RSF Project 20-41-09018_ANR

NORMA

NOise of **R**otating **MA**chines

NORMA structure

Workpackage 1. Evaluation of hybrid RANS-LES methods of scale-resolving simulation of turbulent flows developed by partners, their further development and adaptation to the problems of turbulent flow past rotating rotor blades of helicopters.

Workpackage 2. Further development of jointly developed by the partners EBR schemes based on quasi-one-dimensional edge-based reconstruction of variables, as applied to the simulation of flows around rotating elements. Comparative analysis and development of ENO and WENO reconstructions for better simulation of solutions with high gradients and discontinuities. Development of edge-based adaptive artificial viscosity. The implementation of modifications of the methods for the approximate solution of Riemann's problem, suitable for all-Mach numbers flows

Workpackage 3. Adaptation of the developed immersed boundary method based on the Brinkman penalization method to problems with the rotational motion of aerodynamic elements in combination with the fast-working technique of level set function to define the geometry of elements and methods of dynamic unstructured mesh adaptation of two types (based on the deformation and local addition of mesh nodes).

Workpackage 4. Development of efficient time integration algorithms, namely the multirate scheme and the LU-SGS method, and a comparative analysis of their efficiency, including the efficiency of parallel implementation as applied to the tasks to be solved.

Workpackage 5. Simulation of the model problems for single-rotor and multi-rotor configurations for the purpose of evaluating the developed particular methods and approaches, as well as demonstrating the effectiveness of the full computational algorithm built on their basis.

NORMA cases – First category

MP1.1 Simulation of the flow around a single isolated rotor and the noise generated by it in the hover mode in a non-inertial rotating frame of reference using hybrid RANS-LES scale-resolving methods. The goal of solving this problem is to compare the scale-resolving methods among partners in application to the simulation of turbulent flow and noise (including broadband noise) in the near and far field.

The case MP1.1 we suggest is described below (see slides 9-12)

MP1.2 Simulation of the external flow around a single solid obstacle (helicopter fuselage) by the traditional method with a mesh aligned to the body surface and a method of immersed boundary conditions. The goal of this case is to compare two approaches to modeling the flow around solid bodies.

MP1.3 Simulating of the rotor + fuselage system in hovering mode. In this case, the rotor is modeled in a non-inertial rotating frame of reference with a fuselage rotating relative to the rotor, and the fuselage described by the method of immersed boundary conditions. The goal of this case is to study the effect of the fuselage on acoustic noise in the far field.

NORMA cases – Second category

MP2.1 Simulation of an isolated rotating rotor on the hover mode using two methods: the traditional method is to simulate an external turbulent flow near a rotor using the Euler equations or a RANS approach on a mesh aligned with the rotor surface in a non-inertial rotating frame of reference and the method of immersed boundary conditions. The goal of this case is to compare two approaches to modeling the tonal noise of a single rotor in a far field.

MP2.2 Simulation of a system of 4 rotors using the method of immersed boundary conditions. The purpose of solving the model problem is to study the influence of the rotor's location on the total tonal noise when rotating rotors described using the immersed boundary method.

MP2.3 Simulation of the full system of 4 rotors and fuselage in hovering mode. In this case, the rotating rotors are modeled by the method of immersed boundaries and the fuselage - using the traditional approach with a mesh aligned with the surface of a solid body. The goal of this problem is to study the noise in the far field of the system of 4 rotors and the fuselage, as well as to study the influence of the fuselage on the noise in the far field.

NORMA plan for KIAM for 2020 – WP 2

2020.2.1 Comparative analysis of the accuracy of edge-based ENO and WENO [1] reconstructions (together with INRIA)
A series of test computations of problems with smooth and discontinuous solutions using EBR schemes with ENO and WENO reconstructions will be carried out, and the accuracy and efficiency of the approaches will be assessed. WENO reconstruction developed by Russian partners. Using the experience of the Russian participants, the French partners will develop an ENO reconstruction.

