

Test Case BL3 – Heaving and Pitching Airfoil

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UC Berkeley and U. Michigan

Fourth International Workshop on High-Order CFD Methods

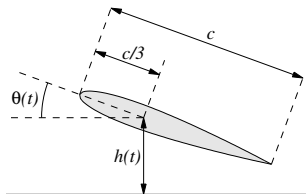


June 4, 2016



Problem Description

- Deforming domain problem: NACA 0012 airfoil undergoing a flapping-type motion
- Freestream Mach = 0.2, Re = 1000
- Steady-state solution as initial condition
- Three different motions:



Case 1 (Pure heaving)

$$\begin{cases} h(t) = b_2(t) \\ \theta(t) = 0 \end{cases}$$

Case 2 (Flow aligning)

$$\begin{cases} h(t) = b_2(t) \\ \theta(t) = A_2 \cdot b_1(t) \end{cases}$$

Case 3 (Energy extracting)

$$\begin{cases} h(t) = b_3(t) \\ \theta(t) = A_3 \cdot b_1(t) \end{cases}$$

where $A_2 = 60\pi/180$, $A_3 = 80\pi/180$,

$b_1(t) = t^2(t^2 - 4t + 4)$, $b_2(t) = t^2(3 - t)/4$,

$b_3(t) = t^3(-8t^3 + 51t^2 - 111t + 84)/16$.

Output Quantities

- First output: The work (energy) which the fluid exerts on the airfoil during the motion:

$$W = \int_0^T \mathbf{F}(t) \cdot \mathbf{v}_0 dt + \int_0^T \mathbf{T}(t) \cdot \boldsymbol{\omega} dt = \int_0^T F_y(t) \dot{h}(t) dt + \int_0^T T_z(t) \dot{\theta}(t) dt.$$

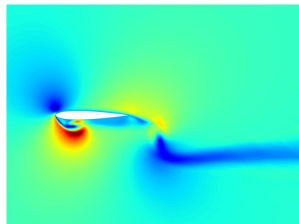
or

$$W = \int_0^T \int_{\text{airfoil}} \vec{v}_G(t) \cdot \vec{f}_{\text{surf}}(t) ds dt$$

- Second output: The vertical impulse from the fluid onto the airfoil during the motion:

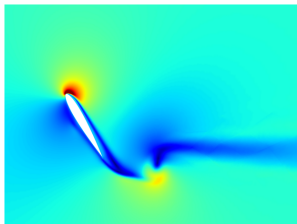
$$I = \int_0^T F_y(t) dt$$

Solution Fields



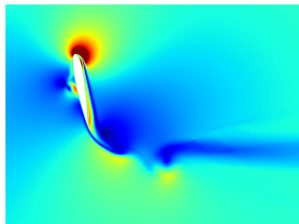
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Case 2 (Flow aligning)

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$$\begin{cases} h(t) = b_3(t) \\ \theta(t) = A_3 \cdot b_1(t) \end{cases}$$

where $A_2 = 60\pi/180$, $A_3 = 80\pi/180$,

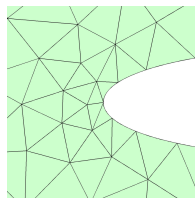
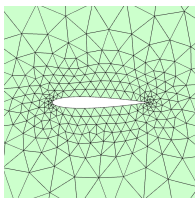
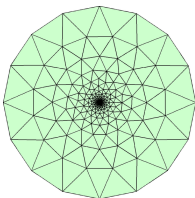
$b_1(t) = t^2(t^2 - 4t + 4)$, $b_2(t) = t^2(3 - t)/4$,

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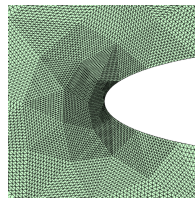
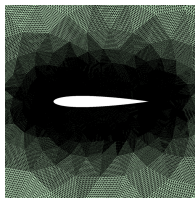
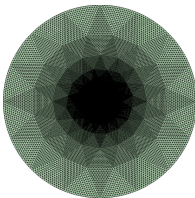
UC Berkeley Results – Meshes

- Base mesh: 971 triangular elements
- Up to four uniform refinements, polynomial degrees $p = 1, 2, 3, 4$
- 3rd order DIRK scheme in time, $\Delta t = 2 \cdot 10^{-3}$

