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ENDPLATE EFFECTIVENESS FOR A NACA 0015 AIRFOIL

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Abstract

Lift and drag of a NACA 0015 airfoil fitted with five differently shaped endplates are measured at M = .114 and M = .15 while sweeping the angle of attack from -4 to 14 degrees at 2 degree increments. The triangular endplate performs well in enhancing lift, while reducing induced drag better than the other endplates. A scaled down version of the airfoil and endplates are run in a flow visualization water tunnel at 10 degrees angle of attack and 1 fps. The triangular endplate causes upwash aft of the airfoil, which cancels out some of the natural downwash due to angle of attack, thus decreasing drag.

Nomenclature

AOA	Angle of attack
C_D	Coefficient of drag
C_L	Coefficient of lift
C_{Lmax}	Max lift coefficient
$C_{L\alpha}$	Coefficient of lift vs angle of attack
fps	Feet per second
M	Mach number
L/D	Lift-to-drag
P	Pressure
S	Surface area
T	Temperature
v	Velocity

Introduction

Past studies reveal that the use of endplates increases the lift curve slope of an airfoil in subsonic flow. In May of 1951, Riley completed a subsonic wind tunnel investigation on the effects of endplates on the aerodynamics of unswept wings for NACA[1]. Several conclusions were reached from this study in conjunction with other research projects done on the same subject:

1. Endplates can provide a significant increase in the L/D ratio when wing aspect ratio is low and the ratio of the wing profile drag to the endplate profile drag is high.

2. Endplates can be very effective in increasing the L/D ratio when used on aircraft with relatively large parasite drag.
3. C_{Lmax} increased when endplates were added. The rate of increase, however, decreased with increasing endplate area.

A more recent study by Payne[2] examines the effects of model size, endplates, and test velocity on the precision of lift curve data for a NACA 0015 airfoil. For our purposes, the most important conclusions reached in this study are:

1. A lower model weight must be used in order to prevent tunnel vibration (as a guideline use 10% of the range of the force balance).
2. The effectiveness of endplates is limited in reducing 3-D airfoil effects.

This report examines the effectiveness of various shaped endplates in enhancing the lift characteristics of a 14" NACA 0015 airfoil at two subsonic Mach numbers. Coefficient of lift curves of the various endplate configurations on the NACA 0015 airfoil are compared with each other and with the NACA 0015 2-D airfoil data. Drag for the various endplates is also analyzed. Flow visualization shows how each endplate effects the wingtip vortices.

Background

A fundamental characteristic of finite wings is the emergence of vortices at the wing tips. Due to the higher pressure on the lower surface of the wing relative to the upper surface, air has a tendency to spill over the tip of the wing, creating a trailing circular flow downstream of the wing. This circular flow, known as a vortex, decreases overall lift and increases drag of the airfoil. One way to increase the lift of an airfoil is to use endplates on the tips of the wings in order to help prevent air from spilling over the wingtips and to spoil the vortices that do form. These endplates make the finite wing act more like an infinite wing[3] but are not 100% effective. They reduce induced drag and increase lift, but also increase profile drag.

Equipment

Wind Tunnel Test:
- -Subsonic wind tunnel with force balance and velocity meter
- -NACA 0015 14" chord, 12" span airfoil
- -A series of 5 endplates, sized to have the same extension past the end of the airfoil (Figure 1)
- -Keithley 500 and existing data acquisition components
- -"Reduces" program (calculates aerodynamic coefficients)
- -Thermometer
- -Barometer

Flow Visualization:
- -Water Tunnel
- -Scaled down NACA 0015 airfoil
- -Scaled down endplates
- -Video and still shot cameras

