Editorial

Underexpanded and Overexpanded Supersonic Jets

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INTRODUCTION

Supersonic jets exhausting from convergent–divergent nozzles are inherently present in all propulsive systems of flight vehicles. The aerodynamic study of such flow configurations represents one of the most challenging issues in aerospace and military applications (rockets, missiles, supersonic aircrafts, etc). Various physical phenomena involved in this basic fluid-dynamics problem, such as shock formation and shock/turbulent boundary layer interaction inside the nozzle, are directly linked to the performance of jet engines. Particularly, when the flow exiting the nozzle encounters a pressure difference (either positive or negative) due to the ambient atmosphere, it leads to the formation of complicated shock-wave structures (direct or inverse Mach reflections, reflected shock, triple point and associated sliplines, which grow to become slip zones as a result of the Kelvin-Helmholtz instability). Generally, as the chamber pressure increases, the flow gradually adapts to the ambient conditions as it passes through the system of expansion and compression waves, forming different types of jet structures (ranging from under- to overexpanded regimes and passing by the adapted nearly shock-free supersonic case). Figure 1, which is based on experimental photography illustrations, highlights the different types of jet structures as function of the nozzle pressure ratio.

In addition to the above mentioned phenomena that are mainly encountered in classical compressible aerodynamics, high-speed jets are also of interest in many other applications. Examples are the needle-free powdered drug and vaccine delivery using supersonic jets for medical purposes [1-3], oxy- and thermal jet plasma for metal cutting process [4,5], transient jet ejecta in astrophysical such extra-galactic jets [6] and the explosion safety associated with accidental puncture of high-pressure vessels or lines designed for the storage of gas fuels, such as hydrogen [6].

Although over several decades of extensive researches (which largely relies on experimental measurements and analytical predictions) into supersonic flows with particular interest in jet structures [7-17], the subject is quite complex and not yet clearly understood. These analyses and measurements provide a useful but sometimes incomplete indication of important flow aspects, such as the starting process, and the jet separation inside the nozzle. In fact, the experimental analysis of such a situation is quite difficult and rather expensive, because it requires flow visualizations and measurements inside the divergent section in the few seconds of the run (or milliseconds for the crucial part of the transient). Since the main finding is revealing the unsteady nature of the jet flow, the quantitative CFD data, if previously well validated through appropriate benchmark calculations, should in principle help to understand and explain the complex jet behavior.

SPECIAL ISSUE

The objective of this special issue is to put together both novel experimental and numerical studies related to supersonic jets in order to shade more physical insight to the considered subject and to help provide a base for future works for further in-depth understanding of this area. This issue includes five original contributions received from experts in the various aspects of supersonic nozzles and jets (physical description, advanced measurements and numerical simulations). All manuscripts have been peer-reviewed according to the IJAI procedure and policy.

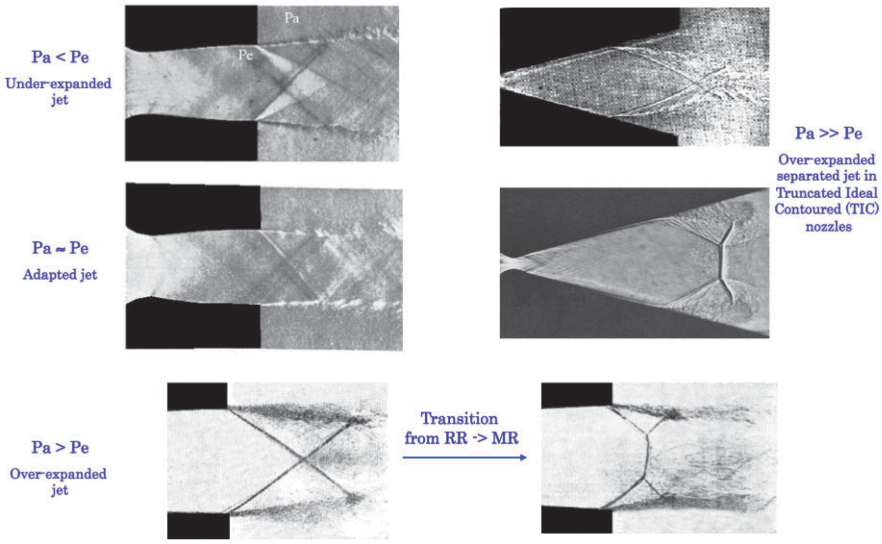

Figure 1: The off-design operating conditions of supersonic nozzles as a function of the nozzle-exit to ambient pressure ratio, Pe/Pa. This leads to the formation of different flow structures with overexpanded (Pe<Pa), adapted (Pe=Pa) and underexpanded (Pe>Pa) jets. In the particularly interesting case of highly overexpanded regime (Pa>>Pe), the boundary layer separates from the nozzle leading to a strong shock/boundary layer interaction at the wall, while at the centreline either regular or Mach reflections are formed. This type of configurations (and their associated RR ⇔ MR transition) is also observed at the nozzle lip in the case of fully expanded jet with attached boundary layer. It is worth noting that in the case of round or axisymetric jet, the regular reflection configuration is unlikely to occur [18]. Further increase of the nozzle chamber pressure will result in a reduction of the height of the Mach disk, which moves further downstream of the nozzle exit until a smooth transition from MR to an apparent regular reflection (aRR), characterized by a very small (and not easily visible) Mach disk. Strictly speaking, the wave structures within the supersonic jet are not steady since they are excited by the surrounding turbulence. However, the average positions of the shock structures, as shown in this set of pictures, are quite well defined. The turbulence can either come from inside the nozzle - through the boundary layer - or from outside - within the jet boundary. This later when it reaches the axis of the jet, the flow becomes subsonic and fully turbulent. Photographs used for the illustration purpose, courtesy of Amann [19], Carafoli [20], Liepmann & Roshko [21].

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