Modeling intermittent leading-edge vortex shedding in unsteady airfoil flows with reduced-count discrete vortices

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Outline

- Background
- Motivation
- Methodology for reducing vortex count
- Results
- Conclusions

Acknowledgments

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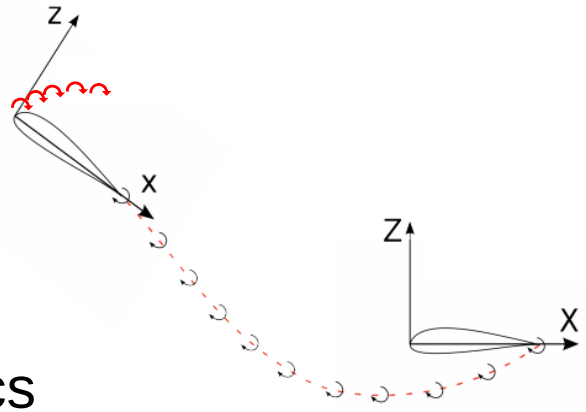
Backgound: LDVM method

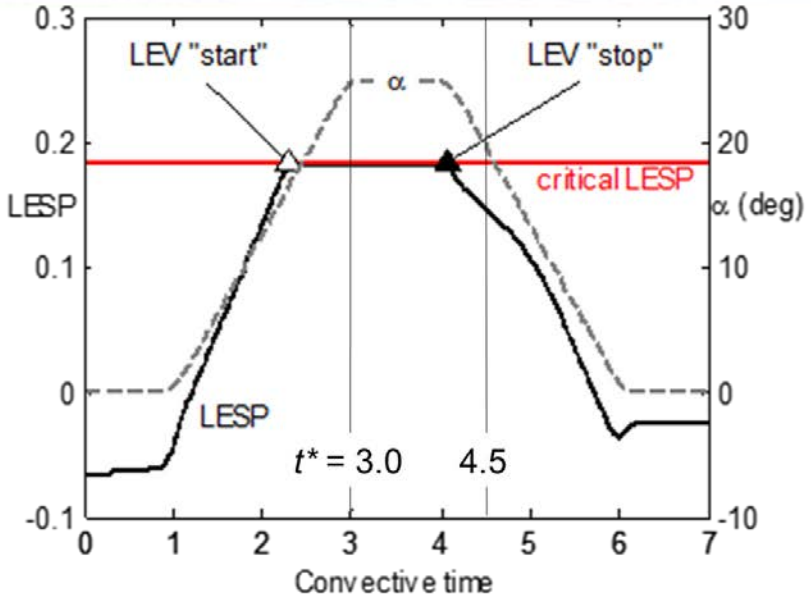
- A low-order method for unsteady airfoil flows with intermittent vortex shedding from rounded leading edges
- LDVM = LESP-modulated Discrete Vortex Method
- LESP = Leading-Edge Suction Parameter
- Details in:

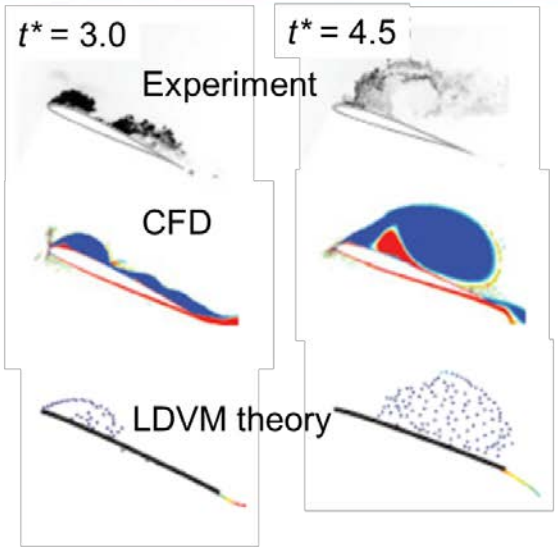
  Ramesh, Gopalarathnam, Granlund, Ol, and Edwards, “Discrete-vortex method with novel shedding criterion for unsteady aerofoil flows with intermittent leading-edge vortex shedding," *Journal of Fluid Mechanics*, Volume 751, July 2014, pp 500-538.

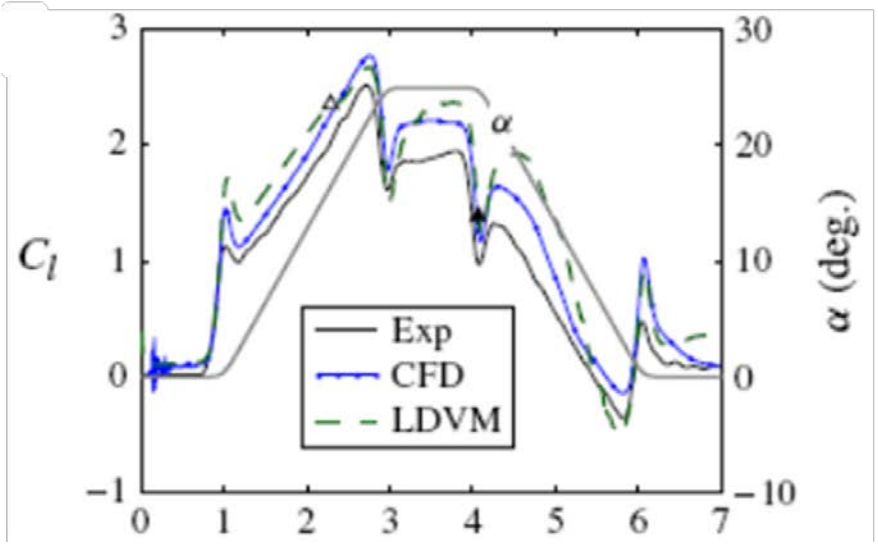
- Unsteady airfoil theory with discrete vortex shedding at LE modulated by LESP
- LE shedding is “on” when LESP > $LESP_{crit}$
- Else LE shedding is “off”
- $LESP_{crit}$ is independent of motion kinematics for low-Re flows if TE separation is negligible