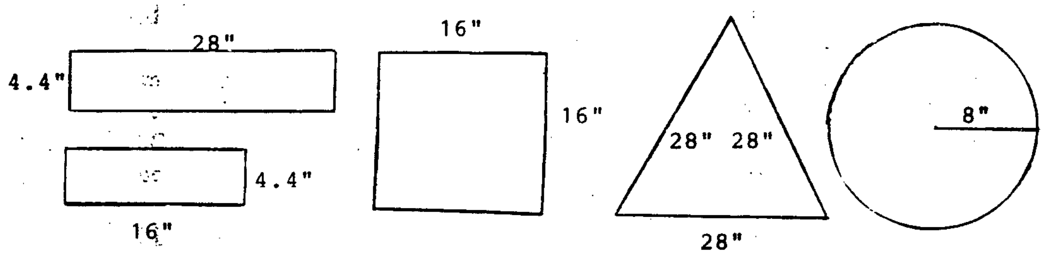

Figure 1. Endplates

Procedure

Wind Tunnel Tests

After mounting the airfoil, the force balance is electrically zeroed to account for the weight of the model. The first set of data is collected at M = .114, while sweeping AOA from -4 to 14 degrees in 2 degree increments. The DAS collects force balance data in the form of voltages for later conversion into C_L, C_D, etc. At each AOA, temperature and pressure readings are entered by keyboard. The above steps are repeated for M = .15. Data is collected in this manner for the no endplate case and for each of the five endplates in Figure 1. A reduction program converts the raw voltages into usable form (C_L, C_D, etc.).

Water Tunnel Tests

A smaller NACA 0015 airfoil is mounted in the water tunnel. Due to the design of the mount, the airfoil is mounted upside down, so that the high pressure side of the airfoil is on top. Dye tubes are placed in front of the airfoil so that the dye flows close to the wingtip. The tunnel is run at 1 fps with each of the endplate combinations in Table 1. On each trial, a still shot and video are made of the front, rear, and side views of the flow at an AOA of 10 degrees.

Port	Starboard
None	None
None	Triangle
None	Square
None	Circle
None	Small Rectangle
None	Large Rectangle
Triangle	Square
Triangle	Circle
Square	Circle

Table 1. Endplate Combinations for the Water Tunnel Tests

Discussion and Results

Wind Tunnel Tests

As can be seen in Figure 2 and Table 2, both the square and triangular endplates have high $C_{L\alpha}$ curves and slopes relative to the other endplates.

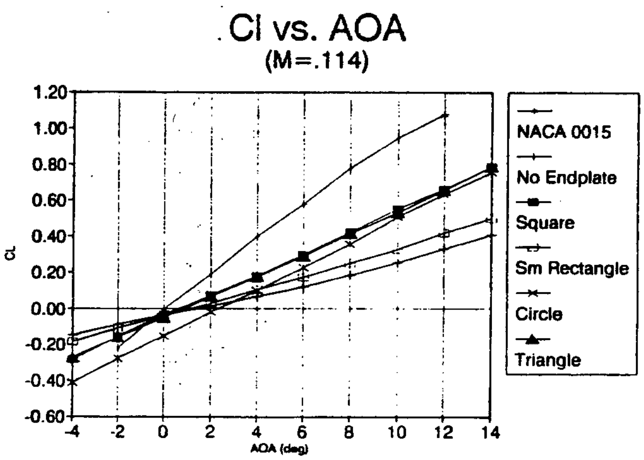

Figure 2. $C_{L\alpha}$ (M = .114)

Type	$CL\alpha$ (/deg)	%diff
Naca	.11	--
None	.031	72
Circle	.065	41
B. Rect.	.039	65
S. Rect.	.038	65
Triangle	.058	47
Square	.059	41

Table 2. $C_{L\alpha}$ Slope Comparison (M = .114)

However, as can be seen in Figure 3, the triangular endplate paid a smaller penalty for drag, and thus is judged as the best endplate by C_L and C_D comparison.

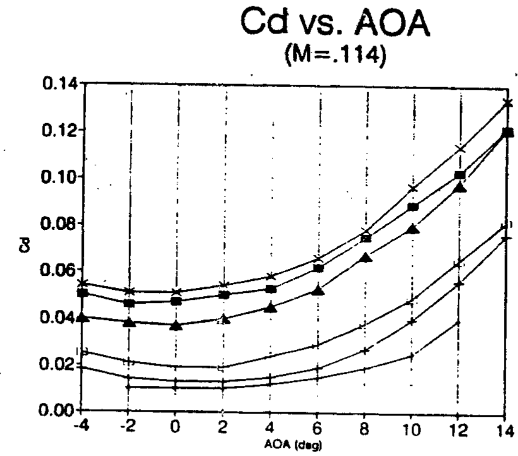

Figure 3. C_D vs AOA (M = .114)

It is also interesting to note that even though the area of the triangle is greater (see Figure 4) than the area of the square, the square has a higher C_D curve.

