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Gas flow in a truncated Laval nozzle with a bell-shaped tip

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Flow in a truncated supersonic Laval nozzle with a bell-shaped tip (“bell”) is investigated. This nozzle configuration can be used in tight layouts of multistage rockets of short length with improved energy-mass characteristics. Similar types of nozzles were developed at the Institute of Technical Mechanics of the National Academy of Sciences and the State Space Agency of Ukraine in the 1990s. Using approximate methods, the parameters of variously configured truncated nozzles were calculated, and their models were made. Some of the models were blown with cold air, and their characteristics were measured. Shadow patterns of gas flow downstream of the nozzle and soot-oil patterns of streamlines on the nozzle wall were obtained. These results were used in the formulation of this work.

In this work, a numerical study with the ANSYS package was carried out for gas flow in a truncated Laval nozzle with a spherical tip. For this nozzle configuration, its model was blown with cold air. The calculated results were verified by comparing the velocity distribution in the gas flow downstream of the nozzle exit with the experimental shadow patterns. An additional confirmation of the correctness of the calculated results was a comparison of the flow downstream of a streamline-profiled Laval nozzle with the underexpanded flow pattern downstream of the nozzle exit in the first “cask” (up to the Mach disk) studied in detail. The same initial data and initial conditions that give the best results in terms of verifiability were chosen in both cases.

The study of flow in a truncated supersonic nozzle showed the following results. Downstream of the corner exit point of the truncated section of a Laval nozzle, flow separation is observed where the gas flow enters the “bell”. The separation is retained as the pressure upstream of the nozzle increases up to a certain critical (for a given tip type) value of the underexpansion ratio, after which (with a further increase in the underexpansion ratio) the flow attaches to the nozzle wall and remains attached with a further increase in the pressure upstream of the nozzle. The impulse response of a truncated nozzle with a bell-shaped tip is lower than that of a streamline-profiled Laval nozzle of the same geometric expansion ratio.

Keywords: *Laval nozzle, truncated nozzle, bell-shaped tip, flow pattern.*

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