COMROTAG

Development and Testing of Computational Methods
to Simulate Helicopter Rotors with Active Gurney Flap

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Publishable Summary

Main Objectives of the Project:

- To develop, implement and validate through computational tests the computational methods enabling to simulate the flow around helicopter rotor with blades equipped with operating Active Gurney Flaps (AGF).
- Based on the developed software, to investigate physical phenomena that may occur in real flight of the helicopter with blades equipped with Active Gurney Flaps
- To assess potential benefits of application of Active Gurney Flaps on helicopter rotor blades as well as to determine the states of the helicopter flight, where these benefits are evident.

The developed software is the User-Defined-Function library, linked with the essential code of the ANSYS FLUENT - the solver of Navier-Stokes Equations, commonly used in Aeronautical Engineering. The developed software is responsible for every computational activities concerning rotorcraft applications, in particular concerning modelling the motion of Active Gurney Flaps mounted on helicopter rotor blades. For this purpose the innovative methodology based on "Dynamic/Deforming Mesh" technique has been developed and implemented. The software has been developed in three variants dedicated for solution of: 3D, 2.5D and 2D computational problems, though significant part of the developed code is common for all these three variants.

Validation and corrections of the developed software have been conducted with respect to accessible results of Wind Tunnel Tests, including:

- Quasi-two-dimensional WTT of rotor-blade segment investigated within the test chamber of wind tunnel. The segment was equipped with deployable Active Gurney Flap. The segment itself stayed motionless (in case of WTT conducted at University o Twente) or was oscillating around pitch axis (in case of WTT conducted in CIRA).
- Truly three-dimensional WTT of 4-blade Model Rotor of blades equipped with both the Active Gurney Flaps and Passive (fixed) Gurney Flaps. The WTT of the Model Rotor have been conducted at Politecnico di Milano.

Blind Tests of Hover and Forward Flight of 5-blade Full-Scale Rotor were focused on prediction of helicopter behaviour during Flight Tests as well as on assessment of potential performance benefits resulting from application of Active Gurney Flap on helicopter rotor blades.

Conducted validation of the developed software confirmed quite good convergence of computational results and accessible results of Wind Tunnel Test. This concerns both the 2.5 and 3D experimental results. Additionally the validation allowed to introduce some improvements in the developed code.

Based on results of conducted rotor Hover simulations, it may be concluded that application of moving Active Gurney Flaps in this state of helicopter flight makes sense and may give some performance benefits. In conducted simulations the evaluated performance benefits were up to 1.5% of relative growth of Figure of Merit, compared to the reference "clean-blade" configuration. Two alternative schedules of AGF motion in the rotor hover: "1-AGF-cycle/1-rotor-revolution" and "2-AGF-cycles/1-rotor-revolution" were investigated and they gave similar performance benefits. However, to fulfil so called "zero-flapping-trimming" conditions, the former schedule required setting of non-zero collective pitch of rotor blades while the latter schedule did not need such setting.

Based on results of conducted rotor Forward Flight simulations, it may be concluded that application of Active Gurney Flaps in this state of helicopter flight may give significant improvement of helicopter performance.

- For higher values of thrust, in presence of the retreating-blade dynamic stall, the application of AGF leads to performance improvement in comparison to the "clean-blade" configuration. In conducted simulations the performance benefits were up to 7.3% of relative growth of Power Loading, defined as a ratio Thrust to Power, compared to the "clean-blade" configuration. The performance benefits in this case for both the Active-Gurney-Flap and Passive-Gurney-Flap (fixed) configuration are similar.
- For lower values of thrust, when the dynamic stall does not occur, the configurations with Active Gurney Flaps, compared to the "clean-blade" configuration, do not indicate the significant power penalty, which is observed for the Passive-Gurney-Flap configurations.
- Optimised ramp schedule of AGF kinematics may improve the rotor performance compared to the sinusoidal schedule.

In the conducted simulations special attention was paid to the trailing-edge unsteady vortex shedding. This phenomenon is characteristic for blades of thickened trailing edge, in particular when the thickening is a result of deflection of Active Gurney Flap. The strong vortex shedding may be a source of unfavourable additional drag and noise.

In case of two-and-half dimensional flow, the computational simulations of flow around the blade segment and accessible experimental results, complied with each other quite well in respect to unsteady-vortex-shedding phenomenon. For lower values of lift coefficient (fully attached flow on both sides of the airfoil) the unsteady vortex shedding was well visible in both the vorticity or Q-criterion contours and in oscillating distributions of pressure on the airfoil surface. Determined computationally and experimentally frequencies of these oscillations were similar to each other. However, this unsteady phenomenon indicated tendency of disappearing for higher values of lift coefficient, especially when strong or even moderate separation of flow over the suction surface of the airfoil appeared. Disappearance of unsteady vortex shedding in such conditions may be explained by asymmetry of vortices generated at the upper and lower surface of the airfoil trailing edge. In presence of flow separation, the upper (suction-side) vortex is much weaker than lower (pressure-side) or even does not exist at all. In such situation the lower vortex is firmly coupled with the trailing edge. In case of fully attached flow, the counter-rotating vortices generated at lower and upper surface of the trailing edge have similar intensities and they influence each other, causing their alternate detachment from the trailing edge of the blade.

In truly three-dimensional flow around the rotating blades of helicopter main rotor, the unsteady-vortex-shedding is much more difficult to investigate both computationally and experimentally. Concerning the computational simulations, for most of considered Hover and Forward Flight priorities and for all rotor-blade configurations, the trailing-edge unsteady vortex shedding has not been observed, at least based on analysis of time-dependant contours of vorticity magnitude or Q-criterion. This applies both to the nominal computational time step (usually 1440 time steps per one revolution of the rotor) and tenfold or even twenty times smaller. However, it is possible that in real flight of the helicopter the vortex-shedding phenomenon may occur. Possible reasons of divergences between the CFD-simulations and the real flight conditions may be:

- insufficiently small time step (even tenfold smaller than nominal),
- constraints of computational model (URANS) or of turbulence model (k-w SST),
- insufficiently fine computational mesh.