The Effect of Vertical Stabilizers on Slender Delta Wing-Rock Vortex Bursting.

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Results of tests on a slender delta wing will be presented to describe the effect vertical stabilizers have on vortex breakdown at high angles of attack. The test will consist of flow visualization using Laser Induced fluorescence. The experimental test will vary vertical stabilizers to compare the effect on the flow. It is anticipated that the presence of vertical stabilizers will spatially lock the position of vortices thereby reducing the wing-rock. Using the experimental data, the geometry of the vertical stabilizers will Be altered to provide for a well behaved flow. Tests were conducted on a modified delta wing to analyze vertical tail influence on delta wing roll oscillation.

Nomenclature

b	=	Wing Span
c	=	Wing Chord
C_L	=	Coefficient of Lift
C_D	=	Coefficient of Drag
$\frac{L}{D}$	=	Lift of Drag ratio
LIF	=	Laser Induced Fluorescent
α	=	Angle of Attack
Λ	=	Sweep Angle

I. Introduction

Delta wings are commonly used for high speed air vehicles due to their unique aerodynamic characteristics such as high critical mach number, high C_{lmax}, Lift to drag ratio, and maneuverability. As a result many combat aircrafts are configured with delta wings. One of the most important features of a delta wing is its ability to sustain lift at a high angle of attack. The flow over a delta wing is dominated by two vortexes which are generated at the leading edge. These leading edge vortices create a favorable pressure region that produces lift (Figure 1). However, a well documented phenomenon associated with the delta wing is an asymmetric breakdown of the leading edge vortices in high angle of attack flight. As this breakdown occurs the vortex begins to grow in diameter and become turbulent. When this breakdown occurs the vortex's velocity drops, this break down results in instability in the system called wing rock. Because

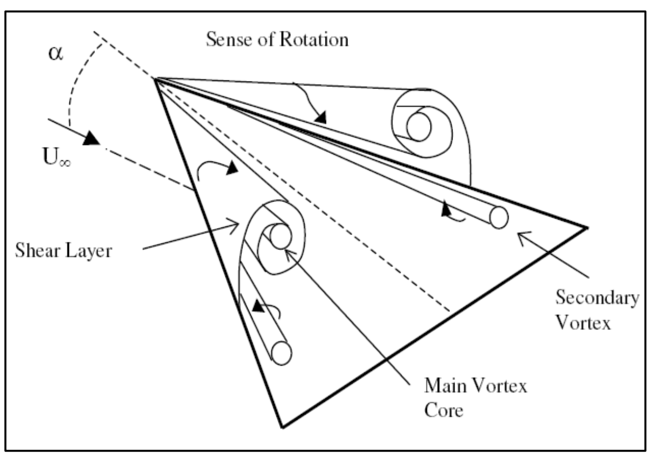

Figure 1 - Vortex Formation[1]

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of the roll-yaw coupling, delta wings encounter nose slicing and loss of control and eventually loss of combat maneuverability. A number of researchers have in the past investigated this phenomenon[1-5].

As angle of attack increases vortices production outgrows vortices convection[2].This causes the asymmetric shedding of the vortices into the flow. The shedding vortices produce unbalanced loads which causes wing rock[3]. Bursting location of these vortices is not fixed; it fluctuates as a function of angle of attack and sweep angle. Several research experiments have been conducted on delta wings in the attempt to produce more symmetric vortex shedding. In an attempt to control the stability of the oscillations several modifications were done on a delta wing model. The purpose of this study was stabilizer effect on vortex bursting. More specifically twin tail configurations were inspected as the main focus. Vertical stabilizers are horizontal components of a vehicle's empennage. A vertical tail is usually configured with a rudder to help with yaw control. Several tail configurations were tested in an attempt to dampen wing-roll; these tail configurations can be seen in Figure 2.

