

AFFTC-PA-11316



# Can Wing Tip Vortices Be Accurately Simulated?

Ryan Termath, Science and Teacher  
Researcher (STAR) Program,  
CAL POLY SAN LUIS OBISPO

Jason Lechniak, and Keerti Bhamidipati  
AIR FORCE FLIGHT TEST CENTER  
EDWARDS AFB, CA

JULY 2011

Approved for public release A: distribution is unlimited.

AIR FORCE FLIGHT TEST CENTER  
EDWARDS AIR FORCE BASE, CALIFORNIA  
AIR FORCE MATERIEL COMMAND  
UNITED STATES AIR FORCE

A  
F  
F  
T  
C



## Can Wing Tip Vortices Be Accurately Simulated?

Ryan Termath, Jason Lechniak

Modeling and Simulation (M&S) computational fluid dynamics (CFD) techniques were used to better understand wing tip vortices about a wing section. The CFD results were compared to experimental wind tunnel data derived from the University of Iowa (Ref. 2). The experiment used Stereoscopic Particle Image Velocimetry (SPIV) to measure the flow field. The SPIV data from the experiment illustrates the vortex core development and behavior downstream of the trailing edge of the wing section. Three CFD simulations using various mesh sizes and time steps were completed and compared to the experimental results. Two dimensional plots of modeled local flow field velocity over freestream velocity were visualized using *VisIt*. *VisIt* is used to graphically represent the numerical results of the simulations. Once the M&S results were visualized, the approximate vortex core size and position were measured and compared to the experimental data. The results show that the larger meshes closer approximate the experimental data. Further refinement of the mesh sizes in future simulations are expected to improve the approximate numerical solutions from the simulations, which would allow for more accurate predictions of vortex formation and behavior.

# **Can Wing Tip Vortices Be Accurately Simulated?**

**Ryan Termath (rtermath@calpoly.edu)<sup>a</sup>, Jason Lechniak<sup>b</sup>**

**<sup>a</sup>Science and Teacher Researcher (STAR) Program, Cal Poly San Luis Obispo**

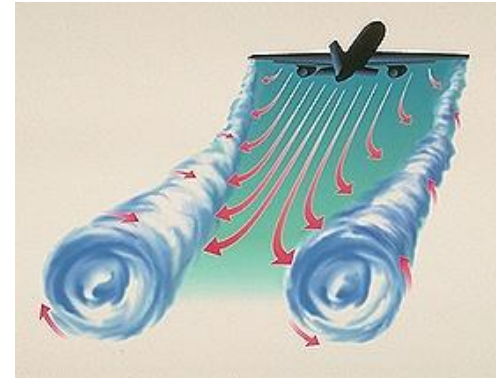
**<sup>b</sup>Air Force Flight Test Center, Edwards Air Force Base, CA**

## Wingtip Vortices and the Rationale of This Project

Wingtip vortices are the result of a pressure difference between the top and bottom of an aircraft wing or helicopter rotor moving through air. In military applications, wing tip vortices have adverse effects on towed vehicles and cause additional tail buffeting.<sup>2</sup> In commercial applications, winglets have been installed on passenger aircraft to minimize vortex formation and reduce lift-induced drag.<sup>2</sup>

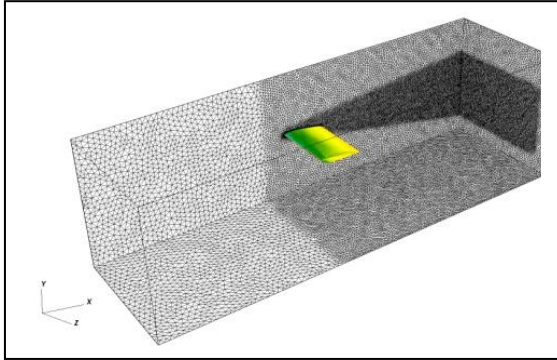
Visually, wingtip vortices can be thought of as a horizontal tornado (as shown in Figure 1), whose cross-sectional area increases with increasing downstream distance.

From a computational standpoint, modeling wingtip vortices has been a challenging area of study. It has only been in recent years that computational tools that better resolve and approximate wingtip vortices have been developed. This project sought to expand on gains made by using incrementally more computationally intensive simulations. Determination of the accuracy of the model wingtip vortices was accomplished by comparing simulation results to experimental data.



