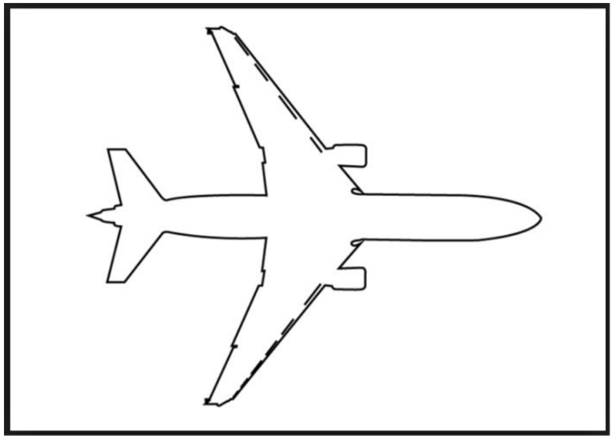
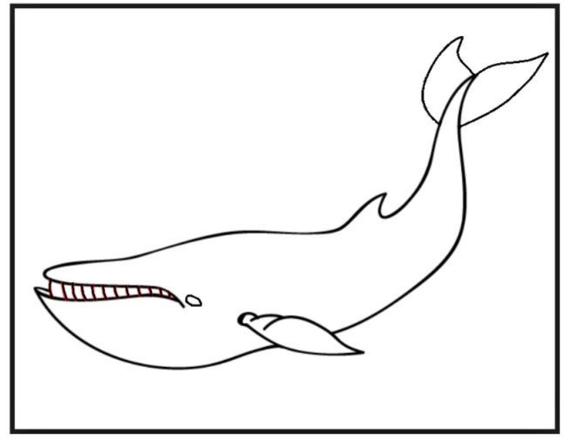
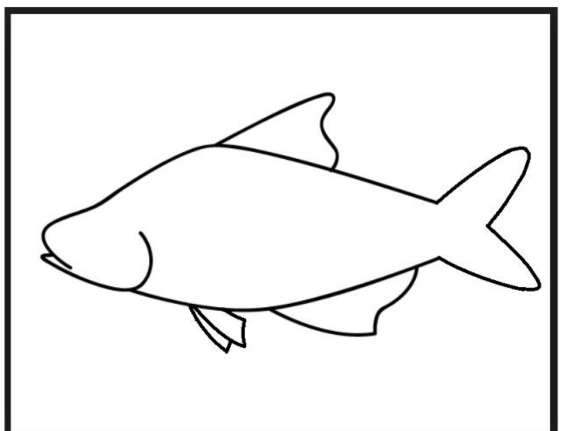
Application of mode analysis method for the unsteady lifting surface problem

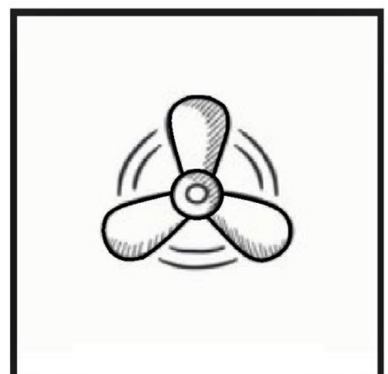
Diploma Thesis : Constantine Iliopoulos
Supervisor :   Gerasimos Politis

Lifting surface



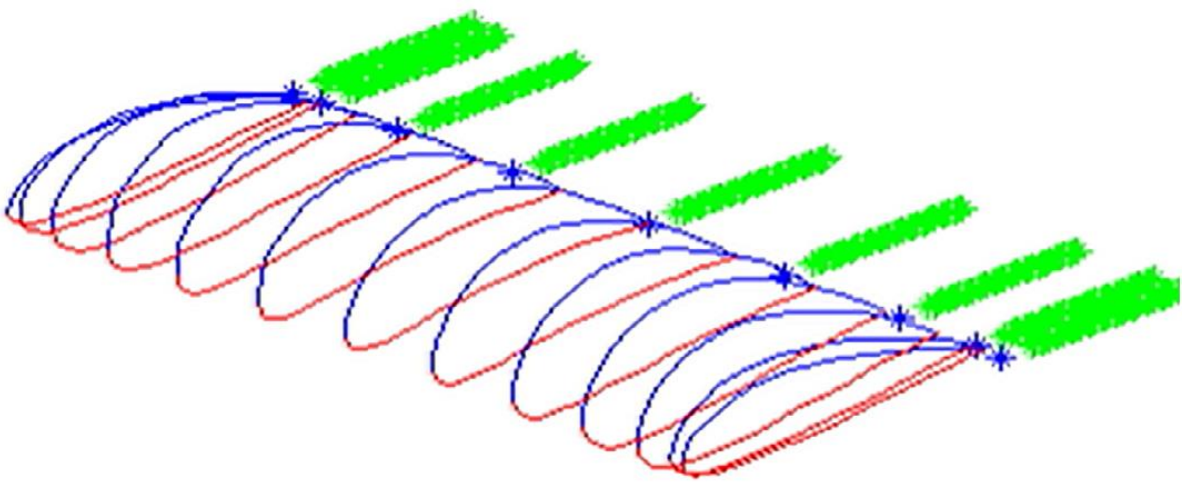






Goal :