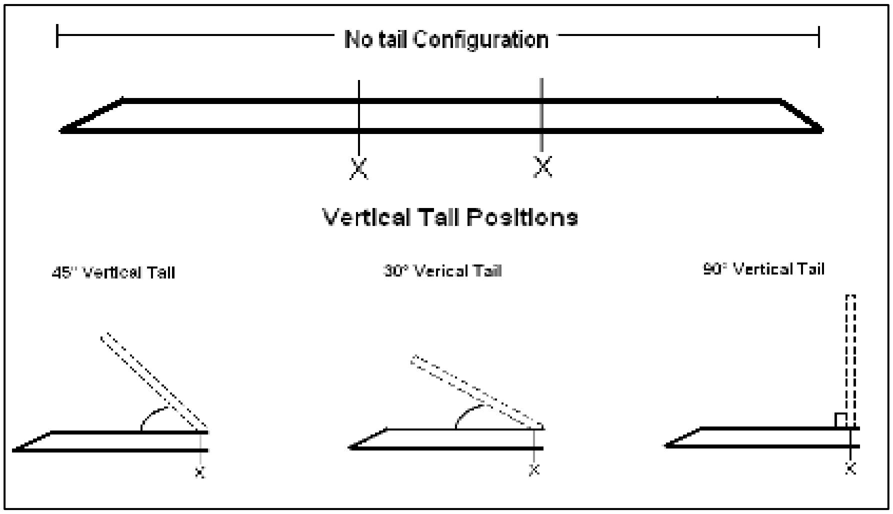

Figure 2 - Vertical Tail Configuration

The purpose of this paper is to describe the results of modifications on a delta wing in the attempt to better grasp the fluctuations in burst location and to help determine the receptiveness of the vortex core to external disturbances.

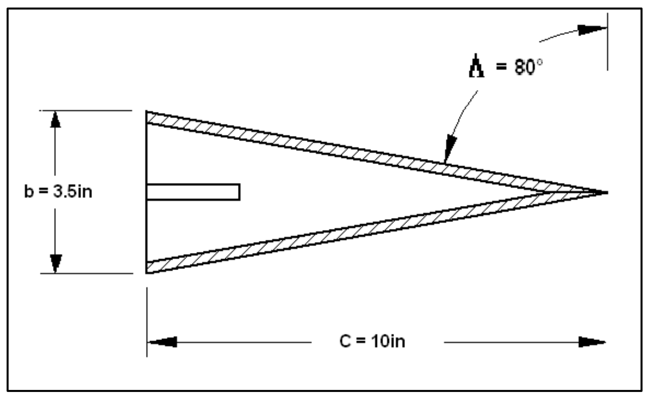

Figure 3 - Delta Wing Model

II. Experimental Setup and Procedure

A brief overview of the experimental setup for all methods of testing is given to understand the methods used in testing. The two testing methods used were: water tunnel testing for flow visualization, and wind tunnel testing for aerodynamic analysis.

A. Water Tunnel Flow Visualization

The experiments were carried out in the Auburn University Vortex Dynamics Laboratory 45cm by 45cm water tunnel. A frequency controller allowed the variation of tunnel speed from 0 to 1.1m/s. At the tunnels peak velocity there is a free stream turbulence level less than1%.A delta wing model was made 0.25in thick with a leading edge bevel of 45°, sweep root of 80°, root chord of 10in and span of 3.5in (Figure 3). This model was designed to allow for the injection of dye and allowing interchangeable vertical stabilizers. The model was mounted in the water tunnel using a C-mount device (Figure 4). This mounting mechanism was designed for free or fixed roll axis testing. A glass bearing system was used to allow for free rolling of the wing.

Fluorescent dye was injected through the model with the use of dye ports. The visual results were amplified with the use of a LIF system and hydrogen bubble wire. Initial data was collected using a fixed axis system to better establish the wing-rock characteristics of the specific model. The model was placed at 45° angle of attack. No wing rock was present in this system due to the fixed axis mount. The tunnel was run at Reynolds numbers of 400,000, 500,000 and 600,000 to allow for a wide range of possible data. Four vertical stabilizer configurations were tested; no vertical stabilizer, 90° stabilizer, 45° stabilizer, 30° stabilizer. A camera and recording system was configured to allow for capturing vortex core data, and origin location. Images were taken at focal points along the centerline chord of the delta wing in increments of 2in from the leading edge to the trailing edge.