Backgound: LDVM sample results



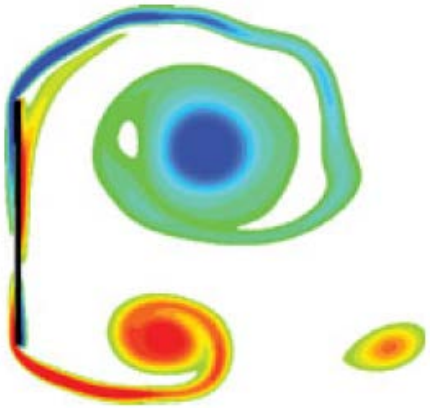


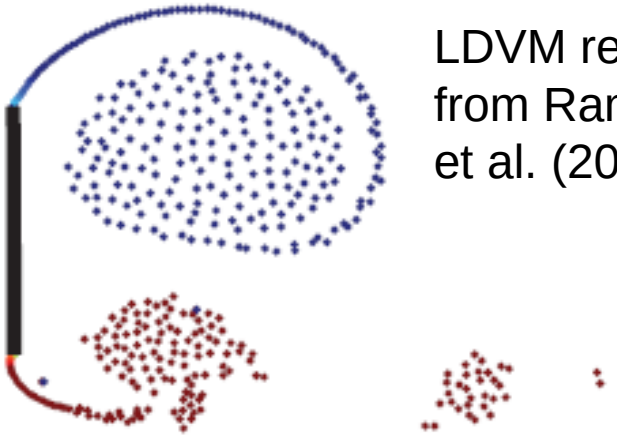


Comparison of results from experiment, RANS CFD, and LDVM theory for a SD 7003 airfoil undergoing pitch up-hold-return motion at Re = 30,000.

Motivation for current work

High-order computations for 0-90 pitch-up motion of flat plate from Wang & Eldredge (2013)





LDVM results from Ramesh et al. (2014)

- The computational expense increases with increasing number of discrete vortices
- Replacing a group of point vortices that form a concentrated structure with a single vortex can save computational time
- Current focus only on the leading-edge vortex (LEV) structure
- Reduced-order model should keep the overall structure: a “feeding” shear layer from the leading edge rolling up into a concentrated LEV structure

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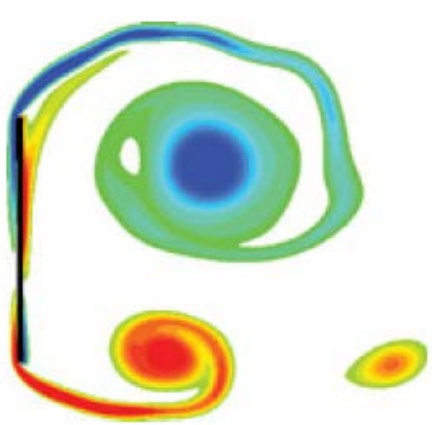
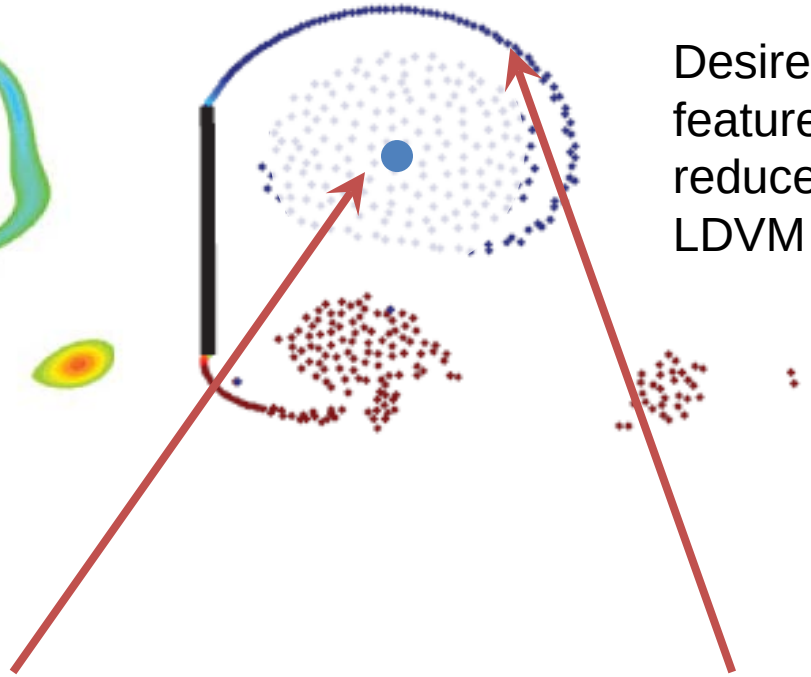