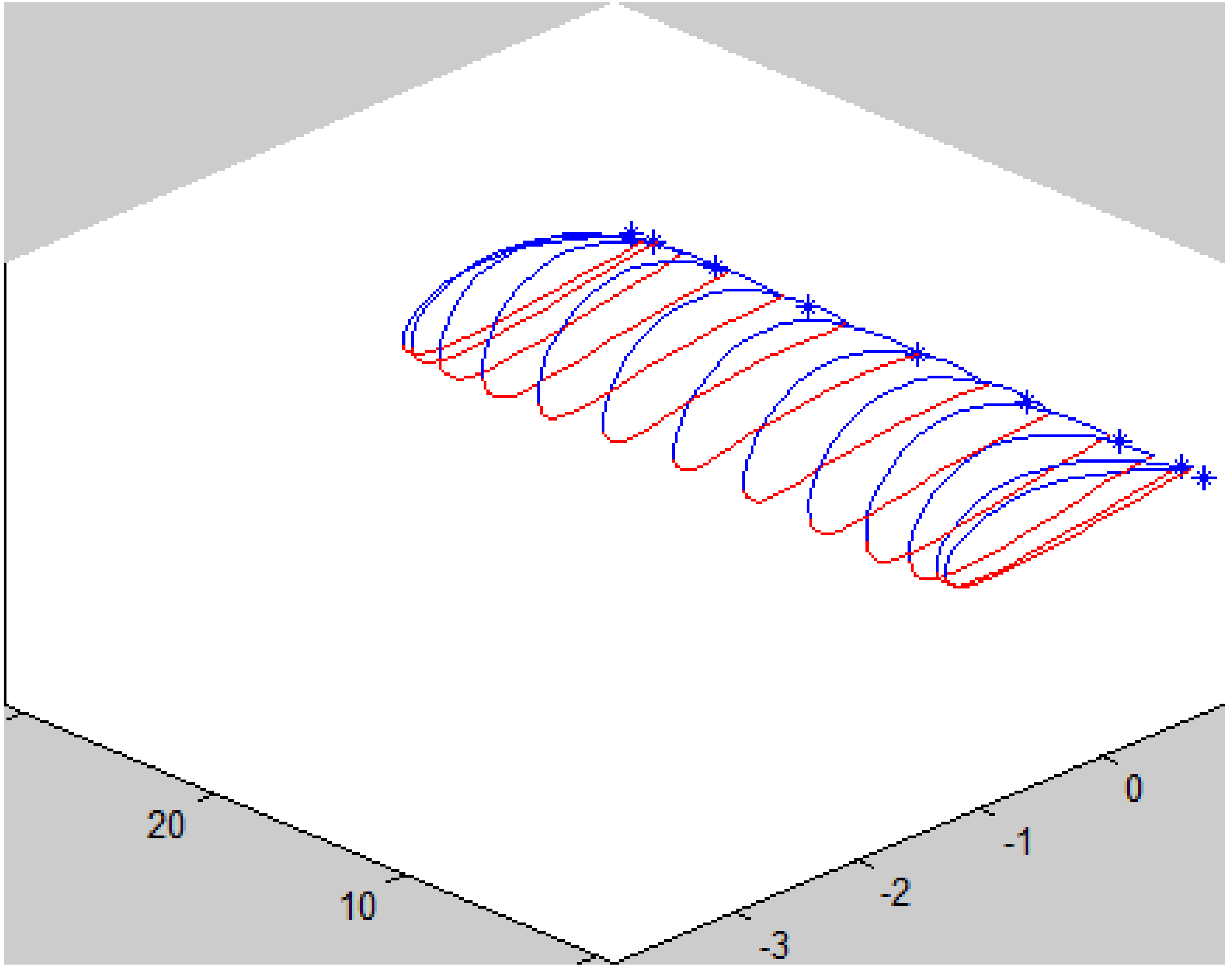
Calculation of velocities and forces around a lifting surface that performs a general motion in space.



Sections of a rectangular hydrofoil. Upper side - (blue), lower side (red), wake (green).

Applications

- First approximation for other programs (Navier – Stokes)
- Dynamic control programs (fast response)
- Elasticity /Ultimate strength programs
- Alternative propulsion systems (biomimetic)



Movement of a rectangular hydrofoil at constant velocity

Steady high aspect ratio hydrofoil
Results at midspan and comparison with the respective 2D

