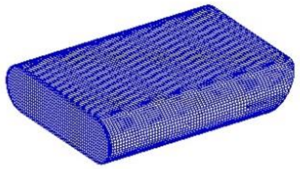
Indicator diagram of WE with base combustion chamber

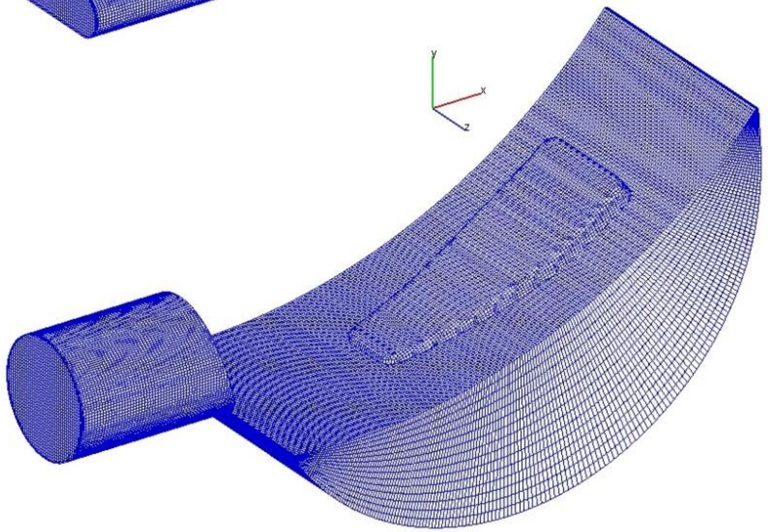


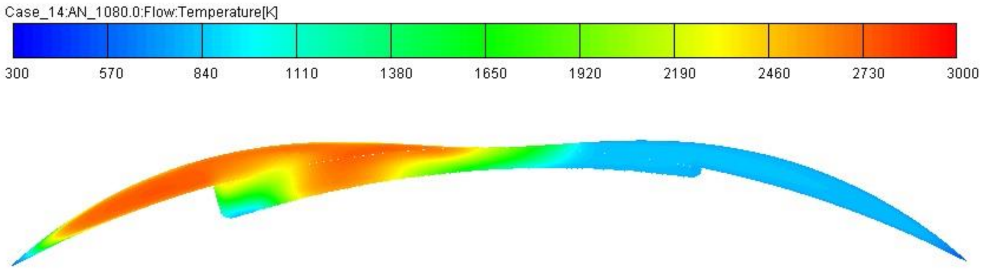
Indicator diagram of WE with modified combustion chamber