2020.2.2. Adaptation of artificial viscosity to the edge-based formulation and its implementation in the EBR scheme
The artificial viscosity recently developed by A.V. Rodionov [2] will be generalized to edge-based reconstructions. Separately, the inclusion of artificial viscosity in a hybrid low-dissipative reconstruction and the corresponding solution sensors will be investigated.

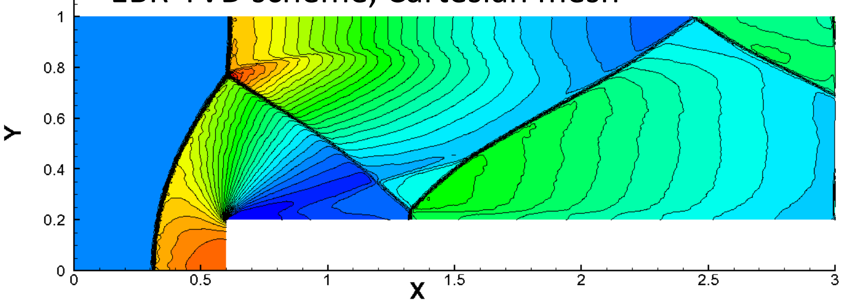
1. Bakhvalov P.A., Kozubskaya T.K. Reprint of: EBR-WENO scheme for solving gas dynamics problems with discontinuities on unstructured meshes, Comput. Fluids 169 (2018) 98-110. .DOI: 10.1016/j.compfluid.2018.03.050

2. Rodionov A. V. Artificial viscosity to cure the carbuncle phenomenon: The three-dimensional case, J. Comp. Phys., 361 (2018) 50-55

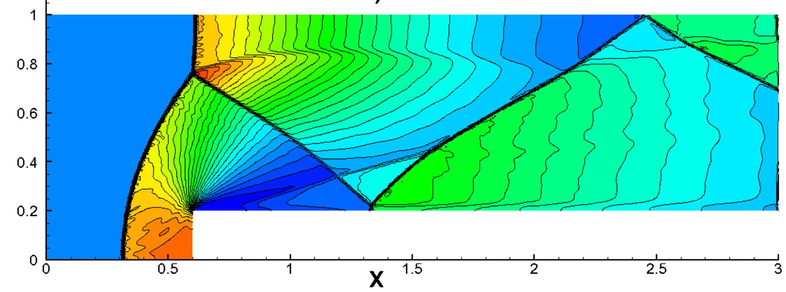
Verification of Shock Capturing EBR schemes

