AXIAL VELOCITY IN THE TRAILING VORTEX CORE OF A NACA 0015 AIRFOIL

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Abstract

Summary of research performed on a NACA 0015 airfoil in USU's low speed windtunnel to validate parameters derived by Spalart, which relate the circulation strength with the relative axial velocity of the core. Experiments were performed for several Reynolds numbers and angles of attack at a distance of 1 chord length from the trailing edge of the airfoil. Data was collected using a triple sensor hot-wire anemometer to allow resolution of the velocity into three orthogonal components.

Symbols

C	=chord length (30 inches)
Re	=Reynolds number based on chord length
	$= \dfrac{U_{\inf} * c}{\nu}$
U_{inf}	=free stream velocity
v	=velocity in the y-direction
V_{Θ}	=tangential velocity
	$= \sqrt{v^2 + w^2}$
w	=velocity in the z-direction
Γ	=circulation
	$= \oint_{surface} V_{\Theta} \bullet ds$
ν	=kinematic viscosity

Introduction

There is a great deal of research being performed in the area of numerical modeling of wingtip vortices. At present, the emphasis is on matching numerical solutions to experimental data, and while this can be done, it adds very little to the knowledge base. By providing more information about the character of vortices, numerical researchers will be able to validate their models without always relying on experimental data.

The area of interest in this research was studying the nature of the vortex core. As the fluid rolls from the pressure side of a lifting surface to the suction side (see figure 1) it creates a vortex with velocity components normal to the main flow. These vortices induce drag on the structure increasing fuel costs. In aviation, they pose a hazard because they can be strong enough to overpower the control ability of trailing airplanes.

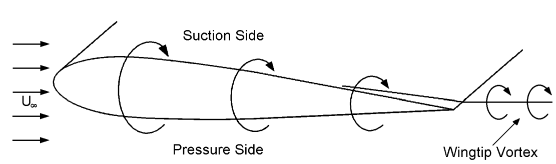

Figure 1: Vortex Formation

Background

In 1998, Spalart examined the nature of vortices and introduced a relationship between a loading parameter and the behavior of the vortex core. The loading parameter is defined as the circulation strength divided by the product of the wingspan and the free stream velocity. The circulation consists of integrating the velocity around a closed path, in this case, a square box centered around the vortex core and in a plane perpendicular to the free stream velocity. His suggestion was that a loading parameter below 0.1 would result in a wake profile, and a loading parameter above 0.1 results in a jet-like profile in the vortex core.

Using the experimental results of Devenport, Green, and Chow et al, this analysis was performed and found to hold. However, this was a limited group of cases, using NACA 0012 airfoils with either a flat or round endcap.

Experimental Approach

The focus of this research was to add a set of data that would assist in validating Spalart's idea, using a wing with variable geometry, and allowing for multiple Reynolds numbers and angles of attack. By allowing these variables to change systematically, a much fuller data set could be compared with his proposal.

Apparatus

This research was performed in USU's low speed windtunnel, an open loop tunnel; with a 4-foot square test section, and a 9:1 contraction ratio inlet. A 200 horsepower AC motor connected to a variable pitch prop provides mean flow. A computer attached to a variable speed drive controls speed. This allows the system to run at a constant velocity over the course of experiment.

The windtunnel was recently refurbished, replacing the flow conditioning screens and straitening several sections of the tunnel. This has led to a tunnel where the turbulence intensity level in the area where tests where performed to be less than 0.5%.

The wing section used for this research is a NACA 0015 airfoil with a 30-inch chord and a 24-inch semi-span (flat endcap). This model was constructed by CNC machining two aluminum templates slightly smaller than the profile of the airfoil. Hot wire was then used to create a foam core to the airfoil profile. Fiberglass was then laid along the surface of the wing and sanded. This led to a buildup that continued until the dimensions matched the NACA 0015 profile.

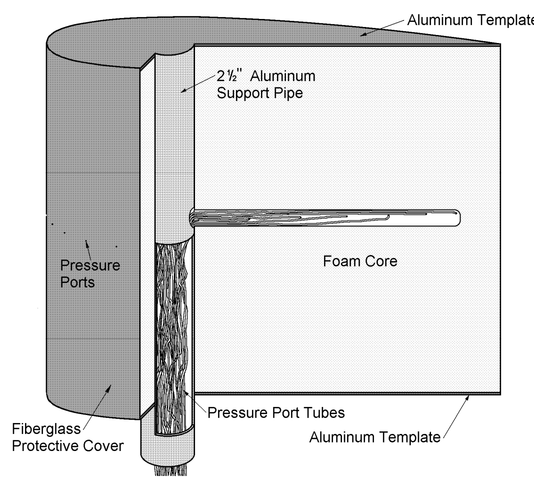

Figure 2: Wing Section Model

In addition, 25 pressure ports were placed ½ the way along the span, using a sine distribution so that more ports were located on the leading edge and fewer along the trailing edge of the section. The surface was then sanded very smooth and painted to reduce surface roughness.

This airfoil was then mounted on a splitter plate approximately 3" off the floor of the windtunnel. The splitter plate separates the wall boundary layer of the tunnel from the airflow that will go over the wing. In addition, the splitter plate can be slid along the tunnel, allowing measurements to occur at multiple chord-wise locations without needing to move instrumentation.

After mounting the section in the windtunnel, the pressure ports were attached to a PSI 16 port pressure scanner, and the pressures on both sides of the wing were compared for different angles of attack to determine the zero degree angle of attack location.

