JOURNAL OF PROPULSION AND POWER
Vol. 25, No. 3, May–June 2009

Technical Notes

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Buzz Instability in a Mixed-Compression Air Intake

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DOI: 10.2514/1.39751

I. Introduction

THE buzz instability in an air intake was first observed by Oswatitsch [1]. Ferri and Nucci [2], via detailed experiments on an axisymmetric external compression air intake, attributed the occurrence of buzz instability to the velocity discontinuity across the vortex sheet originating at the intersection of the conical shock and strong shock ahead of the intake entrance. The fluctuations began when this vortex sheet approached the inner surface of the cowling. Dailey [3] attributed the origin of the buzz oscillations to a random pressure pulse from the subsonic diffuser. He related the frequency of oscillations to that of an organ pipe with one end closed and the other end open. Fisher et al. [4] conducted experiments on a rectangular external compression intake with a variable ramp. Two kinds of oscillations were found in their tests: “big” and “little” buzz. They had the same frequency of oscillation but different amplitudes. The little buzz was found to be caused by the flow separation below the cowl and is similar to the Ferri type of buzz. The big buzz, on the other hand, was caused by the separation of the boundary layer along the ramp. It is very similar to the Dailey type of buzz. It was also observed that the little and big buzz occur for lower and higher mass flow reduction, respectively. Trapier et al. [5] conducted an experimental as well as a computational study of flow in a rectangular mixed-compression intake for a Mach number range of 1.8–3.0. Both little and big buzz were observed. The little buzz was of the Ferri type They related the oscillations to the acoustic resonance of the shear layer instabilities under the cowl lip. The big buzz was of the Dailey type and occurred due to the separated flow on the ramp in a supersonic diffuser that blocks the intake. The oscillations were caused due to the periodic filling and discharging of the intake. The oscillation frequency of the little buzz was found to be higher than that of the big buzz.

Efforts to numerically investigate the mixed-compression inlets have been very few. Knight [6,7] studied two- and three-dimensional supersonic diffuser flows in simple geometries using the Reynolds-averaged Navier–Stokes equations. Chan and Liang [8] carried out a numerical study of a two-dimensional mixed-compression inlet whose geometry was similar to the one experimentally studied by Anderson and Wong [9]. Jain and Mittal [10] carried out a finite element flow analysis in a mixed-compression inlet by solving the Euler equations. The starting as well as the unstarting of the intake was studied. Recently, Trapier et al. [11] carried out a detached-eddy simulation and compared the results with their own experiments.

The present work is a part of our ongoing work [10] to study flow in mixed-compression intakes. The viscous effects have been included in this work. The geometry of the inlet is very similar to the one experimentally studied by Anderson and Wong [9]. The governing equations for the flow analysis are the compressible Navier–Stokes equations in the conservation law form. A stabilized finite element formulation based on conservation variables is used to solve the flow equations. The streamline-upwind/Petrov–Galerkin stabilization method [12,13] is employed to stabilize the computations against spurious numerical oscillations due to advection-dominated flows. A shock capturing term is added to the formulation to provide stability to the computations in the presence of discontinuities and large gradients in the flow [14–16]. The time integration of the flow equations is done via the generalized trapezoidal rule. For unsteady computations, we employ a second-order accurate-in-time procedure. The role of bleed in starting/unstarting the intake and controlling the buzz instability is investigated. The flow during the buzz is studied in detail to bring out the difference between the little and big buzz.

II. Problem Setup

The mixed-compression intake that is modeled in this work has two ramps. The first ramp is at an angle of 7 deg to the freestream and its length is 28 in. These numbers for the second ramp are 14 deg and 24.1 in., respectively. The two ramps are followed by a throat and a subsonic diffuser. The total length of the intake is 119.02 in. The specification of backpressure at the exit of the intake leads to flow reversal and, therefore, difficulties in carrying out the numerical computations. To alleviate this difficulty, a duct is attached at the exit of the intake and the backpressure is specified at the end of this duct. The duct walls are assumed to be inviscid so that the duct is associated with minimal pressure loss. The length of the duct is twice that of the intake. The cross-sectional area of the duct, compared with that of the throat, is large enough to allow the startup shock to pass through. Computations with Euler equations for the $M = 3$ were reported in an earlier work [10]. With the viscous flow, the intake is unable to start even without the application of any backpressure. An increase in throat area is used to start the flow. The throat area of the original geometry from Anderson and Wong [9] is referred to as A_{to}.

All the results in this paper are shown with respect to the nondimensionalized variables. The length of the intake is used as the characteristic length to nondimensionalize all the length scales. The origin of the coordinate axis is fixed at the leading edge of the first ramp. The inflow and upper boundaries are located 0.2 and 1.0 units, respectively, from the leading edge of the inlet. The flow internal as well as external to the intake is computed. The vertical location of the upper boundary is chosen such that the shock from the engine cowl leaves the computational domain through the outflow boundary. At the inflow boundary, freestream conditions corresponding to $M = 3$ flow are specified. The density, velocity, and temperature are assigned freestream values. A no-slip condition for the velocity and an adiabatic condition for the heat flux are specified on the walls of the intake. On the upper and lower boundaries of the computational domain, the component of velocity normal to the boundaries is specified to be zero. In addition, the component of the

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Received 14 July 2008; revision received 25 December 2008; accepted for publication 26 January 2009.

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