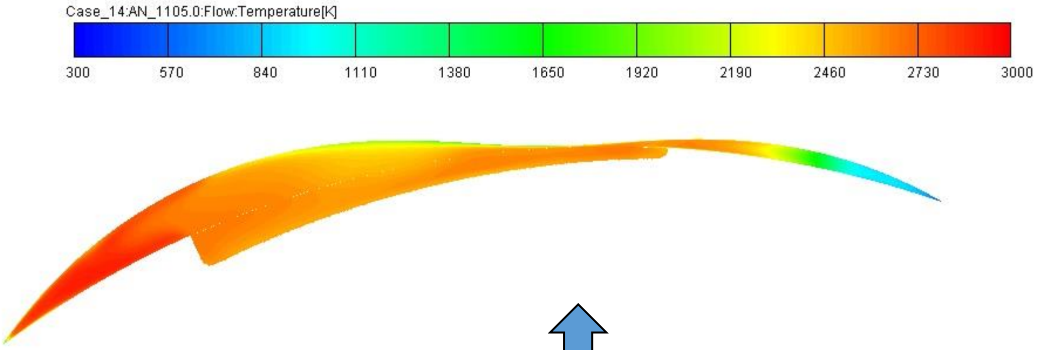
Shaping of combustion chamber

CV discretization of modified combustion chamber

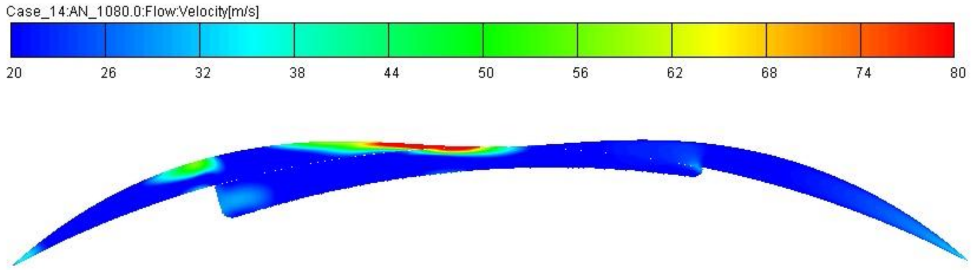


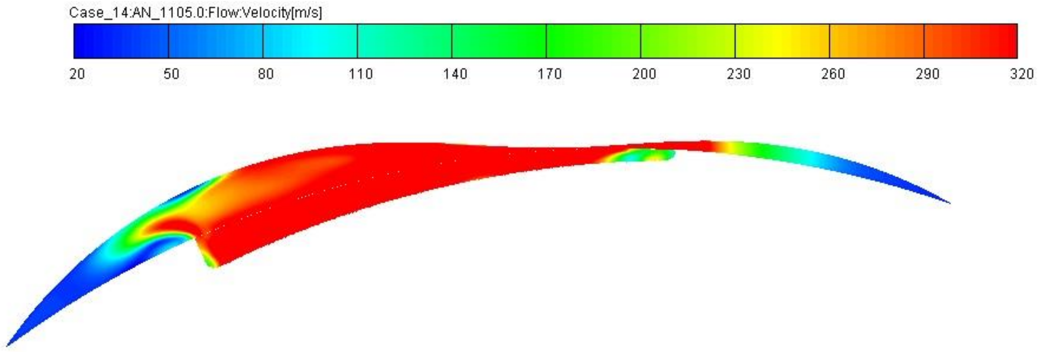




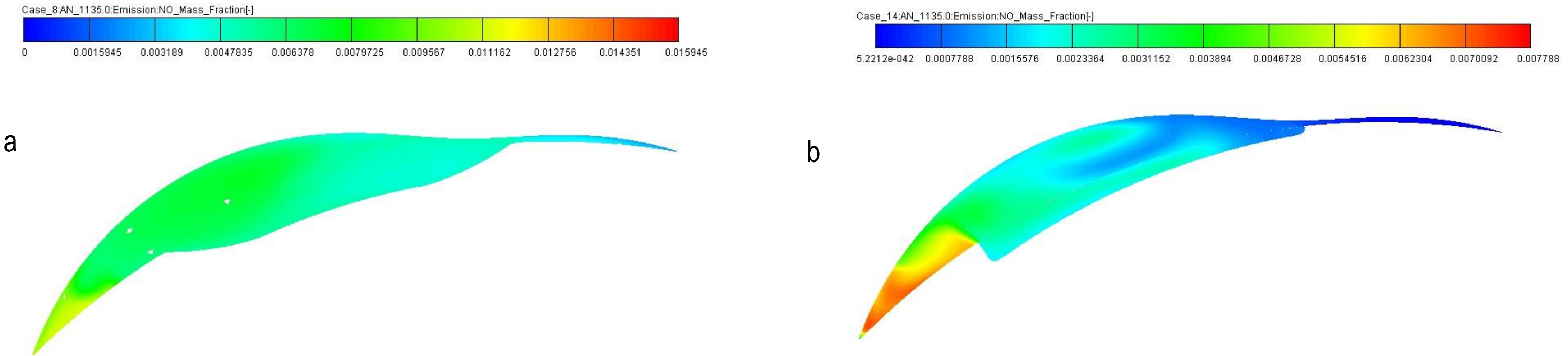


Temperature and velocity values in cross-section of WE combustion chamber (Top Dead Center and Max pressure angle position of rotor)