Base

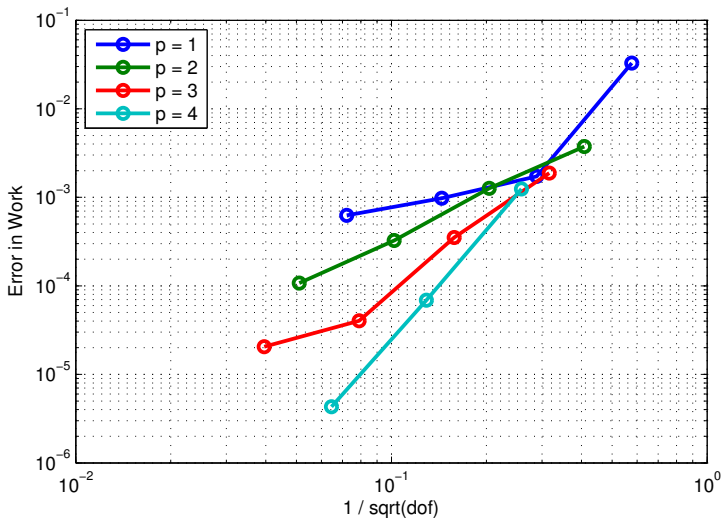


4 refs



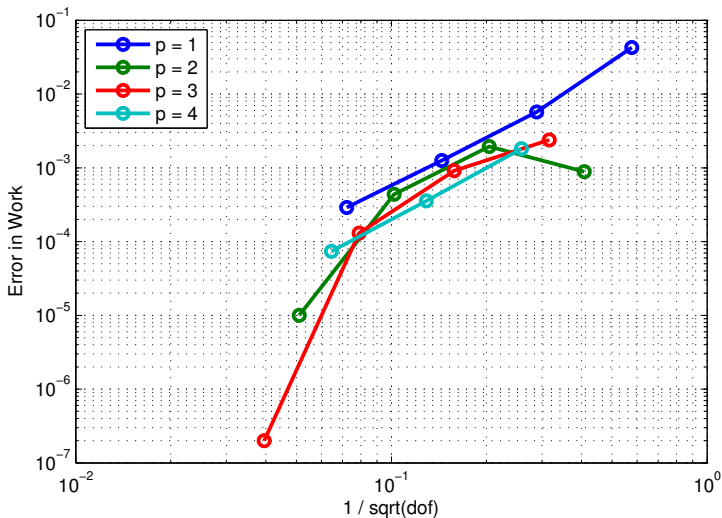
UC Berkeley Results – Convergence

Case 1, work convergence



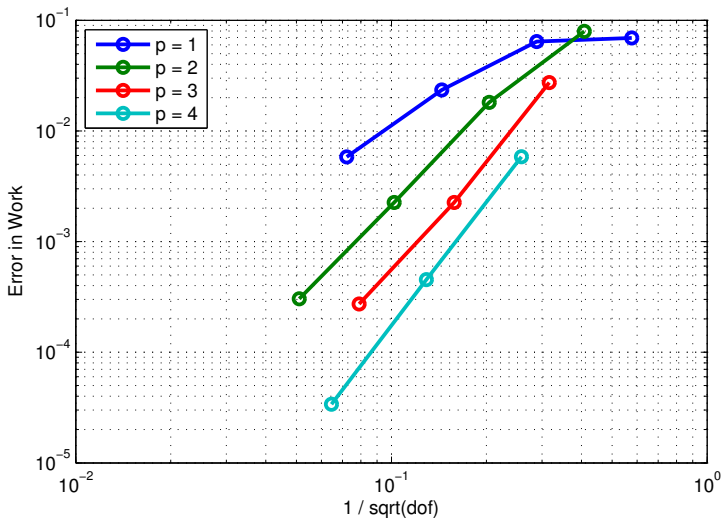
UC Berkeley Results – Convergence

Case 2, work convergence



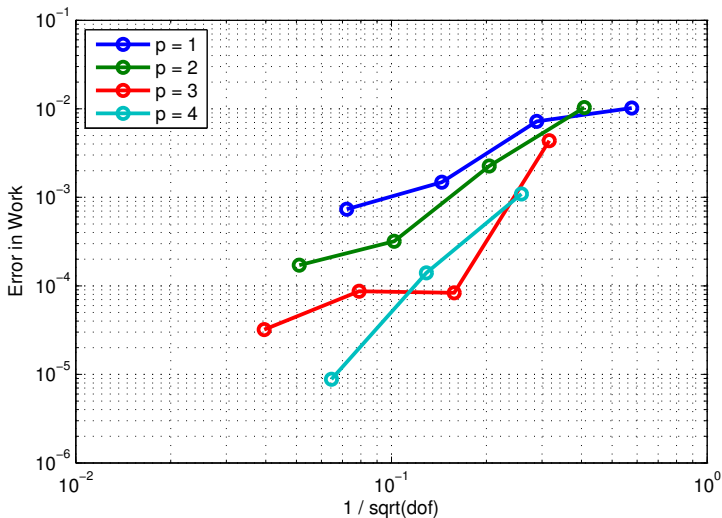
UC Berkeley Results – Convergence

