The 23rd Offshore Symposium

Feb 14, 2018 | Houston, TX

VISVE – A VIScous Vorticity Equation model applied to cylinders, hydrofoils and propellers in wetted and cavitating conditions

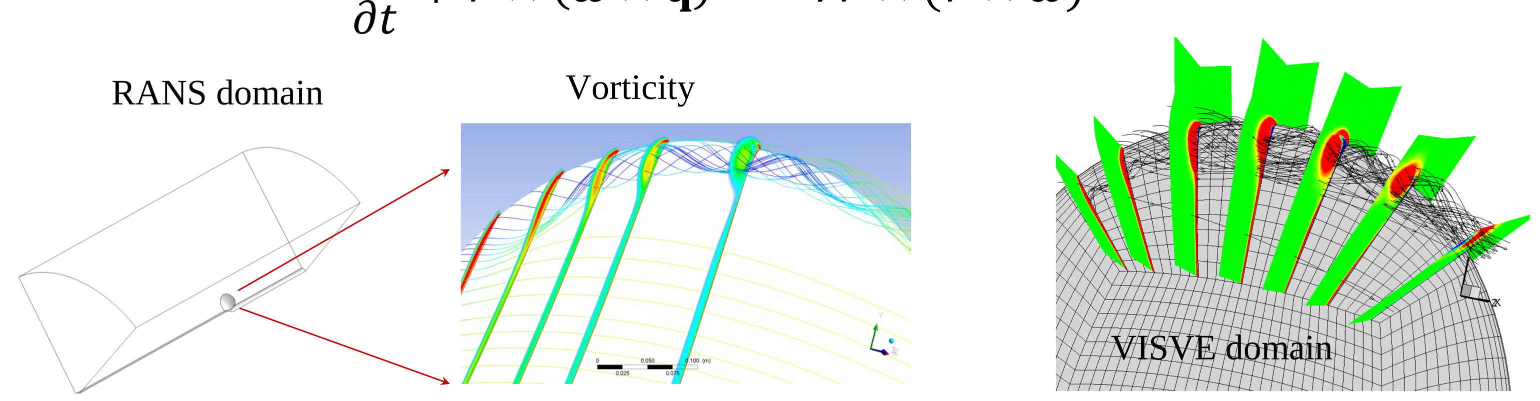
Lu Xing, Chunlin Wu , Zhihao Li, and Spyros A. Kinnas

Ocean Engineering Group, The University of Texas at Austin

Introduction

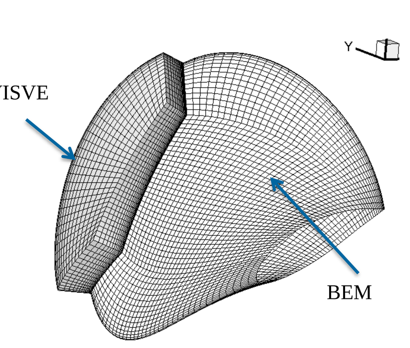
Unlike velocity, vorticity is a locally concentrated quantity. So, if we solve the vorticity equation, the computational domain can be significantly reduced.

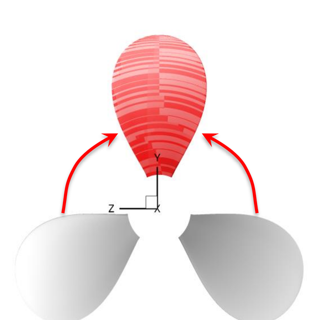
$$\frac{\partial \boldsymbol{\omega}}{\partial t} + \nabla \times (\boldsymbol{\omega} \times \mathbf{q}) = -\nu \nabla \times (\nabla \times \boldsymbol{\omega})$$



