Progress Toward a Model to Describe Jet/Aerodynamic-Surface Interference Effects

R. L. Fearn*
University of Florida, Gainesville, Florida

Abstract

A FIRST-generation model is presented that relates the pressure distribution on an aerodynamic surface to properties of the jet plume. The characteristics of a jet in a cross flow that are of primary importance in determining the pressure distribution on the aerodynamic surface are assumed to be: 1) a pair of contrarotating vortices associated with a jet in a cross flow, 2) entrainment of cross-flow fluid into the jet plume, and 3) a wake region near the aerodynamic surface and extending downstream from the jet orifice. The model is applied to the configuration of a round jet exhausting perpendicularly through a flat plate into a uniform cross flow for a range of jet-to-cross-flow velocity ratios of 3-10. It is demonstrated that the model is capable of describing the measured pressure distribution on the flat plate with model parameters that are compatible with the known properties of the jet plume.

Contents

Introduction

In the transition from hover to conventional flight, vertical or short takeoff and landing (V/STOL) aircraft supplement wing-generated lift with direct thrust from lift jets, lift fans, or tilt proprotors. The proposed configurations all involve the injection of relatively high velocity jets of air and/or exhaust gases into the crosswind caused by the forward motion of the aircraft. The interaction between these jets in a cross flow and the aerodynamic surface of the aircraft usually results in a loss of lift and an increment of nose-up pitching moment. One approach to such a complicated problem is to study the simplest configuration that retains the essential features of the jet/aerodynamic-surface interference during transition: a subsonic round jet exhausting through a flat plate into a subsonic cross flow.

The purpose of the present paper is to describe the framework for a first-generation model describing the jet/aerodynamic-surface interference effect. The model is based on pertinent physical characteristics of the flowfield of a jet in a cross flow, and it is applied to the case of a round jet exhausting perpendicularly through a large flat plate. Although it has not been a primary goal of the study, the model should be applicable to the problem of estimating wind tunnel wall effects for V/STOL configurations.

Model with Example

The most thoroughly studied configuration for a jet in a cross flow with application to V/STOL aerodynamics is a round jet exhausting perpendicularly through a flat plate. Even for this case, the significant features of the flow needed for a jet interference model have not been described adequately. The present paper utilizes information about the flow that is available to determine if the proposed jet interference model is compatible with measured pressure distributions for a range of jet-to-cross-flow velocity ratios for this simple configuration.

Some features of a jet in a cross flow are illustrated in Fig. 1 for a velocity ratio of approximately eight. The stippled area represents the observed smoke plume within which the relative locations of the jet centerline and vortex penetration curves are shown. The diffuse contrarotating vortex pair is illustrated at a cross section to the jet plume: mirror symmetry through the plane $y=0$ is assumed. No attempt has been made to depict the distortion of the initial vorticity distribution into the vortex pair. Also shown in this figure are the coordinate axes used to describe the jet properties.

Currently, there is no quantitative description of the vortex system in the region near the jet orifice where distortion of the initial vortex distribution into the contrarotating vortex pair occurs. Once the vortex pair is established, however, there is available a model to infer the properties of the diffuse vortex pair from selected velocity measurements in cross sections of the jet plume.[1] In a region near the jet orifice, the strength of each vortex is expected to increase with downstream distance due to the vortex pair being fed by the distortion of the original vortex system. In a region sufficiently far downstream, the strength of each diffuse vortex is expected to decrease with the downstream distance due to the diffusion of vorticity of opposite sign across the plane of flow symmetry. To calculate the pressure distribution on the surface through which the jet exhausts, only the velocity field external to the jet plume is needed. At a given cross section to the jet plume, the properties of each diffuse vortex are represented by the first term in a multipole expansion of the vorticity in the appropriate half-plane. This results in the diffuse vortex pair being represented by a pair of filament vortices of changing strength.

The vortex system for the model consists of a pair of line vortices along trajectories specified by the vortex penetration and vortex spacing curves.[1,2] A free vortex condition is used to calculate vortex strength from this geometry and the

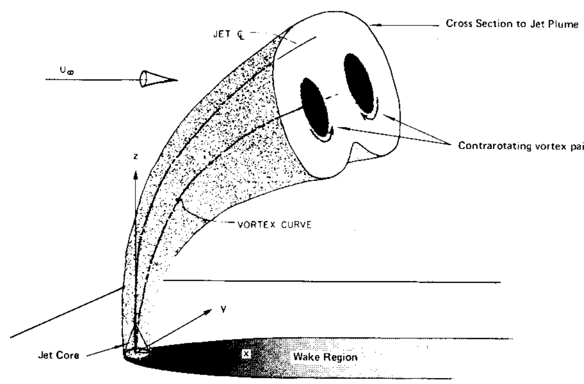

Fig. 1 Some features of a jet in a cross flow.