Desired features of the reduced-order LDVM

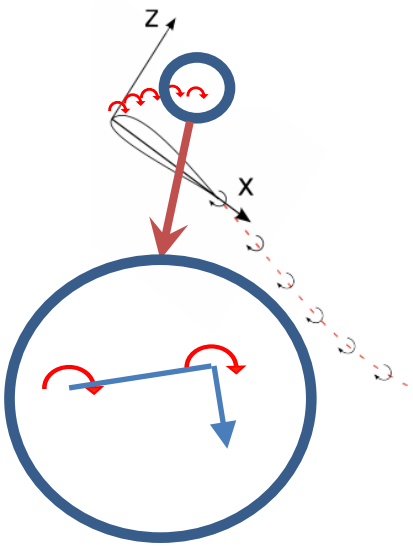
Large number of discrete vortices forming the LEV core replaced with an equivalent single discrete vortex of growing strength

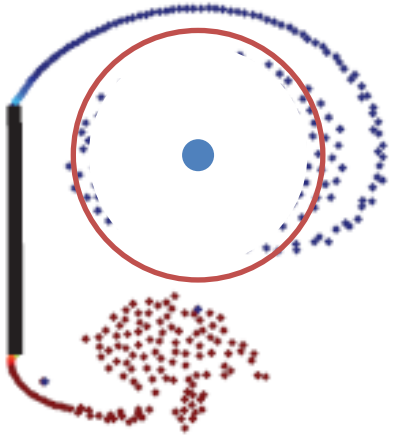
Feeding shear layer retained

- Aim: The reduced-order model should automatically merge discrete vortices in the LEV core into an equivalent single vortex

Methodology: Reducing vortex count

- Initiation of merging procedure
  - Track pair of vortices at edge of evolving shear layer for start of roll up
  - When velocity of the vortices in the pair relative to each other has an angular (rotational) component greater than a threshold value of 0.001 rad/s, merging algorithm is initiated
  - The last vortex is identified as the single, growing vortex, called “SLEV”
- Merging procedure
  - At each time step, all discrete vortices within a specified threshold radius of the SLEV are examined
  - The one that has highest relative velocity towards the SLEV is merged with the SLEV: their strengths are added and location is moved to the centroid
  - Theshold radius of 10*(core radius) = 0.2*chord is used in all cases





Examples of past work

- Amalgamation of discrete vortices not in proximity to airfoil
  - Spalart, 1988
  - Sarpkaya, 1989
- Single, growing LEV models for delta wings
  - Brown & Michael, 1954
  - Edwards, 1954
- Single, growing LEV

  No shedding criterion (continuous shedding, for sharp LE)

  No shear layer

  Developed impulse-matching approach for vortex evolution

  Inspiration for current work
  - Wang & Eldredge, 2013
  - Hemati, Eldredge, Speyer, 2014

Results

- Reduced-order method compared to LDVM
- List of cases presented:

1. Flat plate undergoing 0-25-0 pitching motion about mid-chord
2. SD7003 airfoil undergoing 0-25-0 pitching motion about leading edge
3. Flat plate undergoing 0-90 pitching motion about leading edge

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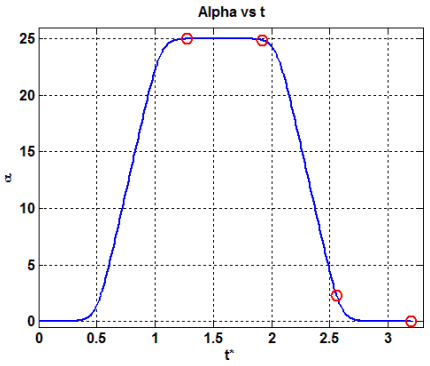

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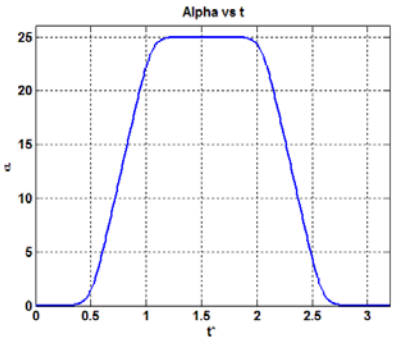
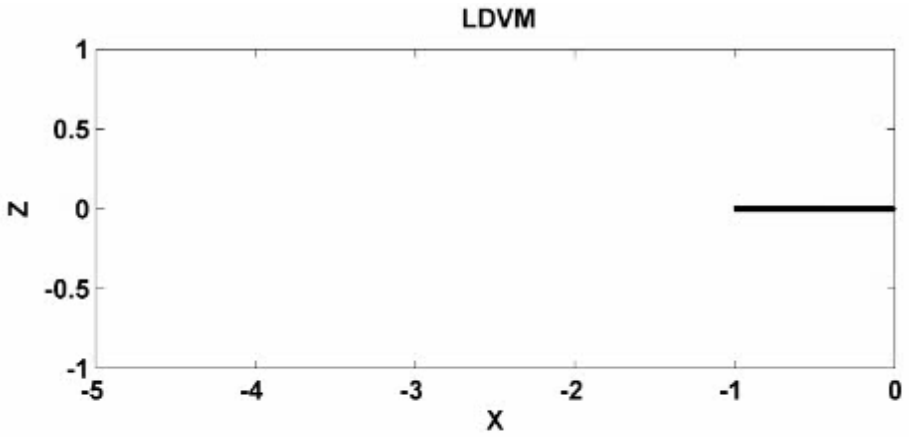
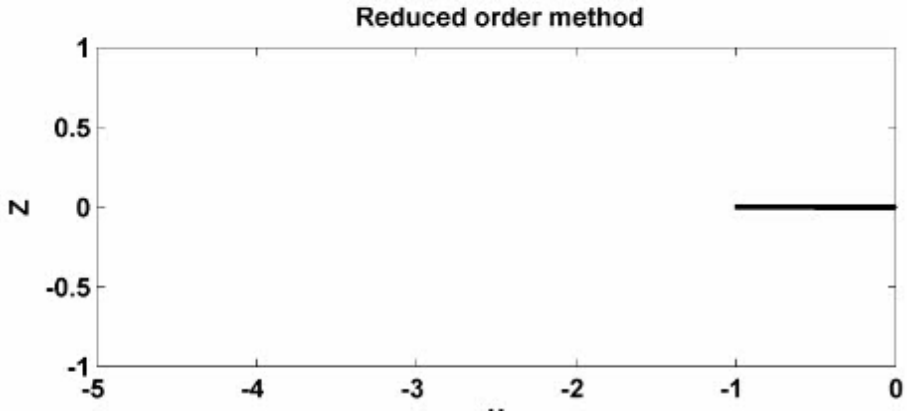
Case 1: Animation of discrete vortices