**Figure 1 – Visual Representation of Wingtip Vortices**

## Methods



Numerical results of  
simulations sent to  
visualization program  
*VisIt*

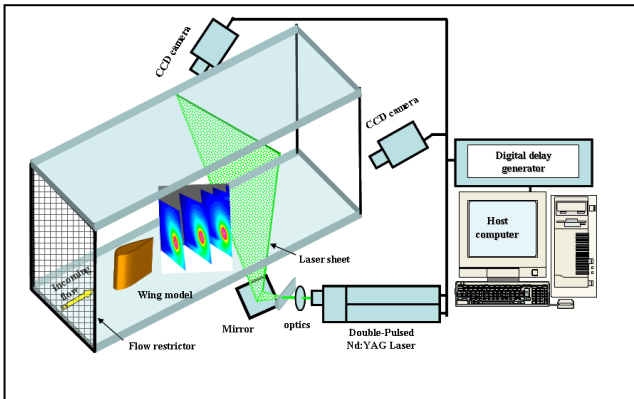
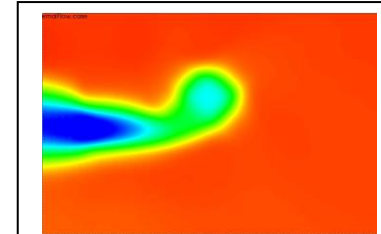
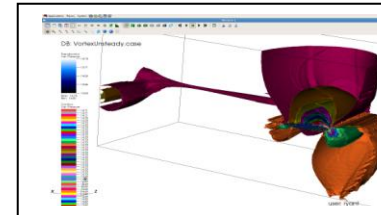
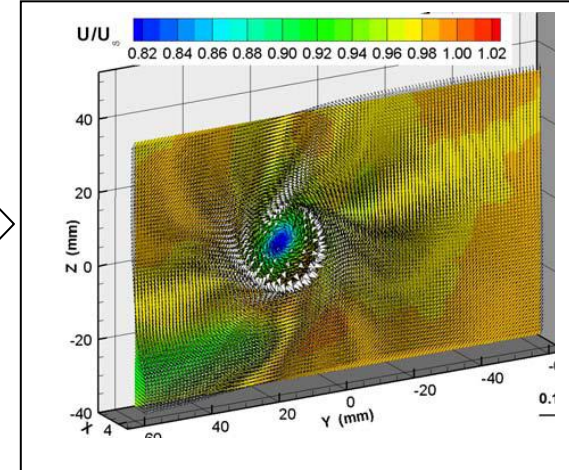