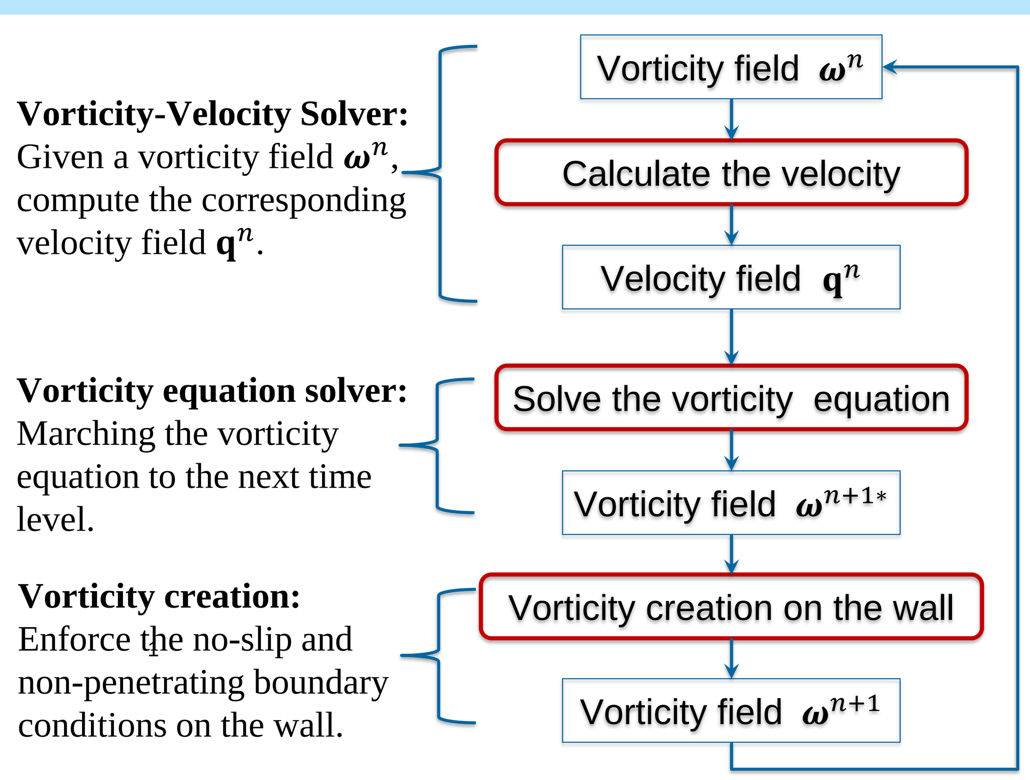
Objectives

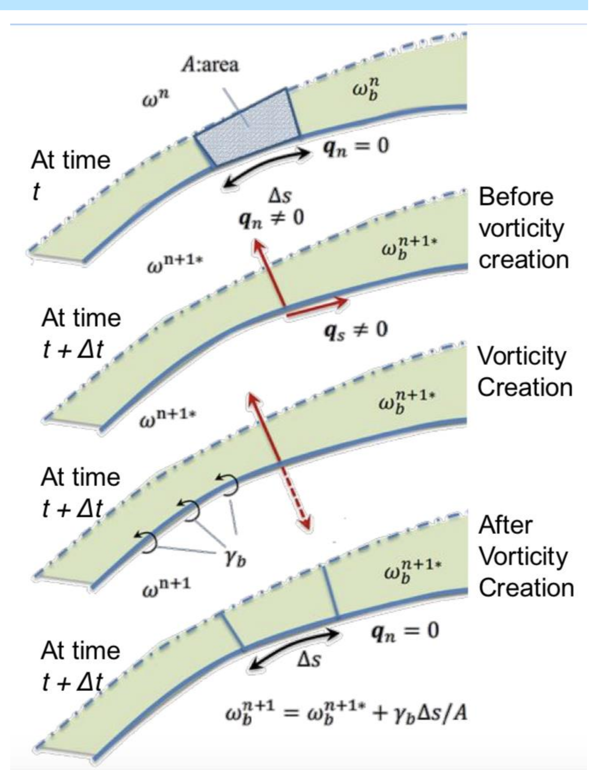
- A computationally efficient and spatially compact vorticity equation solver (VISVE) with automated grid generation is developed.
- The solver is applicable to flow around hydrofoils and propellers in backing and forward conditions.
- The solver is applicable to cavitating flow around hydrofoils and propellers.
- Also, this method is a potentially efficient tool to simulate tip vortex cavitation inception and tip gap flow for ducted propeller.
- The effect of other blades is considered in an iterative manner, which is similar to the method used in PROPCAV and MPUF-3A.
- Unlike RANS, only the flow on key blade is needed to be modeled. For axisymmetric case: duplicate the variables of the key blade. For non-axisymmetric case: use the variables of the key blade at different blade angles.