Flat plate undergoing 0-25-0 pitching motion about mid chord

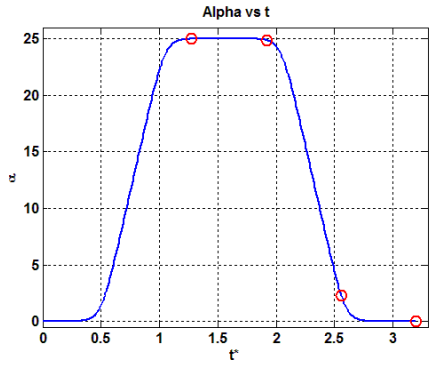
LDVM vs. Reduced-order method







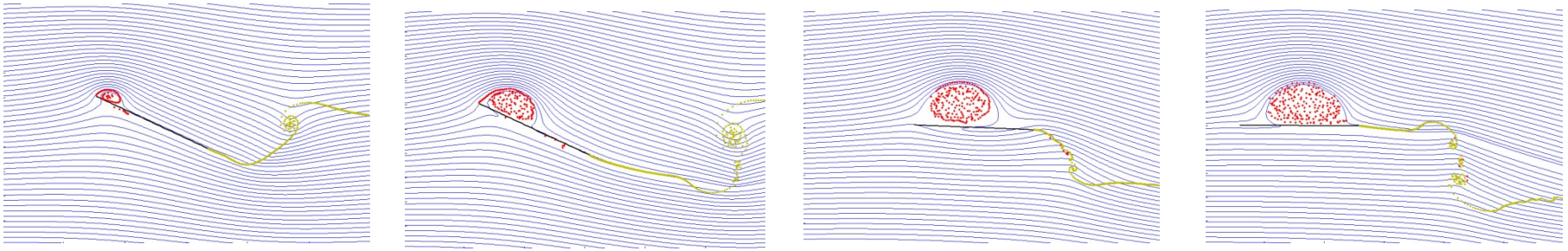
Case 1: Streamline plots



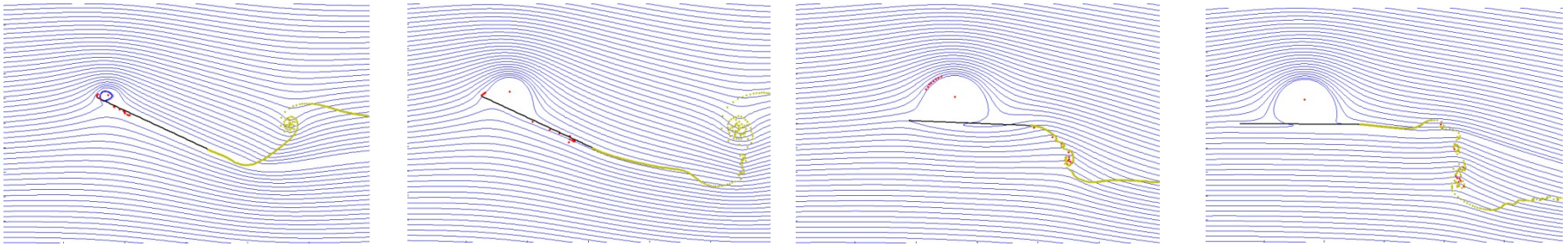
	LDVM	Reduced-order
# of discrete LE vortices	214	11
Run time (seconds)	23	16

