

A Stereoscopic PIV Study of a Vectored Rectangular Jet

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An experimental study using Stereoscopic PIV measurements was conducted to determine the response of a $M = 0.6$ rectangular jet to a countercurrent secondary flow in the presence of a collar (Figure 1). This secondary flow causes the jet to deflect from its original position thus creating a vectored jet. This technique, when applied to the exhaust of an aircraft's engine is known as Counter Flow Thrust Vectoring (CTV). Thrust vectoring is in use for many years in high performance aircraft as a means of improving performance at critical points of the flight envelope such as: high angles of attack and low speed. It is desirable to attain continuous control of the jet during all operating conditions, thus creating an extra control force in addition to the typical aerodynamic control forces of an aircraft.

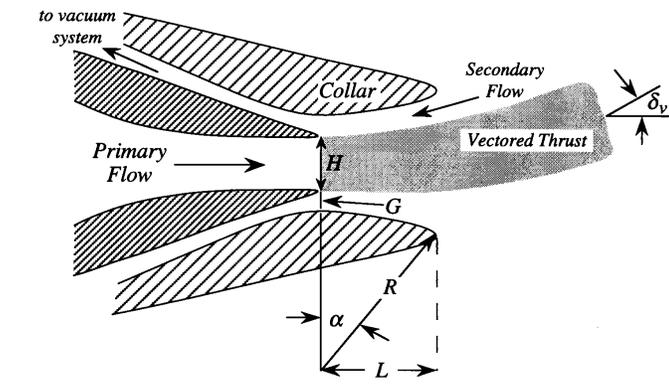


Figure 1. A schematic of the counterflow thrust vectoring nozzle.

The physical phenomena responsible for the deflection of the jet can be explained as follows: applying counterflow to one of the jet's free shear layers, will cause a rapid

increase of the entrainment rate for that particular shear layer. The presence of the collar, though, will be a constraint to that entrainment causing the pressure to decrease in the direction of the collar. This results in a transverse pressure gradient that causes the jet to deflect towards the collar wall. A problem occurs if the jet deflection is too severe: the jet impinges on the collar wall cutting off entirely all the free stream air to be entrained into the shear layer, creating a circulation region. This situation, called attachment, is not desirable in the operation of an aircraft because it compromises the continuous control regime since it has strong bistable characteristics, thus having a hysteretic response.

Typical PIV results obtained using a supersonic rectangular jet are shown in Figure 2. Uniformly scaled velocity vectors representing a $M=2$ rectangular jet in the central plane containing the small dimension are shown in Figure 2. With the presence of