Methodology





Applications

➢ 2-D hydrofoils in cavitating flow

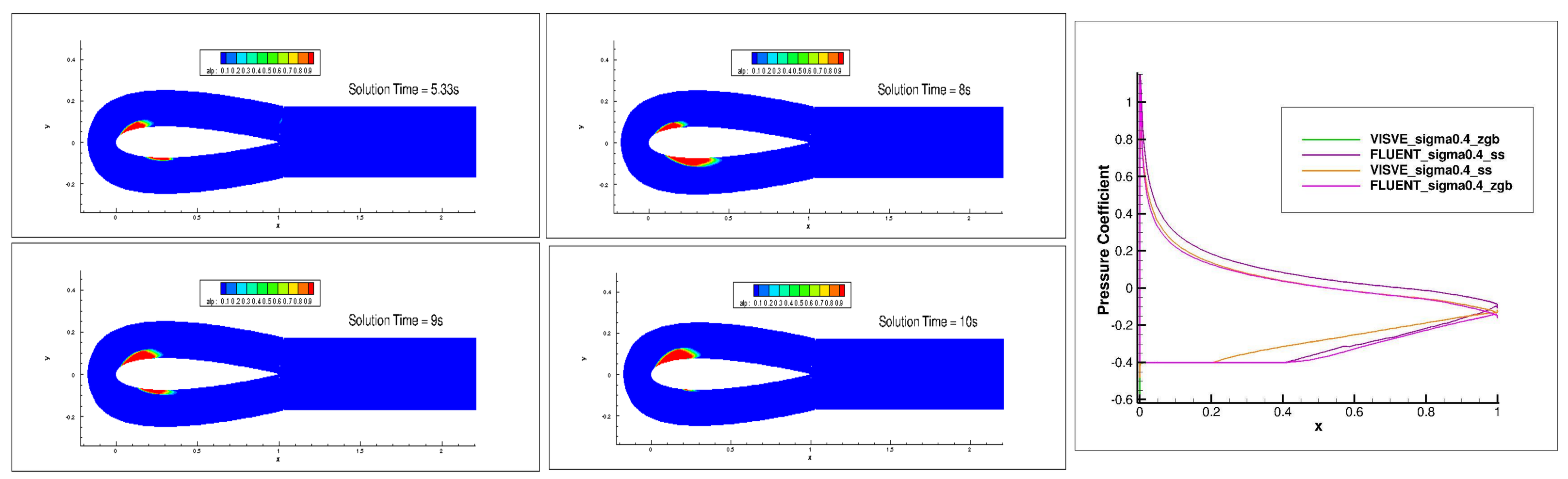
The cavitation mixture model assumes that the bubble-liquid flow under investigation is a single fluid with homogeneous mixture of two phases. Therefore, only one set of equations is needed to simulate the cavitating flows. Besides the vorticity equation there are two more equations to govern the mixture.

$$\frac{\partial \alpha}{\partial t} + \vec{\nabla} \cdot (\alpha \vec{u}) = R, \qquad \vec{\nabla} \cdot \vec{u} = R\rho_l \left(\frac{1}{\rho_l} - \frac{1}{\rho_v}\right)$$

