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O. D. Ihnatiev, N. S. Pryadko, G. O. Strelnikov, K. V. Ternova

Thrust characteristics of a truncated Laval nozzle with a bell-shaped tip

Institute of Technical Mechanics
of the National Academy of Sciences of Ukraine and the State Space Agency of Ukraine
15 Leshko-Popel St., Dnipro 49005,Ukraine; e-mail: np-2006@ukr.net

This paper presents the results of a thrust performance study of an unconventionally shaped supersonic nozzle in the form of a truncated Laval nozzle with a bell-shaped tip. This nozzle shape may be used in the development of compact layouts of multistage rockets. The study was carried out using the ANSYS software package in a 3D formulation. The methodological approaches to the numerical calculation of a complex separated gas flow used in this study were verified in a previous study of the flow pattern in similar nozzle. Some results of exact calculations were compared with the results of experimental studies carried out at the Institute of Technical mechanics of the National Academy of Sciences of Ukraine and the State Space Agency of Ukraine for a model of a similar truncated nozzle with a bell-shaped tip blown with a cold air.

This study detailed the features of the separated gas flow in a spherical tip connected (at the corner point) to a truncated supersonic Laval nozzle of conical shape. It was found that the pattern of the separated flow in the tip depends on the nozzle flow expansion degree (nozzle inlet pressure). At a relatively low nozzle inlet pressure, a developed separation zone is observed in the nozzle tip (between the jet boundary and the nozzle wall) with a subsonic flow from the external environment, which forms an almost constant static pressure from the tip inlet cross-section to the tip exit. At a nozzle inlet pressure at which the free boundary of the jet flowing from the truncated nozzle adjoins the nozzle wall, the static pressure in the tip varies almost linearly along the tip length from the corner point with the minimum pressure to the tip exit. The dependence of the thrust of a tipped nozzle on the nozzle inlet pressure is nonlinear. As the pressure upstream of the nozzle increases (or the ambient pressure decreases), the effect of the external environment on the tipped-nozzle thrust diminishes. It is shown that under "terrestrial conditions" the thrust of a truncated nozzle with a tip exceeds the thrust of a profiled nozzle with the same geometric expansion degree (due to the atmosphere “entering” the tip). Under "vacuum” conditions, the former is 8% less than the latter.

Keywords:. *truncated supersonic nozzle, bell-shaped tip, static pressure distribution, nozzle thrust characteristic, ambient pressure*

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