LDVM

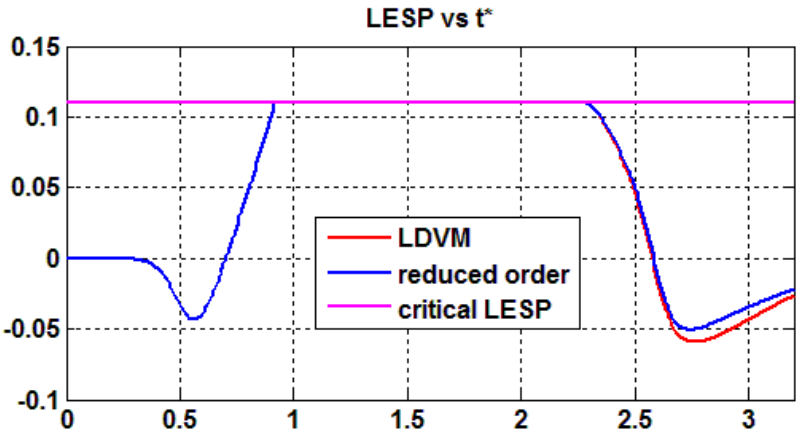
t* = 1.28 t* = 1.92 t* = 2.56 t* = 3.20

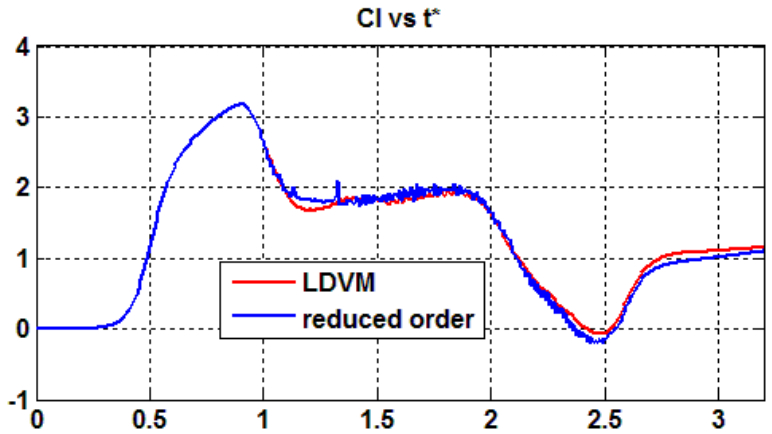


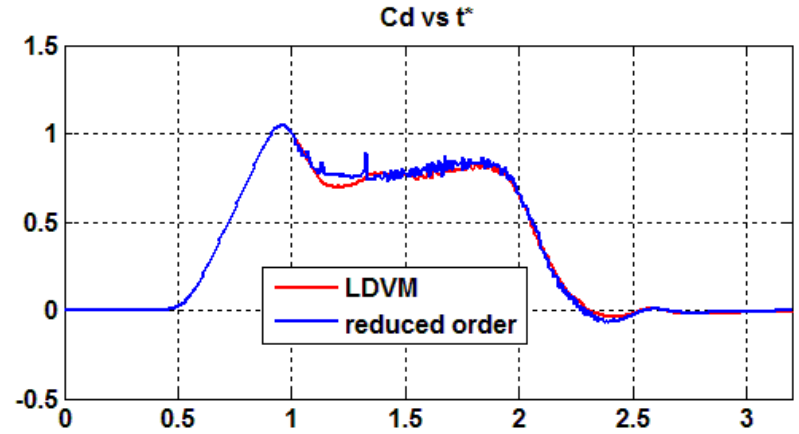
Reduced order method

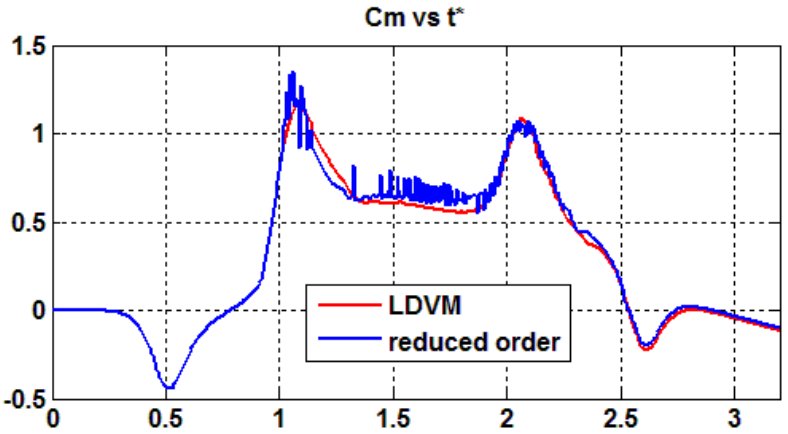


Case 1: LESP and Force Variations









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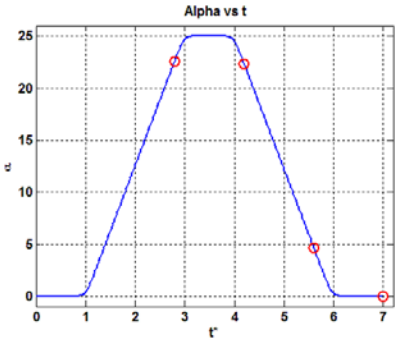
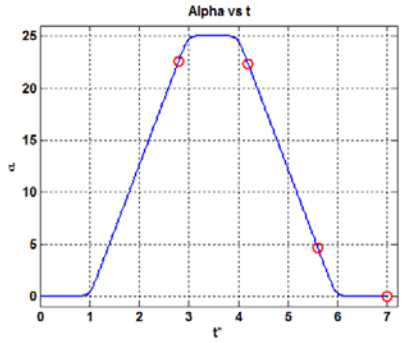