Data Acquisition

Data acquisition for this experiment was performed using an IFA 300 Constant Temperature Anemometer with five channels, and a pressure transducer. The anemometer is connected to a triple wire probe mounted on a traversing system that allows it to be moved in a plane perpendicular to the flow field. A grid to be tested is then put into the TSI ThermalPro software, and it moves the traverse to the appropriate location and measures the temperature and the three components of velocity. When the software has completed the data acquisition and analysis, the data is collected and analyzed by hand.

During the first stage of each experiment, the center of the vortex is found. A coarse grid is set up, and the software takes the data. Then looking at the collected data, the center can be found by determining where the velocities change sign. As you move thought the center of the vortex in either the y or z direction, that component of velocity will change sign. Another indicator of the vortex core is a low rotation velocity (V_Θ).

Once the core is located, a finer grid is created in that area to ensure that the actual center is measured. Another grid is set up that consists of a box centered on the core, with 6-inch sides for computing the circulation. Data is then taken over these grids. A software program then takes the results from the circulation and numerically integrates to find the circulation parameter. The velocity at the core of the vortex is then found, and non-dimensionalized by dividing by the free stream velocity.

One of the limitations of a triple wire probe is the flow angles over which it can measure velocities. The range over which they are accurate is within a cone of about 30 degrees from the free stream direction. The IFA 300 software checks for velocities outside this range and writes a zero velocity in the resulting data file. These points are then removed when finding the average velocity used in the calculations. Experience has shown that velocities outside this angle occur intermittently during the data acquisition mode, and there are enough good data points to make the average values valid.

Results

A comparison of data collected at Re=0.75E6, 1E6, and 1.25E6 is shown in figure 3, for angle of attack from 4 to 12 degrees in 2 degree increments. Also included in this figure are the results of analyzing the data from Devenport, Green, and Chow et. al. This data all fits the principle proposed by Spalart. This would appear to validate the idea that once the circulation of a particular geometry is known, the core velocity can be estimated through the use of this loading parameter.

An interesting phenomenon can be seen at the left side of Figure 3. At very low angles of attack (4 degrees for this research, the non-dimensional core velocity begins to return to 1. There are two possible causes for this. First, the vortex may not dominate the flow, and in the limit, as angle of attack goes to zero (no vortex formation) Bernoulli's equation would suggest that U/Uinf should be zero everywhere in the flow.

The other possibility is that at lower angles of attack, the vortex has already begun to dissipate at one chord length, and its effects on the core are diminishing.

Future Work

Further research needs to be conducted with different airfoil profiles, and over a broader range of Reynolds numbers. Once this parameter is well established, the effect of the core velocity on the dissipation of the vortex can then be analyzed, leading to designs where the vortex is minimized and the additional drag and danger to other craft can be minimized.

References

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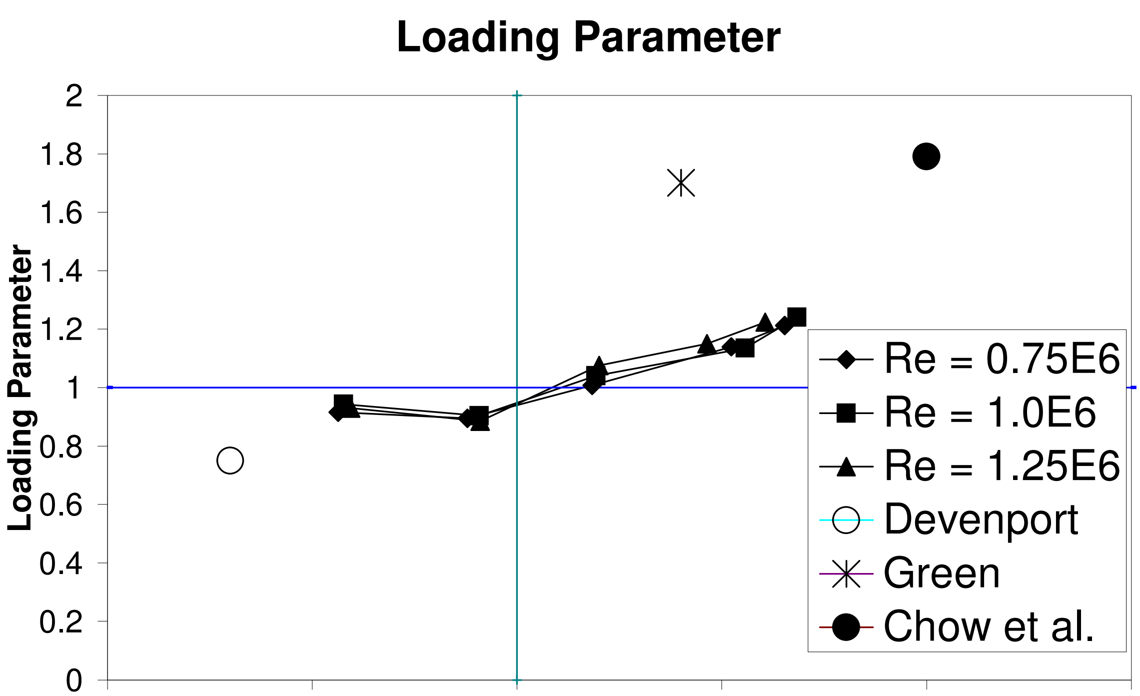

Figure 3: Spalart's Parameter