Case 3, work convergence



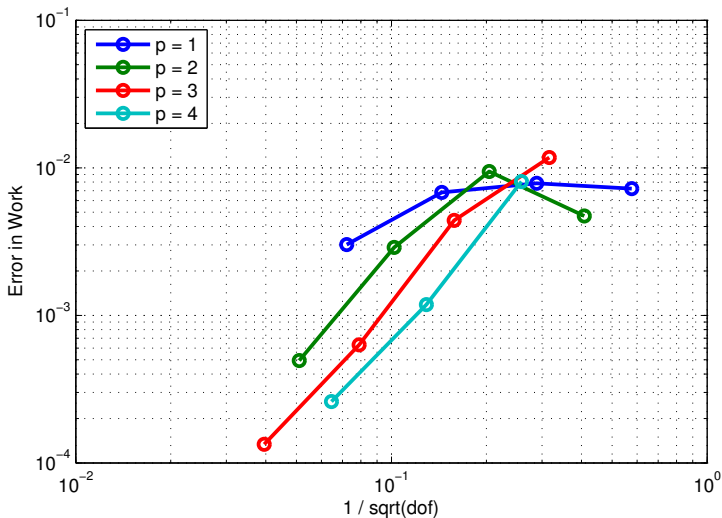
UC Berkeley Results – Convergence

Case 1, y -impulse convergence



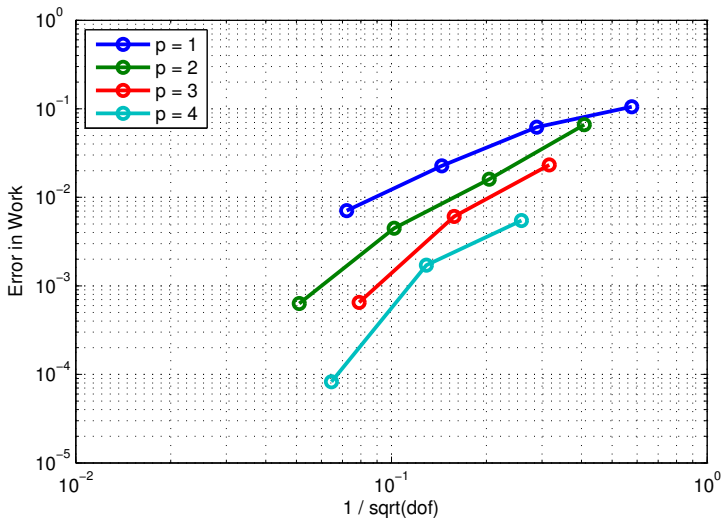
UC Berkeley Results – Convergence

Case 2, y -impulse convergence



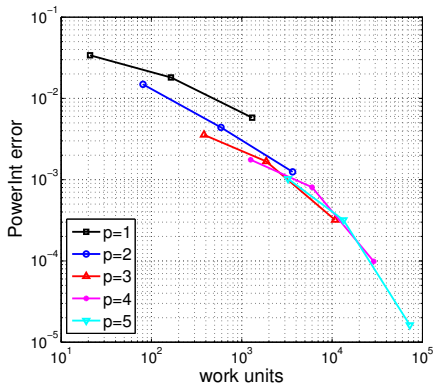
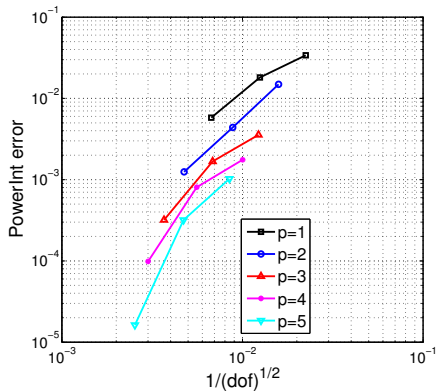
UC Berkeley Results – Convergence

