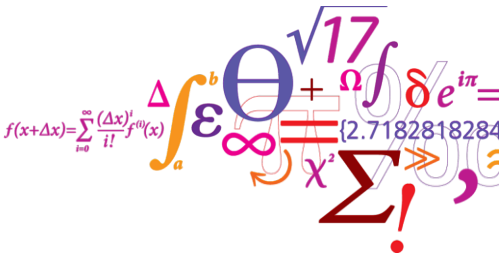
HAWC2 course

Lesson 8: Adaptive Trailing Edge Flaps in HAWC2

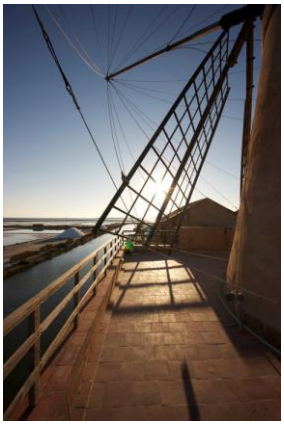
Leonardo Bergami



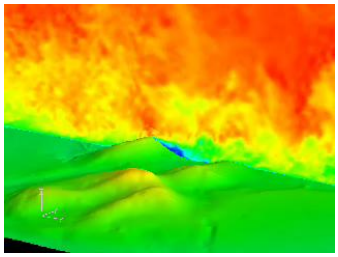
DTU Wind Energy
Department of Wind Energy

Agenda

- *Why having a flap?*
- *Aerodynamic model of flaps*:
  - Steady inputs
  - Attached flow dynamics
  - Flow Separation dynamics
  - Steady inputs for the dynamic stall model
- *How to set up flaps in HAWC2:*
  - Required inputs
  - Customize your flaps
- *Small exercise:*
  - Blades are nice, with flaps are better

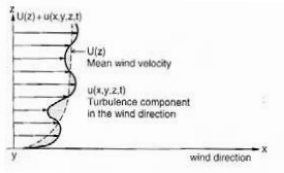


Why having a flap?



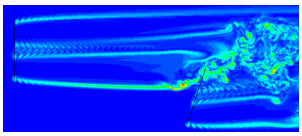
Problem…

- Blades longer and more flexible
- Not uniform flow
  - -> variable aerodynamic forces
  - -> dynamic loading on structure
  - -> fatigue (and ultimate) loads



Solution?

- Alleviate dynamic loads
- Acting on aerodynamic forces to compensate for flow variations
  - -> Act on the 'source' of loadings
  - -> Act 'fast'
  - -> Act locally along the blade span



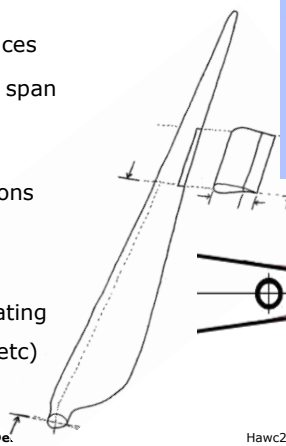
"Active load alleviation"

Why having a flap? (2)

Acting on aerodynamic forces, fast, locally along the blade span

How to?

- Looking at a kestrel…
- Modify geometry of lifting surfaces
  - -> Fast, locally along the blade span



And without feathers?

- Modify geometry of airfoil sections
- Several solutions in different research institutions to provide actuators to a *smart-rotor* (rotating flaps, micro-tabs, micro-flaps, etc)
- Adaptive Trailing Edge Flap

Why having a flap?

Adaptive trailing edge flap

↓

Modify airfoil geometry

↓

Act on aerodynamic forces fast and locally

↓

Compensate for flow variation

↓

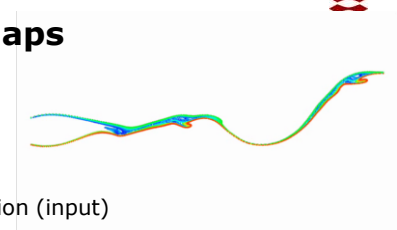
Active load alleviation of fatigue (and ultimate?) loads