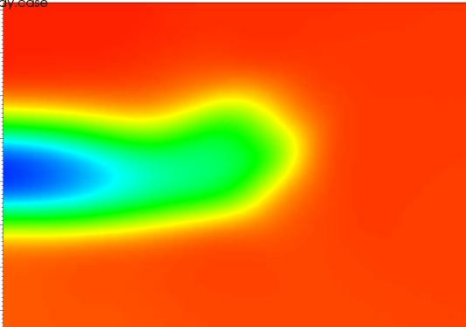
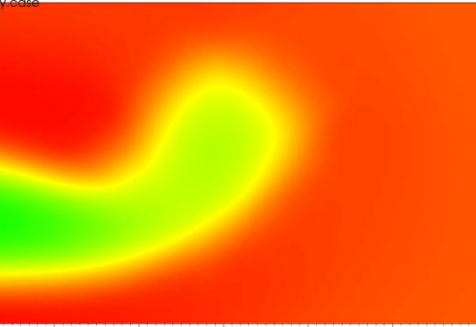
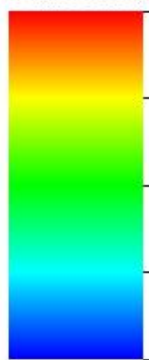
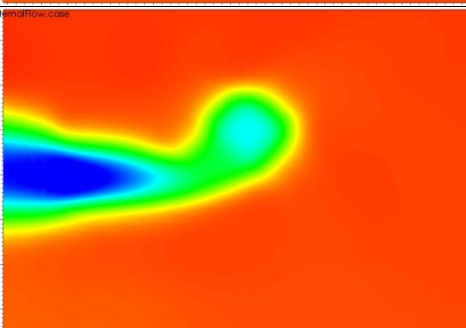
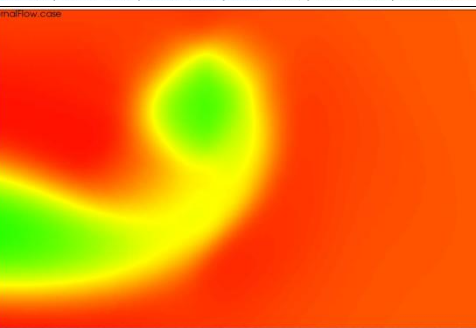
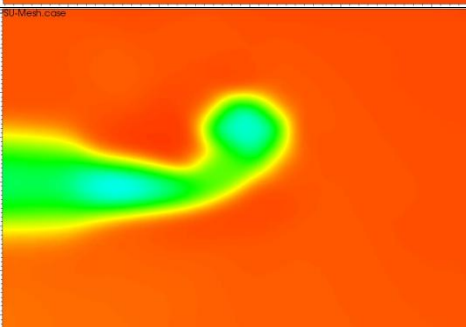
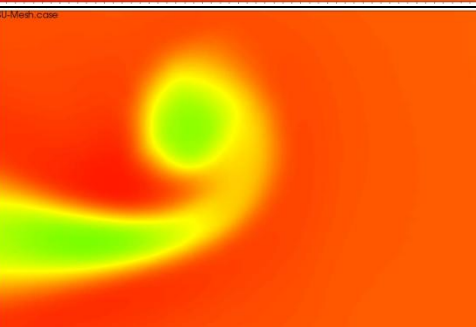
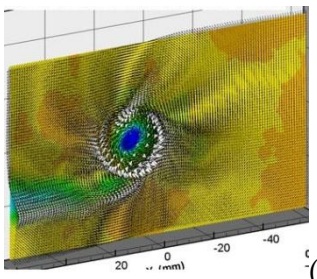
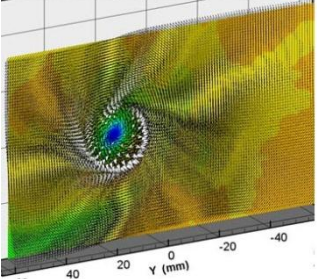
Figure 2 – Experimental Setup using  
StereoSopic Particle Image Velocimetry  
(SPIV) (Ref 2)

Data from Iowa State  
University wind tunnel  
experiment compared  
to simulation.



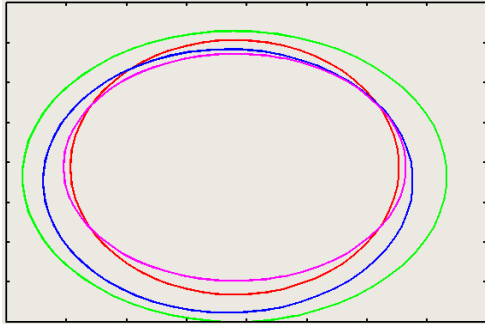
Ref 2

# Plots of Instantaneous Velocity over Freestream Velocity and Equivalent SPIV Images

Simulation	4" downstream of trailing edge	16" downstream of trailing edge	Legends
Sim0			<p data-bbox="1449 138 1585 170"><i>Simulation</i></p> <div data-bbox="1375 560 1659 1063"> <p data-bbox="1386 568 1575 592">Pseudocolor</p> <p data-bbox="1386 592 1596 617">Var: UoverU_inf</p>  <p data-bbox="1386 990 1533 1015">Max: 1.201</p> <p data-bbox="1386 1015 1533 1039">Min: -0.6317</p> </div>
Sim3			
Sim7			
SPIV <sup>2</sup>	 <p data-bbox="651 1356 735 1388">(Ref 2)</p>	 <p data-bbox="1155 1356 1239 1388">(Ref 2)</p>	

## Approximate Size and Location of Vortex Cores

From the 2D data collected, the vortex cores were approximated to be ellipses, and size and location were found and plotted for 4", 8", 12", 16" downstream of TE.



