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On the acoustics of a circulation control airfoil

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ABSTRACT

A two-dimensional elliptical circulation control airfoil model is studied in the Florida State Aeroacoustic Tunnel. Far-field acoustics are obtained via a 55 microphone phased array. Single microphone spectra are also obtained, and it is shown that background noise is significant. In order to circumvent this problem, beamforming is employed. The primary sources of background noise are from the tunnel collector and jet/sidewall interaction. The deconvolution approach to mapping acoustic sources (DAMAS) is employed to remove the effects of the array point spread function. Spectra are acquired by integrating the DAMAS result over the source region. The resulting DAMAS spectral levels are significantly below single microphone levels. Although the DAMAS levels are reduced from those of a single microphone or delay and sum beamforming (DAS), they are still above those of a NACA 0012, estimated using *NAFNoise*, at the same geometric and free-stream conditions. A scaling analysis is performed on the processed array data. With a constant free-stream velocity and a varying jet velocity the data scale as jet Mach number to the 6th power. If the momentum coefficient is held constant and the free-stream velocity is varied the data scale as free-stream Mach number to the 7th power.

1. Introduction

Traditionally, lift is proportional to the square of the forward velocity of a body. This means that vehicles moving at very low speeds, such as submarines or aircraft during approach, have drastically reduced maneuverability, making them more difficult to control. Circulation control (CC) provides a mechanism for increased lift and maneuverability even at low forward speeds. On air- and hydro-foils, CC generally provides these advantages by issuing a high speed jet from a spanwise slot, tangential to a curved trailing edge. The jet entrains low-momentum fluid, and the flow stays attached longer due to the Coanda effect. This delays separation and increases circulation by shifting the stagnation point, which results in augmented lift [2]. Due to this lift increase, CC could allow for reduced mechanical complexity on aircraft and underwater vehicles in the event that it replaces current mechanical systems that change the angle of attack. The fluid dynamic mechanisms and benefits of CC have been studied extensively and are well understood [1]. Though the advantages gained from CC are significant, it comes with drawbacks [3].

One of the issues presented by CC is the production of significant levels of undesirable acoustic noise. This additional noise is detrimental to its implementation both in air and underwater. In air, strict requirements are placed on acoustic levels for the areas surrounding airports. Underwater, CC noise reduces stealth capabilities and sonar system reliability and

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therefore lifespan of the vehicle. Compared to the copious number of studies on CC fluid dynamics, there is a relative scarcity of work regarding CC acoustics.

The first study on CC acoustics was performed by Williams and Cheeseman [4] who suggested ten primary sources of rotor-craft CC noise. Later Salikuddin et al. [5] performed experiments varying jet speed and slot height, finding that noise levels increased as either parameter increased. Howe [6] then created an analytic model to predict CC acoustic radiation. He suggested that three CC sources dominate: (1) curvature noise generated by free-stream turbulence interacting with the trailing edge dominates at low frequencies, (2) passive-slot noise generated by free-stream turbulence interacting with the slot lip dominates at middle frequencies, and (3) Jet-slot noise generated from turbulence in the jet interacting with the slot lip dominates at high frequencies. In recent years, Shannon and Morris [7], Morris et al. [8], Wetzel [1], and Wetzel et al. [9] performed experiments to determine CC noise. Morris et al. [8], Wetzel [1] and Wetzel et al. [9] show that the model of Howe considerably underestimates the CC noise.

These recent studies make use of phased acoustic arrays for a limited subset of cases but focus primarily on spectral results from single microphones. Phased acoustic arrays employ a large number of microphones at known spatial locations and are processed using various beamforming algorithms [10]. Using knowledge of the source locations relative to objects of interest, one can integrate over areas relevant to the model noise effectively eliminating background noise [11]. This offers a significant advantage over single microphone measurements, which can be envisioned as simply integrating over the entire field (including the external noise). In the current study, it is shown that background and external noise are significant and tend to saturate the single microphone results, especially at low jet velocities. In order to remove these effective background noise sources, beamforming and selective integration regions are employed.

While previous studies provide beammaps, the results are limited to those from delay-and-sum (DAS) beamforming and only for a limited number of cases. In DAS beamforming the source field is convolved with the array geometry for an ideal point source, or the array's point spread function (PSF) [12]. The PSF represents the ideal point source that the array geometry can provide at each location in space. In the best case, the PSF causes a point source to appear spread spatially over several locations, especially at low frequencies while in the worst case, it generates erroneous sources (known as sidelobes) causing imprecise source locations and magnitudes [12]. The current study performs both conventional (DAS) beamforming as well as a deconvolution approach for the mapping of acoustic sources (DAMAS) [13] to remove the effects of array geometry and to obtain more accurate estimates of the source locations and spectra.

The purpose of the present study is to gain a better understanding of noise generated by circulation control via (1) isolation of the sources of interest from effective background noise, (2) comparison to traditional lifting appendages, and (3) presentation of an acoustic scaling analysis. The following section includes an overview of the experimental setup, including a discussion of the beamforming methods employed. Then, results are provided regarding single microphone, DAS, and DAMAS, followed by a comparison of CC noise with estimated NACA 0012 noise. Finally, a scaling analysis of the source levels is provided, followed by the conclusions. The results are expected to provide some guidance for development of advanced noise prediction methods involving circulation control.

2. Experimental setup

2.1. Model overview

The circulation control airfoil employed in these experiments is the one described by Wetzel [1], whose design is based on the hydrofoil design of Rogers and Donnelly [14], and is briefly discussed here for completeness. The airfoil is two-dimensional and dual-slotted to allow for both upper and lower slot blowing; however, only the upper slot is used in this work. The model is elliptical with a 20% thickness-to-chord ratio, no camber and a circular trailing edge, detailed in Fig. 1. The airfoil has a chord of 0.521 m and a span of 0.914 m. The trailing edge geometry is shown in Fig. 2 where t_l indicates the lip thickness.

The interior of the model acts as a plenum and is split in order to separate the supply for the upper and lower blowing slots. The plenum is supplied from a dried, filtered, compressed air source external to the wind tunnel facility. In order to set the height of each slot, eight sets of push-pull screws are placed on each side. All cases discussed have one slot height set to 1 mm ($h/c = 0.0019$) while the other slot is closed and sealed with tape. The height of the slot is set by a shim material. Several measures are taken to reduce internal noise. First, the plenum is supplied from both spanwise ends of the model. This decreases plenum noise by reducing the flow rate required by either side, thereby reducing the velocity of the flow

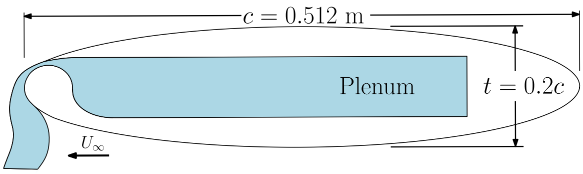

Fig. 1. Single side blowing circulation control airfoil with geometric dimensions. (Adapted from [1].)

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