↓

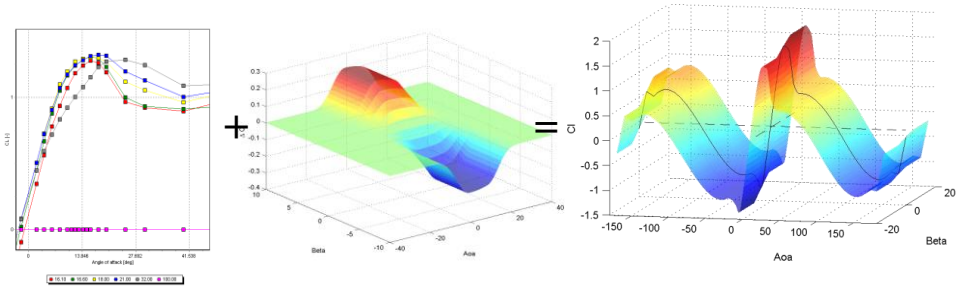
[…]

Why having a flap? …because it's (probably) good

Model of a rotor with ATEFlaps



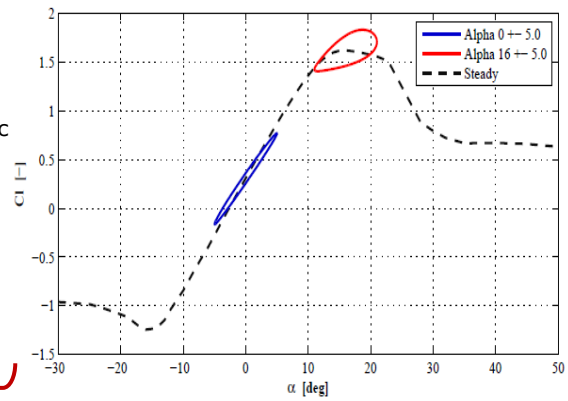
- HAWC2 simulates aeroelastic response
- Aerodynamic model for the flap:
  - Aerodynamic effects of flap deflection
    - *Steady effects*:
      Dependency on Aoa + Flap Deflection (input)
    - *Unsteady effects*: dynamics of forces.
  - Simple model for integration with aeroelastic tool



Dynamics of forces

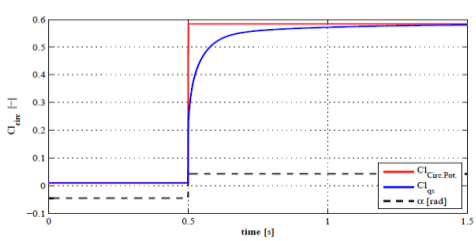
As for a rigid airfoil, the model accounts for dynamics (unsteady forces) in:

- ***Attached flow*** :
  Memory effects of vorticity shed into the wake.
- ***Flow separation*** (dynamic stall):
  Dynamics of the boundary layer, delay in flow separation.
- ***Non-circulatory terms***:
  added mass, acceleration terms.

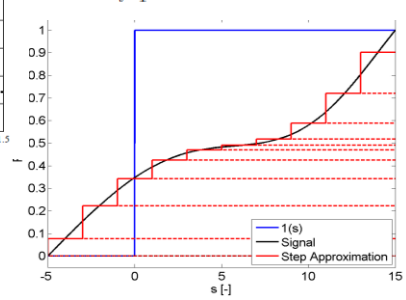


Dynamics depend on flow changes, aoa change AND flap deflection

Attached flow: indicial response function



$$\Phi = 1 - \sum_{i=1}^{N_{\text{lag}}} A_i \exp^{b_i \tau}, \qquad \tau = \frac{U_0 t}{b_{hc}}.$$



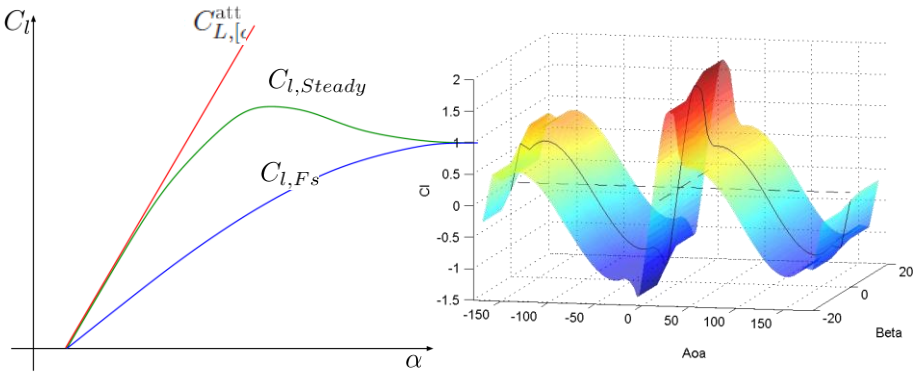
- Same approach as for rigid airfoil
- Response to step, described by *Indicial lift response function* Phi.