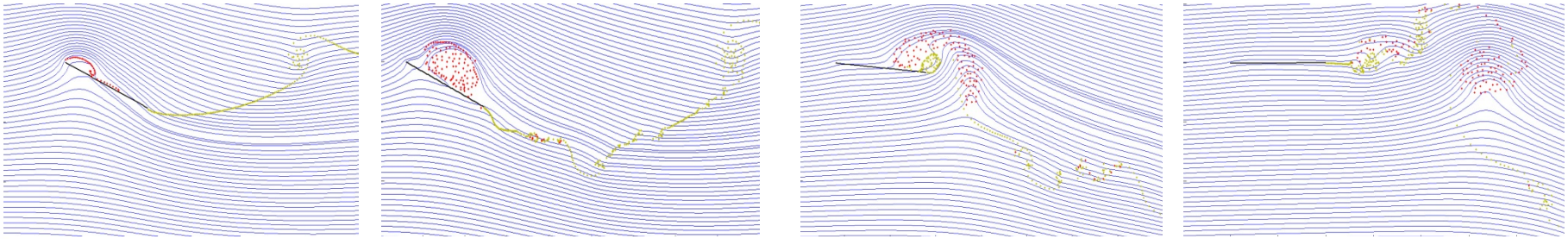
Case 2: Streamline plots



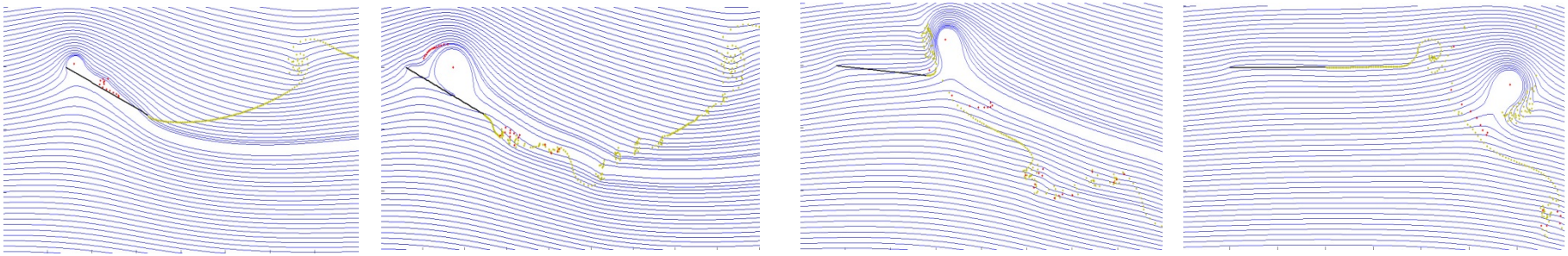
	LDVM	Reduced-order
# of discrete LE vortices	155	62
Run time (seconds)	20	17

LDVM

t* = 2.8 t* = 4.2 t* = 5.6 t* = 7.0



Reduced order method



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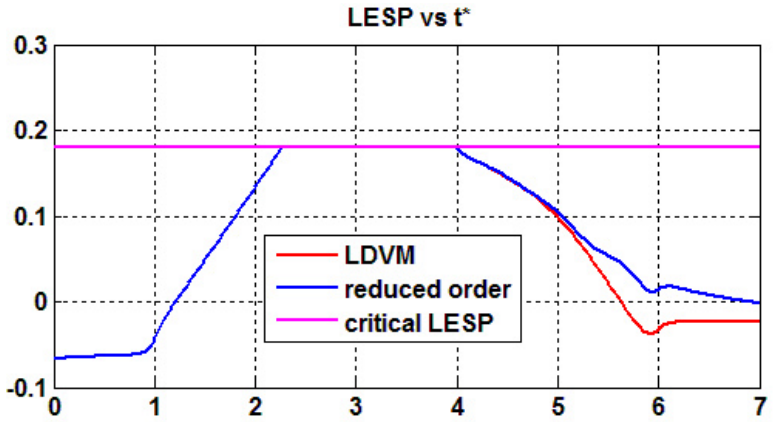