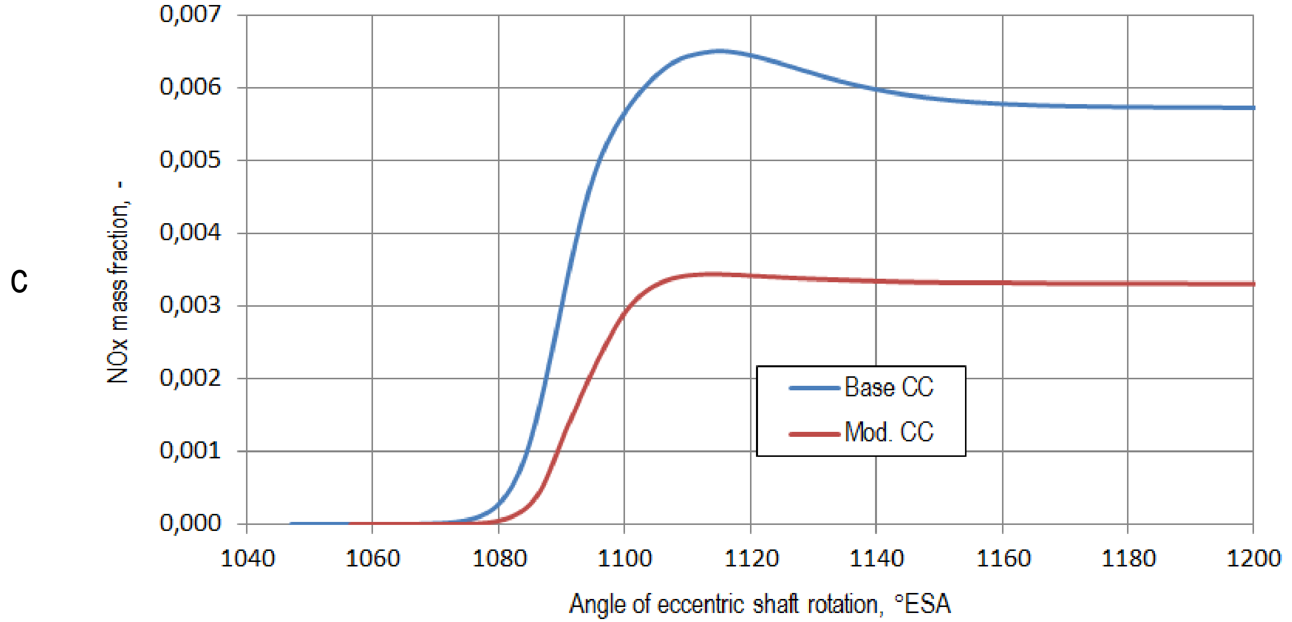




Shaping of combustion chamber

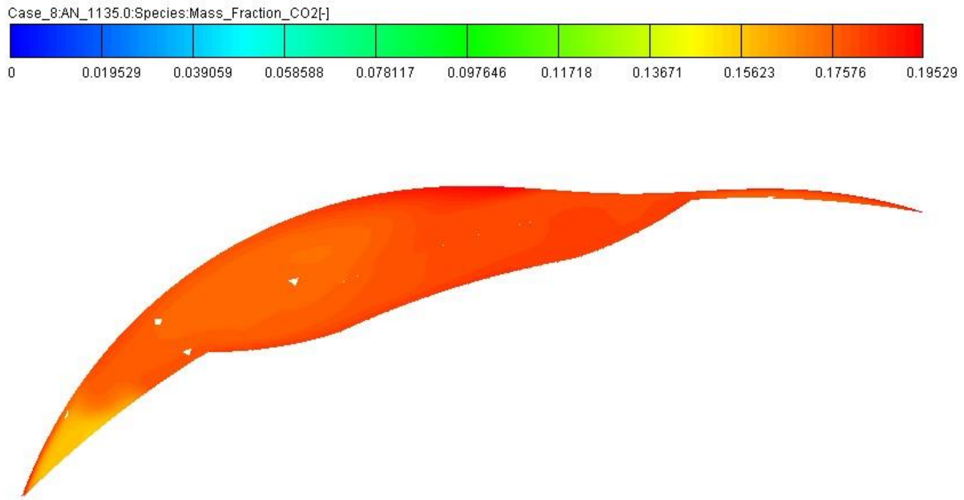


Local NO_x mass fractions in cross-section of base (a) and modified (b) WE combustion chamber, and its mean values (c)