- Same Indicial lift response function -> also applies to flap
- Response to arbitrary motion: superposition of step responses (Duhamel's integration)

Flow separation: dynamic stall model

- Similar to BL for rigid airfoil: Lift as weighted sum:

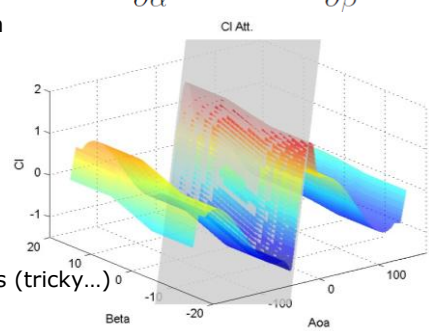
$$C_L^{\mathrm{Circ.Dyn}} = C^{\mathrm{att}}_{L,[\alpha_{\mathrm{eff}};\beta_{\mathrm{eff}}]} f^{dyn} + C^{\mathrm{fs}}_{L,[\alpha_{\mathrm{eff}};\beta_{\mathrm{eff}}]} \left(1 - f^{dyn}\right)$$



Dynamic stall model (2)

- Tricky to get steady components (function of aoa and flap): $C_l^{st} = C_l^{att} f^{st} + C_l^{fs}(1 - f^{st}).$

1. Fully attached lift, linear assumption: $C_l^{lin} = \frac{\partial C_l}{\partial \alpha}(\alpha - \alpha_0) + \frac{\partial C_l}{\partial \beta}(\beta);$
2. Steady separation function (eq. plate in Kirchoff flow):
$$f(\alpha, \beta) = \left(2\sqrt{\frac{C_l^{st}}{C_l^{lin}}} - 1\right)^2$$
3. Fully separated lift:
$$C_l^{fs} = \frac{C_l^{st} - C_l^{lin} f^{st}}{1 - f^{st}}$$



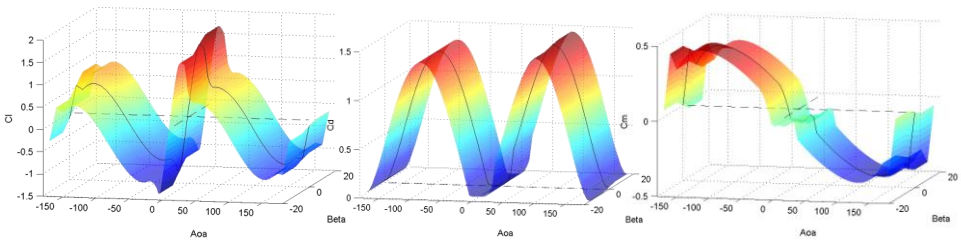
- Can give singularity points, discontinuities (tricky…)
  -> External preprocessor (user's control)
- Component passed as INPUT

ATEFlap Aerodynamic Model

- How does it work:
  - Attached flow: indicial response superposition
  - Flow Separation: BL type dynamic stall model

- Required inputs (external file):

1.	2.	3.	4.	5.	6.	7.	8.
Aoa [deg]	Flap β	C_l^{st}	C_l^{att}	C_l^{fs}	C_d	C_m	f sep.fun.



Flaps in HAWC2

How to set up the flaps in 4+1 easy steps…

1. Define position and steady aerodynamic input.
2. Make sure aerodynamic model sees the flap.
3. Move the flaps (control).
4. Monitor the flaps (output).
5. (Customize flap sections)
   - » Indicial response function
   - » Flap shape (defl. shape integrals)

1. Flap position and input

1. Define position and steady aerodynamic input.
2. Make sure aerodynamic model sees the flap.
3. Move the flaps (control).
4. Monitor the flaps (output).
5. (Customize flap sections)
   - » Indicial response function
   - » Flap shape (defl. shape integrals)

1. Flap position and input

- In the .htc input file – In the ***aero*** block – In the ***dynstall_ateflap*** subblock.

```
begin aero ;
    ; standard aero commands… ;
      …
    begin dynstall_ateflap ;
        ; - Define Flap Positions and input - ;
        flap 45.0 55.0 ./Input1.ds;
        flap 56.0 61.0 ./Input2.ds;
        ; … and so on … ;
        …
    end dynstall_ateflap ;

end aero ;
```

1. Command ***flap***
2. Where does it start, spanwise position [m]
3. Where does it end [m]
4. Input file location

NB: The order (and not the position) gives the flap number.

