Aeroacoustics of Single and Multiple Supersonic Impinging Jets

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In this paper, we describe the results of an ongoing extensive study on the aeroacoustic properties of single and dual supersonic impinging jets, such as those occurring in the next generation of STOVL aircraft. We conclusively demonstrate that the highly unsteady flowfield, ubiquitous in both configurations, is due to a feedback loop between the fluid and acoustic fields. This unsteady behavior can lead to a number of performance diminishing effects, collectively referred to as ground effect, when such flows occur in a STOVL aircraft during hover. A unique active control technique was attempted with the aim of disrupting the feedback loop - both for single and dual impinging jets - and diminishing the flow unsteadiness and ultimately reducing the adverse effects of this flow. Flow control was implemented by placing an array of very small (400μm) supersonic microjets around the periphery of the main jet(s). This control approach was very successful in disrupting the feedback loop in that the activation of the microjets led to dramatic reductions in the lift loss (as much as 40%), unsteady pressure loads (10-14 dB) and nearfield noise (6-8 dB). This relatively simple and highly effective control technique makes it a suitable candidate for implementation in practical aircraft systems.

1. INTRODUCTION

While hovering in close proximity to the ground, Short Take-off and Vertical Landing (STVOL) aircraft experience a suckdown force, commonly known as "lift loss". This lift loss is due to the entrainment flow associated with the lifting jets which induce low surface pressures on the airframe resulting in a force opposite to lift. The lift loss in hover increases in magnitude as the aircraft approaches the ground. When the aircraft is in vertical landing mode and is near touch down, in addition to lift loss, the impingement of the high speed lifting jets on the ground plane leads to significant ground erosion[1]. Increased Over All Sound Pressure Levels (OASPL) associated with the supersonic jets is also of concern with respect to sonic fatigue of structural elements in the vicinity of the nozzle exhaust. These problems become more severe when the jets operate at supersonic speeds, which is the case for the future generation, STOVL aircraft (e.g. the Joint Strike Fighter). Fig. 1 shows a schematic of a STVOL aircraft in hover where some of these adverse effects, collectively referred to as ground effect, have been indicated. When two or more jets are impinging on a ground plane, as shown in Fig. 1, the resulting wall jets create a 'fountain' between the jets, a phenomenon commonly called the fountain flow. The impingement of the fountain flow on the aircraft body produces an upward force, which partially offsets the suckdown due to entrainment associated with lifting jets[2]. However, as described by Elavarasan et al[2] and briefly discussed later in this paper, the positive contribution to lift due to the fountain flow is observed only for limited jet operating conditions.

Using very simple configurations, such as that shown in figure 2, an extensive series of experiments have been (and are being) conducted at our laboratory aimed at providing a better understanding of the flow physics and identifying the main factors which contribute to hover lift loss and sonic fatigue[3-6]. Experimental studies relating to jet flows representative of STOVL (or V/STOL) aircraft in ground effect have been carried out in our laboratory to provide a basic understanding of the flow phenomena involved. Although much literature exists on this topic[7], our focus has been on the role of flow-generated noise and its mitigation on the aerodynamic performance of STOVL aircraft in hover, in particular, at higher jet exhaust velocities. As such, the aeroacoustics of twin impinging jet configuration constitutes a significant portion of the paper. Finally, as a result of a better understanding of the aeroacoustics governing this flow, we have implemented a unique flow control technique, which significantly alleviates the ground effect for single[7] and dual impinging jets. A discussion of this control approach is also included in this paper.

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