DETERMINING AN OPTIMUM VORTEX GENERATOR CONFIGURATION FOR A PIPER CHEROKEE WING

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Introduction

When progressing through a preliminary design, engineers must make many compromises. In fact, very little of an initial concept even survives to see the detail design phase. Many factors are involved with aircraft design--mission requirements, time constraints, cost effectiveness. Design teams often-times find that their optimal solution may not be readily manufactured...at least not without special tools or even machines, which can easily cause the cost of manufacturing an aircraft to skyrocket. In order to meet the mission requirements without exceeding a project's budget, last-minute quick-fixes are nothing short of reality. To increase directional stability on an aircraft that cannot support a larger vertical tail, a strake or ventral fin can be added. To increase the range of an aircraft to meet a business' needs, external fuel tanks are an option. To reduce the landing speed of an aircraft, vortex generators can be added to the surface of a wing.

Although the concept and use of vortex generators (VG's) is not new, there really is no comprehensive source of generalized design data for aircraft applications. Designers--especially those at the student level--are aware that they exist and understand what they are capable of as far as performance enhancement goes, but few if any know what types of VG's they need (or have to choose from), as well as how many and what size they need to do the job. Many after-market VG kits are available for existing aircraft. But what if a manufacturer chooses to put them on prior to sale (as seen on the Beech Starship)? Even if he were to contract out to have the VG's made, he would need to specify dimensions as well as quantity.

Purpose

Flight testing with various VG configurations is certainly an option. However, this can prove costly, time-consuming, and even dangerous. Altering the flow over a wing without being able to predict the effects is not wise. The author has performed an extensive series of wind tunnel tests on a 1/4-scale Piper Cherokee wing in hopes of removing some of the guesswork in the VG and VG configuration design processes.

Test Conditions

All tests were performed in the 36"x52" closed test section, closed-circuit, subsonic wind tunnel at Embry-Riddle Aeronautical University. Although the landing speed of a Cherokee is approximately 100 ft/sec, the VG optimization tests were performed at approximately 85 ft/sec. (Based on this, the test Reynold's number was $7.2x10^5$, compared to the full-scale Reynold's number of $2.8x10^6$.) This was done to avoid over-stressing the Aerolab 6-component pyramidal force balance. The tunnel's relatively low turbulence factor of 1.3 and the appropriate wall divergence for the test velocity offer the assurance of 'good' data.

1/4-Scale Model

The 1/4-scale wing was modeled using parametric, feature-based, solid modeling software. Tool paths were then generated for milling on a Komo VR408P CNC 3-axis milling machine. The model was cut from laminated birch-veneered plywood in 2 halves (upper and lower surfaces). Once manufactured, the surfaces were joined, filled, sanded, and finally painted. A 3/16" flat plate of birch ply was attached to the inboard portion of the wing to replicate the fuselage of the aircraft. To assure transition on the wind tunnel model at the same (x/c)-location as the full-scale, a 1/8" wide strip of standard roughness was applied to both surfaces. By fixing the transition location, the model's VG's would experience a boundary layer with similar characteristics (turbulent) as those VG's placed on the real aircraft[3].

VG Selection and Variables of Concern

For ease in manufacture, the VG's chosen were the flat plate vane type (see Fig. 1, below). Each VG had a chord of 1/4", a value roughly 1/4 of those VG's used on

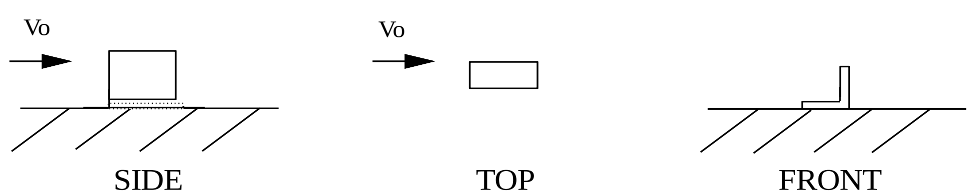

Figure 1: Flat plate vane type vortex generator.

full-scale aircraft. They were constructed of 0.0115" thick aluminum sheeting. The shortest VG height of 0.05" was determined by manufacturability. The other 2 VG heights tested were 0.1" and 0.2", which would give a good range of (h_{VG}/δ)-values to help determine how tall--relative to the local boundary layer thickness (δ)--a VG should be. Three planforms (see Fig. 2, below) were also tested to determine if taper has a noticeable effect on VG performance.