Case 3, y -impulse convergence



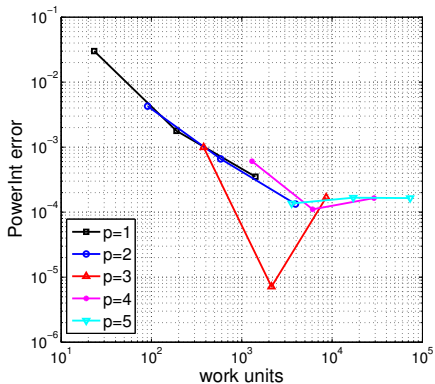
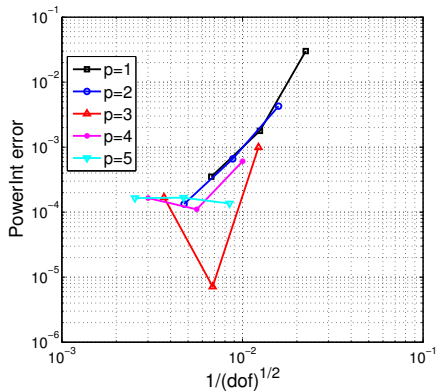
U. Michigan Results – Convergence

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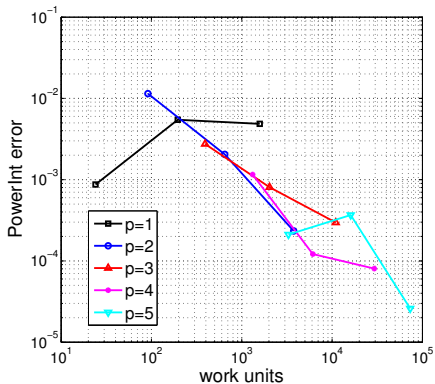
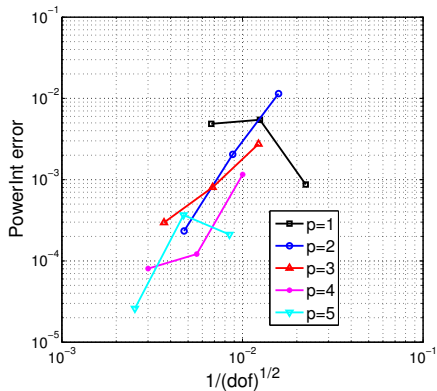
U. Michigan Results – Convergence

Case 2, work convergence



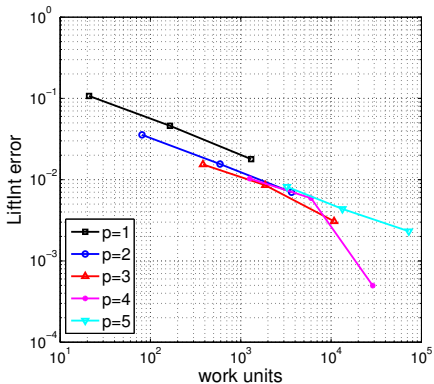
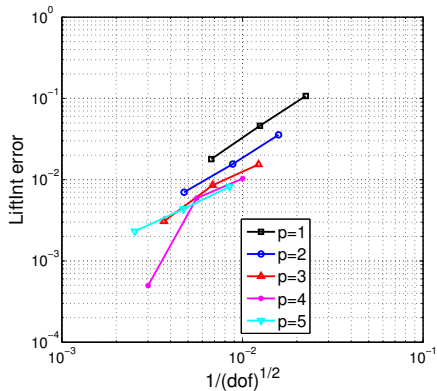
U. Michigan Results – Convergence