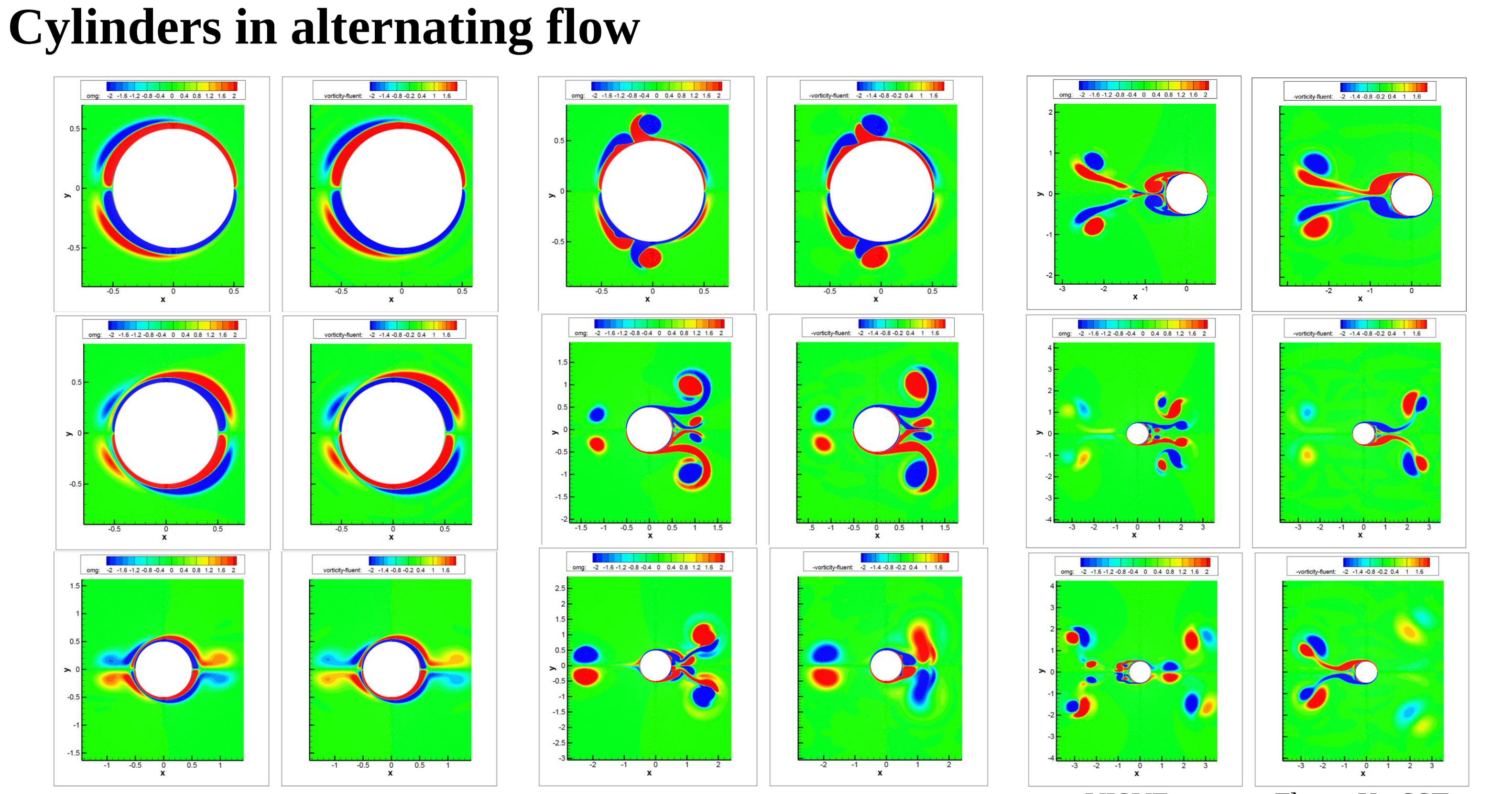
Where α is the vapor volume fraction The net phase change rate R is modeled based on Rayleigh- Plesset equation

$$\frac{P_B(t) - P_\infty(t)}{\rho_l} = R\frac{d^2R}{dt^2} + \frac{3}{2}\left(\frac{dR}{dt}\right)^2 + \frac{4\nu_l}{R}\frac{dR}{dt} + \frac{2S}{\rho_l R}$$