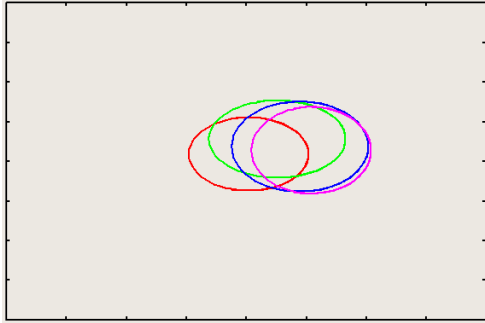
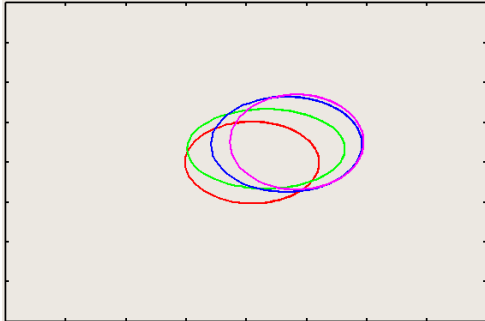
### Legend

Purple = 4" downstream

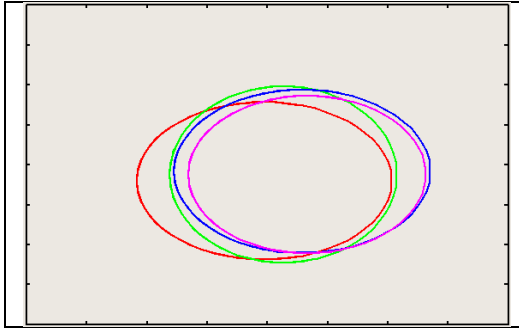
Blue = 8" downstream

Green = 12" downstream

Red = 16" downstream







## Discussion

### Instantaneous Velocity over Freestream Velocity with Equivalent SPIV Images

- All three simulations and SPIV show a counterclockwise “curl” forming downstream of the right edge of the wing and from the color scale confirms an expected inverse relationship between vortex velocity and distance from the center (Ref 1).
- The shapes of Sim3 and Sim7 more closely resemble that of SPIV for both downstream locations.
- Sim7 shows more detail than Sim3 and is most like the SPIV plots, as at the 16” mark the plot clearly shows a defined vortex core separated from the horizontal “wash” of the wing.

### Vortex Core Size and Location Approximation

As downstream distance from the trailing edge increases:

- Sim0 only shows increase in vortex core area with no core displacement
- Sim3 shows increasing change in area and a core displacement up and to the left.
- Sim7 shows a change in area and a core displacement that approximately follows a concave down parabolic trajectory from right to left which, while exaggerated, resembles what is seen in the SPIV approximation.

## Conclusion

- Simulated wingtip vortex development and behavior more closely resembles that of SPIV for finer and denser mesh sizes. The same can be said for vortex core area, and thus the size of the vortices can be approximated by future simulations using a mesh size at least that of Sim7.
- Future work for the simulations need more accurately measured dimensions and coordinates of vortices in the 2D plane, as well as have more exact data from the SPIV experiments. With more accurate measurements there is a need to numerically verify the error of the simulations in comparison to SPIV data to make a better judgment about whether the simulations are reliable to use.
- If the simulations for wingtip vortices are reliable, they can be used to make more efficient use of wind tunnel tests and aid in the design process of aircraft.

### Acknowledgements

An additional thank you to the following people: *Russell Billings* at NASA DFRC for his role in my placement at Edwards AFB, and for investing time into our professional development as STAR interns. This material is based upon work supported by the S.D. Bechtel, Jr. Foundation and by the National Science Foundation under Grant No. 0952013 and Grant No. 0833353. Any opinions, findings, and conclusions or recommendations expressed in this material are those of the authors and do not necessarily reflect the views of the S.D. Bechtel, Jr. Foundation or the National Science Foundation.