Case 3, work convergence



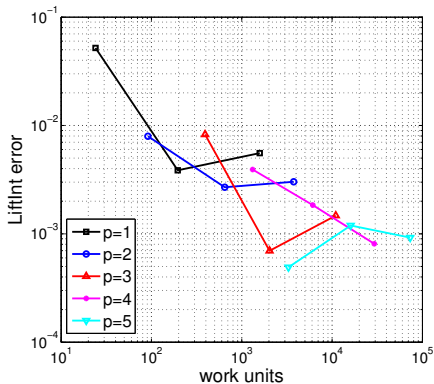
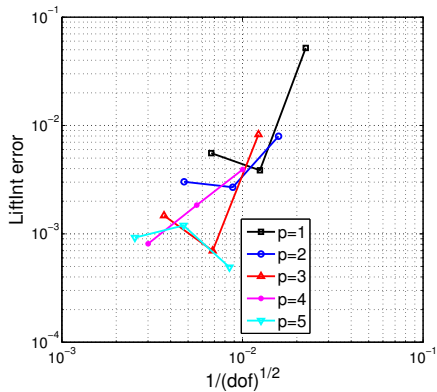
U. Michigan Results – Convergence

Case 1, y -impulse convergence



U. Michigan Results – Convergence

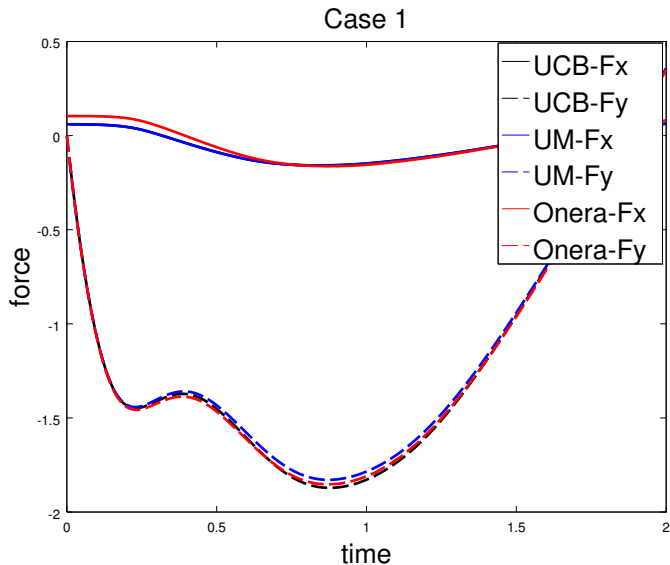
Case 3, y -impulse convergence



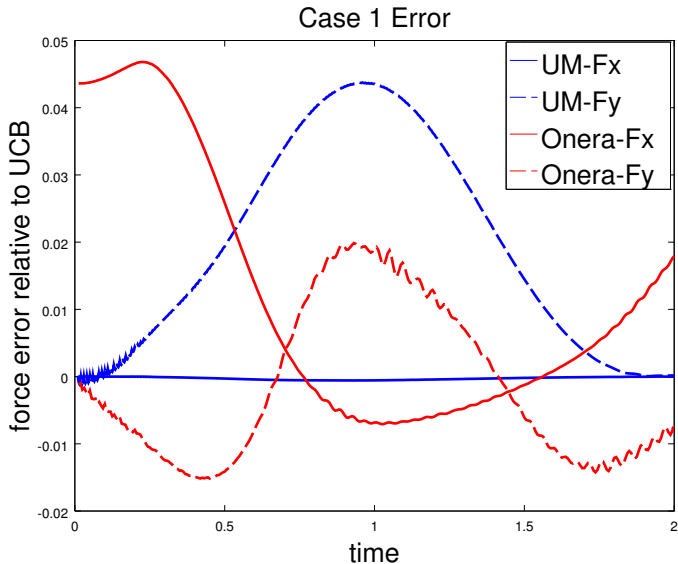
Participating Groups – Results

	UC Berkeley	U. Michigan	Onera
Scheme	DG	DG	FV
Degree p	1,2,3,4	1,2,3,4,5	2,4
Time-stepping	DIRK3 impl.	ESDIRK5 impl.	BDF3 impl. dual ts
ALE motion	rigid	blended	blended
Steady x-force	0.06000705055	0.06000682777	0.1028
Case 1, work	-1.40945	-1.38350	-1.40493
Case 1, impulse	-2.37606	-2.33125	-2.37286
Case 2, work	-0.22029	-0.20490	-0.20788
Case 2, impulse	0.58978	0.61004	0.59123
Case 3, work	0.40089	0.36377	0.33388
Case 3, impulse	1.69529	1.67047	1.70758

