MULTIDIMENSIONAL SIMULATIONS AND TEST FIRES OF A HYDROGEN-FUELED RAMJET WITH AN ANNULAR DETONATIVE COMBUSTOR AT APPROACHING AIR FLOW OF MACH 2 AND 1.5

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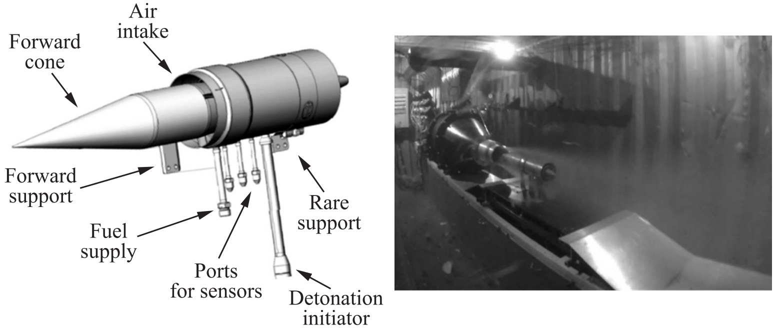
Modern high-speed unmanned aerial vehicles are powered with small-size turbojets or ramjets. Existing ramjets operating on the thermodynamic cycle with deflagrative combustion of fuel at constant pressure are efficient at flight Mach numbers M ranging from about 2 to 6.



(*a*) (*b*)

Figure 1 Hydrogen-fueled CDR: (*a*) 3D-model; and (*b*) video frame of CDR test fire in the free-jet wind tunnel before ignition

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One of the most important characteristics of a ramjet-powered aircraft is the minimum Mach number (start-up Mach number M_S) at which an autonomous flight of an aircraft becomes possible after a launch boost provided by auxiliary boosters such as solid propellant rocket engines. For existing ramjet-powered aircraft, $M_S \approx 2$.

The objective of the present work is to explore the possibility of reducing the value of M_S for the hydrogen-fueled continuous-detonation ramjet (CDR) 120 mm in diameter and 700 mm long. As shown in [1] based on three-dimensional (3D) numerical simulations, the start-up Mach number of the hydrogen-fueled CDR designed for the Mach 2 flight (Fig. 1) is as low as $M_S = 1.3$. Test fires in a free-jet wind tunnel show that the designed CDR exhibits a stable detonative-combustion operation process and provides a positive effective thrust at both $M = 2$ and 1.5. As an example, Fig. 2 shows the frames of CDR test fires at different air-to-fuel equivalence ratios α and $M = 1.5$. Figure 3 shows the effect of α on the measured CDR total thrust and fuel-based specific impulse. At $0.8 < \alpha < 1.6$, the CDR is seen to exhibit a total thrust with the maximum value of 650 N at $\alpha \approx 1$ for $M = 1.5$.

Based on the numerical simulation of the CDR cold drag, the estimated effective thrust reaches 200 N for $M = 1.5$. For the conditions of $M = 2$, the corresponding values are 860 and 160 N. The maximum fuel-based specific impulse of 1600 s is attained at $\alpha \approx 1.4$. The value of $\alpha \approx 1.6$ is considered as the margin of CDR operation at both $M = 1.5$ and 2.0 conditions since further increase in α re-

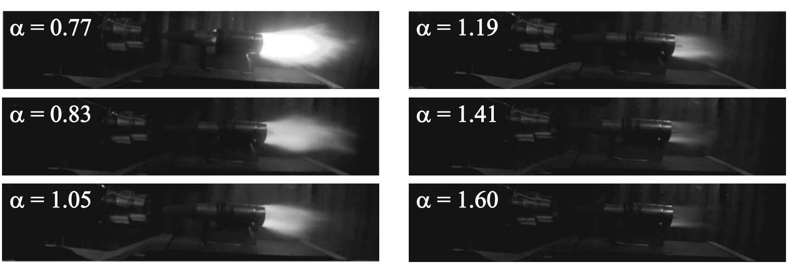

Figure 2 Video frames of CDR test fires in the free-jet wind tunnel at different α; $M = 1.5$

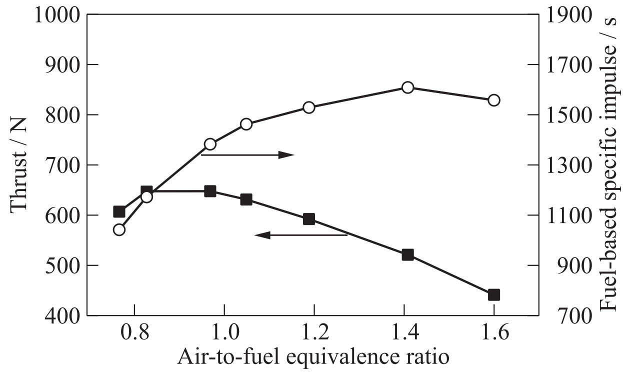

Figure 3 Measured thrust and specific impulse of the CDR vs. the air-to-fuel equivalence ratio α in test fires with M = 1.5

sults in ignition failure. At M = 1.5 and 2.0, the positive effective thrust is obtained for α ranging from 0.8 to 1.6 and from 0.8 to 1.3, respectively. The deterioration of thrust performance at M = 2.0 is explained by unstable operation of the CDR intake with boundary layer separation upstream the combustor inlet. The future work will be focused on the adjustment of the CDR design using multivariant numerical simulations.

Acknowledgments

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References

1. Ivanov, V. S., A. E. Zangiev, and S. M. Frolov. 2019. Hydrogen-fueled ramjet with an annular detonative combustor. *Recent progress in detonation for propulsion*. Eds. S. M. Frolov and J. Kasahara. Moscow: TORUS PRESS. 61–64. doi: 10.30826/IWDP201923.