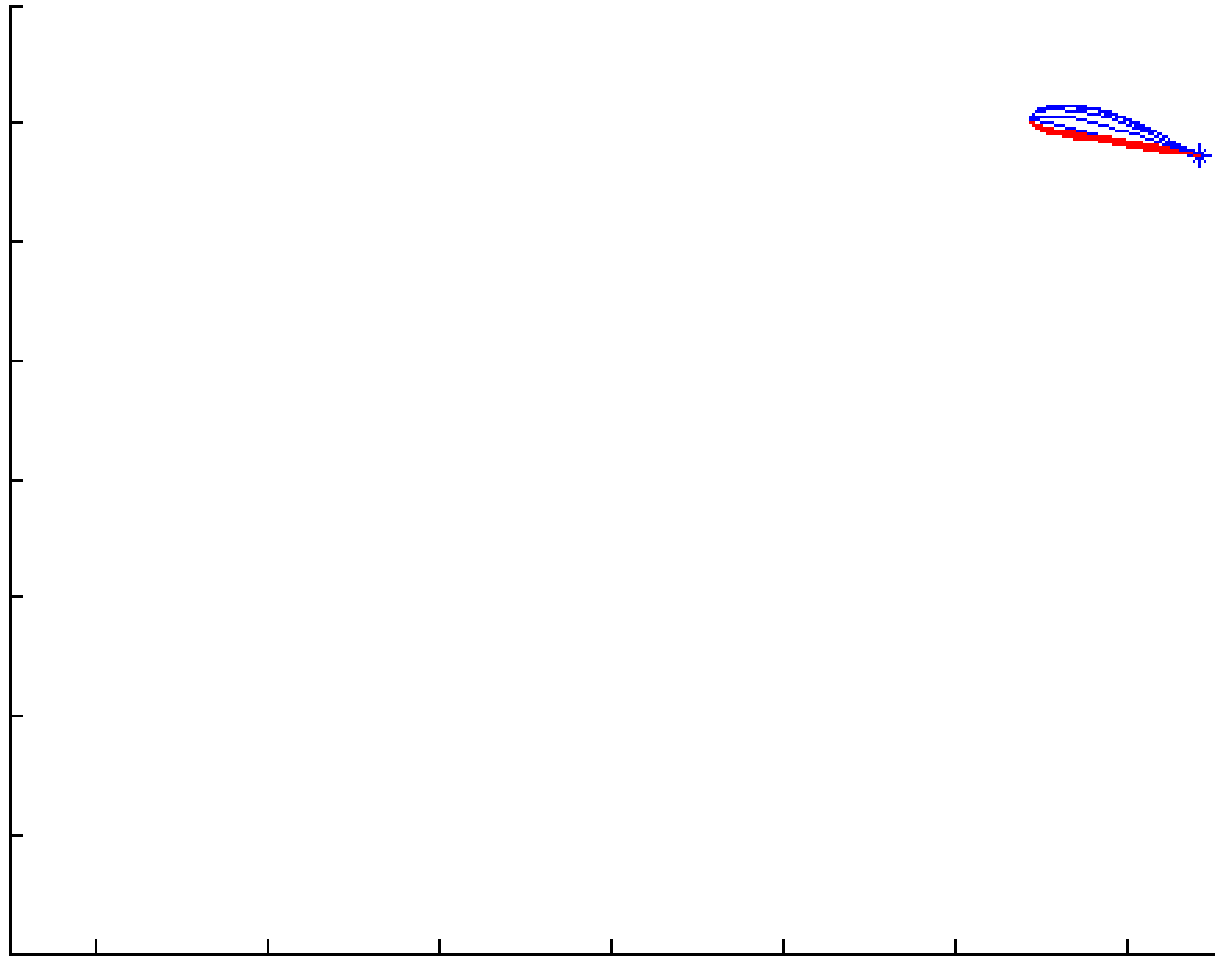
Comparison of lifting coefficients

$$C_L = \frac{Lift}{\frac{1}{2}\rho\, U^2\, c}$$

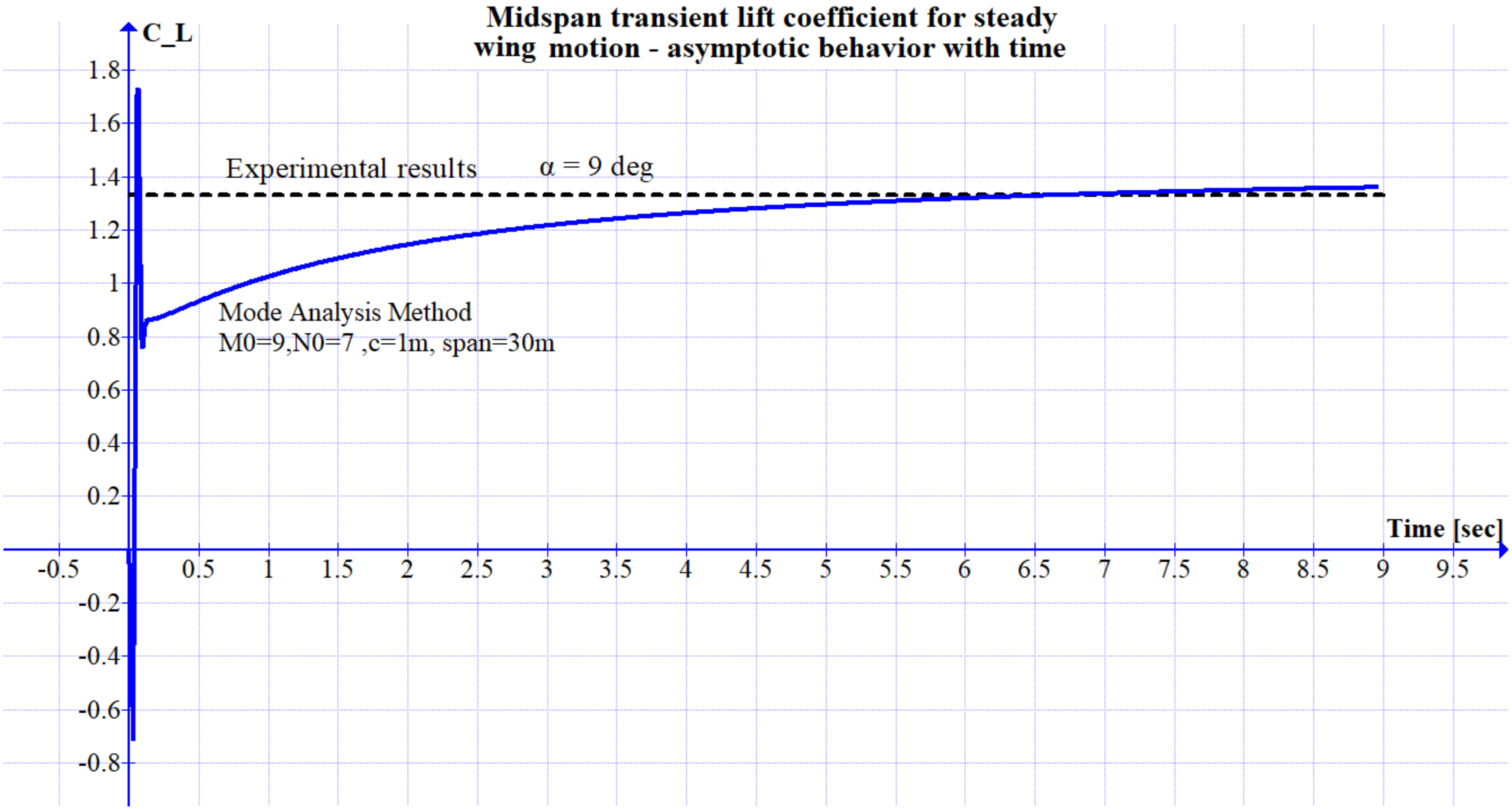
Hydrofoil geometry :