Flow visualization data was also evaluated with a free rolling base to better describe the dynamic rolling effects on the delta wing due to vortex bursting. The model was mounted with a free axis glass ball bearing system to allow for free roll. Fluorescent dye was injected through the model's dye ports. The visual results were amplified with the use a LIF system and hydrogen bubble wire. The model was placed at 60° angle of attack to allow for classic wing-rock. The tunnel was run at Reynolds numbers of 400,000, 500,000 and 600,000 to match the fix axis test results. Four vertical stabilizer configurations were tested dynamically; no vertical stabilizer, 90° stabilizer, 45° stabilizer, 30° stabilizer. A Camera and recording system was configured to allow for capturing of dynamic vortices core data, origin location and amplitude frequency of oscillations. Images were taken at focal points along the centerline chord of the delta wing of 8in and 10in from the leading edge. Since the desire of the dynamic test was to determine the effect vertical stabilizers have on wing-rock the surface in front of the area of interest was ignored.

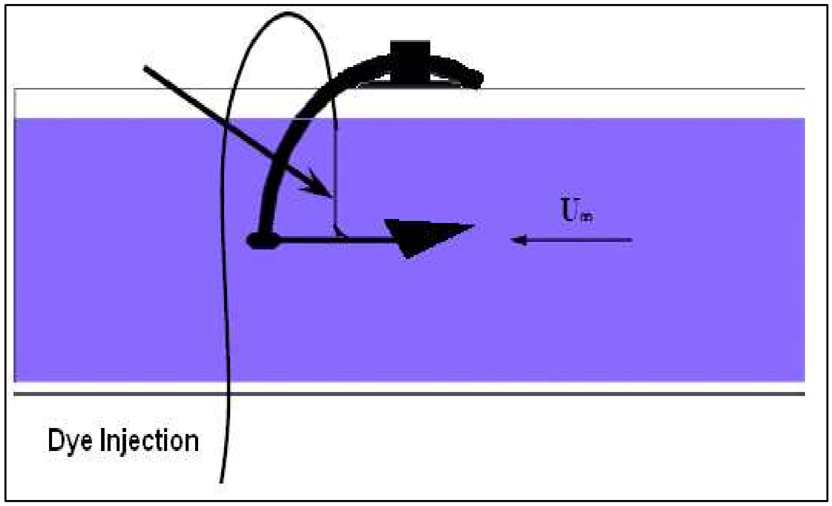

Figure 4 - C-mount device

B. Wind Tunnel Testing

Experiments were conducted in the Aerospace Engineering 3ft by 4ft cross-section, closed loop wind tunnel. Force data was measured using a 6 component external pyramidal balance (Figure 5). Prior to testing the pyramidal balance and the angle of attack potentiometer were calibrated. The model used for wind tunnel testing was the same used in water tunnel testing to allow for similar trends. Before a test was run in which the model was modified, an initial weight tare was calibrated effectively negating the weight of the model in the data acquisition.

The model was attached to the pyramidal balance via a fixed axis mounting system. Data was collected for all six vertical stabilizer configurations: no vertical stabilizer, 90° stabilizer, 45° stabilizer, 30° stabilizer. The tests were run at 80, 100, and 120 ft/s to match the corresponding Reynolds numbers of 400,000, 500,000 and 600,000 calculated from the delta wing's chord. The forces measured from the pyramidal balance were analyzed using Labview data acquisition software.