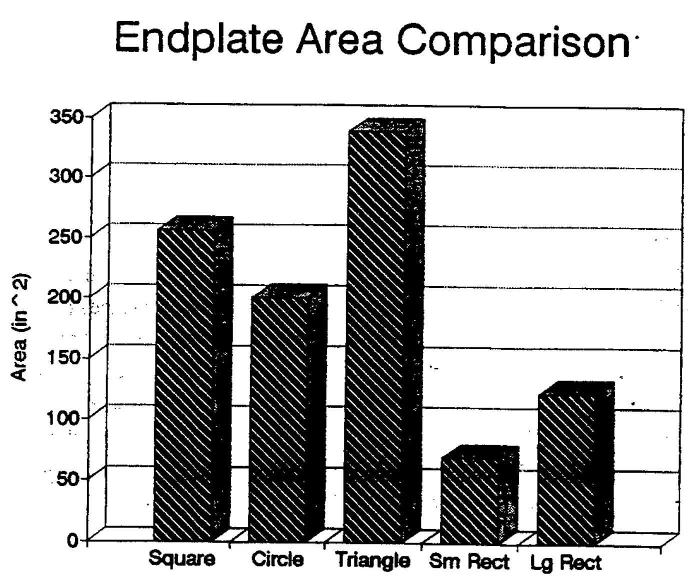

Figure 4. Endplate Area Comparison

In L/D comparison (see Table 3), the small rectangle actually is about the same as the triangle, but the triangle performs better than the other shapes. The square, circle and large rectangle have poorer L/D ratio performance than the airfoil without endplates.

Endplate	L/D
None	6.30
Triangle	6.64
Square	6.21
Circle	5.23
Small Rectangle	6.67
Large Rectangle	5.78

Table 3. L/D Comparison at 10 Degrees AOA (M = .114)

Endplate	CL	CD	L/D
Triangle	110.7	100.0	5.4
Square	119.4	122.5	-1.4
Circle	101.6	142.5	-17.0
Sm Rect	29.8	22.5	5.9
Lg Rect	35.3	47.5	-8.3

Table 4. Percent Difference from No Endplate Case of C_L C_D and L/D at 10 deg AOA (M = .114)

Although only the M = .114 results are presented in the tables and figures above, similar results are observed for the M = .15 case.

Flow Visualization

The vortices generated by the airfoil without endplates using ink flow visualization in the water tunnel give a comparison standard to gage the performance of the other endplates. With no endplate, spillage develops early and the vortex is fully developed (see Figures 5 and 6). Both rectangular endplates delay spillage somewhat and break up the vortex (see Figures 5 and 6). The other three endplates seem to control the tip vortices quite well. No spillage is observed over the circular, triangular, and square endplates.