Mesh size h=1/160

EBR-TVD scheme, Cartesian mesh

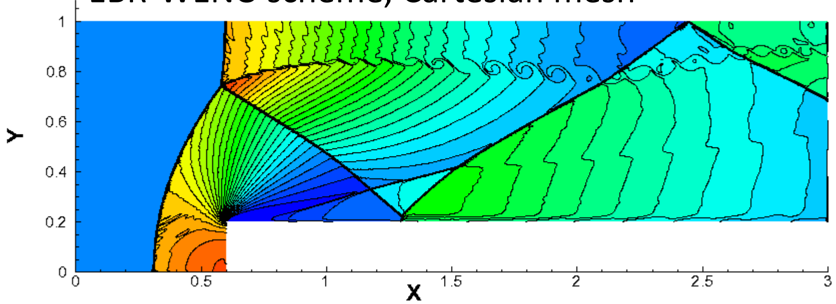


EBR-WENO scheme, Cartesian mesh

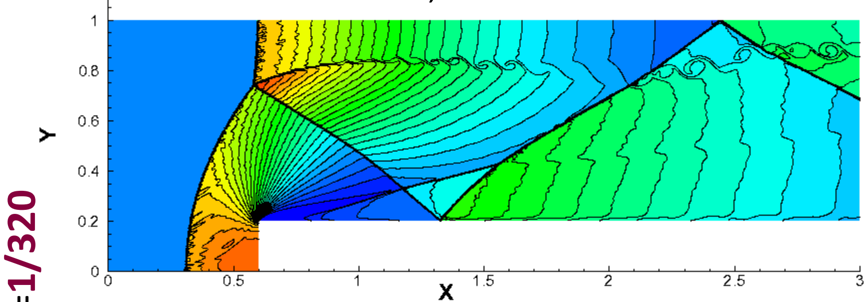


Mesh size h=1/320

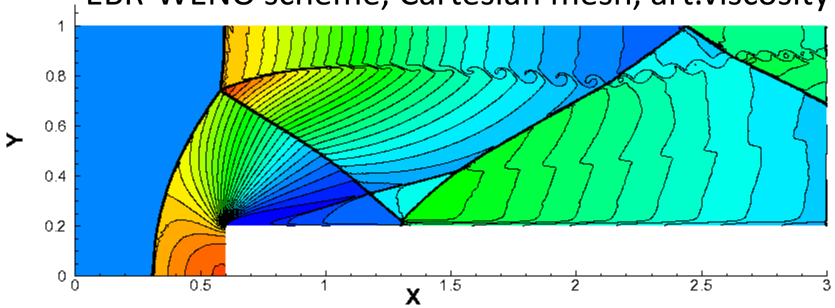
EBR-WENO scheme, Cartesian mesh



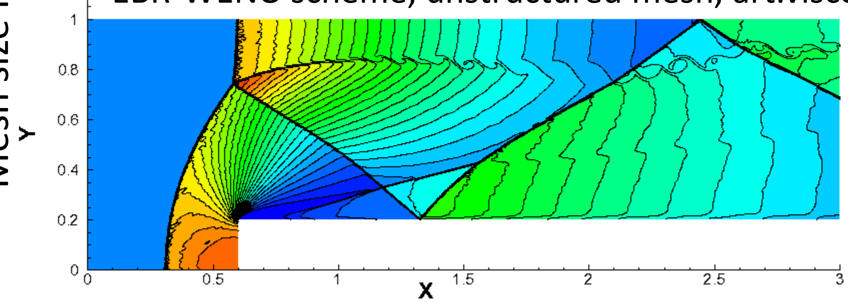
EBR-WENO scheme, unstructured mesh



EBR-WENO scheme, Cartesian mesh, art.viscosity



EBR-WENO scheme, unstructured mesh, art.viscosity



$$\mu_{AV} = \begin{cases} -k_1 \rho l^2 (\mathrm{div}\,\mathbf{u} + k_2 a / l), & \mathrm{div}\,\mathbf{u} + k_2 a / l < 0 \\ 0, & \mathrm{div}\,\mathbf{u} + k_2 a / l \geqslant 0 \end{cases}$$

l — cell size, a — sound speed,

$k_1 = 0.5$, $k_2 = 0.02$

Rodionov A. V. Artificial viscosity to cure the carbuncle phenomenon: The three-dimensional case, J. Comp. Phys., 361 (2018) 50-55

NORMA plan for KIAM for 2020 – WP 5

2020.5.1 Physical and computational formulation of the cases for single-rotor and multi-rotor configurations. Together with the French partners, the physical set-ups of all the cases of the Project, as well as the numerical algorithms to be used will be defined.

2020.5.2 Carrying out two dimensional simulation of case MP1.1 on the total noise generated by the helicopter's isolated main rotor. Vortex-resolution simulation of turbulent flow around the helicopter rotor in the hover mode. Estimation of the total far-field noise generated by it based on the integral method of Fox Williams and Hawkins (FWH).

2020.5.3 Carrying out two dimensional preliminary simulation of case MP2.1 on the tonal noise of an isolated quadrotor using the immersed boundary method, level set techniques and dynamic mesh adaptation. It is assumed that the area of the rotating rotor is filled with a polar mesh, while the mesh in the surrounding arias is unstructured. The sound source domain is calculated based on the Euler equations or in the framework of the RANS approach. The tonal noise in the far field is modeled by the FWH method.

2020.5.4 Carrying out the preliminary simulation of model case MP2.2 on modeling the tonal noise of a system of 4 quadcopter rotors using the immersed boundary method, techniques of level set function and dynamic mesh adaptation. The same model and methods are used as in the case of 2020.5.3. The question of the mutual influence of tonal noise generated by each of the rotors on the overall acoustic picture depending on the set distance is investigated.