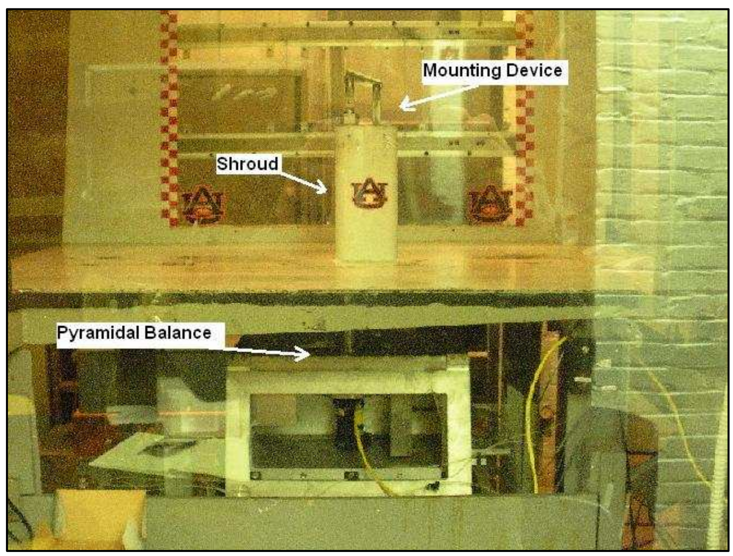

Figure 5 - Pyramidal balance

III. Results and Discussion

Initial testing was done in the water tunnel using LIF to better understand the flow over the delta wing. Images were taken at 2in increments from the leading edge for all configurations. Since effects of vertical stabilizers were the main goal of this research only 8in and 10in points were studied. All videos were digitized and analyzed frame by frame. Water tunnel testing showed shedding vortices that produced wing-rock fluctuations. Configurations of no tail, 90°, 45°, 30° all produced images that showed vortices. Dye was injected in the flow at the leading edge via dye tubes. This dye is drawn to the flow with the highest velocity, thus indicating bursting by lack of fluorescence.

All tail configurations showed core vortices following the model's body. A trend that was observed was linear growth of core diameter in the stream wise direction. While formation of the two main vortices is an inviscid formation on, which does not depend on Reynolds number, the vortex core diameter is dependent upon Reynolds number[4, 5].

Figure 6 shows the 90° tail configuration in a free roll case. This frame-by-frame shot shows the cross-section of a vortex passing through the image plane. For all tail configurations was a trend for the circulating flow to attach itself to the vertical body. This had an effect in stimulating the flow and affecting the bursting location. Since the vortex core is receptive to external disturbances caused by the presence of vertical tails. With the no tail configurations this disturbance is not present as an external disturbance on the flow. At time step t=0, the vortex core development is clearly defined. As progression down the body of the model continues the vortex continues dilation. The vortices' inability to maintain a tight structure is evident over time steps t=0 through t=5. In frame t=3, an attachment is evident. The vortex tends to move towards its image in the vertical tail.