Re= 10,000 $\sigma = 0.4$ $NACA0015$

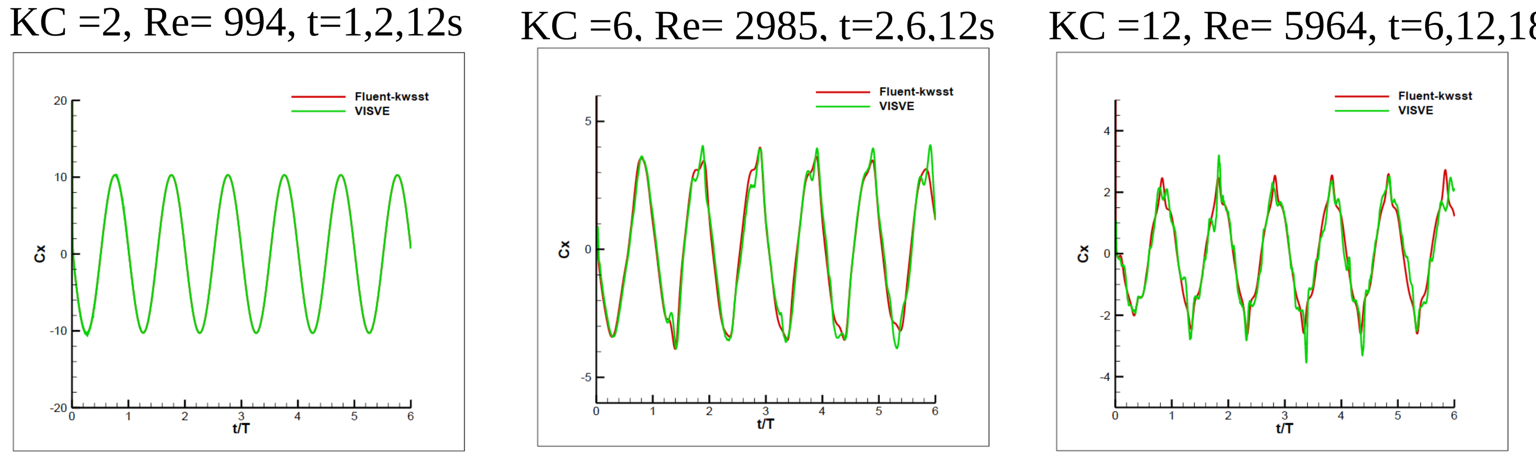


➢ Cylinders in alternating flow



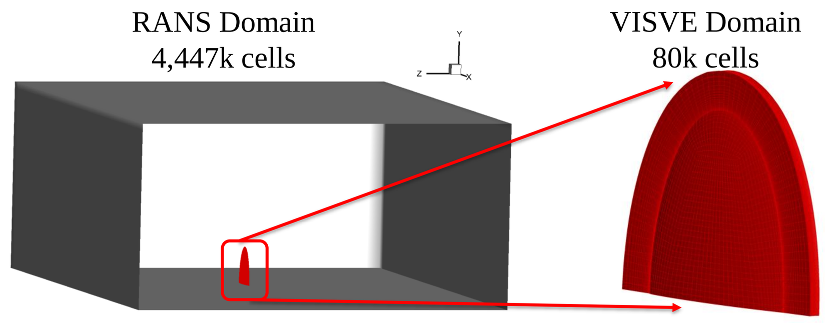
VISVE Fluent-KωSST VISVE Fluent-KωSST VISVE Fluent-KωSST

KC =2, Re= 994, t=1,2,12s KC =6, Re= 2985, t=2,6,12s KC =12, Re= 5964, t=6,12,18s

