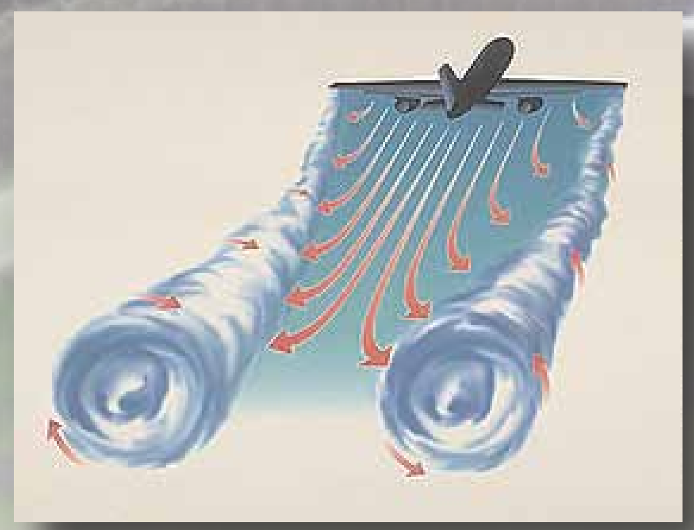
Simulation of Wingtip Vortices

Ryan Termath, Science and Teacher Researcher (STAR) Program, Cal Poly San Luis Obispo
Jason Lechniak, Keerti Bhamidipati, Air Force Flight Test Center, Edwards Air Force Base, CA

Wingtip Vortices and the Rationale of This Project

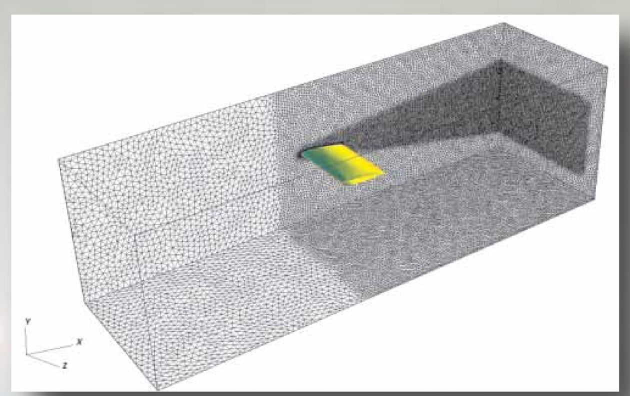
Wingtip vortices are the result of a pressure difference between the top and bottom of an aircraft wing or helicopter rotor moving through air. In military applications, wing tip vortices have adverse effects on towed vehicles and cause additional tail buffeting (Ref 2). In commercial applications, winglets 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.



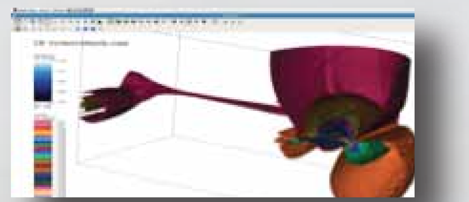
Visual Representation of Wingtip Vortices (Ref 3)