1.	2.	3.	4.	5.	6.	7.	8.
Aoa [deg]	Flap β	C_l^{st}	C_l^{att}	C_l^{fs}	C_d	C_m	f sep.fun.

2. Does the model 'see' the flaps?

1. Define position and steady aerodynamic input.
2. Make sure aerodynamic model sees the flap.
3. Move the flaps (control).
4. Monitor the flaps (output).
5. (Customize flap sections)
   - » Indicial response function
   - » Flap shape (defl. shape integrals)

2. Does the model 'see' the flaps?

Make sure the aerodynamic model knows about the flaps!

- Run with an aerodynamic model that supports flaps

  (NB: no warnings are given…)
- Distribution of aerodynamic computation points.

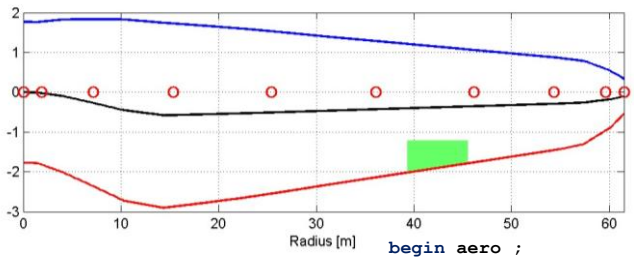
```
begin aero ;
    ; standard aero commands… ;
    dynstall_method   3 ;
       …
    begin dynstall_ateflap ;
    ; here you had defined the flaps;
    end dynstall_ateflap ;

end aero ;
```

- ***3*** corresponds to **dynstall_ateflap** model (for flaps!)
- ***2*** is normal model (no flaps)

2. Does the model 'see' the flaps?

Distribution of aerodynamic computation points:

Careful not to 'skip' the flap (or to alter its spanwise length…)



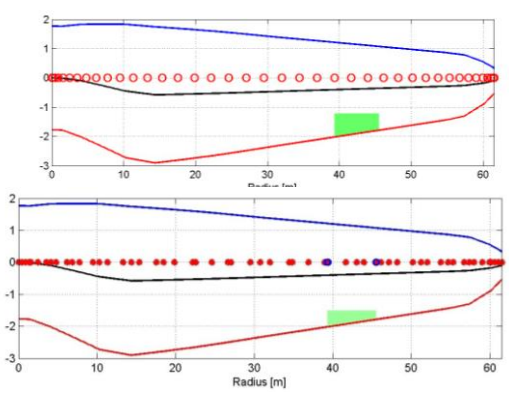
Aerodynamic forces evaluated in a finite set of points.

Number of pts. Specified f.ex. by the *aerosections* command

```
begin aero ;
    aerosections   10;
      …
    begin dynstall_ateflap ;
    ; here you had defined the flaps;
    end dynstall_ateflap ;
end aero ;
```


2. Does the model 'see' the flaps?

How to ensure that?



- Increase the number of points

OR (better)

- Specify position of aero sections:

  2 pts at each flap boundary

```
begin aero ;
  …
  aero_distribution ae_file 1;
  …
end aero ;
```

NB: you can check in the .log file which sections are assigned to the flap

3. Move the flaps (control)

1. Define position and steady aerodynamic input.
2. Make sure aerodynamic model sees the flap.
3. Move the flaps (control).
4. Monitor the flaps (output).
5. (Customize flap sections)
   - » Indicial response function
   - » Flap shape (defl. shape integrals)

3. Move the flaps (control)

.Usual control interface: In the ***dll*** block – In ***type2_dll*** (or ***hawc_dll***) subblock.

```
begin dll;
    ; … standard turbine controllers …
    begin hawc_dll;
        filename          testfile.dll;
        dll_subroutine    echodll ;
        arraysizes        13 12;
        ; -- Data passed TO .dll: -- ;
        begin output ;
          general constant 3 ;
          general step      20 0 10 ;
             ...
        end output ;
        ; -- Data FROM .dll TO hawc2 -- ;
        begin actions ;
          aero beta  1  1 ;
             ...
        end actions ;
    end hawc_dll ;
end dll ;
```

- .dll properties
- Output from Hawc2 to the .dll
- *Actuate the flap:*
  - Fixed command
  - Blade nr. (from link)
  - Flap nr. (from order)