- Rectangular reference surface
- Sections NACA 4412
- Chord = 1 m
- Span / chord = 30
- Angle of attack : α = -9 έως 9 deg

Motion midspan section (angle of attack 9 deg)

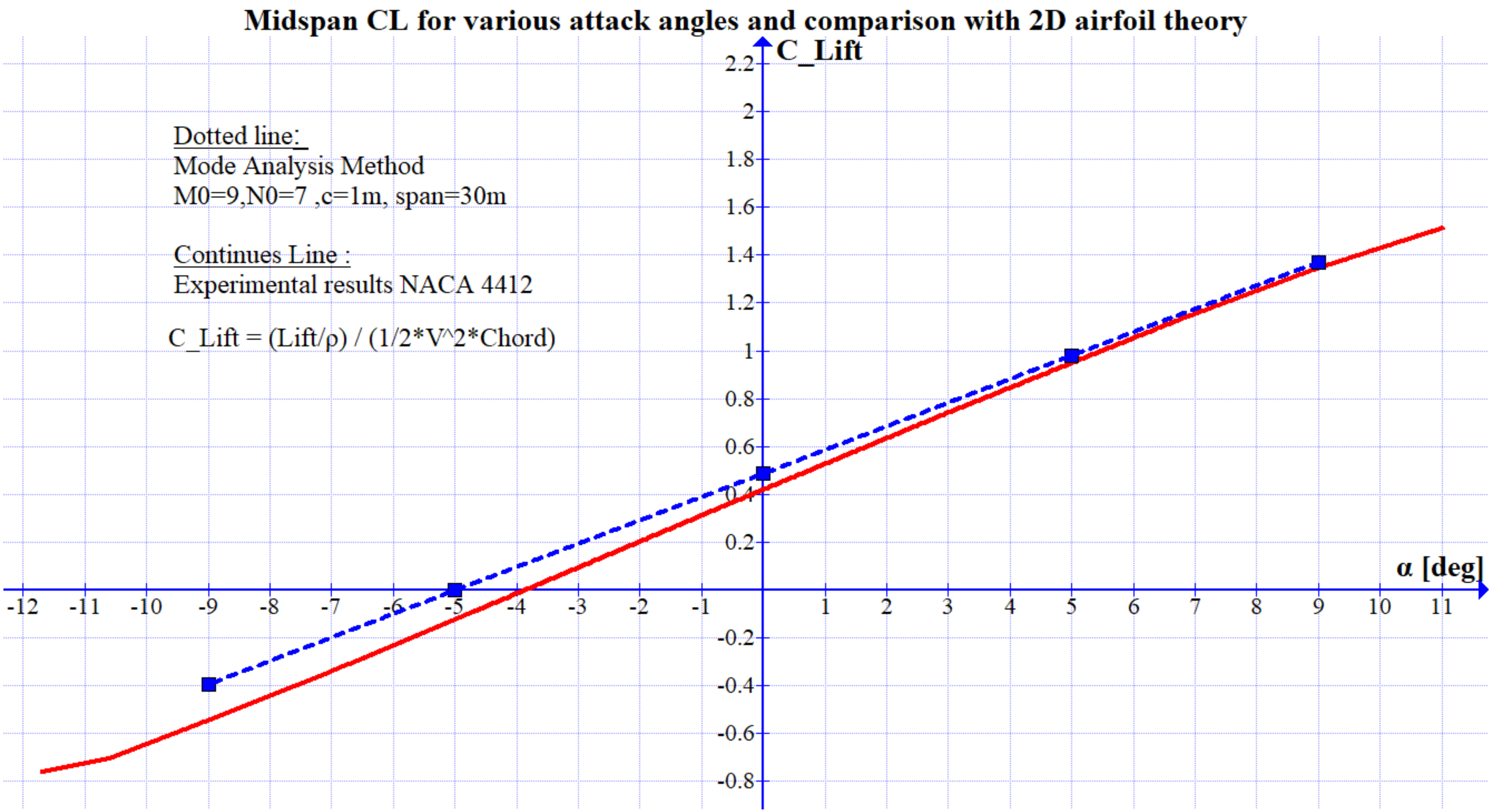


Results (1)



Midspan transient lift coefficient for steady wing motion - asymptotic behavior with time
C_L
1.8
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
-0.2
-0.4
-0.6
-0.8
Experimental results
α = 9 deg
Mode Analysis Method
M0=9,N0=7 ,c=1m, span=30m
Time [sec]
-0.5
0.5
1
1.5
2
2.5
3
3.5
4
4.5
5
5.5
6
6.5
7
7.5
8
8.5
9
9.5

Results (2)



Midspan CL for various attack angles and comparison with 2D airfoil theory
C_Lift
α [deg]
Dotted line:
Mode Analysis Method
M0=9,N0=7 ,c=1m, span=30m
Continues Line :
Experimental results NACA 4412
C_Lift = (Lift/ρ) / (1/2*V^2*Chord)
2.2
2
1.8
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
-0.2
-0.4
-0.6
-0.8
-12 -11 -10 -9 -8 -7 -6 -5 -4 -3 -2 -1 1 2 3 4 5 6 7 8 9 10 11

Comparisons with panel methods (Polits-Tsarsitalidis [10])

For the examination of the 3D unsteady problem we consider the flapping movement which is a combination of :

$$h(t) = h_0 \sin(2\pi\, n\, t) \qquad \text{(vertical oscillation - heave)}$$

$$\theta(t) = \theta_0 \cos(2\pi\, n\, t) \qquad \text{(rotational oscillation – pitching)}$$

