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Introduction

In the transition from hover to wingborn flight, V/STOL aircraft rely on the direct thrust of lift jets to supplement wing generated lift. The lifting jets interact with the flow over the aerodynamic surface to produce a complex flow around the aircraft. This usually results in a loss of lift and an increase in nose-up pitching moment (Ref. 1). Hence, the jet/aerodynamic-surface interference effect is a significant problem in V/STOL aerodynamics.

The simplest configuration which retains the essential characteristics of the jet/aerodynamic-surface interaction problem is a subsonic round jet exhausting perpendicularly through a large flat plate into a uniform crossflow (Fig. 1). This configuration has been studied extensively, both by experiment (Refs. 2-7) and by analysis (Refs. 8-15). As a result, a fairly complete experimental data base exists for comparison with the numerical calculations.

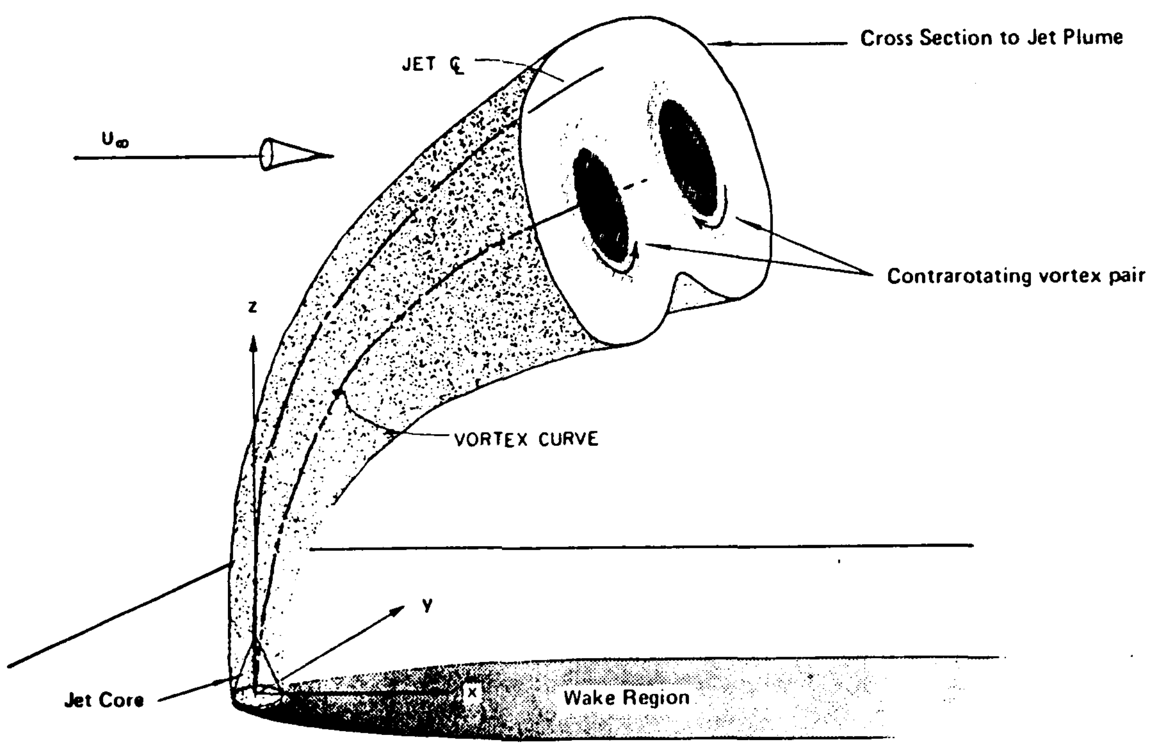

Figure 1. Sketch of the Jet in a crossflow

SUMMARY OF PUBLICATIONS AND PRESENTATIONS

The research supported by this grant was presented to the research community in the following presentations and publications. Each citation is followed by an abstract of the work.

1. Fearn, Richard L. and Weston, Robert P.: Velocity Field of a Round Jet in a Cross Flow for Various Jet Injection Angles and Velocity Ratios. NASA TP-1506, Oct. 1979.

   An experimental investigation of a subsonic round jet injected from a flat plate into a subsonic crosswind of the same temperature has been conducted in the Langley V/STOL tunnel. Velocity and pressure measurements in planes perpendicular to the path of the jet are presented for nominal jet injection angles of 45°, 60°, 75°, 90° and 105° and for jet/cross-flow velocity ratios of 4 and 8. These velocity measurements were obtained for the purpose of inferring the properties of the vortex pair that is associated with a jet in a cross flow. Jet centerline and vortex trajectories are determined and fit with an empirical equation that includes the effects of jet injection angle, jet core length, and jet/cross-flow velocity ratios.

2. Fearn, Richard L. and Benson, J. Paul: Velocity Field Near the Jet Orifice of a Round Jet in a Crossflow. NASA CR-137,857, Dec., 1979.