### References

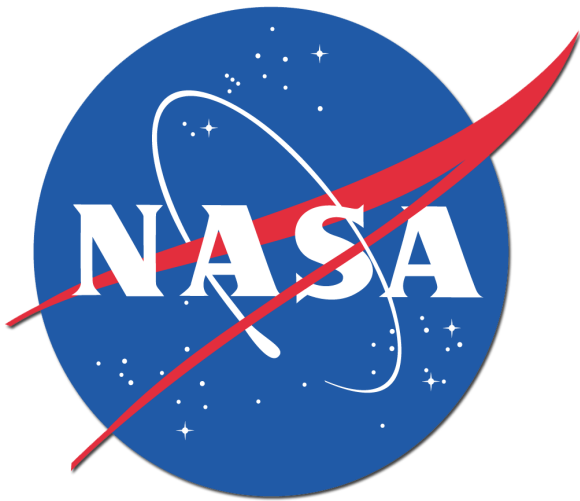
- Ref 1: Abbott, I. H., & von Doenoff, A. E. (1959). *Theory of Wing Sections - Including a Summary of Airfoil Data*. Mineola: Dover Publications, Inc.
- Ref 2: Igarashi, H., Durbin, P. A., Ma, H., & Hu, H. (2010). *A Stereoscopic PIV Study of a Near-Field Wingtip Vortex*. Orlando: American Institute of Aeronautics and Astronautics, Inc.
- Ref 3: Stewart, R. (2002, October 2). *Wake Turbulence Commentary*. Retrieved July 16, 2011, from Robyn's Flying Start: <http://www.flyingstart.ca/FlightTraining/PSTAR/7As.htm>