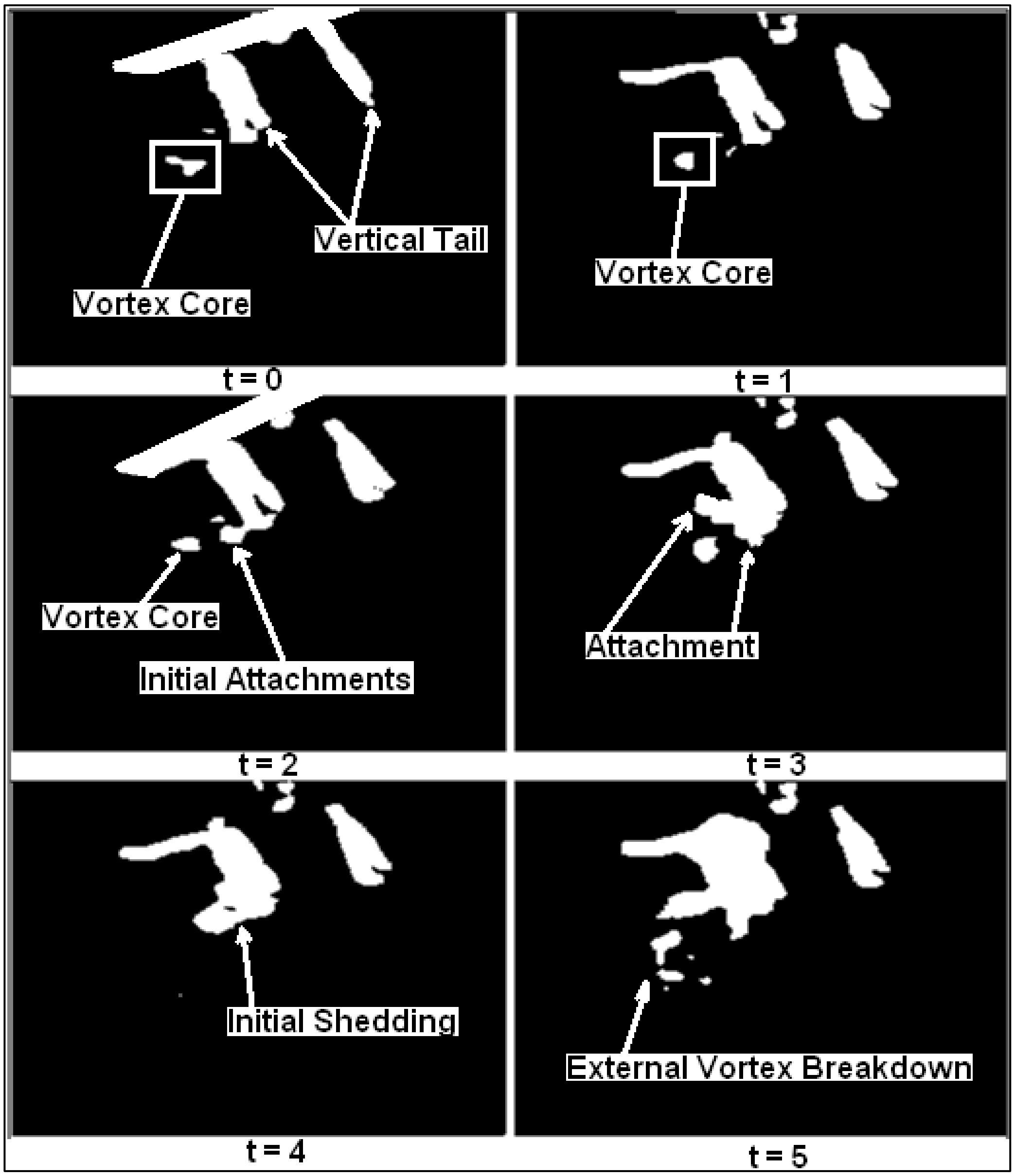

Figure 6 - Vortex Formation and Breakdown

Wind tunnel testing showed that in a no tail configuration C_L and C_D increases non-linearly with $\boldsymbol{\alpha}$. Adding a vertical tail produces a linear fit to the coefficient curve (Figure 7, 8). This linear fit correlates closely with the theoretical cure slope of 2π. It is noted that the slope of the C_L curves, with all tail configurations, are similar to the slope of a flat plate. The addition of a vertical tail also increased the Lift over Drag ratios. For all tail configurations a less rapid decrease in $\frac{L}{D}$ was observed (Figure 9).