   Experimentally determined velocities at selected locations near the jet orifice are presented and analyzed for a round jet in a crossflow. Jet-to-crossflow velocity ratios of four and eight were studied experimentally for a round subsonic jet of air exhausting perpendicularly through a flat plate into a subsonic crosswind of the same temperature. Velocity measurements were made in cross sections to the jet plume located from one to four jet diameters from the orifice. Jet centerline and vortex properties are presented and utilized to extend the results of a previous study into the region close to the jet orifice.

3. Fearn, R.; Kalota, C. and Dietz, W. E., Jr.: A Jet/Aerodynamic Surface Interference Model. Proceedings of a Workshop on V/STOL Aircraft Aerodynamics, Naval Postgraduate School, Monterey, CA, May, 1979.

   A model is presented that relates the pressure distribution on an aerodynamic surface to properties of the jet plume. The primary characteristics of a jet in a crossflow that determine the pressure distribution on the aerodynamic surface are assumed to be:

(1) the pair of contrarotating vortices associated with the jet.
(2) entrainment of fluid by the jet.
(3) a wake region near the aerodynamic surface immediately downstream of the jet.

The model is applied to the configuration of a round jet exhausting through a flat plate into a crossflow. Experimentally determined properties of the vortex pair are utilized in the model for perpendicular jet injection and a range of jet to crossflow velocity ratios. Reasonable values of entrainment and a simple wake assumption are used. Comparisons of the calculated pressure distributions and aerodynamic loading with experimental results are included.

4. Braden, Susan: Vorticity Associated with Multiple Jets in a Crossflow. AIAA 31st Annual Southeastern Region Student Conference, Atlanta, GA, 1980.

A preliminary investigation vortex patterns from multiple subsonic jets exiting perpendicularly through a flat plate into a subsonic crossflow has been conducted at the Engineering Sciences Department, University of Florida. Two multiple jet configurations, tandem and transverse, were examined. A paddle wheel sensor was utilized to indicate the presence and relative magnitude of streamwise vorticity in the flow. This method is shown to be an effective and inexpensive way to obtain qualitative information about streamwise vorticity associated with a jet in a crossflow. Results are presented in the form of contour plots of rotational speed of the paddle wheel as measured in planes downstream from the jets and perpendicular to the crossflow. These contour plots indicate the presence of well developed diffuse contrarotating vortices for the configurations studied. The location and strength of these vortices depends on the multiple jet configuration and the distance downstream from the jets. The results for single jet cases are compared with those of previous experiments.

5. Furlong, Kelly L. and Fearn, Richard L.: A lifting Surface Computer code with Jet-in-Crossflow Interference Effects, vol. 1-Theoretical Description, vol. 2-Users Guide for WBWJAS. NASA CR-166524, Aug., 1983. This work was also supported by NASA Grant NCC2-133.

A method is proposed to combine a numerical description of a jet in a crossflow with a lifting surface panel code to calculate the jet/aerodynamic-surface interference effects on a V/STOL aircraft. An iterative technique is suggested that starts with a model for the properties of a jet/flat plate configuration and modifies these properties based on the flow field calculated for the configuration of interest.

The method would estimate the pressures, forces, and moments on an aircraft out of ground effect.

A first-order approximation to the method suggested is developed an applied to two simple configurations. The first-order approximation is a non-iterative procedure which does not allow for interactions between multiple jets in a crossflow and also does not account for the influence of lifting surfaces on the jet properties. The jet/flat plate model utilized in the examples presented is restricted to a uniform round jet injected perpendicularly into a uniform crossflow for a range of jet-to-crossflow velocity ratios from three to ten. Numerical results for a streamlined body of revolution and a symmetrical airfoil are presented. The numerical results show that there is good agreement between experimental and model calculated surface pressure data for the body of revolution and the non-lifting wing, but indicate the need for iterative techniques for handling the interactions between lifting surfaces and a jet in a crossflow.

This report is divided into two volumes. The first volume is a theoretical description of the computer code developed. The second volume is a detailed Users Guide for the computer code.

6. Fearn, R.L.; Progress Toward a Model to Describe Jet/Aerodynamic-Surface Interference Effects. Synoptic in AIAA Jour., vol. 22, pp. 752-753, June, 1984. Full paper in <u>Recent Advances in Aerodynamics</u>, Proceedings of an International Symposium at Stanford, Aug., 1983, ed. A. Krothapalli and C.A. Smith, Springer-Verlag, 1985.

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 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 first plate with model parameters that are compatible with the known properties of the jet plume.

7. Roth, K.R.: Stability of Closed Loop Filaments as Computational Elements for a Three-Dimensional Vortex Filament Algorithm. MS thesis, University of Florida, 1986.

A three-dimensional vortex filament model is developed and validated for inviscid flow calculations. The propagation of a single vortex ring and the leapfrogging of two vortex rings are simulated. Results of these simulations are compared with theoretically and numerically predicted values. A parametric study is conducted to assess the stability of the closed loop filaments which are the basic computational element. Simulation of the jet/aerodynamic-surface interference effect for V/STOL aircraft with the three-dimensional vortex filament method is discussed.

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