Received Jan. 18, 1983; synoptic submitted July 29, 1983. Full paper available from National Technical Information Service, Springfield, Va. 22151 as N83-34903 at the standard price (available upon request).

*Professor of Engineering Sciences. Member AIAA.

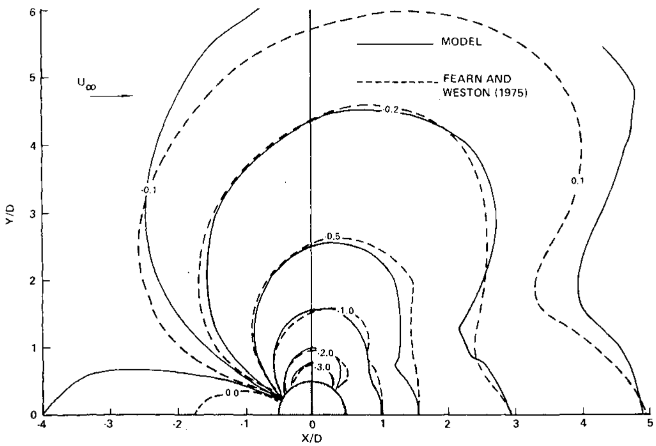

Fig. 2 Contours of constant pressure coefficient, $R = 6.1$.

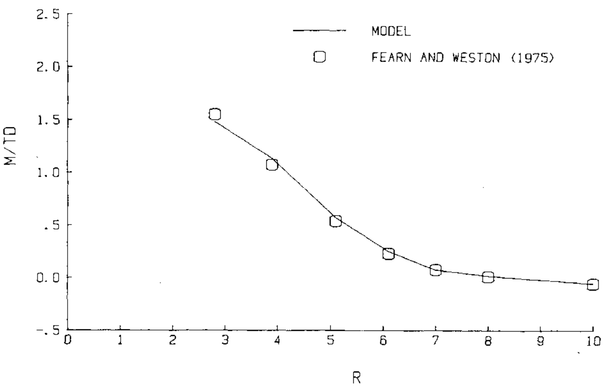

Fig. 3 Pitching moment on references area.

resulting curve of circulation vs x exhibits a maximum. The location of this maximum is used as a convenient separation between a near-jet region and far-field region. In the near-jet region the model uses a Padé approximate to specify vortex strength as a function of x. The purpose for this is to introduce some undetermined parameters into the model to compensate for the lack of an adquate description of the vortex system in this region. The near-jet description of the vortex strength is matched smoothly with the free vortex description at the location of the maximum.

The effect of entrainment on the external flow is represented by a line sink placed along the jet centerline. There is little or no realistic information about entrainment for a jet in a cross flow. It is speculated that the line sink representing the effect of entrainment on the flow external to the jet plume has the same mathematical form as entrainment for a submerged jet (no cross flow).

The effects of the vortex system and entrainment on the flow external to the jet plume constitute the potential flow part of the model. For the example considered, the flat plate is represented by the method of images. All variables are dimensionless. Distances are nondimensionalized by the jet diameter, velocities by the cross-flow speed, and circulation by dividing by twice the product of the jet diameter and the cross-flow speed.

The experimental pressure distribution along the downstream ray from the jet orifice is used to estimate a one-parameter correction factor applied to the pressure distribution calculated by the potential flow model in the wake region. The correction factor is essentially a function that blends the potential flow pressure coefficient at a point in the wake region with an experimentally determined pressure coefficient along the downstream ray.

The model contains two parameters that are determined to provide a least squares fit to the experimental pressure distribution[3] for each velocity ratio. One of these parameters describes the effect of entrainment rate on the flow external to the jet plume and the other parameter specifies the initial value of the circulation vs x curve in the near-jet region.

An example of the experimental and model calculated pressure distributions is shown for a velocity ratio of 6.1 in Fig. 2. Comparison of the moment calculated on a reference circle from the model generated and experimental pressure distributions is shown in Fig. 3. (The moment is nondimensionalized by the product of jet thrust and jet diameter.) Evolution of the model can occur as more complete descriptions of the flowfield become available. The usefulness of the model can be evaluated by considering additional simple examples and by patching the model to existing panel methods to study an extension of the model to calculate the jet interference effect for realistic V/STOL configurations.

Acknowledgment

The work reported in this paper is supported by the NASA Ames Research Center under Grant NSG-2288 with Mr. K. Aoyagi as the technical monitor.

References

[1]Fearn, R. and Weston, R.P., "Vorticity Associated with a Jet in a Cross Flow," *AIAA Journal,* Vol. 12, Dec. 1974, pp. 1666-1671.

[2]Fearn, R. L. and Weston, R. P., "Induced Velocity Field of a Jet in a Crossflow," NASA TP-1087, 1978.

[3]Fearn, R. L. and Weston, R. P., "Induced Pressure Distribution of a Jet in a Crossflow," NAA TN D-7616, 1975.