We compare the thrust coefficient :

$$C_T = \frac{T}{\frac{1}{2}\rho\, U^2 S}\ , \quad \text{όπου}\ \ S = span \cdot h\ ,\ (h = 2\, h_0)$$

Selection of non - dimentional parameters (c=1 m) :

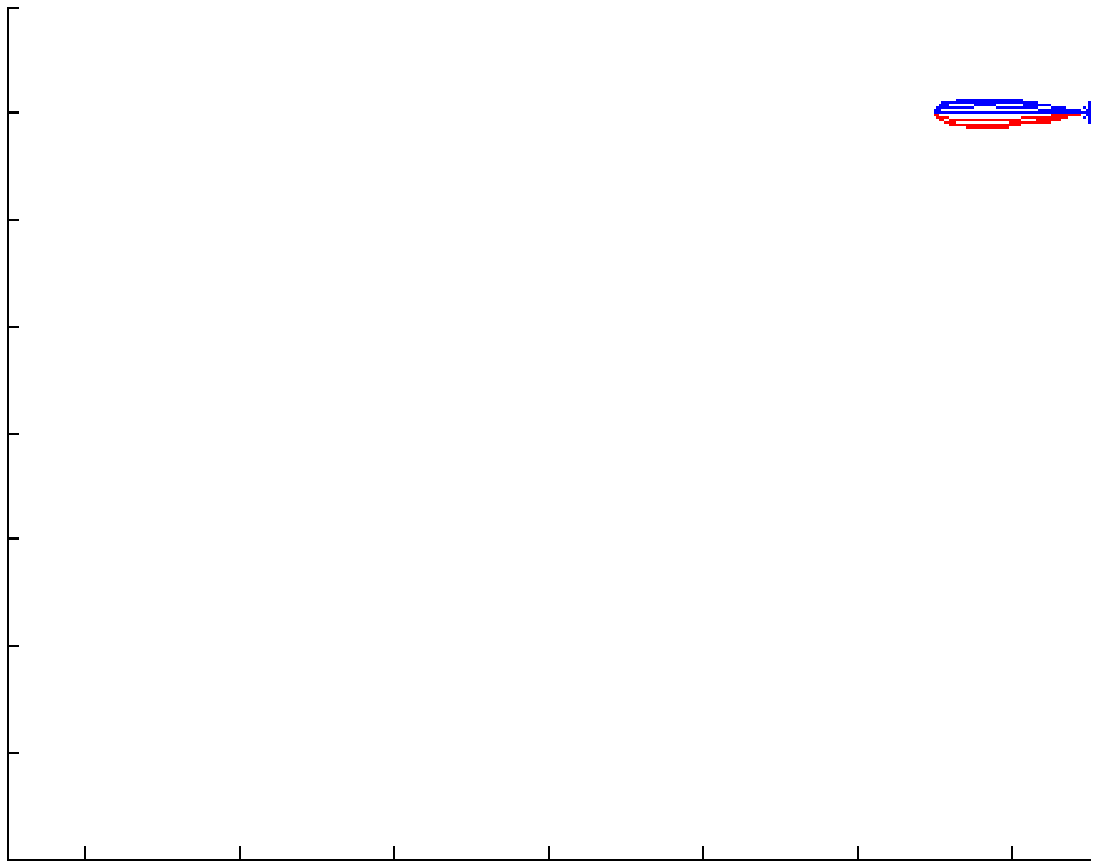
- $span/c = 4\ ,\ 6$
- $h_0\,/c = 0.5\ ,\ 1\ ,\ 2$
- $b/c = 0.1$ (position of rotation axis from the L.E)
- $Str = \frac{n \cdot h}{U} = 0.1 - 0.3$
- Airfoil Sections NACA 0012

[10] Gerasimos K. Politis, Vasileios T. Tsarsitalidis,
'Flapping wing propulsor design: An approach on systematic 3D-BEM simulations'

Results 3D Flapping Hydrofoil (2)

Presentation of midspan section unsteady motion

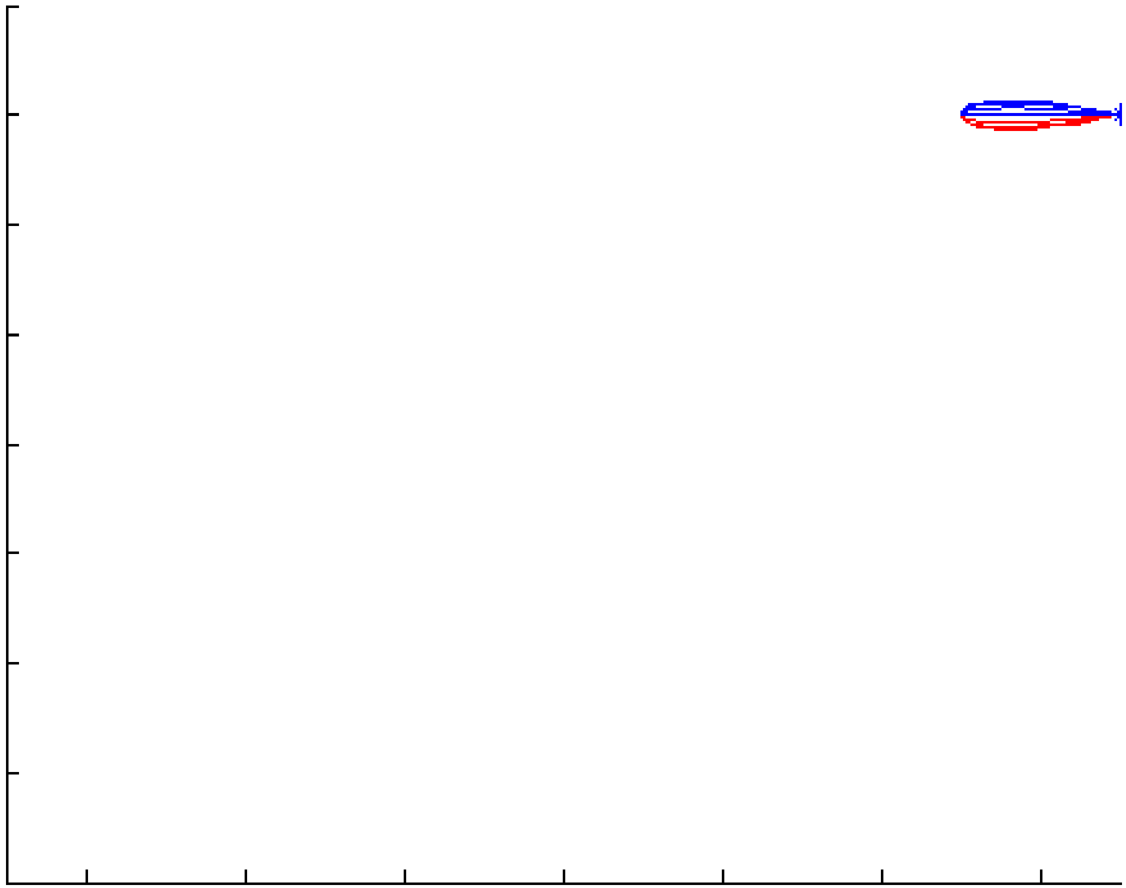
$h_0/c = 0.5$ $Str = 0.10$ $\theta_0 = 15^o$