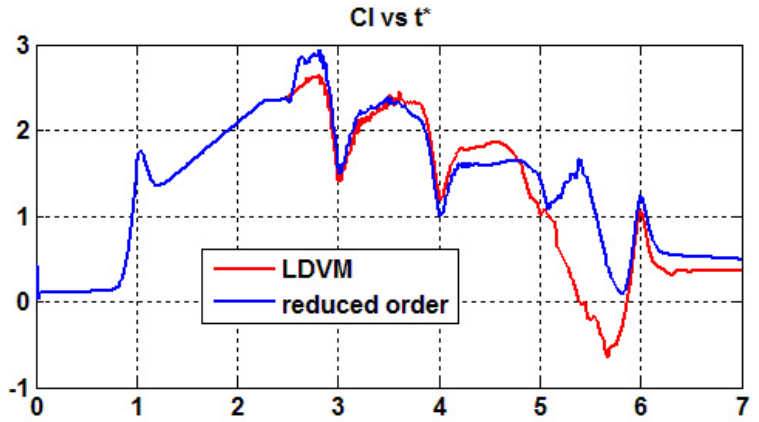

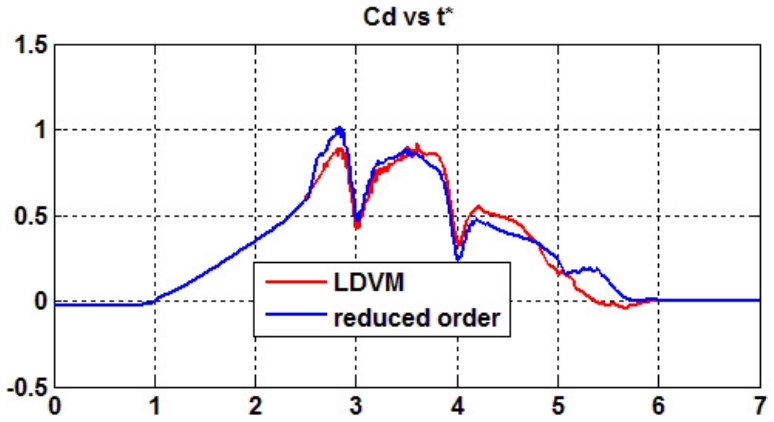

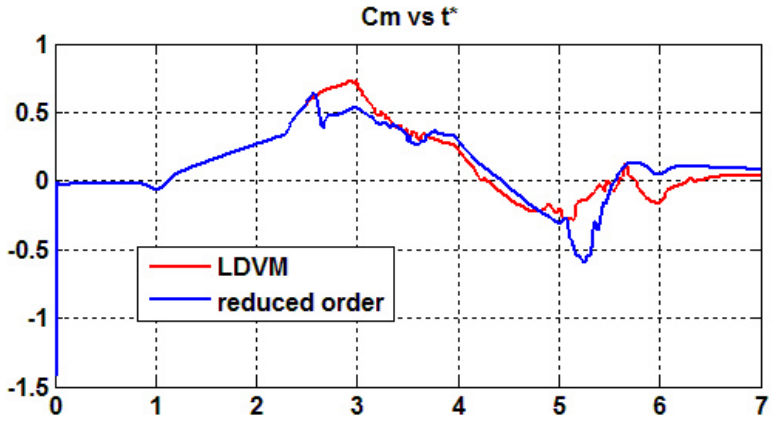

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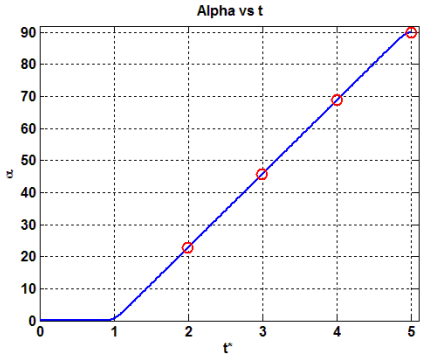
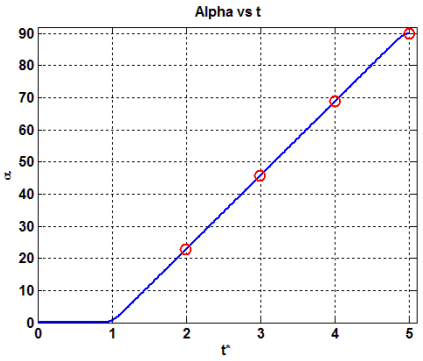


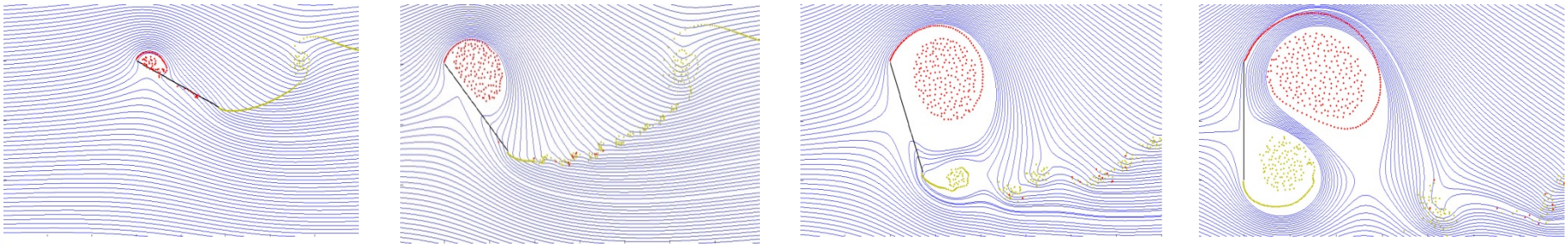
Case 3: Streamline plots



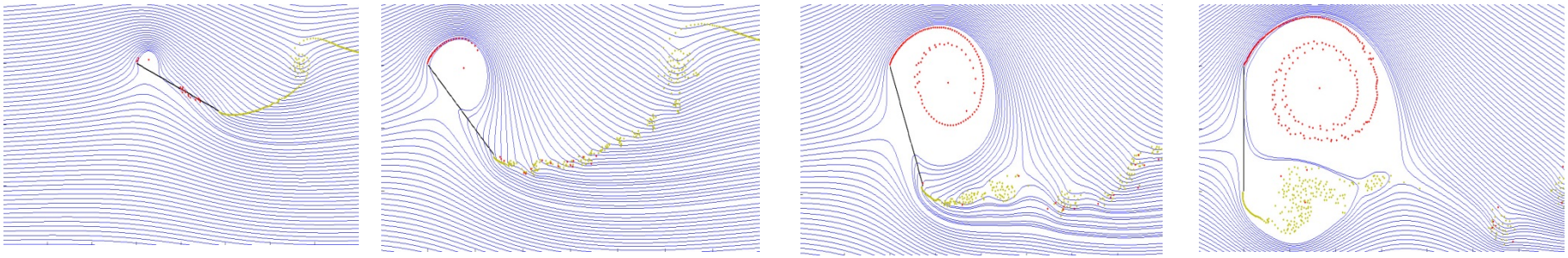
	LDVM	Reduced-order
# of discrete LE vortices	380	245
Run time (seconds)	31	24