**CSU** **The California State University**  
WORKING FOR CALIFORNIA



S. D. BECHTEL, JR.  
FOUNDATION  
STEPHEN BECHTEL FUND

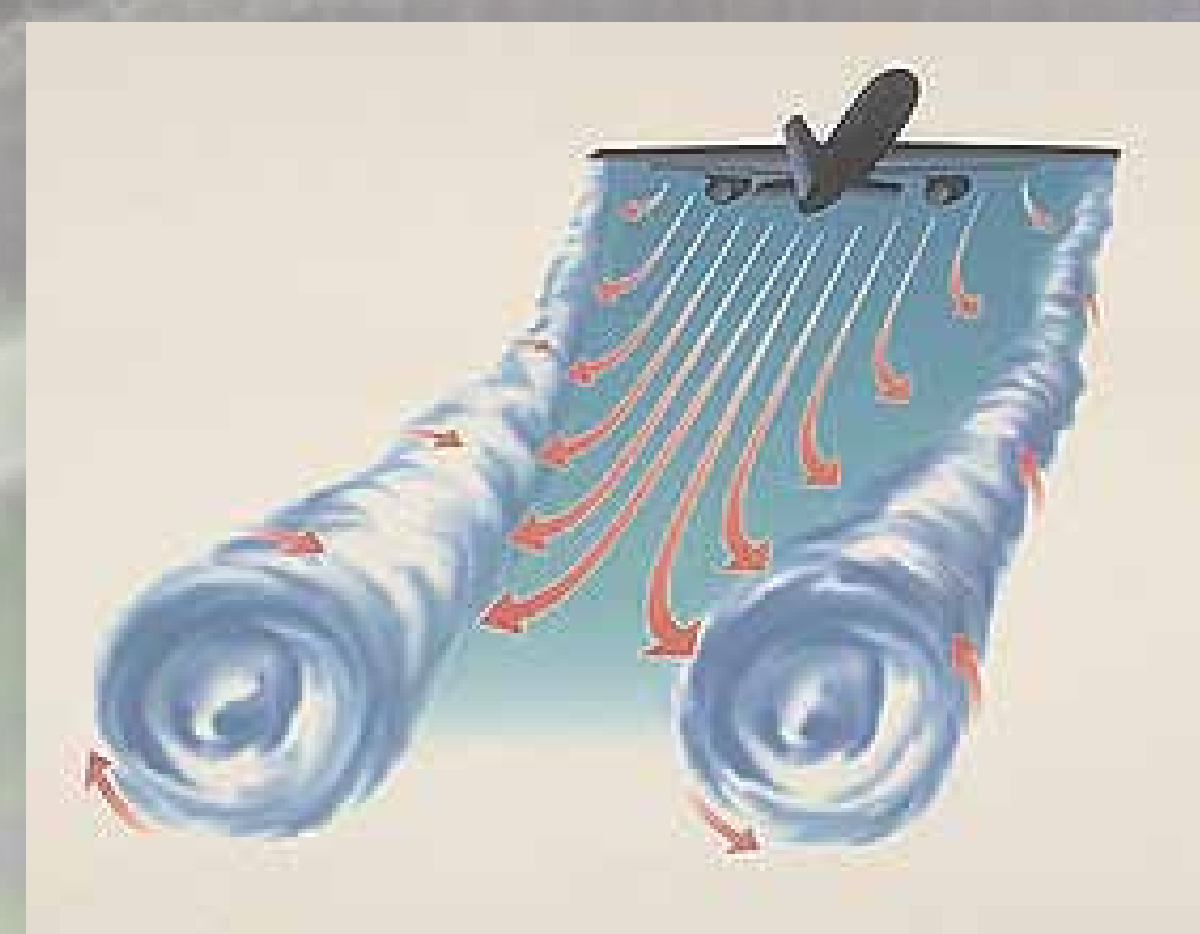


# Simulation of Wingtip Vortices

## Wingtip Vortices and the Rationale of This Project

Wingtip vortices are the result of a pressure difference between the top and bottom of an aircraft wing or helicopter rotor moving through air. In military applications, wing tip vortices have adverse effects on towed vehicles and cause additional tail buffeting (Ref 2). In commercial applications, winglets have been installed on passenger aircraft to minimize vortex formation and reduce lift-induced drag (Ref 2). Visually, wingtip vortices can be thought of as a horizontal tornado (as shown in Figure 1), ... whose cross-sectional area increases with downstream distances.

Computationally, modeling wing tip vortices has been a challenging area of study. It has only been in recent years that computational tools that better resolve and approximate wing tip vortices have been developed. This project sought to expand on gains by using incrementally more computationally intensive simulations. Determination of the accuracy of the modeled wing tip vortices was accomplished by comparing simulation results to experimental data.



Visual Representation of Wingtip Vortices (Ref 3)

## Results

Simulation	Instantaneous Velocity over Freestream Velocity ( $U/U_\infty$ ) and Equivalent SPIV Images		Approximate Size and Location of Vortex Cores
	4" downstream of trailing edge	16" downstream of trailing edge	
Sim0			
Sim3			
Sim7			
SPIV			

## Conclusion

- Simulated wing tip development, behavior and core area more closely resemble that of the SPIV data for denser meshes. The physical size of vortex cores can thus be approximated by future simulations using a mesh size at least that of Sim7.
- Future work for the simulation need more accurately measured dimensions and coordinates of vortices in the 2D plane, as well as have more exact data from the SPIV experiments. With more accurate dimensions there is a need to numerically verify the error of the simulations in comparison to SPIV data to make a better judgment about whether the simulations are reliable to use.
- If the simulations for wingtip vortices are reliable, they can be used to make more efficient use of wind tunnel tests and aid in the design process of aircraft

## Acknowledgements

An additional thank you to Russell Billings at NASA DFRC for his role in my placement at Edwards AFB, and for investing time into our professional development as STAR interns. This material is based upon work supported by the S.D. Bechtel, Jr. Foundation and by the National Science Foundation under Grant No. 0952013. Any opinions, findings, and conclusions or recommendations expressed in this material are those of the authors and do not necessarily reflect the views of the S.D. Bechtel, Jr. Foundation or the National Science Foundation.

## References

- Ref 1: Abbott, I. H., & von Doenoff, A. E. (1959). Theory of Wing Sections - Including a Summary of Airfoil Data. Mineola: Dover Publications, Inc.
- Ref 2: Igarashi, H., Durbin, P. A., Ma, H., & Hu, H. (2010). A Stereoscopic PIV Study of a Near-Field Wingtip Vortex. Orlando: American Institute of Aeronautics and Astronautics, Inc.
- Ref 3: Stewart, R. (2002, October 2). Wake Turbulence Commentary. Retrieved July 16, 2011, from Robyn's Flying Start: <http://www.flyingstart.ca/FlightTraining/PSTAR/7As.htm>