NORMA joint research and joint papers

2020

??? Comparative analysis of the accuracy of edge-based ENO [?] and WENO [1] reconstructions
(together with INRIA)

2021

??? Development of the optimal hybrid RANS-LES approach for scale-rosolving simulation of turbulent flow
as applied to turbulent flow around rotor blades of rotocrafts
based on a comparative analysis of the approaches of partners (together with UM and INRIA)

??? Generalization of EBR schemes on the strand meshes in the boundary layers (together with INRIA)
Currently we are working on this

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??? We are highly interested in developing and implementing
efficient time integration algorithms (multirate scheme???, LU-SGS method???, multigrid???, ???),
in comparative analysis of their efficiency, including the efficiency of parallel implementation

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???

???

Case MP1.1

Caradonna-Tung rotor

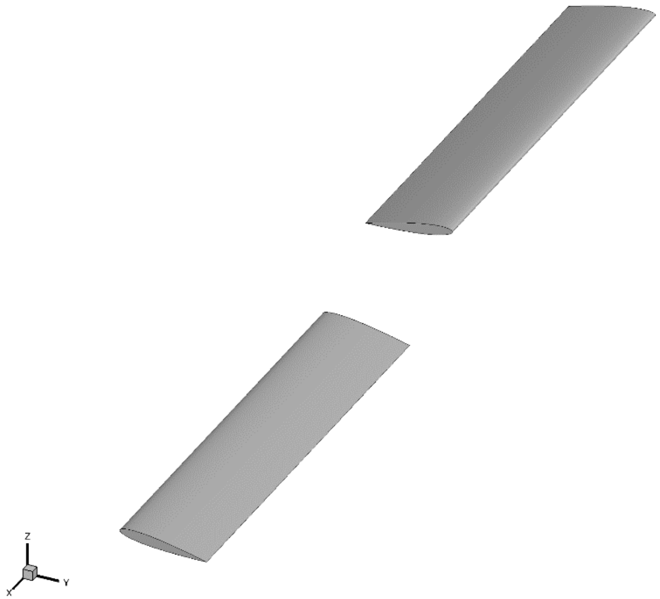
Caradonna F. X., Tung C. Experimental and analytical studies of a model helicopter rotor in hover: tech. rep. ; NASA. — Ames Research Center, Moffett Field, California, Sept. 1981. — NASA-TM-81232.

We already computed this case by RANS (it is convenient for both of us)

In NORMA we would like to compute it be RANS-LES in order:

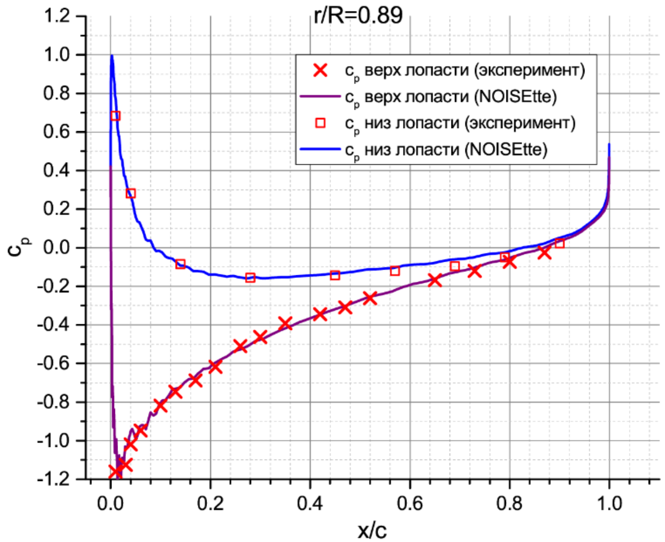
- to validate RANS-LES methods for aerodynamics;
- to compare our RANS-LES methods;
- hopefully to improve vortex-drift (see fig. at slide 12);
- to investigate far-field acoustics (unfortunately, no experimental data