4. Monitor the flaps (output)

1. Define position and steady aerodynamic input.
2. Make sure aerodynamic model sees the flap.
3. Move the flaps (control).
4. Monitor the flaps (output).
5. (Customize flap sections)
   - » Indicial response function
   - » Flap shape (defl. shape integrals)

4. Monitor the flaps (output)

Check if the flaps are doing something… add "sensors" in the output section:

```
begin output;
    ; intro commands …
    ; Other output sensors …
    ; - Check if flaps are deflecting: -
    aero beta 1 1 ;
    aero beta 1 2 ;
     ; … and so on … ;
    ; - Check effects (f.ex.) - ;
    aero cl  1  50.00 ;
    aero cm  1  50.00 ;
     ; … and so on … ;
    ; - Any effect on structure? - ;
    mbdy momentvec blade1 1 0.0 blade1 # lab ;
     ; … and so on … ;
end output ;
```

- Output the flap deflection.
- same syntax as in control.
- check on manual for different possibilities.

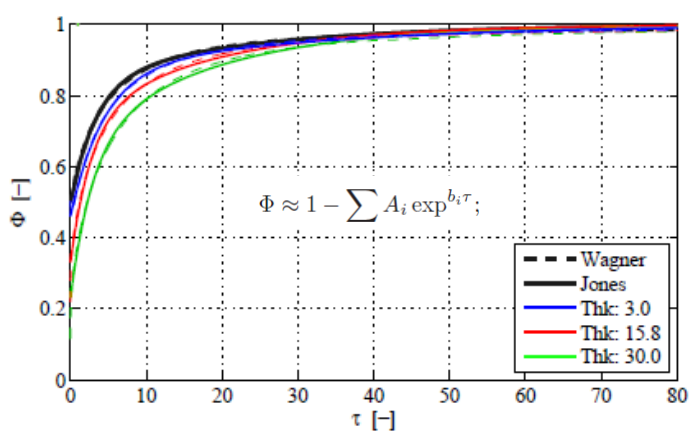
4+1… Customize the flaps

1. Define position and steady aerodynamic input.
2. Make sure aerodynamic model sees the flap.
3. Move the flaps (control).
4. Monitor the flaps (output).
5. (Customize flap sections)
   - » Indicial response function
   - » Flap shape (defl. shape integrals)

5. Customize Indicial response function

- Indicial response function of finite thickness airfoil differs from flat plate one.
- Possibility to specify (3) coefficients of exponential approximation:

  ais , *bis* inputs



5. Customize Indicial response function

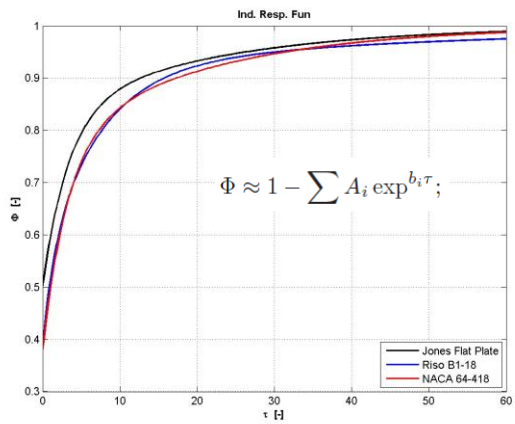
- In ***aero*** command block – in ***dynstall_ateflap*** sub-block (similar in ***mhh***)

- Jones Flat Plate (default mhh)

```
begin dynstall_ateflap ;
      …
    ; - Jones Flat Plate - ;
    ais 0.1650 0.3350 0.000 ;
    bis 0.0455 0.3000 0.000 ;
      …
end dynstall_ateflap ;
```

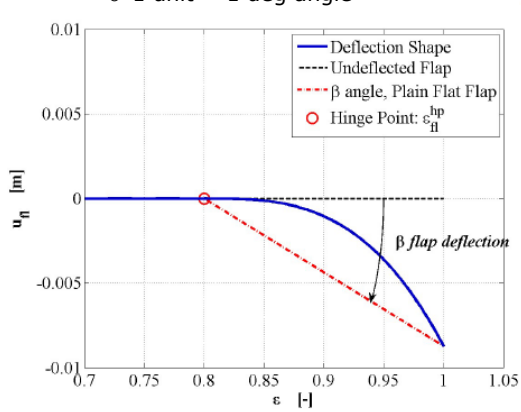
- Naca 64-418 (default ateflap)