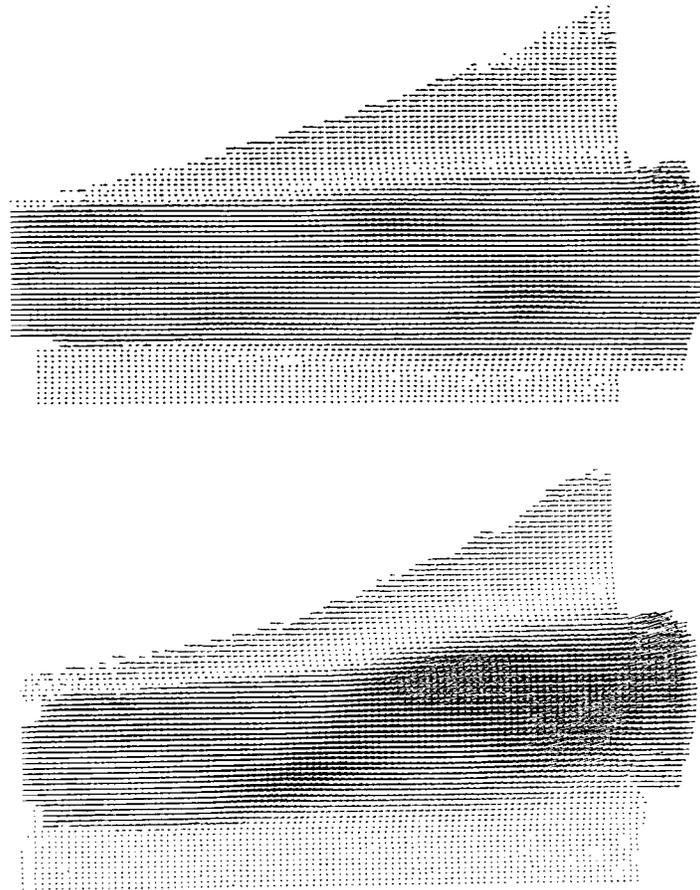


Figure 2. $M = 2$ rectangular jet flow field in the central plane containing the small dimension of the nozzle. Top: Normal jet, Bottom: Vectored jet.

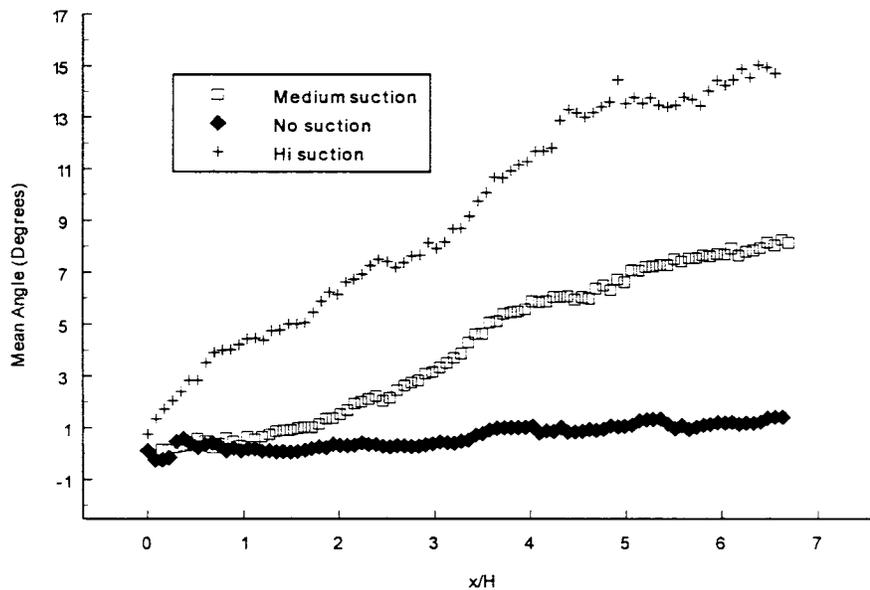


Figure 3. The effect of the suction pressure on the mean jet centerline velocity.

Suction on the topside of the jet. The effect of the suction levels on the determination of the vector is depicted in Figure 3 where two different suction pressures are used. Typical mass flows applied in this experiment are less than about 1% of the main jet. These results clearly demonstrate the technique's ability to vector high speed jets using a small amount of counter flow. However, the detailed flow dynamics of the problem is still not fully understood and it is the purpose of the present investigation to address it using advanced diagnostic tools such as the Stereoscopic PIV.

In this study a small-scale gas turbine engine was used. It produces about 88N of thrust force. The exit nozzle was rectangular with an aspect ratio of 2:1, the longer dimension measuring 56mm. This aspect ratio was chosen because the present study will be extended to multi-axis thrust vectoring, thus requiring a small aspect ratio in order to obtain a bidimensional jet. The collar was a circular arc with a radius of curvature of 140mm and a length of 70mm.

The experimental study consisted of three parts:

- Determining the basic jet characteristics of a heated rectangular jet without the presence of the collar

- Study the effect of the collar on the overall development of the jet
- Using a fixed gap height between the nozzle and the collar, the vectored jet characteristics were obtained for different values of counter flow.

For all the parts of the present study, Stereoscopic PIV measurements were obtained in the two central axial planes as well as cross planes at different distances downstream from the jet exit plane. In the case of the vectored jet, the secondary countercurrent flow was characterized in terms of mass flow rate and vacuum pressure at the gap between the nozzle exit and the collar wall. The response of the vectored jet was characterized in terms of the deflection angle, which was obtained using a control volume analysis. For parts 2 and 3 pressure along the collar wall was also measured, to determine the pressure force developed in the collar wall.