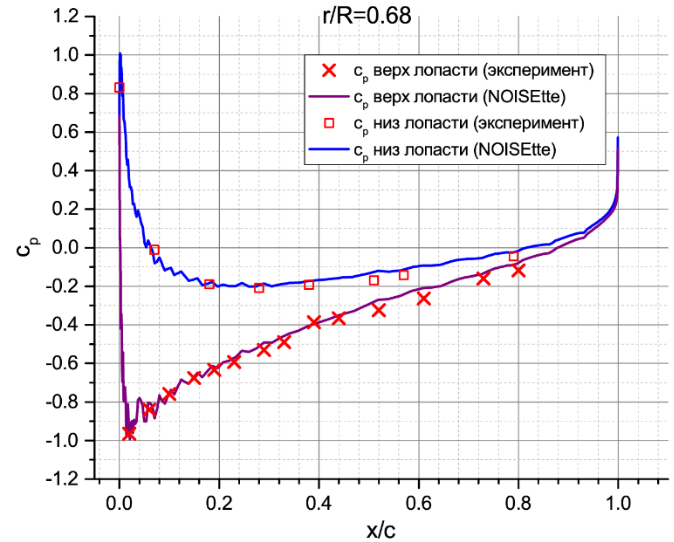
Case MP1.1. Setup

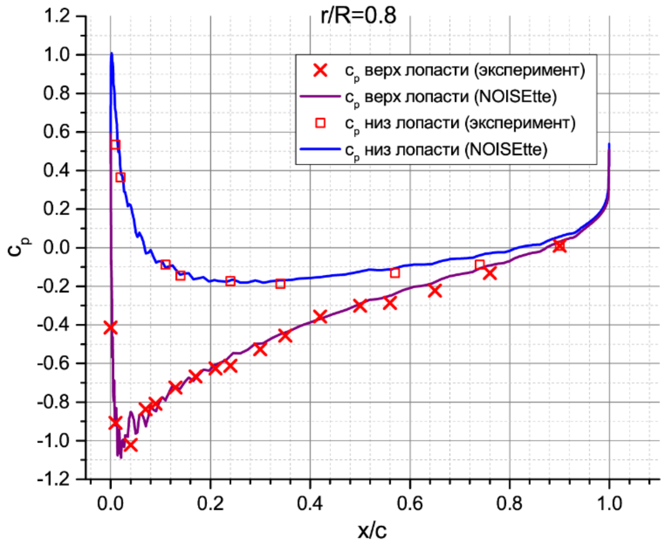


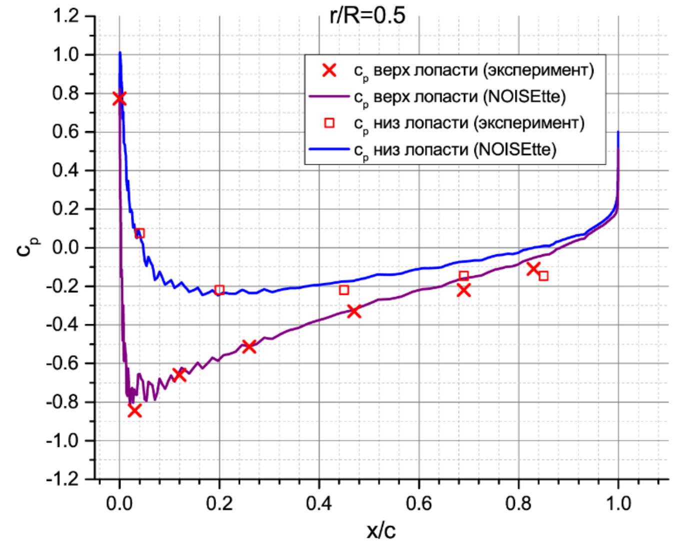
N – blades number	**2**
R – rotor radius	**1.143 m**
b – blade chord length	**0.1905 m**
blade base airfoil	**NACA-0012**
pitch angle	**8^o**
rotation speed	**650 RPM**
blade tip velocity V_{tip}	**77.8 m/s**
tip Mach	**0.228**

Case MP1.1. Experimental and numerical data









Case MP1.1. Experimental and numerical data