# SEARCH FOR DETERMINING PHYSICAL FACTORS IN VALIDATION CALCULATIONS OF THE ONERA LAPCAT II EXPERIMENTAL MODEL TAKING INTO ACCOUNT THE DUCT WALL ROUGHNESS

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**Abstract:** The results of the second stage of numerical simulation of the ONERA LAPCAT II experiment on high-speed hydrogen combustion in a model duct are described. At this stage, calculations were carried out taking into account a duct wall roughness. The results of calculations based on the IDDES-SST approach are presented. It is shown that the effect of wall roughness is significant but does not allow achieving a good agreement with experimental data. The search for determining physical factors was carried out on the basis of Reynolds-averaged Navier–Stokes calculations. The influence of chemical kinetics, variable turbulent Prandtl number, and roughness height was tested. The temperature of duct walls (in addition to wall roughness) has the greatest influence on the pressure distribution along duct walls. The temperature of walls that ensures a good agreement with the ONERA experiment was found.

**Keywords:** supersonic combustion; roughness; heat transfer; numerical simulation; experimental validation

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## Figure Captions

**Figure 1** Duct geometry and block structure of the computational mesh for calculations of the ONERA LAPCAT II experimental model: arrows — fuel supply; *1* — segment with constant cross section; *2* — segment with an extension of 2°; *3* — segment with an extension of 6°; *4* — segment with an extension of 2°; and *5* — expanding buffer segment with slip walls

**Figure 2** Comparison of calculations (curves) with experimental (signs) static pressure distributions along the upper wall of the duct [6]: (*a*) RANS calculations by ONERA [9] and TSAGI [11]; (*b*) IDDES-TsAGI calculations, "wall law" with roughness taken into account; *1* — ONERA experiment, without fuel supply; *2* — ONERA experiment, with fuel supply; *3* — RANS-calculation of ONERA, smooth walls; *4* — RANS-calculation of ONERA, rough walls; *5* — RANS-calculation of TsAGI, smooth walls; *6* — basic IDDES-calculation of TsAGI; *7* — IDDES-calculation of TSAGI, $h_s = 65$ $\mu$m; and *8* — IDDES-TsAGI calculation, corrected flow rate

**Figure 3** Comparison of the Mach number fields obtained in IDDES calculations: (*a*) with smooth duct walls; and (*b*) with rough walls. White colour — isolines $u = 0$

**Figure 4** Comparison of calculations (curves) with experimental (signs) static pressure distributions along the duct upper wall [6]: (*a*) IDDES-calculations of TSAGI with roughness taken into account; (*b*) RANS-calculations of TsAGI [11]; *1* — ONERA experiment, without fuel supply; *2* — ONERA experiment, with fuel supply; *3* — IDDES-calculation of TsAGI, $h_s = 65$ $\mu$m and corrected flow rate, "wall law" boundary condition; *4* — IDDES-calculation of TSAGI for the same parameters, no-slip condition; *5* — RANS-calculation for the same parameters; *6* — RANS-calculation, kinetics with 19 reactions; and *7* — RANS-calculation, $\mathrm{Pr}_t = 0.7 = const$

**Figure 5** Field of heat release rate obtained in RANS-calculations: (*a*) calculation of ONERA [9]: field of the heat release rate, averaged over the duct side width, superimposed on the density gradient field; (*b*) calculation of TSAGI 2021, instantaneous field of decimal logarithm of the local heat release rate in the duct symmetry plane, the temperature of walls is 716 K, the vertical scale is increased by a factor of 2, contours of the longitudinal velocity are shown; and (*c*) analogous field for wall temperature 1413 K

**Figure 6** The structure of the calculation meshes in the region of hydrogen injection: (*a*) TsAGI mesh, which was used in the calculations of 2021 (in the background — the longitudinal velocity field); and (*b*) ONERA mesh from [10]

**Figure 7** Comparison of 2021 RANS calculations of TSAGI based on the no-slip condition for rough walls with experimental static pressure distributions along the duct upper wall [6]: (*a*) initial stage of the study; (*b*) influence of temperature and approximation errors; *1* — ONERA experiment, without fuel supply; *2* — ONERA experiment, with fuel supply; RANS calculations: *3* — $h_s = 100\ \mu$m; *4* — heat-insulated walls; *5* — 1st order of approximation; *6* — $T_W = 1000$ K; *7* — 1540; and *8* — $T_W = 1413$ K

**Figure 8** Schlieren image of the flow in the region of the fuel injection: (*a*) figure from [6] with an interpretation of the flow elements and with an enlarged jet blowing region; and (*b*) zoomed jet blowing region with superimposed isolines of the Mach number obtained in the RANS calculation of TsAGI

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