Results 3D Flapping Hydrofoil (4)

Presentation of midspan section unsteady motion

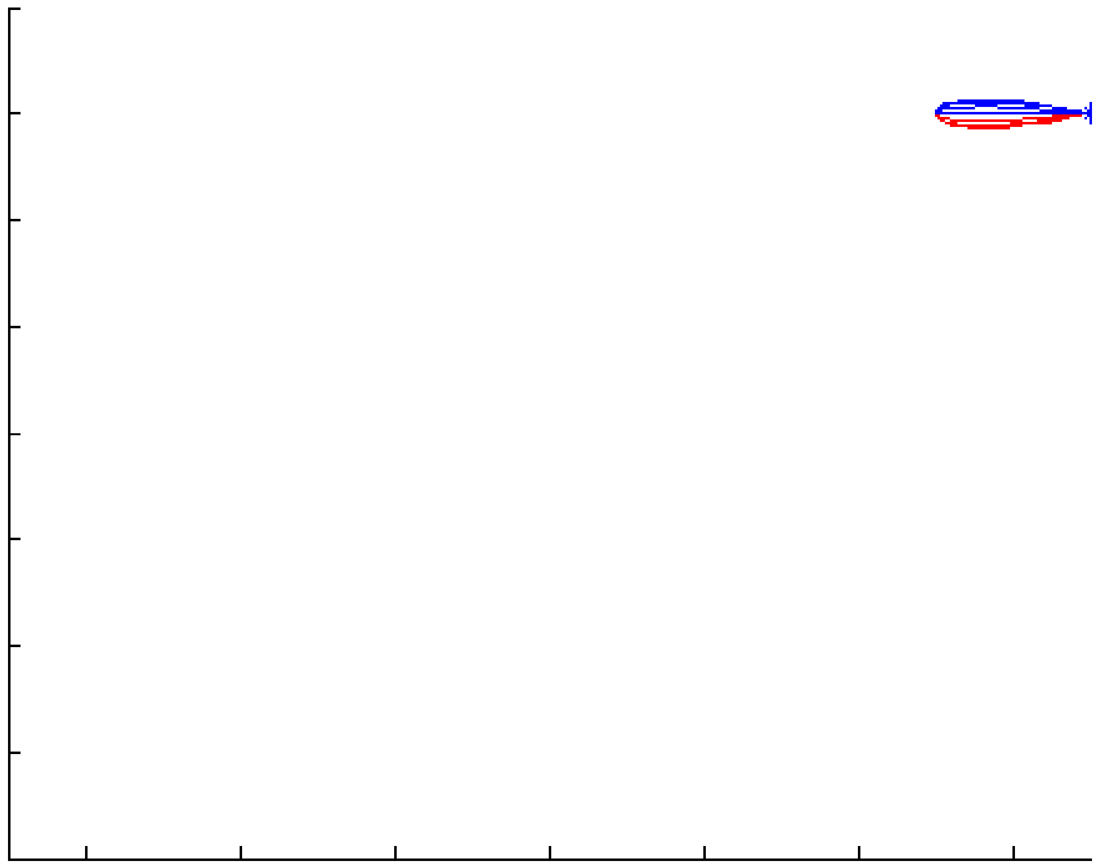
$h_0/c = 0.5$ $Str = 0.20$ $\theta_0 = 25^o$



Results 3D Flapping Hydrofoil (6)