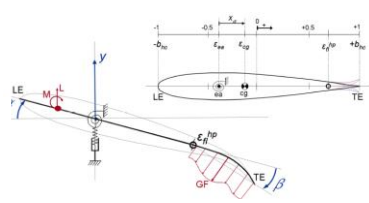
```
; - Naca 64-418 - ;
ais 0.1784 0.07549 0.3933 ;
bis 0.8000 0.01815 0.1390 ;
```



5. Customize Deflection shape integrals

- Flap forces dynamics depend on deflection shape integrals (camberline deformation from flap deflection)
- Default values based on flap:
  - 10 % chord
  - Circular arc deflection shape
  - 1 unit = 1 deg angle





Mac Gaunaa,
Unsteady two-dimensional potential-flow model for thin variable geometry airfoils,
Wind Energy 2010, 13, 167-192

5. Customize deflection shape integrals

- If the flap has a different shape…
- Compute the integrals (refer to Mac's paper for equations).
- Integral values can be entered manually.
- Optional commands in ***aero*** block, ***dynstall_ateflap*** sub-block:

```
begin dynstall_ateflap
            …
         ; - Deflection shape integrals: - ;
    hystar        -4.675844E-003 ;
    fylestar      +4.155446E-004 ;
    fdydxle       +7.236104E-003 ;
    gdydxle       +3.309147E-003 ;
    ; …
end dynstall_ateflap
```

All normalized by the chord length (NO chord length dependency)

Set up your flaps in 4+1 easy steps…

1. Define position and steady aerodynamic input.
2. Make sure aerodynamic model sees the flap.
3. Move the flaps (control).
4. Monitor the flaps (output).
5. (Customize flap sections)
   - » Indicial response function
   - » Flap shape (defl. shape integrals)

Small Exercise?

- Add flaps to the NREL wind turbine … in 4 easy steps.
- You can start from the *Ex_FlapBase.htc* file (./Exerc_Flaps/…)

1. Define 2 flaps, positioned respectively:
   - » From 45.0 m TO 55.0 m
   - » From 56.0 m TO 61.0 m

2. The aerodynamic input file for the flaps is given: *FlapNrel_Thk17.ds*

3. Make sure the aerodynamic model "sees" the flap…
   (TIP: there is an example of ae input file in the folder: *Ae_ExercFlaps_01.txt*)
   (TIP: Verify in the .log file aerosections with flap)

Ok, the flaps are now there…

http://dl.dropbox.com/u/2904102/Exerc_Flaps.rar

Exercise (2)

4. Control: assign flaps deflection to verify they do something:
   - An *echo_t2_v3.dll* is provided, define the input signal for each flap
   - Check the *general outputs* section on the manual for step signals
   - Step flap 1 of 10 deg., 20 seconds later step flap 2.

5. Change the output to monitor the behavior of the flap: for ex.
   - » Monitor their deflection.
   - » Check if they have any effect on the aerodynamic forces
   - » Check effects on blade structure (e.g. Blade root moment, tip position). How does the blade root bending moment respond?

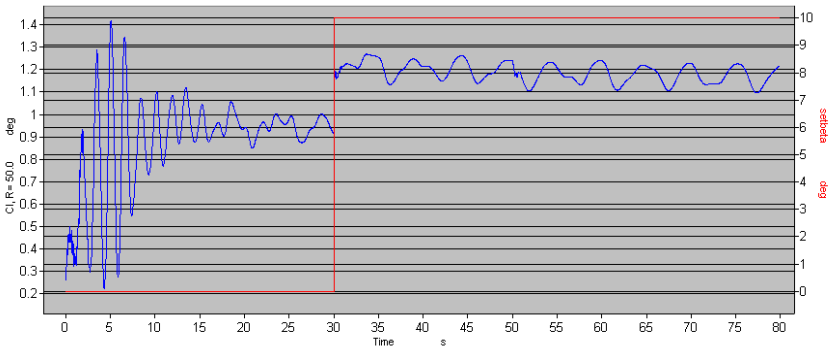
   (the different sensors available and their syntax are given in the output section of the hawc2 manual)

(extra) Try to change the indicial lift response to Jones's flat plate expression:

A1 = 0.463, A2=0.1116 ; b1 = 0.1961, b2 = 0.0252.

Have fun…

Results


Cl, R=50.0 deg
1.4
1.3
1.2
1.1
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
10
9
8
7
6
5
4
3
2
1
0
setvalue
deg
0
5
10
15
20
25
30
35
40
45
50
55
60
65
70
75
80
Time
s