Part 1: Computer Simulation

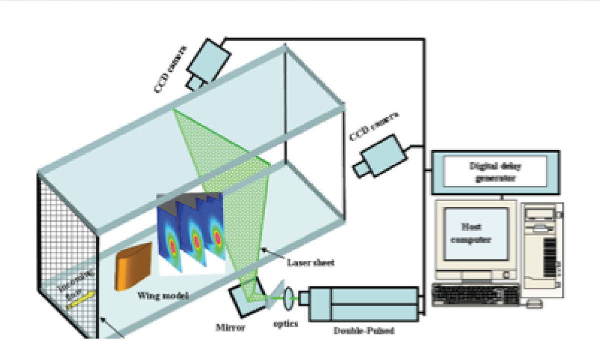


Example 3D mesh used in computer simulation

Numerical results of simulations sent to visualization program *VisIt*

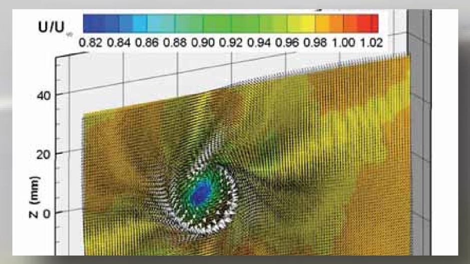


Part 2: Wind Tunnel Data



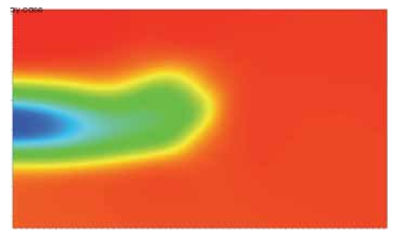
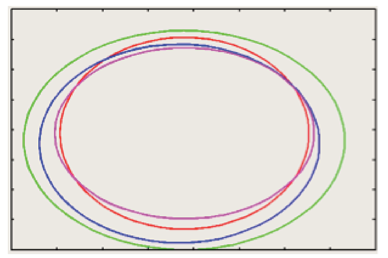
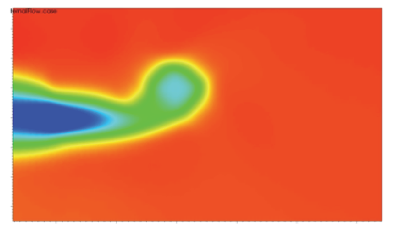
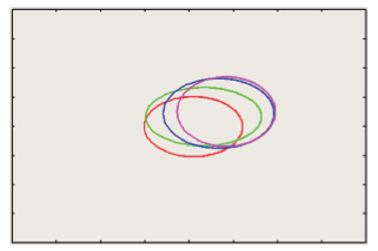
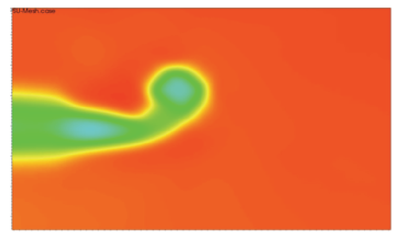
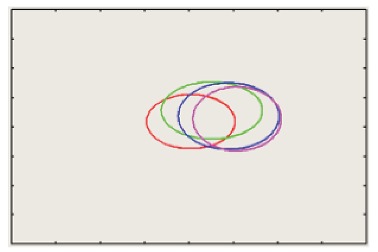
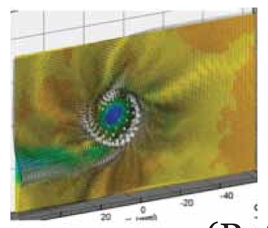
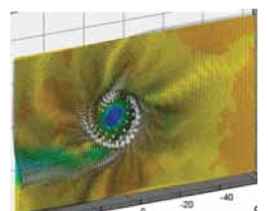
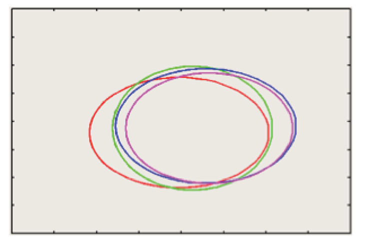
Experimental Setup using StereoScopic Particle Image Velocimetry (SPIV) (Ref 2)

Data from Iowa State University wind tunnel experiment compared to simulation



(Ref 2)

Results

Instantaneous Velocity over Freestream Velocity (U/U_∞) and Equivalent SPIV Images			Approximate Size and Location of Vortex Cores
Simulation	4" downstream of trailing edge	16" downstream of trailing edge	
Sim0			
Sim3			
Sim7			
SPIV	 (Ref. 2)	 (Ref. 2)	

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.

Conclusion

a. 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.

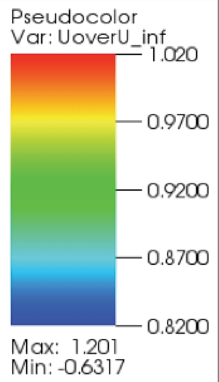
References

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_∞	Vortex Cores
	Purple = 4" downstream Blue = 8" downstream Green = 12" downstream Red = 16" downstream

rtermath@calpoly.edu