## Legends

$U/U_\infty$	Vortex Cores
	Purple = 4" downstream
	Blue = 8" downstream
	Green = 12" downstream
	Red = 16" downstream

rtermath@calpoly.edu



## Discussion

### Instantaneous Velocity over Freestream Velocity and Equivalent SPIV Images

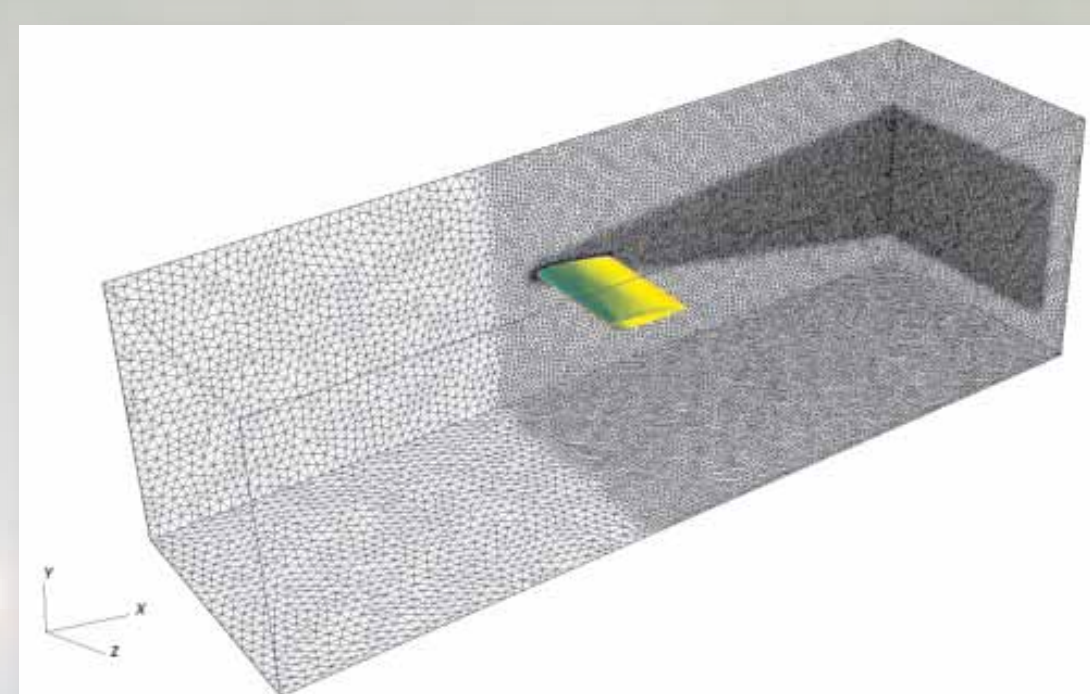
- All three simulations and SPIV show a counterclockwise "curl" forming downstream of the right edge of the wing and from the color scale confirms an expected inverse relationship between vortex velocity and distance from the center (Ref 1).
- The shapes of Sim3 and Sim7 more closely resemble that of SPIV for both downstream locations.
- Sim7 shows more detail than Sim3 and is most like the SPIV plots, as at the 16" mark the plot clearly shows a defined vortex core separated from the horizontal "wash" of the wing.

### Vortex Core Size and Location Approximation

As downstream distance from the trailing edge increases:

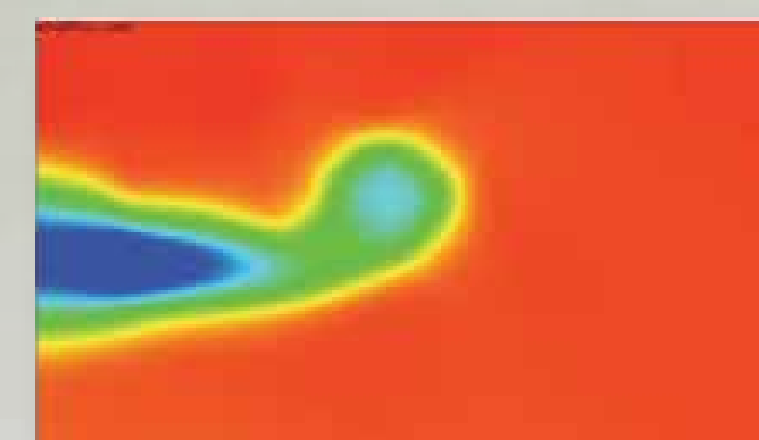
- Sim0 only shows increase in vortex core area with no core displacement
- Sim3 shows increasing change in area and a core displacement up and to the left.
- Sim7 shows a change in area and a core displacement that approximately follows a concave down parabolic trajectory from right to left which, while exaggerated, resembles what is seen in the SPIV approximation.

