RAMJET WITH CONTINUOUS DETONATION OF HYDROGEN: DESIGN OPTIMIZATION AND TEST FIRES AT MACH NUMBERS OF 1.5 TO 2.5

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Abstract: Computational and experimental studies are performed to refine the design of a hydrogen-fueled detonation ramjet (DR) studied earlier. The design is refined using the computational technology of the Federal Research Center for Chemical Physics (FRC) and test fires in the pulsed wind tunnel of the FRC at the approaching airflow Mach numbers of 1.5, 2.0, and 2.5. The design refinement is aimed at increasing the stability of the air intake at $\mathrm{M} = 2.0$, reducing the aerodynamic drag, and increasing the thrust performance of the DR. A new version of the DR is manufactured and tested. The most important result of the test fires is a significant increase in the thrust performance of the new DR version compared to the old version. Thus, at $\mathrm{M} = 1.5$, the increase in the total thrust and fuel-based specific impulse reached 200 N and 1100 s, respectively, and at $\mathrm{M} = 2.0$, it reached 400 N and 1300 s, respectively. In addition, at $\mathrm{M} = 2.0$, the range of stable operation of the DR combustor with continuous detonation of hydrogen is significantly expanded: from the value of the air-to-fuel equivalence ratio ~ 1.6 to ~ 3.3. At the air-to-fuel equivalence ratio of 3.1, the value of the fuel-based specific impulse reached ~ 4760 s. At $\mathrm{M} = 2.5$, a stable continuous-detonation operation process was obtained for the first time in the DR of this type. The maximum values of total thrust and fuel-based specific impulse in test fires with $\mathrm{M} = 2.5$ were 1160 N and 3780 s, respectively.

Keywords: detonation ramjet; hydrogen; three-dimensional gasdynamic calculations; ramjet layout; start-up Mach number; wind tunnel; test fires

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Figure Captions

Figure 1 The layout of the new DR version. Dimension are in millimeters

Figure 2 Three-dimensional model (*a*) and photograph (*b*) of the new DR version

Figure 3 Images of test fires of old ($\alpha_C = 1.05$) (*a*) and new ($\alpha_C = 1.12$) (*b*) DR versions at $\mathrm{M} = 1.5$

Figure 4 Experimental dependences of total thrust (*a*) and fuel-based specific impulse (*b*) on the air-to-hydrogen equivalence ratio α_C for the old (*1*) and new (*2*) DR versions at $\mathrm{M} = 1.5$

Figure 5 Images of test fires of old ($\alpha_C = 1.19$) (*a*) and new ($\alpha_C = 1.25$) (*b*) DR versions at $\mathrm{M} = 2.0$

Figure 6 Experimental dependences of total thrust (*a*) and fuel-based specific impulse (*b*) on the air-to-hydrogen equivalence ratio for the old (*1*) and new (*2*) DR versions at $\mathrm{M} = 2.0$

Figure 7 Experimental records of forces acting on the DR at $\mathrm{M} = 2.0$: *1* — record for the old DR version ($\alpha_C = 1.19$; hydrogen flow rate 51 g/s); and *2* — record for the new DR version ($\alpha_C = 1.25$; hydrogen flow rate 42 g/s). The force is positive if directed against the approaching air flow

Figure 8 Images of supersonic air jet ahead of the DR air intake at $\mathrm{M} = 2.5$ (*a*) and test fire ($\alpha_C = 1.19$) of a new DR version (*b*) at $\mathrm{M} = 2.5$

Figure 9 Experimental dependences of total thrust (*a*) and fuel-based specific impulse (*b*) on the air-to-hydrogen equivalence ratio for the new DR version at M = 2.5

Table Captions

Table 1 The main parameters and results of test fires of the new DR version at M = 1.5

Table 2 The main parameters and results of test fires of the new DR version at M = 2.0

Table 3 The main parameters and results of test fires of the new DR version at M = 2.5

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