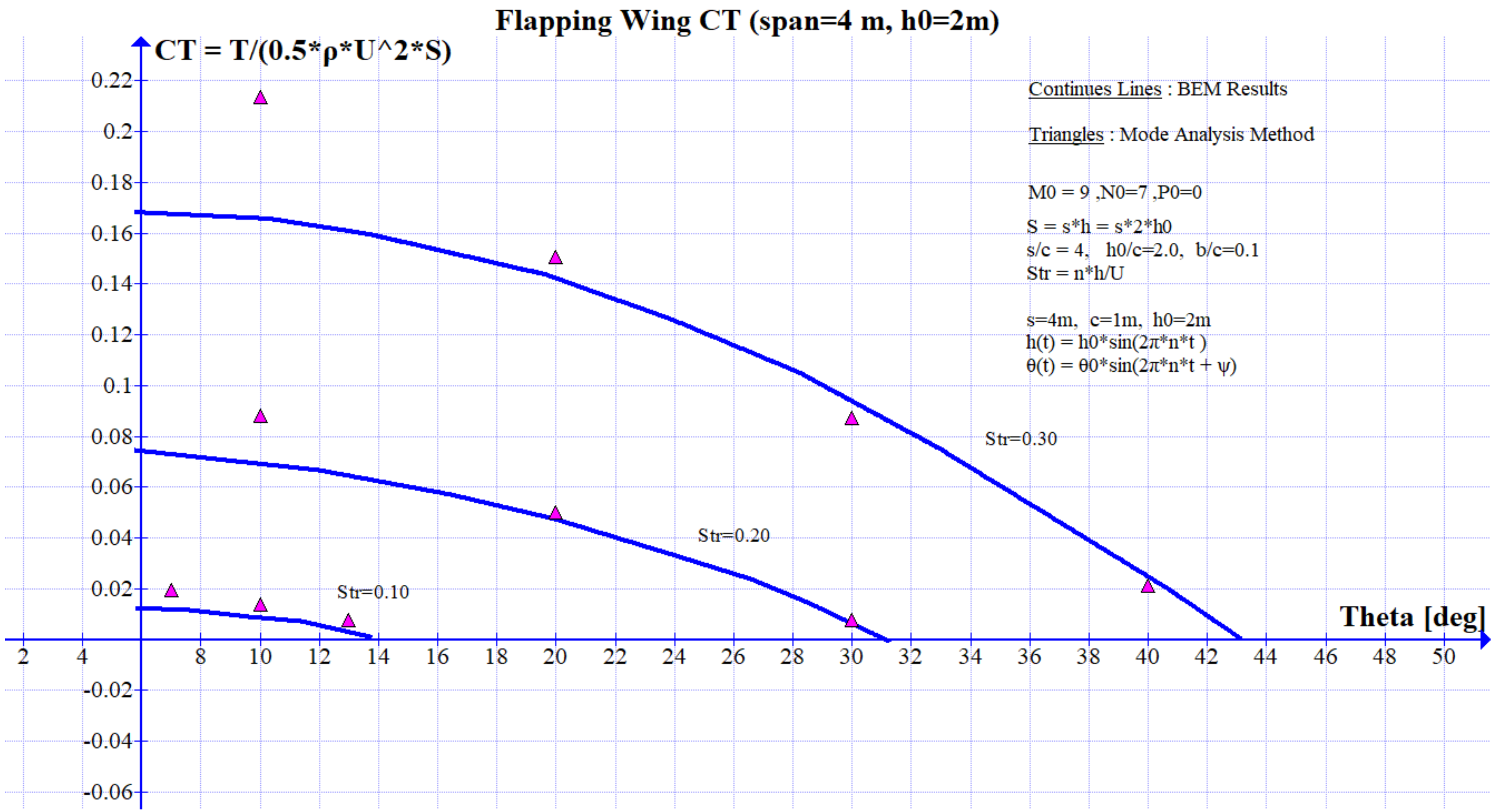
Presentation of midspan section unsteady motion

$h_0/c = 0.5$ $Str = 0.30$ $\theta_0 = 48^o$



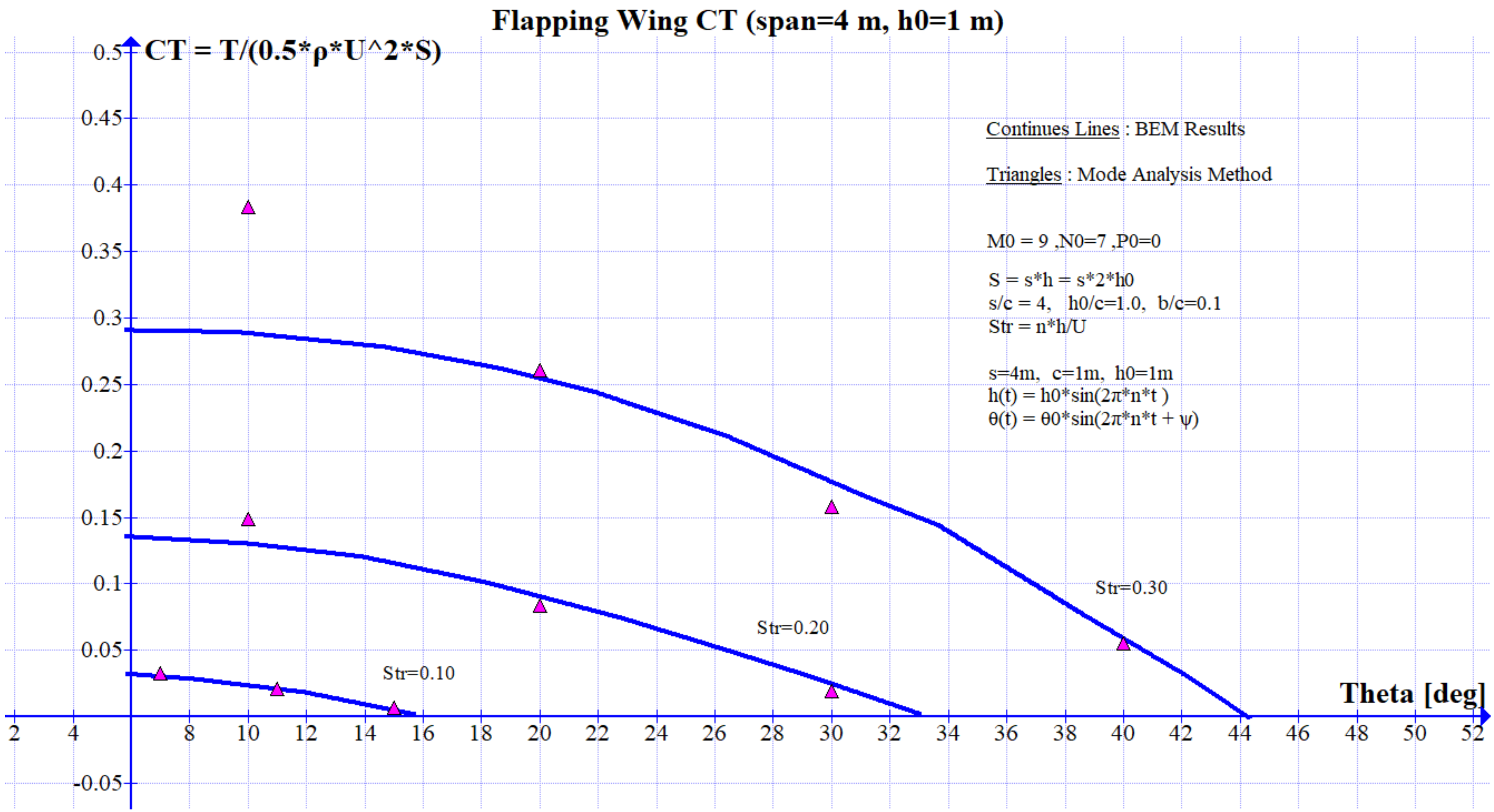
Results 3D Flapping Hydrofoil (7)