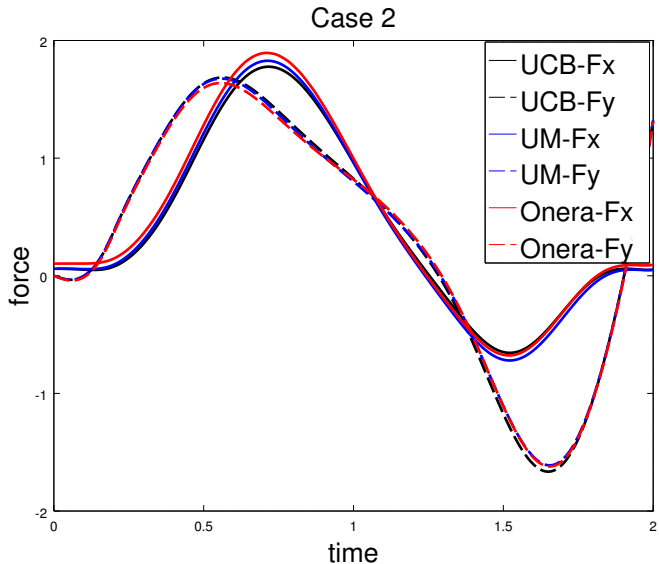
Group comparison – Forces



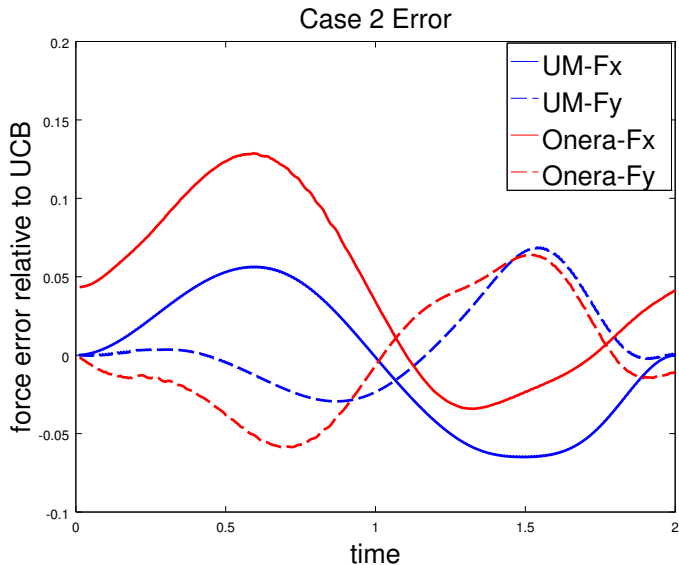
Forces, differences with UC Berkeley Results



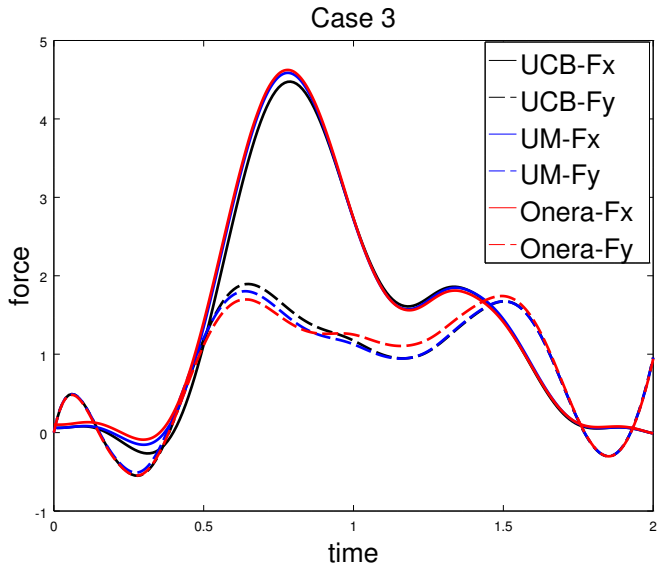
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