## Part 1: Computer Simulation

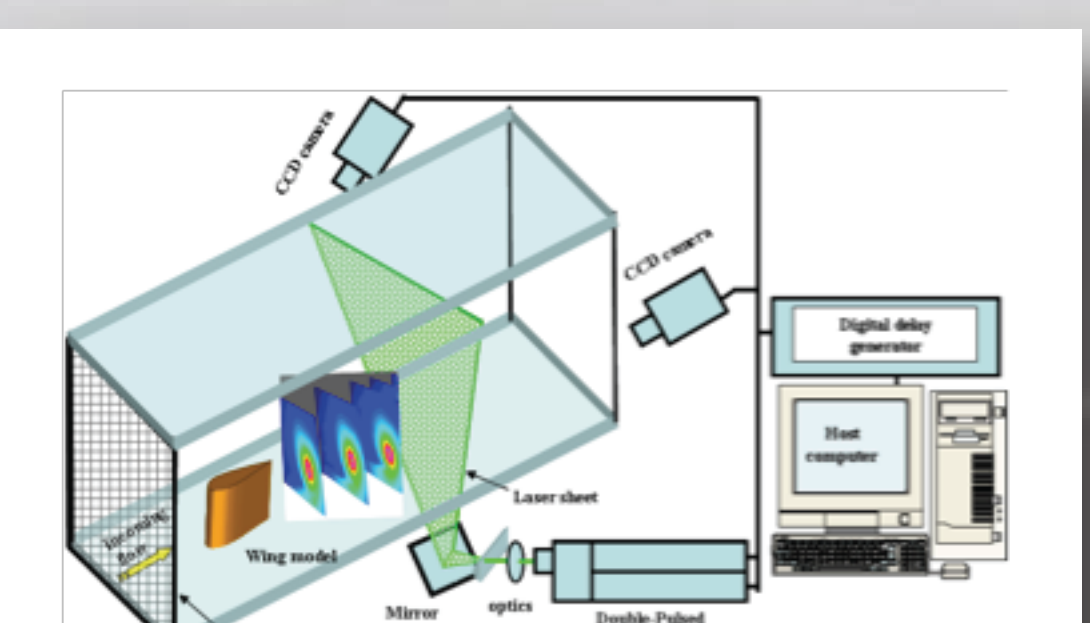


Example 3D mesh used in computer simulation

Numerical results of simulations sent to visualization program VisIt

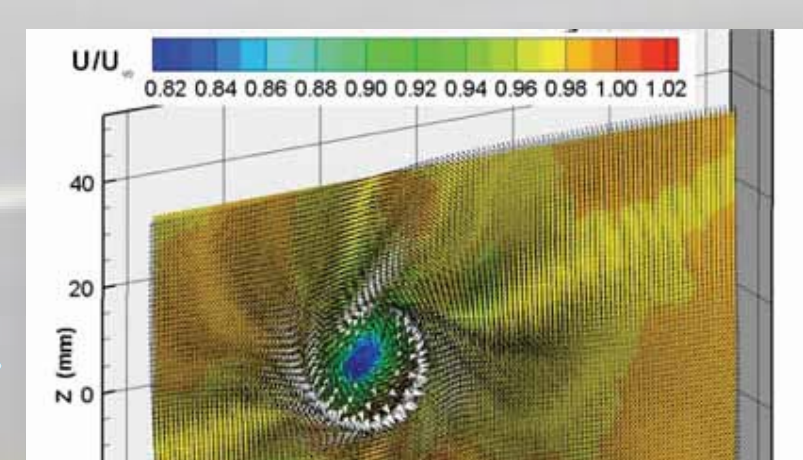


## Part 2: Wind Tunnel Data



Experimental Setup using StereoScopic Particle Image Velocimetry (SPIV) (Ref 2)

Data from Iowa State University wind tunnel experiment compared to simulation



(Ref 2)