Comparison UBEM[10] - M.A lifting surface theory



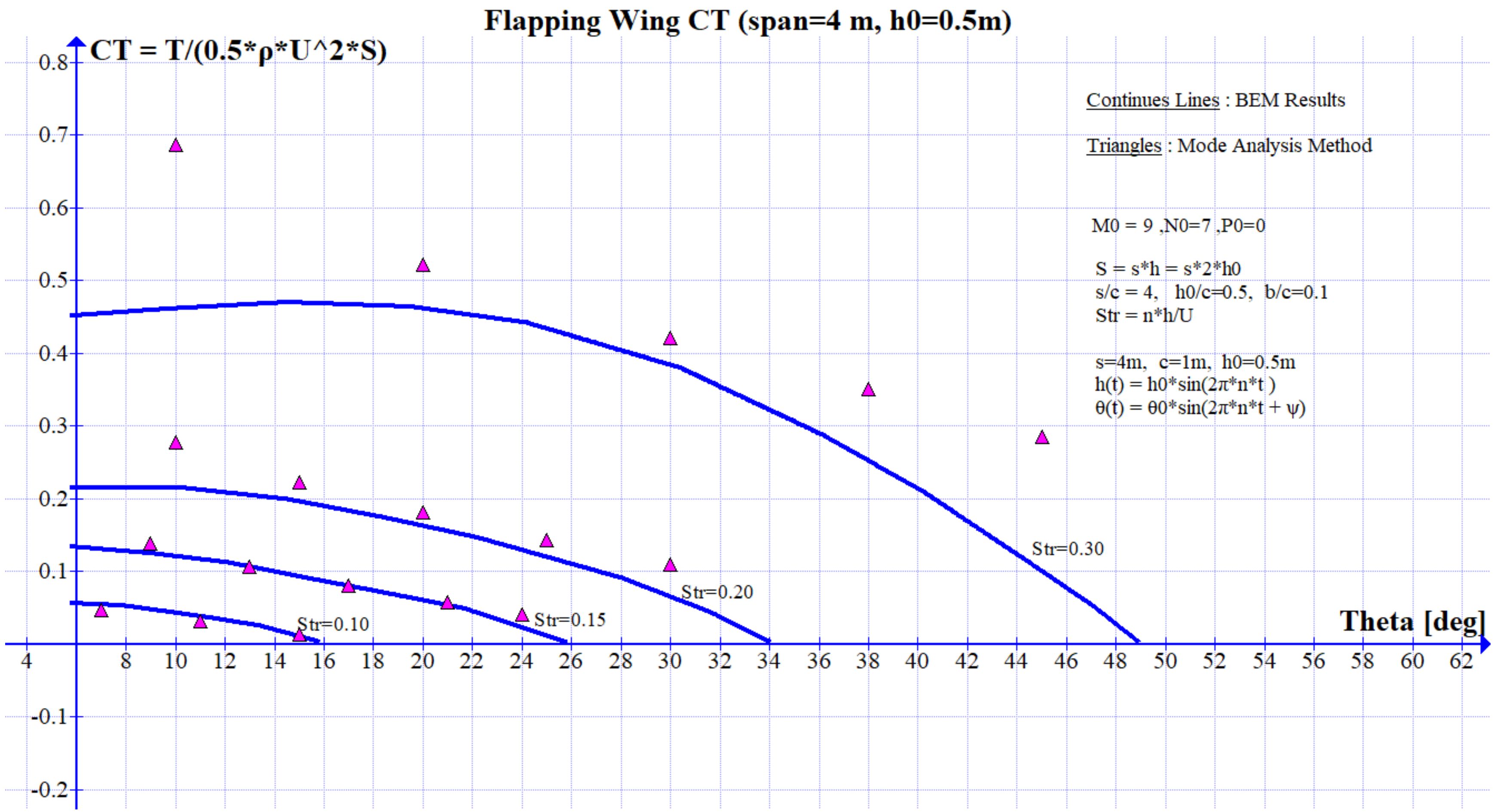
Results 3D Flapping Hydrofoil (8)

Comparison UBEM[10] - M.A lifting surface theory



Results 3D Flapping Hydrofoil (9)

Comparison UBEM[10] - M.A lifting surface theory



Conclusion

Acceptable results in the linear area :

- Small angles of attack
- Small frequencies of motion

Future work :

- Improvement of the numerical method of calculating the induction factors (better distribution of integration points)
- Selection of another Fourier series for the application of different boundary conditions
- Calculation of self induced velocities on the wake (free wake)

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