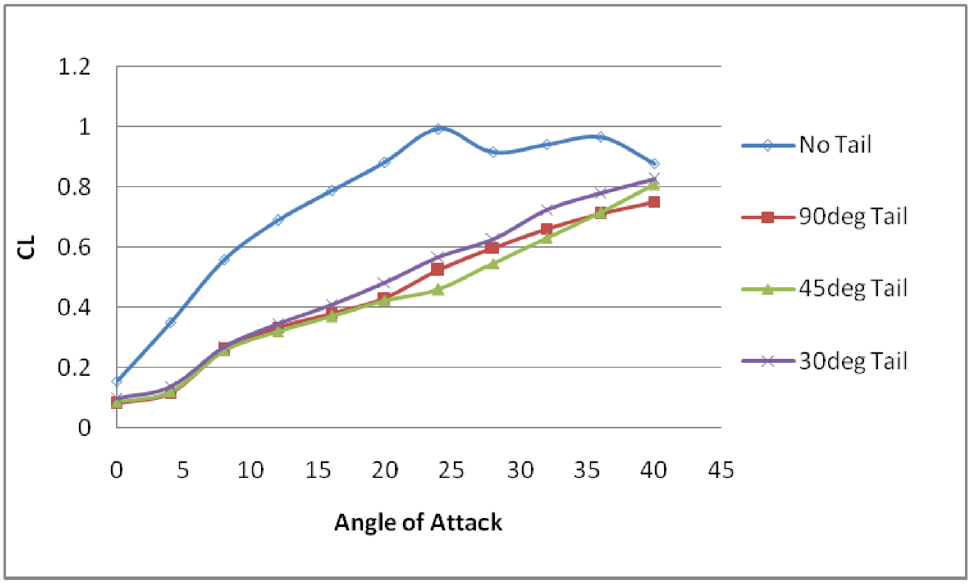

Figure 7 - CL vs. Angle of Attack

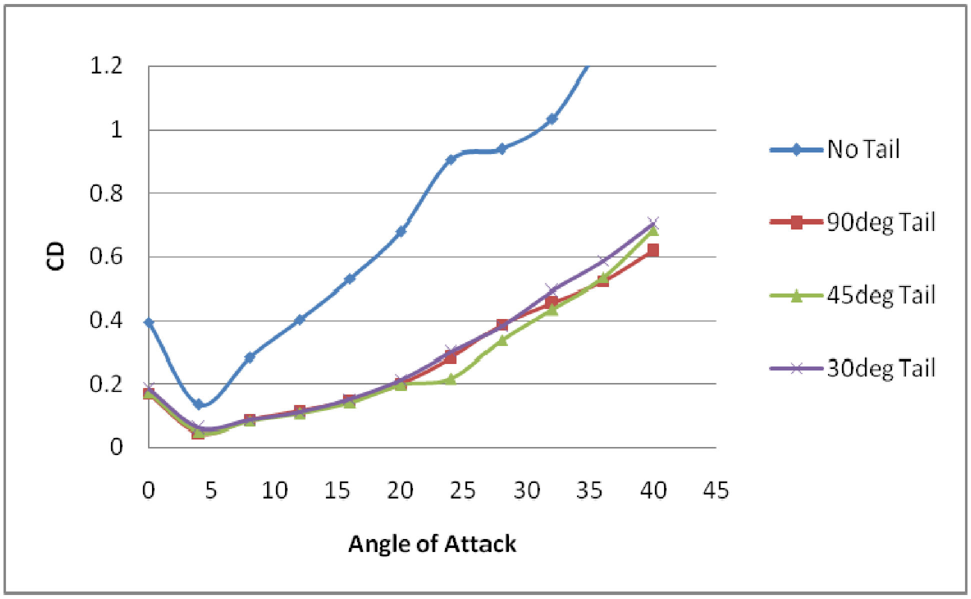

Figure 8 - CD vs. Angle of Attack

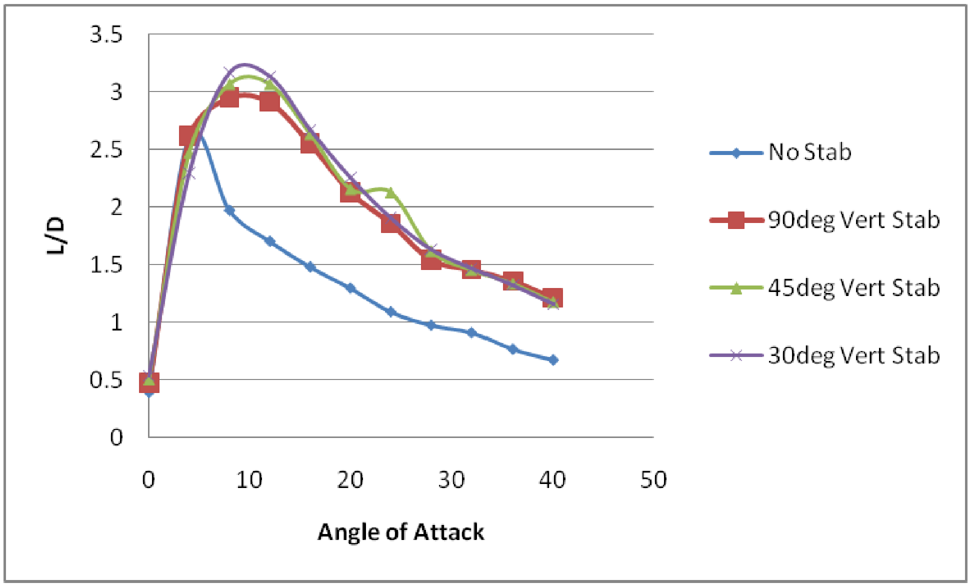

Figure 9 - L/D vs. Angle of Attack

IV. Conclusions

For all tail configurations tested vortex attachment was observed. These attachments were caused by the vortex's attraction to the surface of the tail. All vertical tails were successful in decreasing drag due to the attachment of vortexes to the vertical surface. All vertical tail configurations resulted in similar trends, However the 30° vertical tail resulted in the largest $\frac{L}{D}$ ratio. For C_L a linear curve fit was measured for all tail configurations.

V. References

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