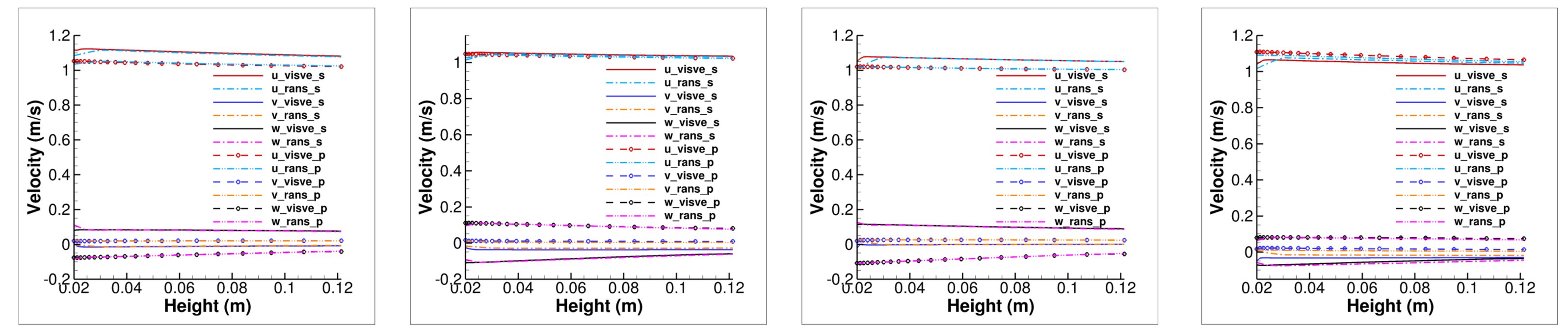


Applications

➢ 3-D hydrofoils in forward & backing conditions



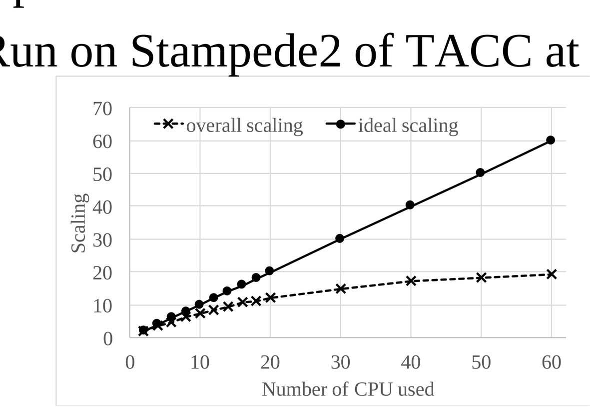
The hydrofoil is an elliptic wing with 10% thickness (NACA 66) and no camber. The chord length is 1 (m). The velocity of inflow is 1 (m/s) with an angle of attack 2 (degrees).



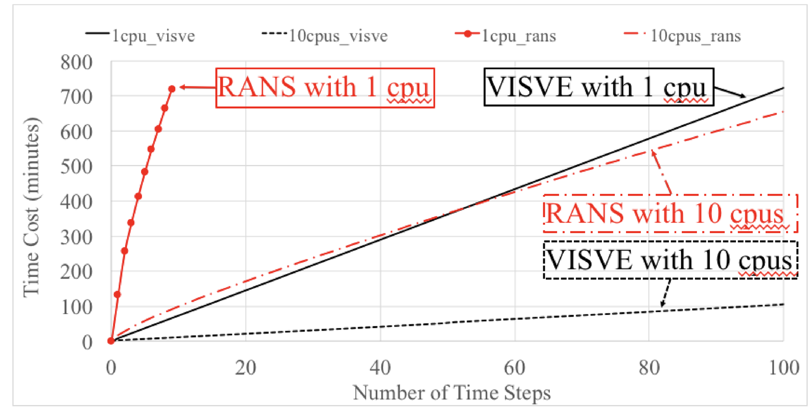
a) 20% of chord length, forward b) 80% of chord length, forward c) 20% of chord length, backing d) 80% of chord length, backing

Open-MP & MPI are both used to accelerate the code.

Run on Stampede2 of TACC at UT.



The overall scaling of VISVE



Efficiency comparison between VISVE and RANS

Conclusions and Future work

- VISVE is capable of predicting flow around cylinders, 2-D and 3-D hydrofoils subjected to uniform or alternating flow with satisfactory accuracy.
- With both Open-MP and MPI parallelization implemented in the code, VISVE model is proved to be computationally efficient and spatially compact.
- VISVE is being extended to predict cavitating flow. Attention is currently focused on 2D sheet cavity. Once the model is well validated, it could be able to predict bubble or cloud cavitation without much modification.
- In the future, VISVE will be improved to handle more applications. Our next goal is to model the tip gap flow in ducted propellers, propellers in backing condition, and flow around 3-D risers.

References

[1] P. J. Zwart, A. G. Gerber, and T. Belamri. "A Two-Phase Flow Model for Predicting Cavitation Dynamics". In Fifth International Conference on Multiphase Flow, Yokohama, Japan. 2004.

[2] Ye Tian. Leading Edge Vortex Modeling and its Effect on Propulsor Performance. PhD thesis, Ocean Engineering Group, The University of Texas at Austin, 2014.

[3] Zhihao Li, VISVE, Applied to Unidirectional and Alternating Flow around a Cylinder – Improved Results, MS thesis, Ocean Engineering Group, The University of Texas at Austin, May 2017.