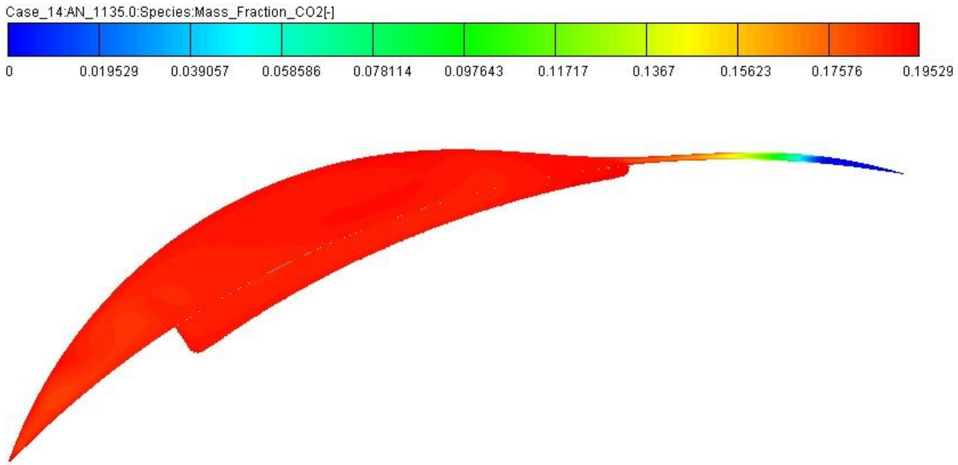


Shaping of combustion chamber

a

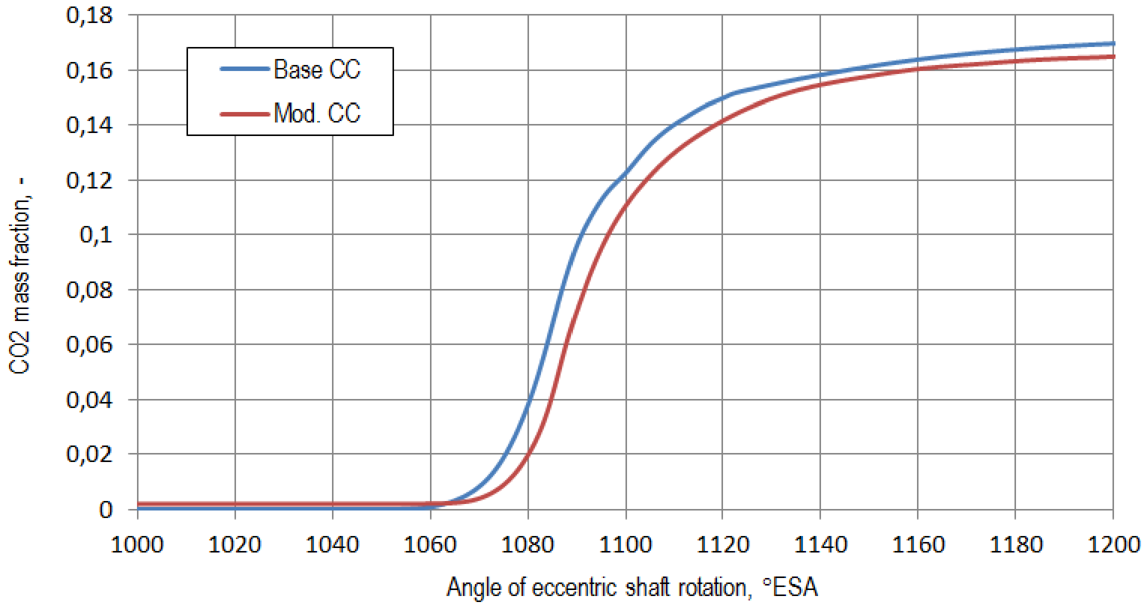


b



Local CO_2 mass fractions in cross-section of base (a) and modified (b) WE combustion chamber, and its mean values (c)

c



Conclusion

- The developed mathematical model of WE allows to determine the parameters of working fluid in the entire calculated volume in a three-dimensional formulation.
- The necessity of individual ignition on the first and second (in the direction of rotor rotation) spark plugs is shown.
- Based on the simulation results of turbulent combustion and transfer processes in the WE working chamber, a significant influence of the bowl-in-rotor shape on the engine performance is determined. An alternative design of the bowl is proposed, which allows to increase the efficiency of WE.
- The proposed modification of the combustion chamber made it possible to reduce the content of both NO_x nitrogen oxides and CO_2 greenhouse gas in the exhaust gases.

Thank You for your attention!

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