ARTICLE IN PRESS

Acta Astronautica xxx (2017) 1–20

Contents lists available at ScienceDirect

Acta Astronautica

journal homepage: www.elsevier.com/locate/actaastro

Ensuring safe descend of reusable rocket stages – Numerical simulation and experiments on subsonic turbulent air flow around a semi-circular cylinder at zero angle of attack and moderate Reynolds number

Sergey Isaev [a,*], Paul Baranov [a], Igor Popov [b], Alexander Sudakov [a], Alexander Usachov [c,**], Sergey Guvernyuk [d,***], Alexei Sinyavin [d], Alexei Chylunin [d], Alexander Mazo [e], Eugeny Kalinin [e]

[a] Saint-Petersburg State University of Civil Aviation, Saint-Petersburg 196210, Russia
[b] A. N. Tupolev Kazan National Research Technical University (Kazan Aviation Institute), Kazan 420111, Russia
[c] N. E. Zhukovskii Central Aerohydrodynamic Institute, Moscow 107005, Russia
[d] Lomonosov Moscow State University Institute of Mechanics, Moscow 119192, Russia
[e] Kazan Federal University, Kazan 420008, Russia

ARTICLE INFO

Keywords:
Semi-circular cylinder
Turbulence
Compressibility
Calculation
Experiment

ABSTRACT

Two-dimensional flow around semi-circular cylinder at zero angle of attack and at $Re = 50000$ during the self-oscillatory regime has been extensively studied within the URANS method with the use of different-structure grids (multiblock, structured overlapping, unstructured composite), the SST turbulence model and its versions (1993) and (2003) considering the streamline curvature influence modified within the Rodi–Leschziner–Isaev approach and numerical different-approximation methods realized in two codes (VP2/3, Fluent). Experiments have been made on flow around a semi-circular cylinder in the wind tunnel of the Lomonosov Moscow State University, Institute of Mechanics to obtain data for verification of numerical predictions. The double-mode character of a periodic time history of a drag force caused by a periodically forming and disappearing jet flap and acting upon a body is explained. With increasing compressibility at a Mach number ranging from 0 to 0.5, it is observed that periodic flow around the semi-circular cylinder is restructured, and the time history of the drag force acting upon it is described by a dependence close to a sinusoidal one. It is found that, as the Mach number is increased, pressure field distortions in the form of concentric cylindrical waves propagating from the semi-circular cylinder and the vortex street behind it grow over the infrasonic range.

1. Introduction

One of the actual problems of ensuring safe descend of rocket stages is associated with predicting the behavior of reusable rocket stages [1], for solution of which it is necessary to assess their aerodynamic characteristics. To calculate these characteristics with the use of modern software and to verify the turbulence models chosen, test problems have been solved. The present article deals with numerical and physical modeling of subsonic air flow around semi-circular cylinder at zero angle of attack and moderate Reynolds and Mach numbers.

Recent interest in turbulent flow around such a cylinder [2] is caused by a specific behavior of its time-averaged aerodynamic characteristics at the angles close to the zero angle of attack α. It has appeared that at $\alpha = 0^\circ$ the lift coefficient C_y takes a low peak value (of the order of −1) and at small deviations of α from zero, C_y sharply increases. The reason for such a behavior is stimulated by restructuring the C_y oscillation period-averaged vortex pattern of flow around the semi-circular cylinder [3] related to the movement of the attachment point of the flow separated from the leading edge of such a cylinder in the vicinity of its trailing edge.

The semi-circular cylinder can also be considered as a thick (50% of the chord) airfoil. In this respect, growing interest in such a cylinder can

* Corresponding author.
** Corresponding author.
*** Corresponding author.
E-mail addresses: isaev3612@yandex.ru (S. Isaev), paul-baranov@yandex.ru (P. Baranov), popov-igor-alex@yandex.ru (I. Popov), sudakov-1950@mail.ru (A. Sudakov), usachov_al@mail.ru (A. Usachov), guv@mail.ru (S. Guvernyuk), sinyavin@mail.ru (A. Sinyavin), chulyu-n@mail.ru (A. Chylunin), abmazo1956@gmail.com (A. Mazo), kalininei@yandex.ru (E. Kalinin).

https://doi.org/10.1016/j.actaastro.2017.10.028
Received 7 September 2017; Received in revised form 16 October 2017; Accepted 21 October 2017
Available online xxxx