LDVM

t* = 2.0 t* = 3.0 t* = 4.0 t* = 4.0



Reduced order method



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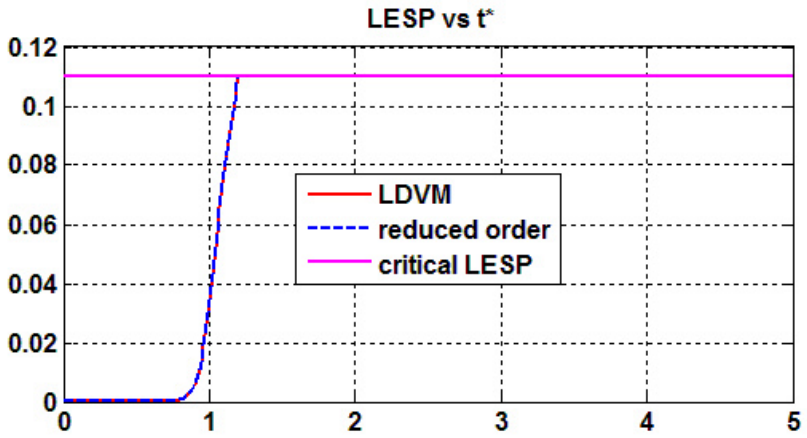

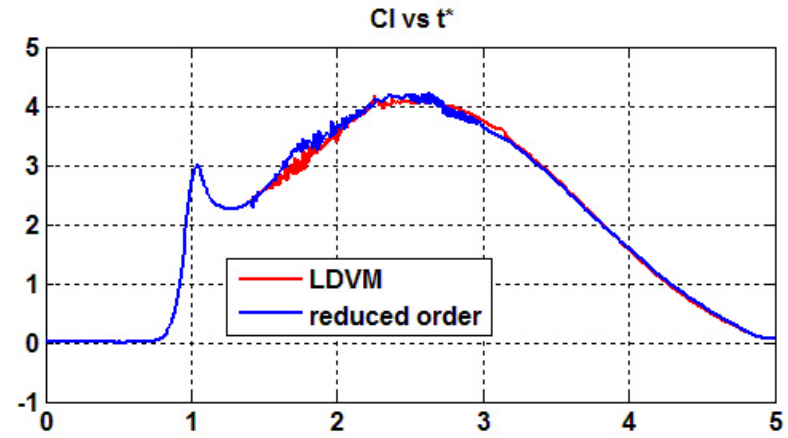

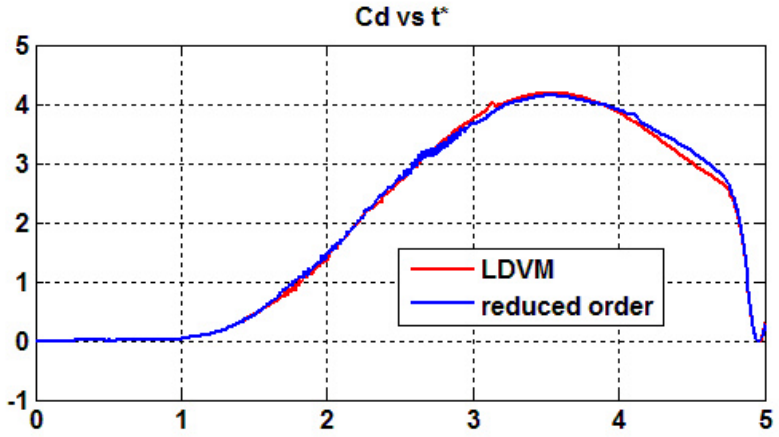

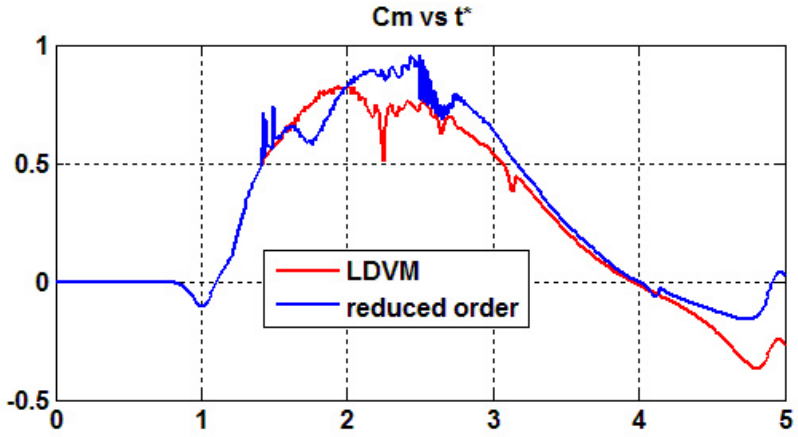

Conclusions

- Reduced-order approach for vortex-count reduction shows promise
- Some high-frequency force oscillations result due to merging (observed by some others as well)
- Force discrepancies appear when LE and TE vortices are in close proximity
- Future extensions will include TE discrete vortices
- Improvements to sorting code for merging algorithm should yield further computational savings