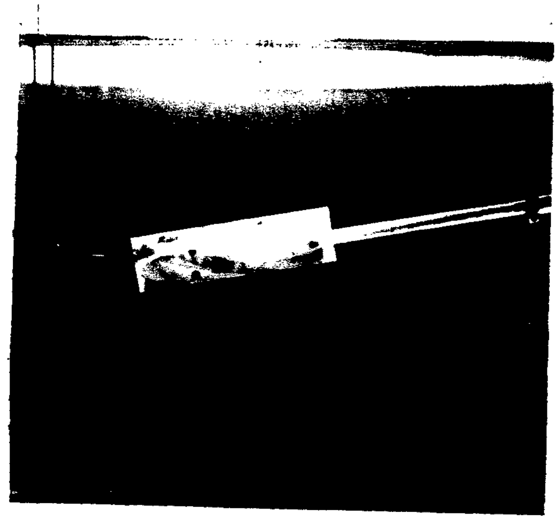

Figure 5. Side View of Airfoil Fitted with None and Small Rectangle

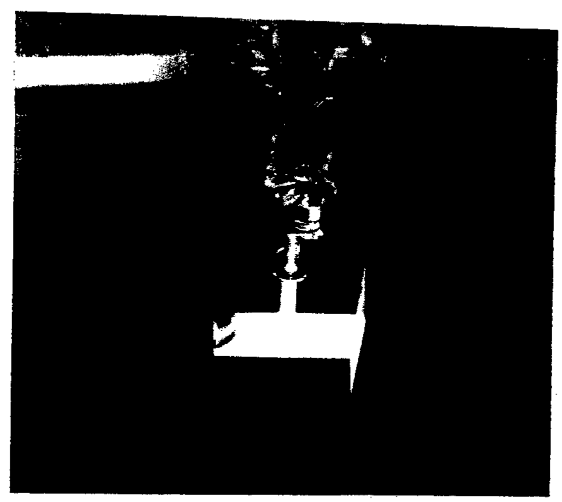

Figure 6. Rear View of Airfoil Fitted with None and Large Rectangle

Examination of the dye flow aft of the airfoil fitted with the triangular and square endplates shows greater displacement toward the "low pressure" side of the airfoil on the triangle's side (see Figure 7).

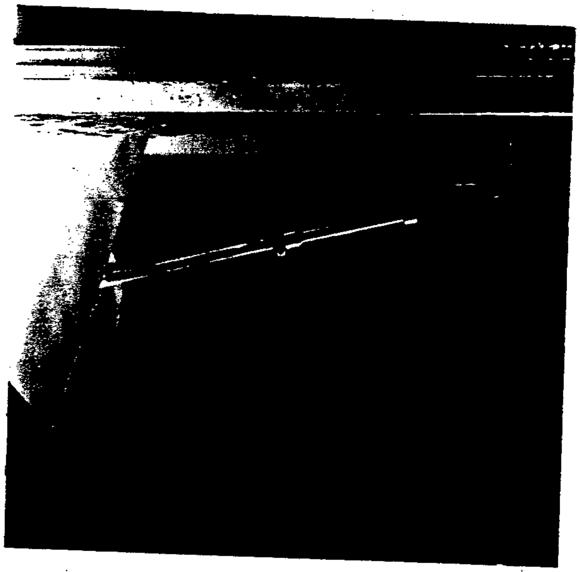

Figure 7. Side View of Airfoil Fitted with Triangle and Circle

Attributing this difference in displacement to upwash explains the superior drag performance of the triangular endplate. The endplate creates upwash by extending the area of high pressure beyond the end of the airfoil. This upwash helps cancel out the downwash caused by the airfoil's AOA and thus improves drag performance.

Conclusion

The triangular endplates seem to outperform the other endplates based on the criteria examined. One interesting point to note is that the triangle also has the largest area. According to previous research[1], area of the endplates does play a part in the reduction of wingtip vortices. Of course an increase in profile drag also results from increasing the size of the endplates. A future experiment may determine how large a part the area of the endplate plays in controlling wingtip vortices and in increasing profile drag. Size limitations made the use of a larger air foil impossible. This would decrease the importance of endplate profile drag and probably yield better results.

The flow visualization establishes a physical explanation for the triangle's superior L/D ratio performance. Unfortunately, water velocity limitations do not allow Reynolds number similarity with the wind tunnel tests. For the wind tunnel tests at M = .114, the Reynolds number is about 795,000, while the water tunnel tests at 1 fps have a Reynolds number of about 41,000. This problem could be overcome in future experiments by using "trip strips" to artificially induce flow separation in the water tunnel.

References

1. Riley, Donald R., Wind-Tunnel Investigation and Analysis of the Effects of End Plates on the Aerodynamic Characteristics of an Unswept Wing. National Advisory Committee for Aeronautics, Technical Note 2440, Langley Aeronautical Laboratory, Langley Field, Va., August 1951.

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6. Roskam, Jan, Airplane Aerodynamics and Performance, Roskam Aviation and Engineering Corporation, 1980.

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