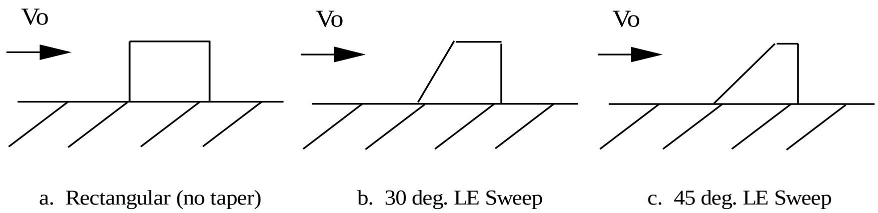

Figure 2: The 3 VG planforms tested.

Non-geometric factors were also varied to determine their influence on VG performance. These include VG angle of incidence relative to the freestream; spanwise row density; chordwise row location, quantity, and interaction; and placement of VG's in a co-rotating or counter-rotating manner.

Experimental Set-Up

The test schedule was set up in a manner that could potentially eliminate some of the variables early-on. The basic test procedure is shown in Fig. 3 below:

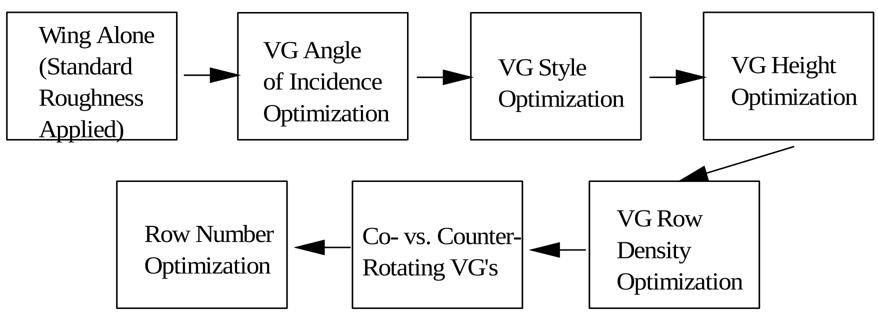

Figure 3: Basic VG optimization test procedure[2].

In most cases, the optimal condition from an earlier test was carried through successive optimization tests. (It should be pointed out that the goal of this experiment was to optimize a VG configuration for the Cherokee wing. In general, tests were not continued with anything other than the optimal design for that test phase.)

Findings

At the conclusion of a series tests including over 40 configurations, the following was determined:

1. Not only are the rectangular planform VG's easier to manufacture, their greatest lift (and therefore most substantial tip vortex) is gained at an angle of incidence shallow enough to keep the amount of VG frontal area to a minimum[1]. This VG proved to be the best candidate of those tested.

2. Vortex generators should be tall enough to extend beyond the local boundary layer. Insufficient mixing between the high-velocity and low-velocity surface layers is a problem with so-called "micro" VG's of the vane type. Figure 4 shows 2 VG configurations, the only variable being VG height. The 0.05" VG is roughly 50% of the

local (calculated) turbulent BL thickness, which could be categorized as a micro VG. The 0.2" VG's are just over 200% of the local (calculated) turbulent BL thickness.

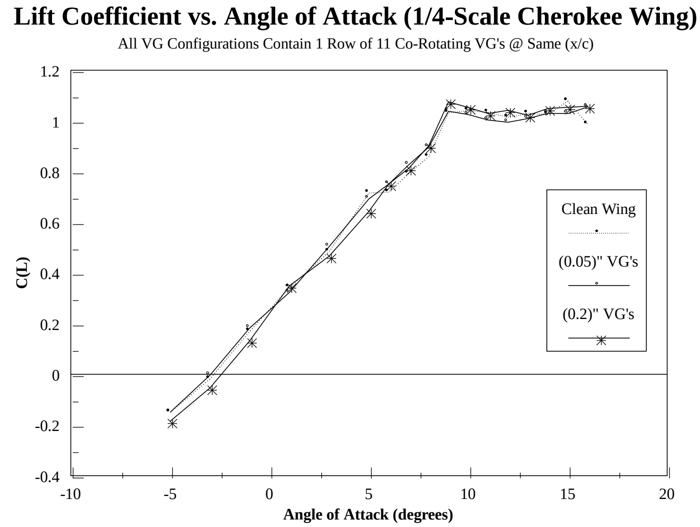

Figure 4: Comparison of Lift Enhancement Using VG's of Different Heights[2]

The difference in performance between the 2 VG configurations can be attributed to the superior mixing capability of the taller VG. Since no other types of VG's were tested, however, it cannot be concluded that this trend will be observed with all VG types.

3. Proper spacing of adjacent VG's is essential. Too many or too few will degrade the performance (maximum lift and cruise drag) of a clean wing. This is demonstrated in Figure 5, which shows the drag **decrease** in addition to the lift increase for the VG configuration with 3" spacing between adjacent VG's. Configurations with 2" and 4" spacing exhibit exactly the opposite--penalties in both lift and drag.

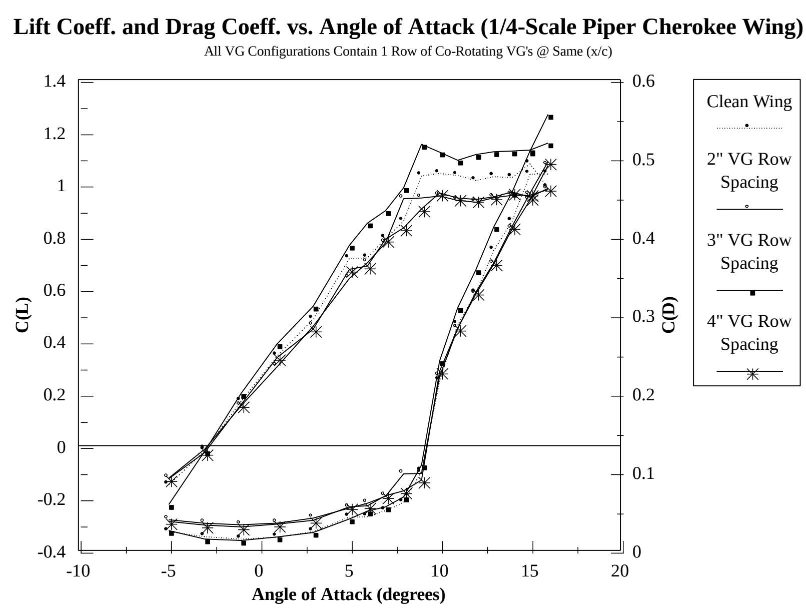

Figure 5: Influence of Spacing Between Adjacent Vortex Generators[2]

4. Multiple rows can enhance the performance of VG's if located properly. Successive rows should be staggered if drag penalty is unacceptable. However, this set-up did not enhance lift, leaving drag reduction as the sole gain.

5. Counter-rotating set-ups allow a significantly smaller quantity of VG's to be used for comparable performance enhancement. These configurations did not increase the maximum lift. The drag reduction did, however, prove substantial enough to suggest this application. Proper spacing of the counter-rotating VG's is much more crucial than for other set-ups.

(Detailed results of this optimization study are not the focus of this discussion and are not provided here. They can be found in Reference 2.)

Summary

The objective of this series of experiments was to provide a multi-variable set of aerodynamic data which is broad enough to supply designers (particularly ERAU design students) with guidance in their consideration of vortex generator usage. Although no single experiment can produce an entirely comprehensive collection of information, this experiment was successful in defining fairly clear guidelines regarding several VG geometric and configuration variables. Among the generic design conclusions are the following: Once a local boundary layer thickness is calculated, a VG height can be determined. More complex VG planforms do not necessarily mean greater performance gains. Contrary to 'standard wisdom,' the drag of an aircraft can actually be reduced by VG's sized and installed properly, making this method of performance enhancement worthy of consideration in design projects.

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